SENET

A DRA Global Group Company

MKANGO

NI 43-101 TECHNICAL REPORT ON THE SONGWE HILL RARE EARTH ELEMENT PROJECT IN MALAWI

Prepared for

MKANGO RESOURCES LIMITED

Prepared by

SENET, A DRA GLOBAL GROUP COMPANY

Report Date

18 AUGUST 2022

Effective Date

1 JULY 2022

DATE AND SIGNATURE PAGE

This report titled "NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi" was prepared for Mkango Resources Limited by SENET, a DRA Global Group Company. This report dated 18 August 2022, the effective date of which is 1 July 2022, is compliant with the Canadian National Instrument 43-101 (NI 43-101) and Form 43-101F, and was signed by the following Qualified Persons:

(signed) *"Nicholas Dempers"*

Nicholas Dempers

MSc Eng (Chem), BSc Eng (Chem), BCom (Man), Pr Eng (RSA), Reg. No. 20150196, FSAIMM (RSA)

SENET, a DRA Global Group Company

Johannesburg, South Africa

(signed) *"Jeremy Charles Witley"*

Jeremy Charles Witley

BSc (Hons), MSc (Eng), Pr Sci Nat, FGSSA

The MSA Group (Pty) Ltd

Johannesburg, South Africa

(signed) *"Scott Swinden"*

Scott Swinden

BSc (Hons), MSc, PhD, P Geo

Swinden Geoscience Consultants Ltd

Wolfville, Nova Scotia, Canada

(signed) *"Graham Errol Trusler"*

Graham Errol Trusler

MSc Eng (Chem), BCom (Man), Pr Eng (RSA), FSAIMM (RSA)

Digby Wells Environmental

Johannesburg, South Africa

(signed) *"Clive Wyndham Brown"*

Clive Wyndham Brown

BSc Eng (Mining), Pr Eng (RSA), FSAIMM (RSA)

Bara Consulting (Pty) Ltd

Johannesburg, South Africa

(signed) *"Guy John Wiid"*

Guy John Wiid

BSc Eng (Civil), MSc Eng (Civil)

Epoch Resources (Pty) Ltd

Johannesburg, South Africa

CERTIFICATE OF QUALIFIED PERSON – NICHOLAS DEMPERS

I, Nicholas Dempers, do hereby certify that

1. I am a principal process engineer at SENET, a DRA Global Group Company, Building 12, Greenstone Hill Office Park, Emerald Boulevard, Greenstone Hill, Greenstone 1609, Modderfontein, Gauteng, South Africa.
2. I am a reviewer of the report titled “NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi”, prepared for Mkango Resources Limited, with an effective date of 1 July 2022.
3. I am a graduate of the University of Cape Town, with a BSc in Chemical Engineering. I also hold an MSc in Chemical Engineering from the University of Cape Town and a BCom from the University of South Africa.
4. I am a registered professional member of the Engineering Council of South Africa (Reg. No. 20150196), and I am a fellow of the Southern African Institute of Mining and Metallurgy.
5. I have practised my profession continuously since 2001. I have over 19 years’ experience in the minerals industry. I have been involved in the process operation (production) and plant design, from conceptualisation to complete project execution, of more than 10 mineral process projects, as well as more than 12 process plant studies for major commodities including cobalt, copper, gold, uranium, rare earths, and platinum group metals (PGMs). I have assisted in or compiled National Instrument 43-101 (NI 43-101) Reports for various projects that have been listed on the TSX stock exchange.
6. I have read the definition of “qualified person” set out in NI 43-101 and certify that, by reason of my education, affiliation with a professional association (as defined in NI 43-101), and relevant work experience, I fulfil the requirements to be a qualified person for the purposes of NI 43-101.
7. I visited the Songwe Hill Project Site on 19 May 2014 and 28 June 2022.
8. I have been involved with the property that is the subject of the Technical Report as an independent consultant since August 2013. All involvement was with the current issuer at various stages of the project, for which remuneration that is not contingent on the outcome of the study work has been received.
9. I am responsible for the preparation of Sections 6, 13, 17, 18, 19, 21, 22 and 23 and contributed to Sections 1, 2, 3, 4, 24, 25 and 26 of the Technical Report.
10. I am independent of Mkango Resources Limited as independence is described in Section 1.5 of NI 43-101. I do not have nor do I expect to receive a direct or indirect interest in the Mineral Properties of Mkango Resources Limited, and I do not beneficially own, directly or indirectly, any securities of Mkango Resources Limited or any associate or affiliate of such company.
11. I have read NI 43-101 and Form 43-101F1, and the part of the Technical Report for which I am responsible has been prepared in compliance therewith.
12. As of the date of this certificate, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to ensure that the Technical Report is not misleading.

Signed at SENET, Johannesburg, South Africa, on 18 August 2022

(signed) *“Nicholas Dempers”*

NICHOLAS DEMPERS
MSc Eng (Chem), BSc Eng (Chem), BCom (Man), Pr Eng (RSA), Reg. No. 20150196, FSAIMM (RSA)

CERTIFICATE OF QUALIFIED PERSON – JEREMY CHARLES WITLEY

I, Jeremy Charles Witley, do hereby certify that

1. I am a principal mineral resource consultant of The MSA Group (Pty) Ltd, Henley House, Greenacres Office Park, Victory Park, Randburg, 2195, South Africa.
2. This certificate applies to the technical report titled "NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi", with an effective date of 1 July 2022.
3. I graduated with a BSc (Hons) degree in Mining Geology from the University of Leicester in 1988. In addition, I obtained a Master of Science degree in Engineering from the University of Witwatersrand in 2015.
4. I am a registered Professional Natural Scientist (Geological Science) with the South African Council for Natural Scientific Professions (SACNASP) and am a Fellow of the Geological Society of South Africa.
5. I have worked as a geologist for a total of 33 years. I have worked in a number of roles, including senior management, in mine geology, exploration projects and Mineral Resource management. I have conducted Mineral Resource estimates, audits and reviews for a wide range of commodities and styles of mineralisation including complex mixed distribution multi-element deposits. Specific REE experience includes deposits in Burundi, Mauritania, Namibia and South Africa as well as the Songwe Hill deposit in Malawi.
6. I have read the definition of "Qualified Person" set out in National Instrument 43-101 (NI 43-101) and certify that by reason of my education, affiliation with a professional association (as defined in NI 43-101) and past relevant work experience, I fulfil the requirements to be a Qualified Person for the purposes of NI 43-101.
7. I visited the Songwe Hill Property for four days from 25 to 28 July 2018 and for three days from 24 to 26 September 2018.
8. I am responsible for the preparation of items 1.5, 12, 14, 24.2.2, 25.1 and parts of 1, 2 and 27 of the Technical Report.
9. I have not had prior involvement with the property that is the subject of the Technical Report.
10. I am not aware of any material fact or material change with respect to the subject matter of the Technical Report that is not reflected in the Technical Report, the omission to disclose which makes the Technical Report misleading.
11. I am independent of the issuer according to the definition of independence described in Section 1.5 of NI 43-101.
12. I have read NI 43-101 and Form 43-101F1 and, as of the date of this certificate, to the best of my knowledge, information and belief, those portions of the Technical Report for which I am responsible have been prepared in compliance with that instrument and form.
13. I consent to the filing of the Technical Report with any stock exchange and other regulatory authority and any publication by them for regulatory purposes, including electronic publication in the public company files on their websites accessible by the public, of the Technical Report.

Signed at MSA, Johannesburg, South Africa, on 18 August 2022

(signed) *"Jeremy Charles Witley"*

____

JEREMY CHARLES WITLEY
Pr Sci Nat

CERTIFICATE OF QUALIFIED PERSON – SCOTT SWINDEN

I, Scott Swinden, do hereby certify that

1. I am a principal geoscience consultant at Swinden Geoscience Consultants Ltd, 224 Main Street, Wolfville, Nova Scotia, B4P 1C4, Canada.
2. This certificate applies to the report titled "NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi", prepared for Mkango Resources Limited, with an effective date of 1 July 2022.
3. I am a graduate of Dalhousie University, BSc(Hons) Geology (1970), and Memorial University of Newfoundland and Labrador, MSc Geology (1976) and PhD Earth Sciences (1988).
4. I am a registered professional geoscientist (PGeo) with the Association of Professional Geoscientists of Nova Scotia.
5. I have practised my profession continuously since 1970. I have worked as an exploration geologist for base and precious metals, rare metals and industrial minerals, as a research scientist for provincial and federal geological surveys, and as a manager and executive for provincial geological surveys. I am an adjunct faculty member at Dalhousie University and have taught economic geology at Dalhousie and Acadia Universities.
6. I have read the definition of "Qualified Person" set out in NI 43-101 and certify that, by reason of my education, affiliation with a professional association (as defined in NI 43-101), and relevant work experience, I fulfil the requirements to be a Qualified Person for the purposes of NI 43-101.
7. I visited the Songwe Hill Project Site most recently on 29 May to 11 June 2018 and 20 to 28 September 2018.
8. I have been involved with the property that is the subject of the Technical Report as an independent consultant since May 2012. All involvement was with the current issuer at various stages of the project, for which remuneration that is not contingent on the outcome of the study work has been received.
9. I am responsible for the preparation of Sections 7, 8, 9, 10 and 11 and contributed to Sections 1 and 2 of the Technical Report.
10. I am independent of Mkango Resources Limited as independence is described in Section 1.5 of NI 43-101. I do not have nor do I expect to receive a direct or indirect interest in the Mineral Properties of Mkango Resources Limited, and I do not beneficially own, directly or indirectly, any securities of Mkango Resources Limited or any associate or affiliate of such company.
11. I have read NI 43-101 and Form 43-101F1, and the part of the Technical Report for which I am responsible has been prepared in compliance therewith.
12. As of the date of this certificate, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to ensure that the Technical Report is not misleading.
13. I consent to the filing of the Technical Report with any stock exchange and regulatory authority and any publication by them for regulatory purposes, including electronic publication in the public company files on their websites accessible by the public, of the Technical Report.

Signed in Wolfville, Nova Scotia, Canada, on 18 August 2022

(signed) *"Scott Swinden"*

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SCOTT SWINDEN
PhD PGeo

CERTIFICATE OF QUALIFIED PERSON – GRAHAM ERROL TRUSLER

I, Graham Errol Trusler, do hereby certify that

1. I am an environmental consultant at Digby Wells Environmental, Digby Wells House, Turnberry Office Park, 48 Grosvenor Road, Bryanston, South Africa.
2. This certificate applies to the technical report titled "NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi", prepared for Mkango Resources Limited, with an effective date of 1 July 2022.
3. I graduated with an MSc (Engineering) degree in Chemical Engineering from the University of Natal in 1988. In addition, I obtained a Bachelor of Commerce degree from the University of South Africa.
4. I am a registered Professional Engineer with the Engineering Council of South Africa (ECSA).
5. I have worked in the Mining Industry for a total of 36 years.
6. I have read the definition of "Qualified Person" set out in National Instrument 43-101 (NI 43-101) and certify that by reason of my education, affiliation with a professional association (as defined in NI 43-101) and past relevant work experience, I fulfil the requirements to be a Qualified Person for the purposes of NI 43-101.
7. I visited the Songwe Property on 11 to 13 June 2018, and employees of Digby Wells, namely Barbara Wessels visited the project in March and April 2022 and Jessica Pryor from 27 to 30 May 2022
8. I am responsible, or co-responsible for, the preparation of Sections 1, 2, 3, 4, 5, 20, 21 ,24, 25 and 26 of the Technical Report.
9. I have not had prior involvement with the property that is the subject of the Technical Report.
10. I am not aware of any material fact or material change with respect to the subject matter of the Technical Report that is not reflected in the Technical Report, the omission to disclose which makes the Technical Report misleading.
11. I am independent of the issuer according to the definition of independence described in Section 1.5 of NI 43-101.
12. I have read NI 43-101 and Form 43-101F1 and, as of the date of this certificate, to the best of my knowledge, information and belief, those portions of the Technical Report for which I am responsible have been prepared in compliance with that instrument and form.
13. I consent to the filing of the Technical Report with any stock exchange and other regulatory authority and any publication by them for regulatory purposes, including electronic publication in the public company files on their websites accessible by the public, of the Technical Report.

Signed at Digby Wells, Johannesburg, South Africa, on 18 August 2022

(signed) *"Graham Errol Trusler"*

GRAHAM ERROL TRUSLER
Pr. Eng.

CERTIFICATE OF QUALIFIED PERSON – CLIVE WYNDHAM BROWN

I, Clive Wyndham Brown, do hereby certify that

1. I am a principal mining engineer at Bara Consulting (Pty) Ltd, PO Box 496 Cresta, Randburg, 2118, Gauteng, South Africa.
2. I am a co-author of the report titled "NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi", prepared for Mkango Resources Limited, with an effective date of 1 July 2022.
3. I am a graduate of the University of Witwatersrand, South Africa, with a BSC (Eng) Mining.
4. I am a registered professional member of the Engineering Council of South Africa (Reg. No. 940312), and I am a fellow of the Southern African Institute of Mining and Metallurgy.
5. I have 30 years of experience in mining operations, management, technical services and mineral reserve estimation. More than five years of this experience has directly involved open pit mine planning in base and precious metals. I have assisted in or compiled National Instrument 43-101 (NI 43-101) Reports for various projects that have been listed on the TSX stock exchange.
6. I have read the definition of "Qualified Person" set out in NI 43-101 and certify that, by reason of my education, affiliation with a professional association (as defined in NI 43-101), and relevant work experience, I fulfil the requirements to be a Qualified Person for the purposes of NI 43-101.
7. I have visited the Songwe Hill Project Site on two occasions, the most recent being on 28 June 2022.
8. I performed consulting services and reviewed files and data supplied by Mkango Resources Limited between 28/04/2020 and 30/03/2021.
9. I am responsible for the preparation of Sections 15 and 16 and contributed to Sections 1, 2, 3, 18, 21, 24, 25 and 26 of the Technical Report.
10. I have had no previous involvement with this project or any other project on this property.
11. I am independent of Mkango Resources Limited as independence is described in Section 1.5 of NI 43-101. I do not have nor do I expect to receive a direct or indirect interest in the Mineral Properties of Mkango Resources Limited, and I do not beneficially own, directly or indirectly, any securities of Mkango Resources Limited or any associate or affiliate of such company.
12. I have read NI 43-101 and Form 43-101F1, and the part of the Technical Report for which I am responsible has been prepared in compliance therewith.
13. As of the date of this certificate, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to ensure that the Technical Report is not misleading.

Signed at Bara, Johannesburg, South Africa, on 18 August 2022

(signed) *"Clive Wyndham Brown"*

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CLIVE WYNDHAM BROWN
BSc Eng (Mining), Pr Eng (RSA), Reg. No. 940312, FSAIMM (RSA)

CERTIFICATE OF QUALIFIED PERSON – GUY JOHN WIID

I, Guy John Wiid, PrEng, CEng, do hereby certify that

1. I am a professional tailings engineer employed by Epoch Resources (Pty) Ltd of Viscount Rd Office Park, 8 Viscount Rd, Bedfordview, Johannesburg, South Africa.
2. This certificate applies to the technical report titled “NI 43-101 Technical Report on the Songwe Hill Rare Earth Element Project in Malawi”, prepared for Mkango Resources.
3. The effective date of the Technical Report is 1 July 2022.
4. I graduated with a BSc Eng (Civil) from the University of the Witwatersrand in 1988. I also obtained an MSc Eng (Civil) from the University of the Witwatersrand in 1995. I have worked as a tailings engineer for a total of 30 years since 1990.
5. I am a member of the Engineering Council of South Africa (No. 940269), and a Chartered Engineer with the American Society of Civil Engineers (No. 9945778).
6. I have read the definition of "Qualified Person" set out in National instrument 43-101 (NI 43-101) and certify that by reason of my education, affiliation with a professional association (as defined in NI 43-101) and past relevant work experience, I fulfil the requirements to be a Qualified Person for the purposes of NI 43-101.
7. I am responsible specifically for Section 18.4 and contributed to Sections 1, 2, 3, 21, 25 and 26 of the Technical Report.
8. I have not visited the property but have reviewed all the technical documentation available for the project to date. Epoch Resources employee Sylvia Przytula visited the project from 27 to 30 May 2022.
9. I am independent of Mkango Resources applying all of the tests set out in Section 1.5 of NI 43-101.
10. I have not had prior involvement with the property that is the subject of the Technical Report.
11. I have read NI 43-101 and Form 43-101F1; the sections of the Technical Report I am responsible for have been prepared in compliance with that instrument and form.
12. As of the aforementioned effective date, to the best of my knowledge, information and belief, the sections of the Technical Report I am responsible for contain all the scientific and technical information that is required to be disclosed to make the Technical Report not misleading.

Signed at Epoch Resources, Johannesburg, South Africa, on 18 August 2022

(signed) *“Guy John Wiid”*

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GUY JOHN WIID
PrEng, CEng (ECSA 940269)

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Unit	Description
%	per cent
% m/m	percentage mass per mass
% w/w	percentage weight per weight
µg	microgram
µm	micrometre (micron)
µS	microsiemens
$µSv.year^{-1}$	microsievert per year
°C	degree Celsius
a	annum
cm	centimetre
d	day
dB	decibel
dtpa	dry tonnes per annum
dmt	dry metric tonnes
g	gram
g/t	gram per tonne
Ga	billion years (10^9 years)
h	hour
ha	hectare
Hz	hertz
kg	kilogram
km	kilometre
km^2	square kilometre
koz	thousand troy ounces
kPa	kilopascals
kV	kilovolt
kVA	kilovolt ampere
kW	kilowatt
kWe	kilowatt energy
kWh	kilowatt hour
lb	troy pound
L	litre
M	million – 1×10^6
m	metre
m^3	cubic metre
mamsl	metre above mean sea level

Unit	Description
mbgl	metre below ground level
mg/L	milligram per litre
min	minute
mm	millimetre
Moz	million troy ounces
MPa	megapascal
Mt	million tonnes
MW	megawatt
N	newton
Nm	newton metre
oz	troy ounce
Pa	pascal
Pa s	pascal second
ppb	part per billion
ppm	part per million
s	second
s^{-1}	reciprocal second
t	metric tonne
t/a	tonnes per annum
t/h	tonnes per hour
t/m^3	tonnes per cubic metre
USD	United States dollar
V	volt
ZAR	South African rand

It is noted that, throughout the report, table columns might not add up due to rounding.

LIST OF ABBREVIATIONS

Abbreviation	Description
AACE	Association for the Advancement of Cost Engineering
ABA	acid-base accounting
Ai	abrasion index
ANZECC	Australian and New Zealand Environment Conservation Council
ARD	acid rock drainage
BBWi	Bond ball work index
BFA	bench face angle
BOQ	bill of quantities
BRWi	Bond rod work index
C&I	control and instrumentation
CAGR	compound annual growth rate
CAPEX	capital cost
CCE	closure cost estimate
CCTV	closed-circuit television
CDF	co-disposal facility
CIM	Canadian Institute of Mining, Metallurgy and Petroleum
CP	Closure Plan
CRM	certified reference material
CWi	crushability work index
DCF	discounted cash flow
DFS	Definitive Feasibility Study
E&I	electrical and instrumentation
E, C&I	electrical, control and instrumentation
EC	European Commission
ECSA	Engineering Council of South Africa
EIA	Environmental Impact Assessment
EMA	Environment Management Act
EN	Endangered
EP	Equator Principle
EPC	engineering, procurement and construction
EPCM	engineering, procurement and construction management
ERM	Environmental Resource Management
Escom	Electricity Supply Commission of Malawi
ESG	Environmental, Social and Governance
ESHMP	Environmental, Social and Health Management Plan
ESHIA	Environmental, Social and Health Impact Assessment
ESMP	Environmental and Social Management Plan
EU	European Union

Abbreviation	Description
EZ	exclusion zone
FCF	free cash flow
FEL	front-end loader
FOS	factor of safety
G&A	general and administration
GIIP	Good International Industry Practice
GIS	geographic information system
GISTM	Global Industry Standards on Tailings Management
GPS	Global Positioning System
HAZOP	hazard and operability
HDPE	high-density polyethylene
HR	human resources
IBC	intermediate bulk container
ICP	inductively coupled plasma
ICP-AES	inductively coupled plasma – atomic emission spectroscopy
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
I/O	input/output
IP	induced polarisation
IRR	internal rate of return
ISO	International Organization for Standardization
IT	information technology
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
LAN	local area network
LBMA	London Bullion Market Association
LC	Least Concern
LCT	locked cycle test
LME	London Metal Exchange
LOO	life of operations
LRP	Livelihood Restoration Plan
LV	low voltage
MCC	motor control centre
MEL	mechanical equipment list
MIA	mining industrial area
MIBC	methyl isobutyl carbinol
Mkango	Mkango Resources Limited
MPL	maximum permissible level
MTO	material take-off
MV	medium voltage

Abbreviation	Description
NAF	non-acid forming
NAG	net acid generation
NdFeB alloy	The NdFeB precursor materials from which sintered NdFeB magnets are manufactured.
NdFeB magnet	The final sintered or bonded magnet form (often coated to protect from corrosion) ready for use in a particular end use or application.
NdPr oxide	didymium oxide (combined form of neodymium (75 %) and praseodymium (25 %) oxide commonly used by NdFeB manufacturers instead of individual neodymium and/or praseodymium oxides)
NEAP	National Environmental Action Plan
NEP	National Environmental Policy
NGL	natural ground level
NGO	Non-Governmental Organisation
NI 43-101	Canadian Securities Administrators' National Instrument (NI) 43-101
NPV	net present value
OEM	original equipment manufacturer
OPEX	operating cost
ORP	Operational Readiness Plan
P&G	preliminary and general
P&ID	piping and instrumentation diagram
PAG	potentially acid generating
PAP	Project affected person
PAS	process automation system
PEA	Preliminary Economic Assessment
PFD	process flow diagram
PFS	Pre-Feasibility Study
PLC	programmable logic controller
Project	Songwe Hill Rare Earth Element Project
PSD	particle size distribution
QA	quality assurance
QC	quality control
QP	Qualified Person
R&R	rest and relaxation
RAP	Resettlement Action Plan
RCP	Rehabilitation and Closure Plan
REE	rare earth element
REO	rare earth oxide
RFBP	request for budget pricing
ROM	run of mine
SAG	semi-autogenous grinding
SAIMM	Southern African Institute of Mining and Metallurgy

Abbreviation	Description
SCADA	supervisory control and data acquisition
SG	specific gravity
SHE	safety health environmental
SIA	Social Impact Assessment
SLD	single-line diagram
SMC	SAG mill comminution
SMPP	structural, mechanical, plate work and piping
SWCD	storm water control dam
SWMP	Storm Water Management Plan
TBA	To be advised
TBC	To be confirmed
TDS	total dissolved solids
TREO	total rare earth oxide
TSF	tailings storage facility
TSS	total suspended solids
TSX	Toronto Stock Exchange
UCS	uniaxial compressive strength
UPS	uninterruptible power supply
UTM	Universal Transverse Mercator
VGF	vibrating grizzly feeder
VSD	variable-speed drive
VU	Vulnerable
WHO	World Health Organisation
WMF	waste management facility
WRD	waste rock dump
XRF	X-ray fluorescence

1 SUMMARY

1.1 INTRODUCTION

Mkango Resources Limited (Mkango) is a Canadian exploration and development company dual listed on the UK AIM (Alternative Investment Market) and Canadian TSX-V (Toronto Venture Exchange) (www.mkango.ca). Through its wholly owned subsidiaries, Mkango owns the Songwe Hill Rare Earth Element Project in Malawi (Songwe Hill) and the Pulawy Separation Plant Project in Poland (Pulawy).

Songwe Hill is expected to produce a purified mixed rare earth carbonate concentrate, which will be shipped to Pulawy for processing into separated rare earth oxides for sale to pre-agreed offtakers.

Mkango commissioned SENET, a DRA Global Group Company, to complete a definitive feasibility study (DFS) for the Songwe Hill Rare Earth Element Project. The Songwe Hill REE Project DFS report dated July 2022 was used as the basis for this NI 43-101 Technical Report.

Rare earth elements (REEs) have become critical to technologies fundamental to clean energy initiatives worldwide, as well as ubiquitous gadgetry and electronics of modern society. Compared to similarly abundant elements in nature, such as copper, lead, and tin, global annual production of REEs is notably low. REEs are used in small, but often necessary, amounts in hundreds of different technologies, materials, and chemicals worldwide for commercial, industrial, social, medical, and environmental applications. In just a few decades, REEs have become entrenched in modern technology and industry and have proven exceptionally challenging to duplicate or replace.

REEs are not remarkably rare in nature, but rather are rarely concentrated into economically significant amounts for extraction and processing owing to certain physical and chemical characteristics that promote their broad dissipation in most rock types.

This report sets out the Mineral Resource Estimate, Mineral Reserve Estimate, production schedules, and the capital cost (CAPEX) and operating cost (OPEX) over the life of the project, culminating in a full economic analysis of the project’s value.

1.2 PROPERTY DESCRIPTION

Songwe Hill is located in south-eastern Malawi, between Lake Chilwa and the Mulanje Massif, and close to the eastern border of Malawi with Mozambique (see Figure 1.1). It lies within Retention Licence (RTL) 0001/21, which is one of a block of 11 retention licences (RTL 0001/21 to RTL 0011/21) that Mkango refers to as the “Phalombe Licences”.

RTL 0001/21 lies entirely within the Southern Region of Malawi, and Songwe Hill is within the Phalombe administrative district. It lies approximately 70 km in a straight line southeast from Zomba (the former capital of Malawi) and approximately 90 km in a straight line east-northeast of the commercial centre of Blantyre. Songwe Hill can be reached from these centres via national highways S144 and S145, respectively. At Migowi, the S145 passes within 15 km of Songwe Hill. Along that distance from Migowi to the Maoni village, the Malawi Roads Authority is currently widening the government road from a single-width dirt track to an all-weather graded and gravelled mine road with new reinforced concrete bridges and culverts.

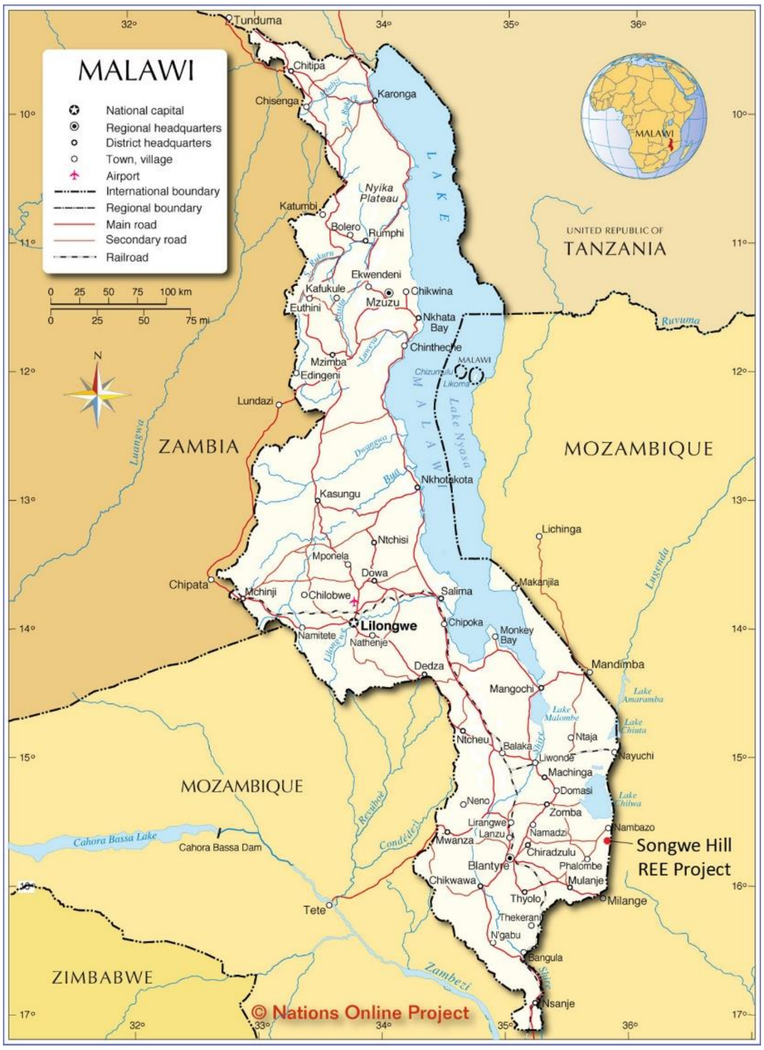


Figure 1.1: Location of Songwe Hill in Malawi

1.3 GEOLOGY AND MINERALISATION

Songwe Hill is interpreted as a carbonatite intrusion–breccia complex expressed as a steep-sided hill approximately 800 m in diameter. The carbonatites are best exposed along the north-eastern slope of Songwe Hill and in a somewhat smaller area along its north-western edge, Surface mapping and diamond core drilling indicate that the complex consists of a multi-phase intrusion characterised by early intrusion of nepheline syenite and phonolite cut by diverse carbonatites and breccias exhibiting a range of alteration from potassic fenitisation to low-temperature hydrothermal/carbohydrothermal overprinting. The entire complex is cut by phonolite dykes, which appear to represent either a continuous event or multiple pulses during and after carbonatite emplacement.

The principal lithologies that comprise the Songwe Hill vent complex are carbonatite, fenite, breccia and phonolite. Three carbonatite phases have been recognised, and all are variably mineralised. The fenites comprise dominantly K-feldspar-rich alteration products of phonolite and nepheline syenite, and broadly occur as an aureole around the carbonatite intrusion. The breccias range from clearly abraded pebble-sized fragments (pebble dykes) to angular blocks that are metres in diameter and include significant volumes of breccia in which the fragments appear to have undergone little or no movement. The breccias can be divided into two types: fenite-rich breccias and carbonatite-rich breccias and are interpreted to be related to high-level explosive processes during the formation of the vent complex. Phonolites are variably altered and occur mainly as dykes that both pre-date and post-date mineralisation and fenitisation.

There are also late calcic, Mn-Fe-rich veins and dykes that are locally mineralised, and minor occurrences of late calcite-barite-apatite-fluorite bearing veins, which are widely dispersed and locally enriched in REEs.

Geological and geochemical modelling of the intrusive-breccia complex suggests that the complex can be broadly described as a central, steep-sided carbonatite plug with complex intrusive margins, that is mantled and intimately associated with the breccias and haloed by fenite. The principal zone of REE mineralisation comprises mainly the carbonatite intrusions and carbonatite-rich breccias that are closely related spatially to the intrusion. The principal REE-bearing minerals are synchysite and apatite, with minor florencite.

The complex has been affected by late faulting, reflected in the geology and magnetics, which has locally produced foliation in the rocks. A number of faults, which help explain map patterns but generally have small displacements, have been tentatively identified.

1.4 STATUS OF EXPLORATION

The first Mineral Resource estimate in accordance with NI 43-101 was reported in 2012 based on geochemical analyses and density measurements of core samples obtained from 38 diamond drillholes completed by Mkango in 2011 and 2012. An additional 91 diamond drillholes were completed by Mkango in 2018. The areas drilled to date are in an elevated position on the northern slopes of Songwe Hill, which rises approximately 230 m above the surrounding plain. The 2018 drillhole programme aimed to increase the confidence in the Mineral Resource by infill drilling as well as to expand the Mineral Resource area. A new Mineral Resource in accordance with NI 43-101 was announced in 2019.

Drilling was carried out on east-west oriented section lines spaced 30 m apart. The drillholes were inclined predominantly to the east and west with additional holes inclined to the north and south. This resulted in a network of drillholes with variable spacing, generally 30 m along sections in the better drilled areas in the south and east of the project and between 40 m and 50 m in the other areas, with the closest spaced drilling being in the upper 120 m of the deposit. Drilling to a maximum of approximately 350 m below surface has demonstrated the existence of mineralised carbonatite at this depth, and the deposit remains open at depth.

There are no exploration activities currently occurring at Songwe Hill.

1.5 MINERAL RESOURCE ESTIMATE

The Mineral Resource estimate is based on REE, thorium, uranium, iron, manganese, aluminium, silica, potassium and density measurements obtained from the cores of 129 diamond drillholes, which were completed in three phases of drilling (2011, 2012 and 2018).

For the purposes of Mineral Resource definition, three lithological domains were identified in the Songwe Hill deposit: a carbonatite domain; a fenite domain; and a “mixed” domain consisting of breccia and/or finely intermixed carbonatite and fenite. The carbonatite domain tends to contain the highest concentration of REE mineralisation with the lowest concentration being in the fenite, which grades to barren in places. A 15 % calcium threshold was used to distinguish between carbonatite and non-carbonatite rocks.

An indicator approach was used to estimate the proportion of carbonatite dominant to fenite dominant rocks in each of the 20 mX by 20 mY by 5 mZ cells in the block model. Ordinary kriging was used to estimate the attributes into the block model separately for carbonatite and non-carbonatite sample composites. The final grade assigned to the block model was proportioned for the two lithological domains using the proportions estimated by the indicator model.

The Mineral Resource forms an irregular, roughly circular surface expression with a diameter of approximately 450 m. The maximum depth of the Inferred Mineral Resource is 390 m below surface, with the Measured and Indicated Mineral Resource occurring to a maximum depth of 200 m, paralleling the topographic surface of the hill and surrounding plain. The majority of the Measured and Indicated Mineral Resource occurs to a depth of approximately 160 m. Extrapolation in the Inferred area was limited to a maximum of 50 m from the drilling area.

The Mineral Resource was estimated using the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Best Practice Guidelines (2003) and is reported in accordance with the 2014 CIM Definition Standards, which have been incorporated by reference into National Instrument 43-101 – *Standards of Disclosure for Mineral Projects* (NI 43-101). The Mineral Resource is classified into the Measured, Indicated and Inferred categories as shown in Table 1.1.

The Mineral Resource is reported at a base case total rare earth oxide (TREO) grade of 1.00 %, which the Qualified Person (QP) considers will satisfy reasonable prospects for eventual economic extraction.

Table 1.1: Songwe Hill Mineral Resource at 1.00 % TREO Cut-Off Grade, 23 January 2019

Category	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
Measured	8.81	1.50	131.9
Indicated	12.22	1.35	165.5
Total M&I	**21.03**	**1.41**	**297.4**
Inferred	27.54	1.33	366.2
NOTES: 1. All tabulated data has been rounded, and as a result minor computational errors may occur. 2. Mineral Resources, which are not Mineral Reserves, have no demonstrated economic viability. 3. Quantities reported are the total quantities for the project regardless of ownership.			
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

The Mineral Resource is tabulated using a number of cut-off grades as shown in Table 1.2 for the Measured and Indicated Mineral Resource and in Table 1.3 for the Inferred Mineral Resource.

Table 1.2: Songwe Hill, Measured and Indicated Mineral Resources Grade and Tonnage, 23 January 2019

Cut-Off Grade (TREO %)	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
0.50	37.64	1.13	425.67
0.75	30.45	1.25	379.90
1.00	**21.03**	**1.41**	**297.40**
1.25	12.44	1.62	201.20
1.50	6.80	1.83	124.08
1.75	3.27	2.05	2.05
2.00	1.12	2.35	26.32
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

Table 1.3: Songwe Hill, Inferred Mineral Resources Grade and Tonnage, 23 January 2019

Cut-Off Grade (TREO %)	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
0.50	59.65	1.02	608.19
0.75	43.74	1.16	507.12
1.00	**27.54**	**1.33**	**366.15**
1.25	14.35	1.52	218.44
1.50	5.92	1.75	103.41
1.75	2.23	2.00	44.44
2.00	0.92	2.21	20.28
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

1.6 DEVELOPMENT AND OPERATIONS

1.6.1 Mining Methods

The mining method at Songwe Hill will be conventional open-pit mining, making use of relatively small-scale trucks and diesel-hydraulic excavators, selected to match the mining conditions and required production rates.

1.6.2 Mining Geotechnical Study

Bara subcontracted Middindi Consulting to carry out an open-pit slope design for the Songwe Hill Project at a DFS level of accuracy. The study addresses the geotechnical characteristics of the rock mass within the planned open-pit area, the methods used for the slope design, and the pit slope configurations obtained.

Figure 1.2 shows the sectors of the open pit for which different slope configurations were developed.

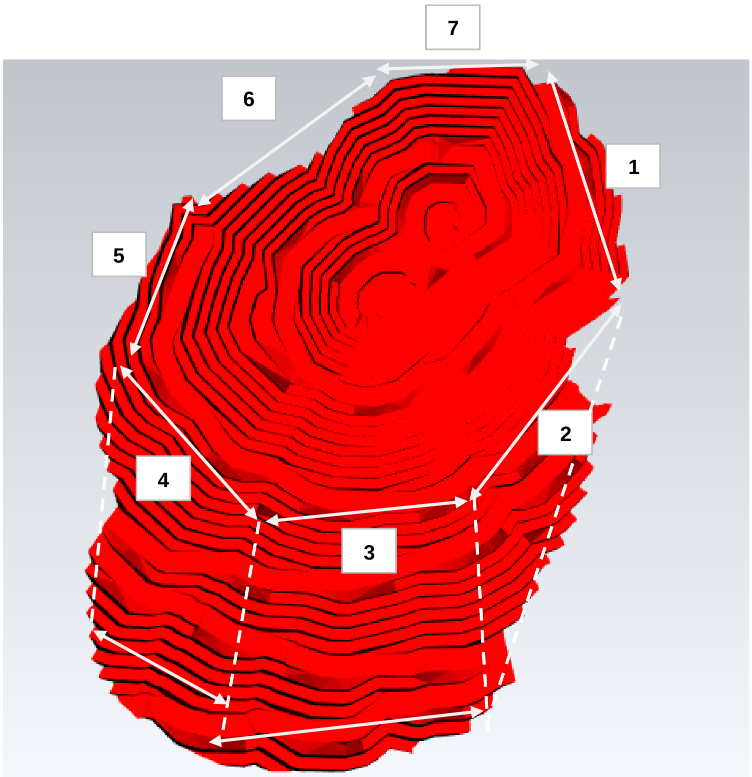


Figure 1.2: Pit Shell Layout Showing Design Sectors of Fresh Material

The final slope configurations recommended by the geotechnical study are given in Table 1.4.

Table 1.4: Summary of Slope Configurations

Design Sector	Stack No.	Geotechnical Domain	No. of Benches	Bench Face Angle (°)	Max. Bench Height (m)	Min. Bench Width (m)	Geotechnical Bench Width (m)	Stack Angle (°)	Overall Slope Angle (°)
1	1	Weathered, Trans-Fresh	5	70	10	5	12	49	47
	2	Transitional	4			5	12.5	49	
	3	Transitional	3			5	Pit floor	49	
2	1	Weathered	2	70	10	5	10	49	44
	2	Trans-Fresh	3			5.5	9	48	
	3	Trans-Fresh	4			5.5	12	48	
	4	Transitional	3			6	10	46	
	5	Transitional	5			6	Pit floor	44	
3 and 4	1	Weathered	2	70	10	5	10	49	40
	2	Transitional	4			8	12.5	41	
	3	Trans-Fresh	4			7.5	12	42	

Design Sector	Stack No.	Geotechnical Domain	No. of Benches	Bench Face Angle (°)	Max. Bench Height (m)	Min. Bench Width (m)	Geotechnical Bench Width (m)	Stack Angle (°)	Overall Slope Angle (°)
	4	Transitional	4			8	12	37	
	5	Poor Quality	3			5	10	49	
	6	Trans-Fresh	4			7.5	12	42	
	7	Trans-Fresh	3			7.5	9	42	
	8	Transitional	4			8	12.5	41	
	9	Transitional	3			8	Pit floor	41	
5	1	Weathered, Trans-Fresh	6	70	10	5	15	45	42
	2	Transitional	4			7	12.5	43	
	3	Transitional	4			7	Pit floor	43	
6	1	Weathered, Trans-Fresh	6	70	10	5	15	45	43
	2	Transitional	4			6	12.5	46	
	3	Transitional	3			6	Pit floor	46	
7	1	Weathered, Trans-Fresh	5	70	10	8.5	12	39	39
	2	Transitional	6			9	Pit floor	36	

1.6.3 Pit Optimisation

A pit optimisation exercise was undertaken based on the input parameters shown in Table 1.5.

Table 1.5: Pit Optimisation Input Parameters

Item	Value	Unit	Comments/Source
Operating Cost			
Waste			
Mining Cost – Free Dig	2.51	US$/t mined	Mining contract submission (Digmin)
Mining Cost – Drill and Blast	3.53	US$/t mined	Mining contract submission (Digmin)
Ore			
Mining Cost – Free Dig	3.28	US$/t mined	Mining contract submission (Digmin)
Mining Cost – Drill and Blast	4.26	US$/t mined	Mining contract submission (Digmin)
Process Cost	106.65	US$/t milled	Provided by SENET
General and Administrative Cost	5.31	US$/t milled	Provided by SENET
Technical			
Slope Angles (Sector 1)	49	degrees	Geotechnical report
Slope Angles (Sector 2)	44	degrees	Geotechnical report
Slope Angles (Sectors 3 and 4)	40	degrees	Geotechnical report

Item	Value	Unit	Comments/Source
Slope Angles (Sector 5)	43	degrees	Geotechnical report
Slope Angles (Sector 6)	46	degrees	Geotechnical report
Slope Angles (Sector 7)	36	degrees	Geotechnical report
Mining Dilution	5	%	Bara
Mining Loss	5	%	Bara
Bench Height	10	m	Bara
Metallurgical Recovery	44.5	%	Based on all metals, recovery to carbonate
To Carbonate	39.4	%	Recovery to carbonate
To Saleable Metal	98.0	%	Separation recovery from carbonate
Ore Production Rate	83,333	kt/month	Per month – **ORE** only, Mkango to advise
Ore Production Rate	1,000,000	kt/a	
Economic			
Royalties	5	%	Covered in basket price calculation
TREO Price (Basket Price)	34.2	US$/kg	Value in carbonate pre-discounts
Separation Costs	2,500	US$/t TREO in carbonate	Based on assumed separation costs
Discount Factor to Use	7.3	%	Provided by Mkango

In order to maximise the net present value (NPV), while maintaining an acceptable LOO, a number of scenarios were tested applying the following:

- A cut-off grade varying from 0.6 % to 1.2 % TREO
- Varying cut-off grades over time

Based on the results, the 0.6 % TREO_PCT cut-off grade produced the most favourable final pit shell. A phased cut-off grade was selected with a cut-off grade of 1.2 % TREO_PCT applied in Years 1 to 5 and a cut-off grade of 0.6 % TREO_PCT applied thereafter. Any medium-grade material mined in the first five years will be stockpiled for processing later in the LOO.

The final selected pit shell contains 18.3 Mt of Type 1 ore at an average grade of 1.22 % TREO.

1.6.4 Mine Design and Schedule

The pit design was structured around the strategy of Phase 1 accessing high-grade Type 1 ore for the first five years and stockpiling any medium-grade Type 1 ore to feed as run of mine (ROM) at a later stage. The high-grade pit shell from the pit optimisation was used as a guide for the design of the first five-year pit.

The final pit pushback Phase 2 was then designed to the final pit limits, and the final pit shell from the pit optimisation was used as a guide.

The final pit design, illustrated in Figure 1.3 and Figure 1.4, is approximately 660 m north to south, 550 m east to west, and has a depth of 354 m from the pit rim on the south side (top of Songwe Hill) and 134 m on the north side (bottom of Songwe Hill).

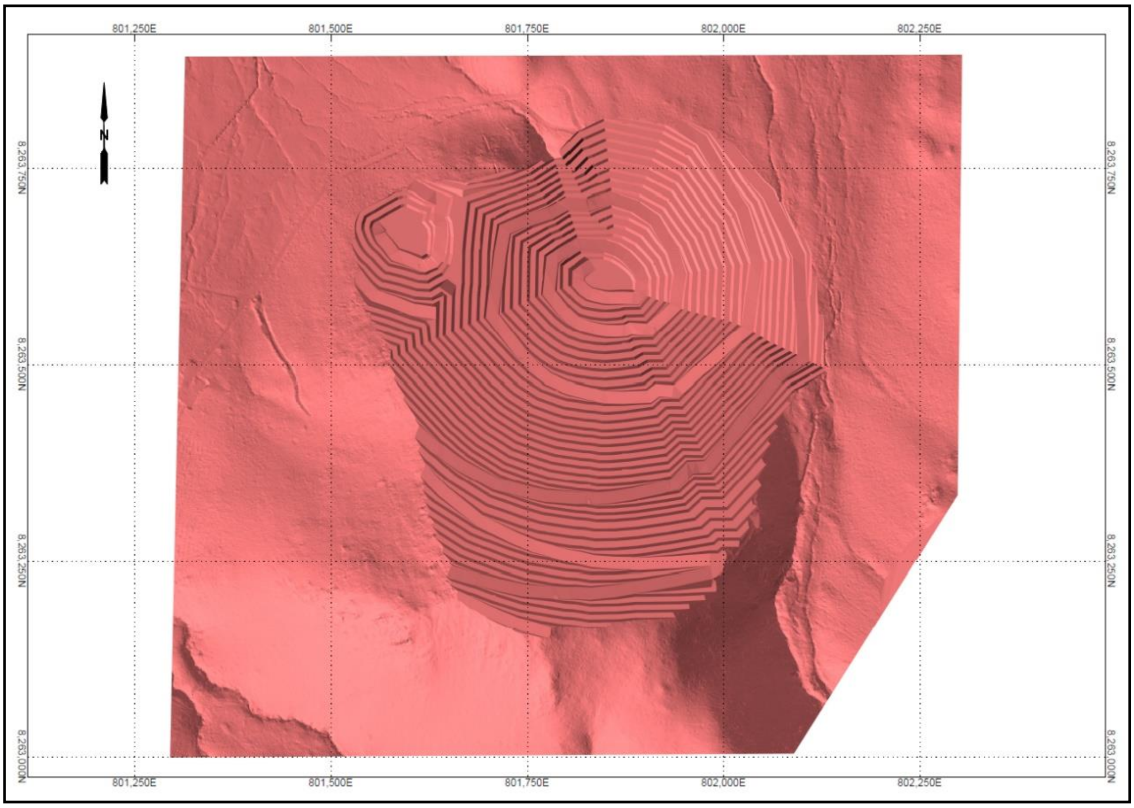


Figure 1.3: Plan View of Final Open Pit

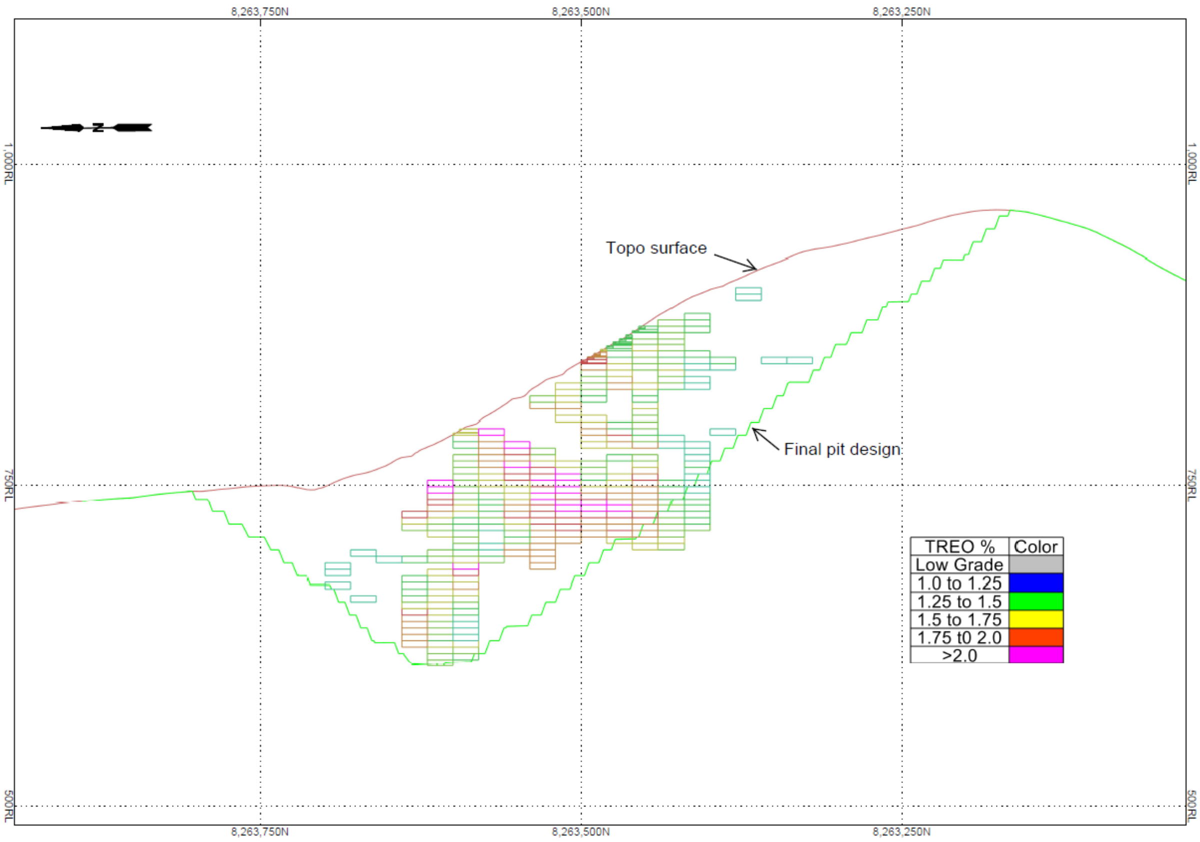


Figure 1.4: Cross Section through Final Open Pit

Modifying factors have been applied to the mineral resource to emulate practical mining conditions and estimate the mining inventory that will be delivered to the plant as ROM production. Modifying factors that have been applied are as follows:

- Ore recovery of 95 %.
- External dilution of 3 % – This is waste at zero grade added to the ore volume to account for inaccuracies in mining.
- Internal dilution of 5 % at a grade of 0.68 TREO %. Internal dilution is made up of a combination of Inferred resources, Type 2 material, and low-grade ore waste, all of which are treated as waste material in the mine design but are included in the mining blocks.

The mining inventory resulting from the final pit design is given in Table 1.6.

Table 1.6: Mining Inventory from Pit

Description	Value
ROM Tonnes Type 1 Ore (high grade and medium grade)	18,246,334
ROM TREO Grade (%)	1.18
Contained TREO (t)	215,619
Waste Tonnes	12,126,184
Tonnes Type 1 Ore (below cut-off grade)	3,948,187
Tonnes Type 2 Material	12,657,310
Inferred Tonnes	11,389,822
Total Waste Tonnes	40,121,503
Strip Ratio	2.23

A mining schedule was developed, targeting the design plant throughput of 1,0 Mt/a of ore. The monthly mining schedule is illustrated in Figure 1.5.

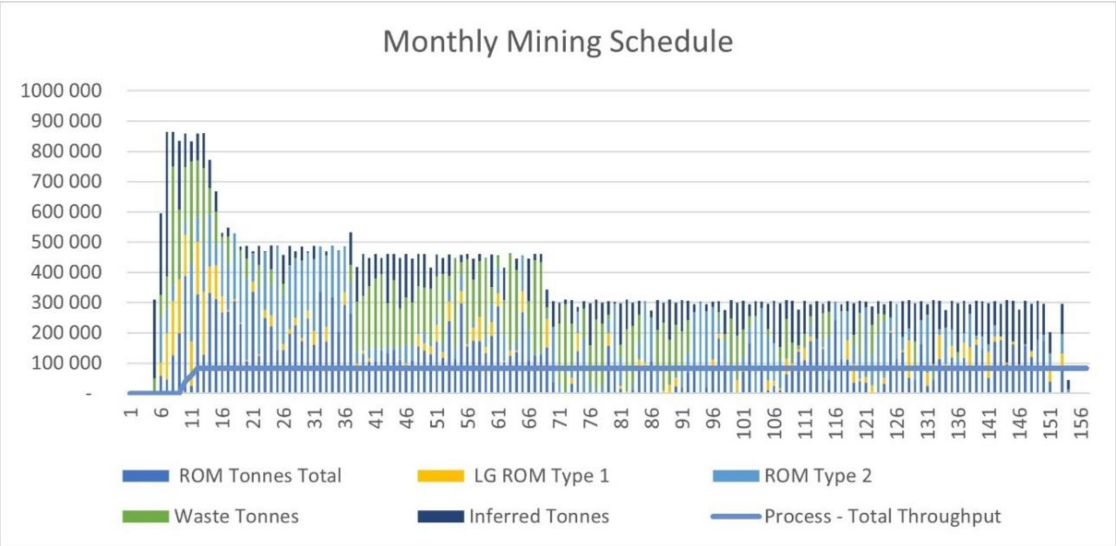


Figure 1.5: Monthly Mining Production Profile

1.6.5 Mining Operations

The mining operation at Songwe Hill will be outsourced to a contract mining company. Ore and waste will be drilled and blasted, then excavated using a hydraulic shovel and loaded onto dump trucks for hauling out of the pit to the ROM stockpile or waste dumps.

The mining will be done using 90 t excavators loading into 40 t articulated dump trucks.

1.6.6 Waste Dump and Stockpiles

The mining of the REE resource at Songwe Hill will produce various grades of ore and waste rock.

The mined materials (excluding high-grade ore) that require storage include the following:

- Waste rock
- Medium-grade ore
- Low-grade ore (Type 2 material)

The high-grade ore will be mined and transported directly from the pit to the ROM pad and blending area.

The positions of the waste dump and stockpiles are shown in Figure 1.6.

Figure 1.6: Positions of Mined Material Storage Facilities

1.7 MINERAL RESERVE ESTIMATE

Table 1.7 shows a summary of the total Mineral Reserves.

Table 1.7: Mineral Reserve Summary as at 31 December 2021

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

1.8 RECOVERY METHODS

1.8.1 Concentrator

Songwe Hill is a rare earth element deposit in the south-eastern region of Malawi. It comprises mostly carbonaceous gangue minerals and rare earths associated with oxides. Minor amounts of sulphide minerals are also present. The purpose of the concentrator plant or “front end” is to produce a rare earth oxide concentrate, which is to be treated in a subsequent hydrometallurgical plant.

Flotation of oxide minerals is typically more difficult to achieve than flotation of sulphide minerals, and a defining characteristic of this project has been to develop a flotation circuit and reagent suite that effectively float the rare earth oxides from the other oxidic gangue. The key in achieving flotation recovery lies in the combination of fine grinding, high-intensity conditioning, elevated temperature, and the correct reagent suite and dosages.

Continuous flotation test work drove the development of the process design, and the current flotation circuit has been proven to produce good recoveries and concentrate grades. SENET also conducted a trade-off study on the comminution circuit in order to develop a circuit in which a fine grind size can be achieved with optimal OPEX and CAPEX.

The crushing circuit consists of a primary jaw crusher and secondary and tertiary cone crushers. Primary and secondary screens are used to optimise the size of the crushers. The crushed product is milled in a ball mill in closed circuit with a primary cyclone cluster. The cyclone overflow is ground in stirred media mills and classified before being pumped to the flotation circuit.

The flotation circuit starts with sulphide pre-float rougher and cleaner cells to remove sulphide minerals ahead of the main rare earth oxide flotation. Pre-float tails are conditioned and fed into rare earth oxide roughers and scavengers. The rougher and scavenger concentrate is treated in cleaner cells, and the cleaner concentrate ultimately reports to the concentrate thickener. The cleaner tails are treated in cleaner scavenger cells, and the concentrate is recycled to the rougher scavenger feed. The rougher, scavenger and cleaner scavenger tails report to the tailings thickener and are pumped to a TSF.

Figure 1.7 shows the high-level flowsheet of the concentrator plant.

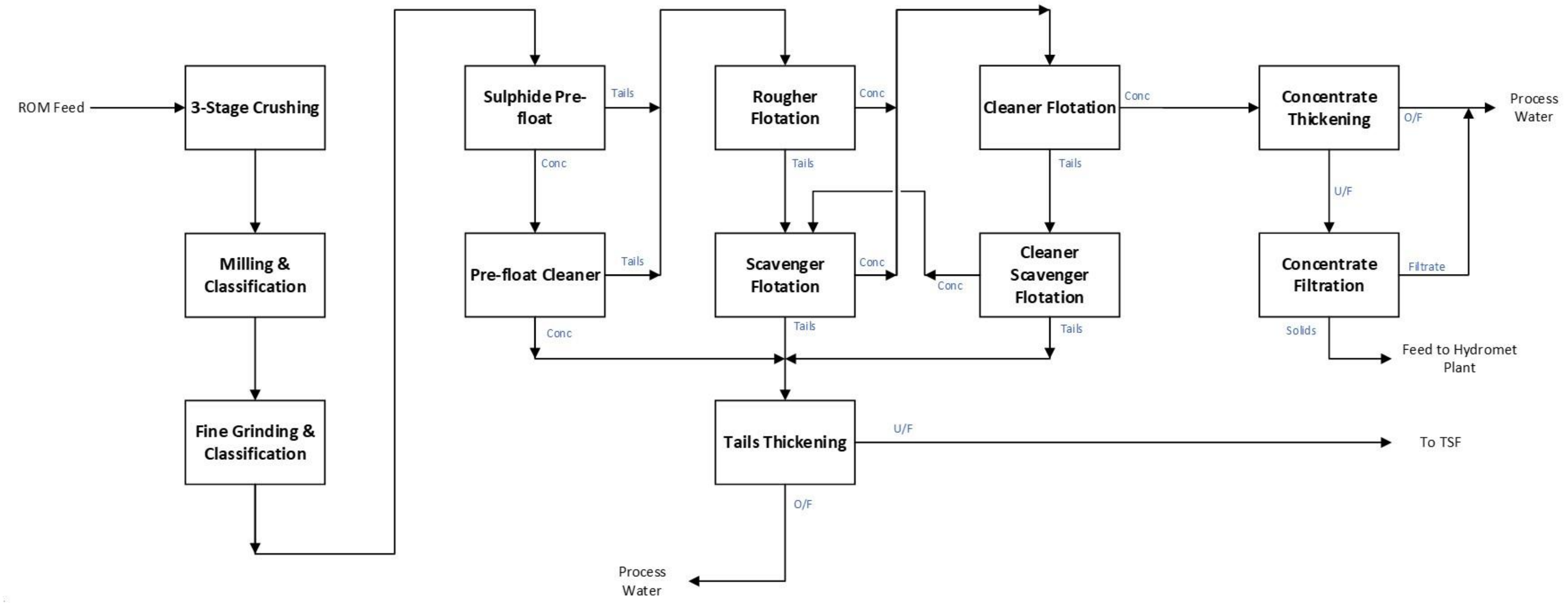


Figure 1.7: Concentrator Plant Flowsheet

1.8.2 Process Water Distribution

The sources of process water are the concentrate thickener overflow, tailings thickener overflow, the raw water top-up, and TSF return water. Process water is used in milling and the flotation circuits for dilution, launder spray water, flushing, hosing, and screen washing applications. Process water from the flotation concentrate thickener and flotation tails thickener is still at the flotation temperature – approximately 50 °C. This thickener overflow is not sent to the TSF because of the contained heat that will be lost. Instead, it is stored in a separate pond with an interchange heat exchanger to salvage heat from the incoming solution and transfer it to the process water stream being pumped to the milling and flotation circuit.

The following solution streams are sent to the TSF:

- Moisture with the flotation tails slurry
- Moisture with the hydrometallurgical plant waste residue filter cakes
- Barren solution from rare earth carbonate precipitation (containing chlorides and ammonium)

The TSF is lined and sized to accommodate the impurities present in the above-mentioned moisture streams based on the geochemical characterisation performed by SGS.

The TSF return stream to the process water pond has the ability to be wholly or partially fed through a reverse osmosis plant, which will prevent the build-up of deleterious elements in recirculating water streams from the plant. Impurities that build up in the process water stream with repeated circulation in the flotation circuit will also be removed in the process water reverse osmosis plant, as will any impurities present in the borehole water entering the system as top-up to accommodate moisture losses in the processing plant.

The SENET mass balance has included hydrological studies from the environmental and tailings consultants to determine the level to which elements such as chlorine and ammonium will build up in the TSF return water stream.

During the next phase of study, options will be evaluated to further reduce the recirculating chloride and ammonium quantities, with the possibility of regenerating reagents for reuse in the plant or for sale to external customers.

1.8.3 Hydrometallurgical Plant

The hydrometallurgical plant receives the flotation concentrate from the flotation plant, and treats it with an up-front gangue leach to dissolve the acid-consuming gangue minerals with dilute acid to decrease the overall acid consumption and to reduce the impurity carry-over to the purification and recovery stages. Gangue leach liquor is purified to precipitate impurities, filtered, and dosed with calcium chloride and sulphuric acid to regenerate hydrochloric acid and produce solid gypsum for possible sale.

Gangue leach residue is contacted with concentrated NaOH solution at a high temperature in order to convert insoluble rare earth phosphates and other minerals into soluble rare earth hydroxides in the caustic conversion. The caustic conversion residue proceeds to cerium oxidation, where the slurry is sparged with air to oxidise cerium and render it insoluble in the subsequent rare earth leach. This is because cerium is an undesirable element in the final rare earth product. The caustic conversion solution is evaporated to reconcentrate it and then undergoes a causticisation process to regenerate sodium hydroxide for reuse in the process.

Cerium oxidation residue is thickened and filtered before being fed into a more severe rare earth leach with hydrochloric acid. The leach residue is thickened and filtered before being repulped in the hydrometallurgical tails neutralisation area, and then combined with flotation and other hydrometallurgical tails streams to be sent to the TSF. Rare earth leach liquor is purified of heavy metals, radionuclides and uranium, before being precipitated as a mixed rare earth carbonate product.

Figure 1.8 shows the high-level flowsheet of the hydrometallurgical plant.

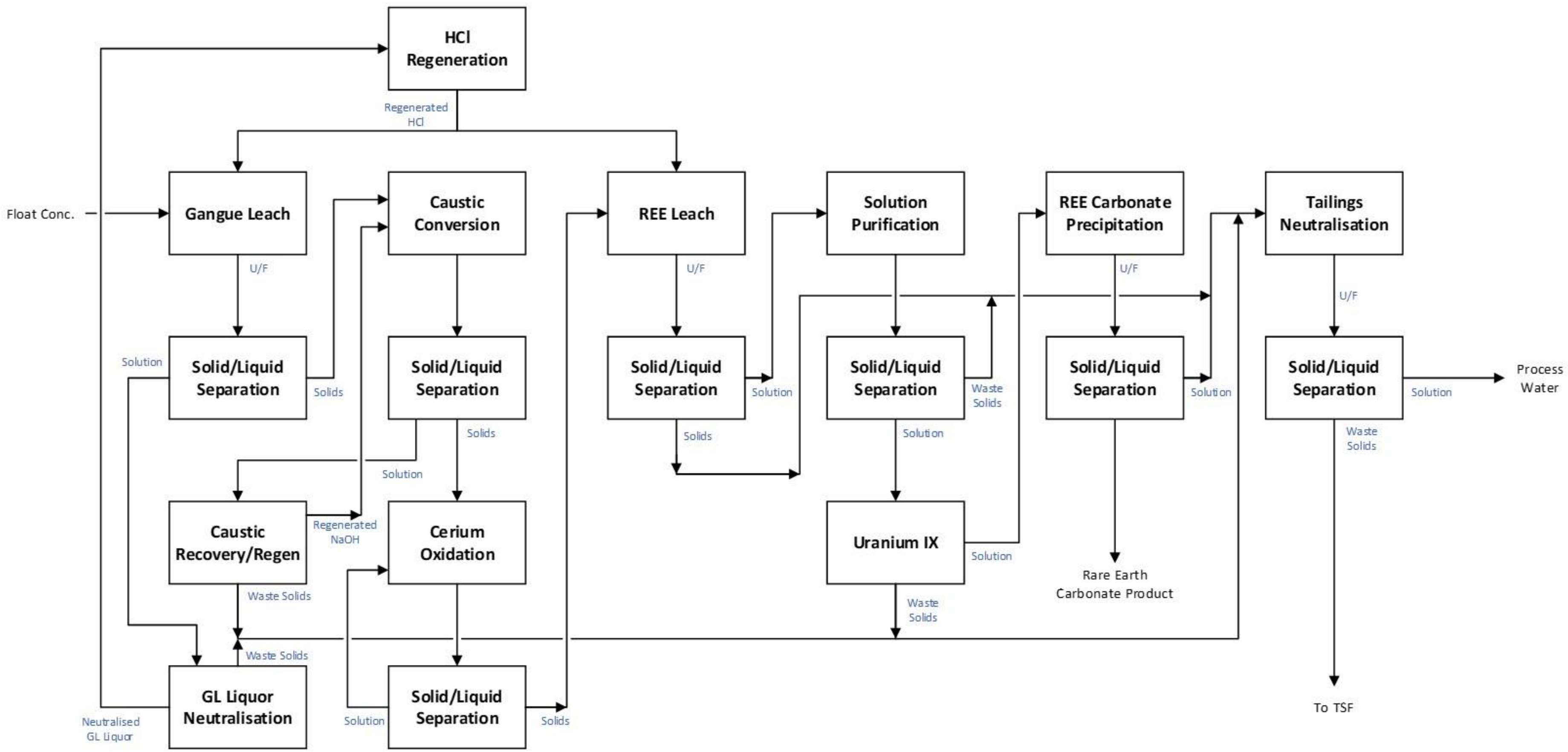


Figure 1.8: Hydrometallurgical Plant Flowsheet

1.9 CAPITAL AND OPERATING COSTS

1.9.1 Capital Costs

The CAPEX estimate includes engineering, procurement, construction, start-up and cold commissioning for the mining, process plant, TSF and infrastructure. Provision has also been made for the Owner's costs.

The estimate is within the required accuracy level of +15 % −10 %. The estimate covers the direct field costs of executing the project; the indirect costs associated with the design, construction and commissioning of the new facilities; and the Owner's support costs for items such as management teams, operational staff, environmental costs, permitting, insurance and utilities such as water supply, PV solar power and emergency power generation.

The total development/initial capital cost for the Songwe Hill Rare Earth Element Project was estimated to be **US$311,157,744,** which includes project execution, EPCM and contingency costs. These capital costs are summarised in Table 1.8.

Table 1.8: Initial/Development CAPEX Summary

Description	Capital Cost	Contingency	Total Capital Cost
	US$	US$	US$
Earthworks	7,470,560	1,120,584	8,591,144
Civil Works – Plant	17,336,477	2,600,471	19,936,948
Civil Works – Infrastructure	1,717,576	257,636	1,975,212
Infrastructure	2,993,326	299,333	3,292,658
Structural Steel	6,239,267	748,712	6,987,979
Plate Work	2,699,408	323,929	3,023,337
Tankage	4,509,659	541,159	5,050,818
Machinery and Equipment	51,550,103	5,155,010	56,705,113
Piping	5,776,188	866,428	6,642,616
Valves	1,763,011	264,452	2,027,463
Electricals	10,505,600	1,050,560	11,556,160
Instrumentation	5,178,489	776,773	5,955,263
Transport	4,389,373	658,406	5,047,778
Electrical and instrumentation (E&I) Installation	6,715,672	1,007,351	7,723,023
Structural, mechanical, plate work and piping (SMPP) Installation	21,862,300	3,279,345	25,141,645
TOTAL DIRECT FIELD COSTS	150,707,010	18,950,150	169,657,160
Commissioning Spares	243,050	36,458	279,508
2-Year Operational Spares	2,633,275	394,991	3,028,266
Insurance and Critical Spares	2,020,419	303,063	2,323,482
Vendor Services	2,596,685	389,503	2,986,188
First Fills	558,554	83,783	642,337
TOTAL INDIRECT FIELD COSTS	**8,051,983**	**1,207,798**	**9,259,781**
TOTAL FIELD COST	**158,758,993**	**20,157,947**	**178,916,941**

Description	Capital Cost	Contingency	Total Capital Cost
	US$	US$	US$
Project Management (EPCM)	23,318,266	3,497,740	26,816,006
Insurances and Guarantees	3,175,180	0	3,175,180
TOTAL EPCM COSTS	**26,493,446**	**3,497,740**	**29,991,186**
TOTAL PROJECT COST	**185,252,439**	**23,655,687**	**208,908,127**
Mobile Plant and Equipment	4,087,295	613,094	4,700,389
Generator Plant	5,469,482	820,422	6,289,904
PV Solar Plant	21,327,663	3,031,646	24,359,308
Construction Camp	3,567,379	535,107	4,102,486
TSF Phase 1 and RWD	31,225,050	2,420,546	33,645,596
Mining Pre-Production	13,972,675	2,095,901	16,068,576
Other	12,460,340	623,017	13,083,357
TOTAL OTHER COST	**92,109,883**	**10,139,734**	**102,249,617**
TOTAL INITIAL COST	**277,362,322**	**33,795,421**	**311,157,744**

The total sustaining capital cost for the Songwe Hill Rare Earth Element Project was estimated to be **US$77,633,048,** which includes TSF, mining, owner's cost, closure cost and contingency costs. These capital costs are summarised in Table 1.9.

Table 1.9: Sustaining CAPEX Summary

Description	Capital Cost	Contingency	Total Capital Cost
	US$	US$	US$
TSF Sustaining Capital – Phases 2 to 5	49,551,380	3,841,192	53,392,572
Mining Sustaining Capital	896,618	134,493	1,031,111
Closure Cost	15,616,797	961,460	16,578,257
Owners Cost	6,028,280	602,828	6,631,108
TOTAL SUSTAINING COST	**72,093,075**	**5,539,973**	**77,633,048**

1.9.2 Operating Costs

The purpose of this OPEX estimate is to provide operating costs, and the associated general and administration (G&A) costs, to an accuracy of +15 % to −10 % that can be utilised for the economic analysis of the Songwe Hill Rare Earth Element Project.

The project's annual OPEX estimate for the first five years of production consists of the following:

- Mining operating costs estimated by Bara
- Process plant operating costs estimated by SENET
- TSF operating costs estimated by Epoch

The OPEX for the first five years of production for the Songwe Hill Rare Earth Element Project is summarised in Table 1.10, with the cost distribution shown in Figure 1.9.

Table 1.10: First Five Years of Production OPEX Summary

Description	Cost				Cost Distribution
	US$ million/a	US$/t ROM	US$/t REE	US$/t REO	%
Mining	28,803,976	28.80	4,896.97	4,837.67	19.1
General and Administration	10,663,466	10.66	1,812.90	1,790.95	7.1
Reagents and Consumables	74,306,490	74.31	12,632.86	12,479.89	49.3
Power	25,499,432	25.50	4,335.16	4,282.67	16.9
Maintenance/Spares	2,816,157	2.82	478.78	472.98	1.9
Personnel	2,893,580	2.89	491.94	485.98	1.9
Site Laboratory	1,054,104	1.05	179.21	177.04	0.7
Product Transport	4,236,297	4.24	720.21	711.49	2.8
TSF	409,000	0.41	69.53	68.69	0.3
TOTAL	**150,682,504**	**150.68**	**25,617.56**	**25,307.35**	**100**

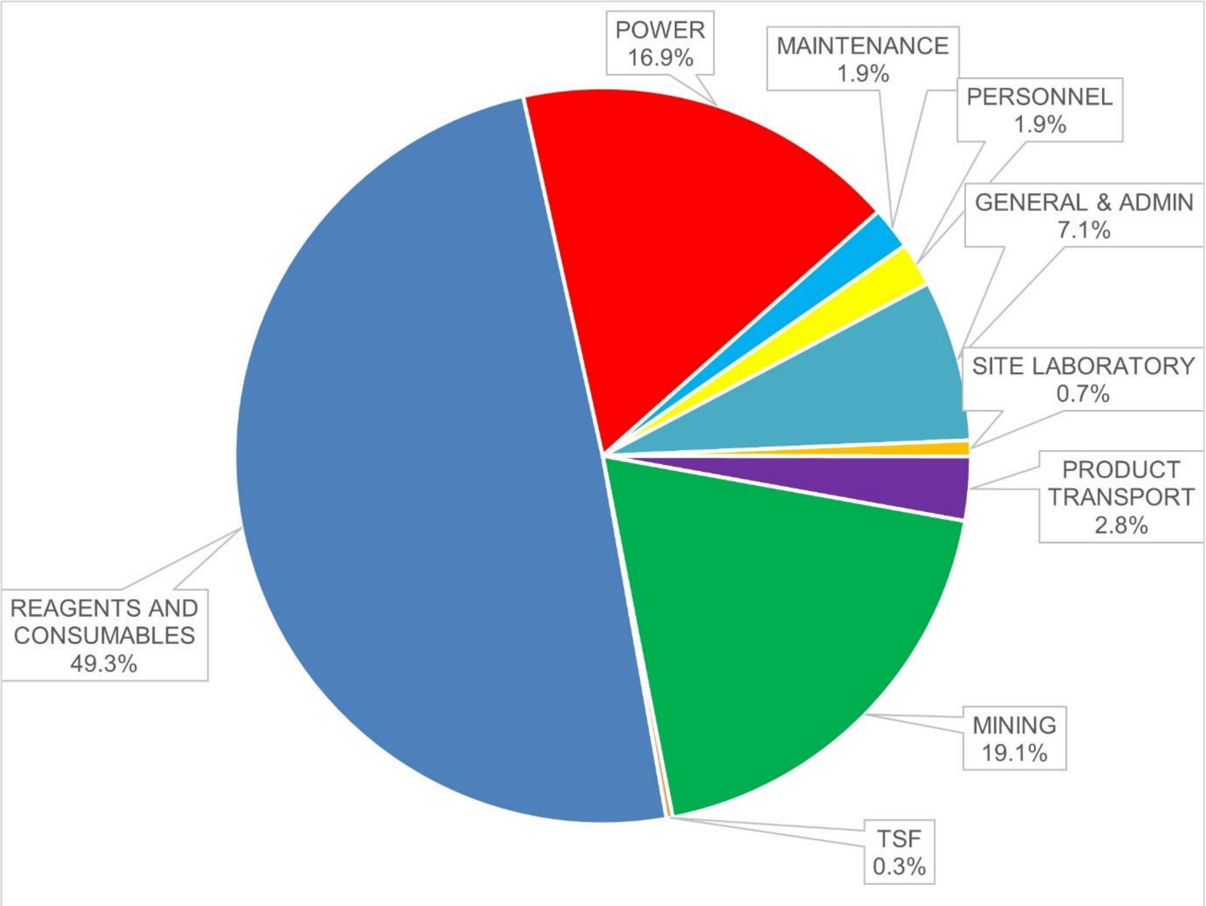


Figure 1.9: OPEX Distribution

1.10 MARKET STUDIES AND CONTRACTS

1.10.1 Rare Earth Market

The rare earth market and forecast information has been compiled by Adamas Intelligence, an independent research and advisory firm contracted by Mkango to forecast long-term supply, demand and prices for REEs as well as emerging trends in the market.

Compared to similarly abundant elements in nature, such as copper, lead, and tin, global annual production of REEs is notably low.

Nevertheless, REEs have become critical enablers of technologies at the heart of clean energy initiatives worldwide, as well as ubiquitous gadgetry and electronics that have pervaded modern society.

REEs are used in small, but often necessary, amounts in hundreds of different technologies, materials, and chemicals worldwide for commercial, industrial, social, medical, and environmental applications.

In just a period of decades, REEs have seeped deeply into the fabric of modern technology and industry and have proven exceptionally challenging to duplicate or replace.

REEs are not remarkably rare in nature, but rather are rarely concentrated into economically significant amounts for extraction and processing owing to certain physical and chemical characteristics that promote their broad dissipation in most rock types.

REEs are used in hundreds of unique end uses and applications that collectively fall into one of eight end-use categories: 1) battery alloys, 2) catalysts, 3) ceramics, pigments and glazes, 4) glass polishing powders and additives, 5) metallurgy and alloys, 6) permanent magnets, 7) phosphors, and 8) other end uses and applications.

By volume, permanent magnets and catalysts were collectively responsible for over 65 % of the global TREO consumption in 2021. However, by value, permanent magnets alone were responsible for 95 % of the total value of the global TREO consumption in 2021, and this share is poised to expand further as the demand for (and prices of) neodymium, praseodymium, dysprosium and terbium continues to rise strongly in the years ahead.

Not only does the demand for neodymium, praseodymium, dysprosium and terbium collectively make up the majority of global value currently, but in the years ahead demand for these four REEs is expected to grow faster than the demand for all the other REEs, challenging the ability of the supply side to keep up.

1.10.2 Forecasted TREO Demand by End-Use Category

Following a 7.1 % pandemic-induced drop in global TREO consumption in 2020, Adamas Intelligence data indicates that global consumption jumped 13.2 % higher in 2021, bolstered by the materialisation of pent-up consumer and industrial demand from 2020 (see Figure 1.10).

From 2022 through 2035, Adamas Intelligence forecasts that the global TREO demand will rise at a compound annual growth rate (CAGR) of 6.0 %, from 190,500 t to 407,500 t, driven primarily by the permanent magnet sector (see Figure 1.10).

The global TREO demand for permanent magnets and “other” end uses and applications is projected to rise at market leading CAGRs of 8.3 % and 7.0 %, respectively.

Conversely, the global TREO demand for all the other end-use categories, except for phosphors, is projected to grow at market lagging CAGRs of 2.1 % to 4.8 %, while the global TREO demand for phosphors is projected to fall at a CAGR of −5.5 %.

In the years ahead, the rapid TREO demand growth expected for permanent magnets will lead the end-use category to continuously absorb the market share from incumbent categories.

By 2030, Adamas Intelligence projects that permanent magnets will drive 55 % of the global TREO demand by volume and over 95 % of the market’s value annually.

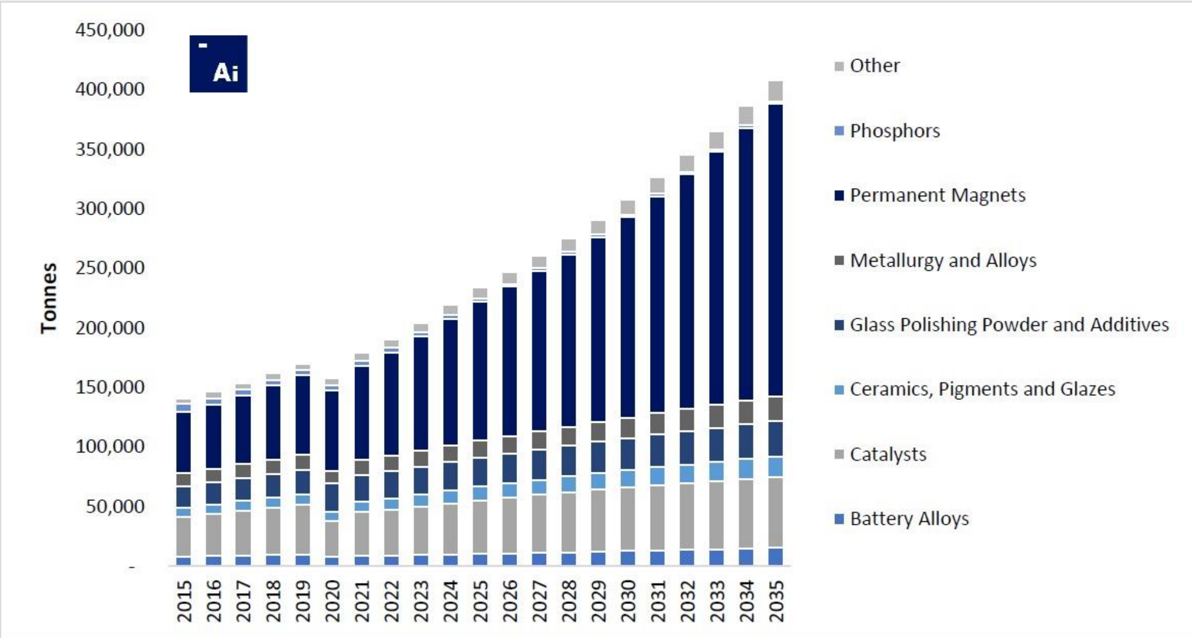


Figure 1.10: Prices of Magnet Rare Earths rising to Compensate for Losses incurred on other Rare Earths

From 2022 through 2035, Adamas Intelligence forecasts that the global TREO demand for

- Permanent magnets will increase at a CAGR of 8.3 %, from 87,000 t to 246,000 t, boosted by strong demand growth from electric vehicle (EV), wind power, general automotive and other applications of NdFeB magnets.
- Passenger EV traction motors, commercial EV traction motors and “other e-mobility” applications will collectively increase at a CAGR of 14.0 %, together representing the single largest demand driver by 2035.
- Automotive micromotors, sensors and speakers will collectively increase at a CAGR of 4.9 %, growing faster than the underlying vehicle market as automakers increasingly

employ NdFeB-powered motors, sensors and speakers in new models to reduce vehicle weight and thereby improve fuel efficiency, reduce emissions and/or maximise electric driving range.

- Direct drive and hybrid direct drive wind power generators for onshore and offshore applications will increase at a CAGR of 13.0 % as the increasingly competitive economics of wind power generation (and the low maintenance of direct drive generators) continue to spur rising adoption.
- All other end uses and applications of NdFeB permanent magnets will increase at CAGRs of 3.4 % to 5.4 %, forgoing the market share to EVs, wind power generators and other high-growth applications.

1.10.3 Rare Earth Price Forecasts

In this section, Adamas Intelligence analyses the historical relationship between rare earth chemical concentrate and rare earth oxide prices in China to forecast the value of the mixed rare earth carbonate concentrate produced at Mkango's Songwe Hill Project in Malawi.

Among the findings of the analysis are the following:

- From 2022 through 2035, Adamas Intelligence envisions three distinct scenarios unfolding for REO prices: base case, upside and downside.
- Since January 2021, comparable mixed rare earth chemical concentrates sold in China were priced at a level equal to 61 % to 82 % of the value of the REOs contained in the concentrate, averaging 73 % through April 2022.
- Taking the above into account, along with Adamas Intelligence's REO price forecasts for each year, Adamas Intelligence projects that the mixed rare earth carbonate concentrate produced by the Songwe Hill Project (55 wt% TREO) will have a value of US$23.70/kg to US$28.34/kg of concentrate in 2022 and will increase overall to US$36.51/kg to US$46.01/kg in 2035.
- The Songwe Hill project offers strong economic exposure to the rare earth permanent magnet sector, which is the fastest-growing end-use category and the one most in need of additional rare earth supplies, according to Adamas Intelligence.

In the three scenarios examined, Adamas Intelligence projects that the REOs used in permanent magnets, namely neodymium, praseodymium, dysprosium and terbium, will collectively make up 95 % of the Songwe Hill project's rare earth basket value in 2035, up slightly from 94 % in 2022.

Figure 1.11 shows the relative distribution of REOs in the mixed rare earth carbonate concentrate from Songwe Hill. By volume, the four critical magnet REOs (neodymium, praseodymium, dysprosium and terbium) make up 33.7 % of the TREO contained in the concentrate.

Oxide	Relative %
La	39.1 %
Ce	18.4 %
Pr	**7.7 %**
Nd	**25.1 %**
Sm	3.3 %
Eu	0.9 %
Gd	1.9 %
Tb	**0.2 %**
Dy	**0.7 %**
Ho	0.1 %
Er	0.2 %
Tm	0.0 %
Yb	0.1 %
Lu	0.0 %
Y	2.4 %
TREO	**100.0 %**

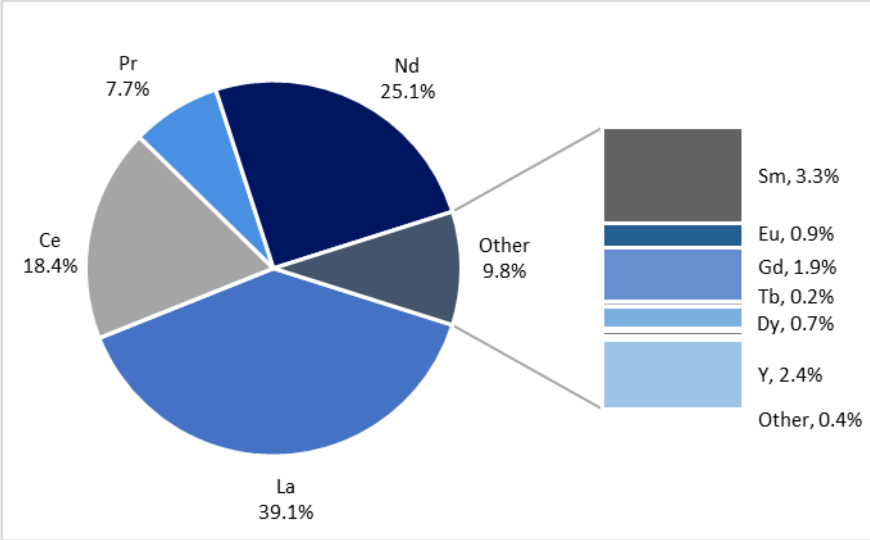


Figure 1.11: Relative Distribution of REOs in Mixed Rare Earth Carbonate from Songwe Hill

Figure 1.12 shows the forecasted contribution per REO to the Songwe Hill TREO basket value in 2035. By value, the four critical magnet REOs (neodymium, praseodymium, dysprosium and terbium) are projected to drive 95.1 % of the Songwe Hill basket value in 2035, up from 94.9 % in 2025 and 94.1 % in 2022.

Oxide	Relative %
La	0.5 %
Ce	0.2 %
Pr	**19.0 %**
Nd	**65.1 %**
Sm	0.2 %
Eu	0.3 %
Gd	2.5 %
Tb	**5.9 %**
Dy	**5.2 %**
Ho	0.3 %
Er	0.1 %
Tm	0.0 %
Yb	0.0 %
Lu	0.1 %
Y	0.6 %
TREO	**100.0 %**

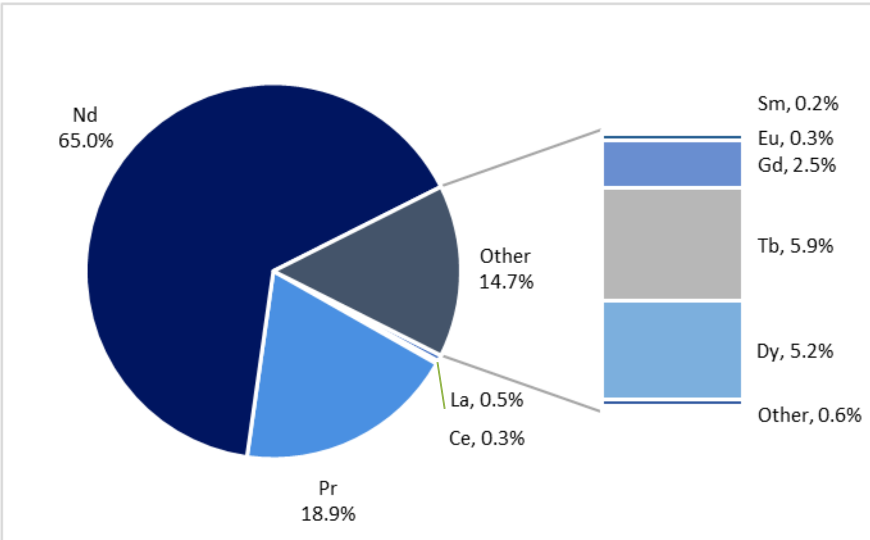
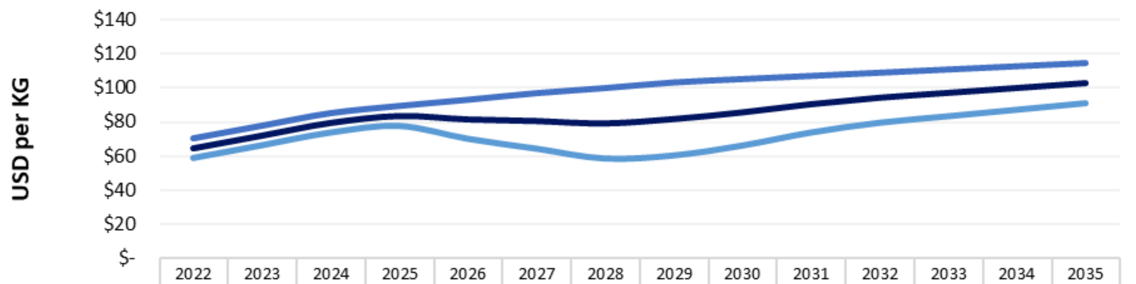


Figure 1.12: Contribution per REO to Songwe Hill Basket Value in 2035

Taking Adamas Intelligence's latest price forecasts into account, along with the relative distribution of REOs in the mixed rare earth carbonate concentrate from Songwe Hill (see Figure 1.11), the Songwe Hill basket value (i.e. the value of the REOs contained in 1 kg of separated TREO produced from the project) was projected for each year from 2022 through 2035 for the base case, upside and downside, as shown in Figure 1.13.



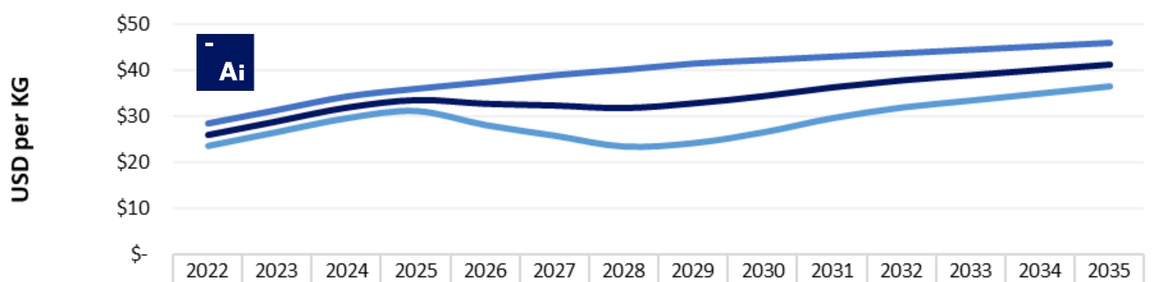
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Upside	$70.59	$77.98	$85.33	$89.54	$93.16	$96.99	$99.99	$103.28	$105.24	$107.11	$108.98	$110.85	$112.72	$114.59
Base Case	$64.81	$72.22	$79.60	$83.62	$81.67	$80.72	$79.33	$81.89	$85.75	$90.50	$94.28	$97.11	$99.94	$102.76
Downside	$59.03	$66.47	$73.86	$77.70	$70.18	$64.45	$58.67	$60.50	$66.26	$73.88	$79.58	$83.37	$87.16	$90.94

NOTES
1. Basket values include 13 % VAT (value-added tax); forecasted prices are in real 2022 dollars.
2. If selling into China, VAT should be deducted. If selling ex-China, the above prices should be taken at face value.

Figure 1.13: Forecasted Songwe Hill Basket Value from 2022 through 2035

Over the past 16 months, comparable mixed rare earth chemical concentrates that were sold in China (the world's largest rare earth market) were priced at a level equal to 61 % to 82 % of the value of the REOs contained in the concentrates, averaging 73 % throughout the observation period.

Adamas Intelligence forecasts that the mixed rare earth carbonate concentrate from Songwe Hill (55 wt% TREO) will have a value of US$23.70/kg to US$28.34/kg of concentrate in 2022 and will increase overall to US$36.51/kg to US$46.01/kg in 2035 (see Figure 1.14).



	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Upside	$28.34	$31.31	$34.26	$35.95	$37.40	$38.94	$40.15	$41.47	$42.25	$43.01	$43.76	$44.51	$45.26	$46.01
Base Case	$26.02	$29.00	$31.96	$33.57	$32.79	$32.41	$31.85	$32.88	$34.43	$36.33	$37.85	$38.99	$40.12	$41.26
Downside	$23.70	$26.69	$29.66	$31.19	$28.18	$25.88	$23.56	$24.29	$26.60	$29.66	$31.95	$33.47	$34.99	$36.51

NOTES:
1. Prices are given in US dollars per kilogram of concentrate; concentrate contains 55 wt% TREO.
2. China REO and concentrate prices were used as the basis for the forecasts, along with assays provided by Adamas Intelligence.
3. All prices include 13 % VAT; forecasted prices are in real 2022 dollars.
4. If selling into China, VAT should be deducted from the above. If selling ex-China, the prices above should be taken at face value.

Figure 1.14: Forecasted Value of Mixed Rare Earth Carbonate Concentrate from Songwe Hill

1.11 ECONOMIC ANALYSIS

A discounted cash flow model prepared by Mkango was reviewed by SENET and incorporates the life of operations (LOO) plan figures, economic assumptions as to the USA inflation rates, and the rare earth oxide and carbonate prices based on the Adamas forecast. The escalation/de-escalation technique has been employed to ensure that the quantum and timing of any taxes payable are calculated correctly. The financial evaluation has been undertaken on an after-tax, unleveraged basis.

A range of discount rates were used to determine the NPV; the NPVs are set at 01 July 2022.

A sensitivity analysis shows the impact on the NPV and internal rate of return (IRR) to changes in the metal prices, CAPEX, and OPEX.

The mining and processing inputs to the financial model are summarised in Table 1.11 to Table 1.13.

Table 1.11: Summary of Mining and Processing Inputs and Results – Average over First Five Years

Item	Unit	Value
Mining		
Average yearly ore mined	kt	2,186
Average TREO grade mined	%	1.19
Average yearly waste mined	kt	3,667
Average strip ratio (waste:ore)		1.68
Processing		
Average yearly flotation plant feed	kt	1,000.8
Average head TREO grade	%	1.50
Flotation TREO concentrate grade	%	15.05
Average TREO recovery to concentrate	%	74.10
Average yearly flotation concentrate feed to hydrometallurgical plant	kt	74.06
Average NdPr oxide hydrometallurgical recovery to carbonate	%	85.26
Average Ce oxide hydrometallurgical recovery to carbonate	%	20.88
Average yearly TREOs in carbonate product	kt	5,954
Average carbonate TREO grade	%	55
Average yearly carbonate production	t/a	10,826
NOTE: The first 5 years refer to the 60 months from the start of processing in September 2025. Mining excludes the first 5 months of mined and stockpiled ore prior to the start of processing (819,437 t at 1.00 % TREO).		

Table 1.12: Summary of Mining and Processing Inputs and Results – LOO

Item	Unit	Value
LOO	Years	18
Mining		
Average yearly ore mined	kt	1,481.5
Average TREO grade mined	%	1.16

Item	Unit	Value
Average yearly waste mined	kt	3,310.5
Average strip ratio (waste:ore)		2.2
Processing		
Average yearly flotation plant feed	kt	1,000.80
Average head TREO grade	%	1.16
Flotation TREO concentrate grade	%	11.64
Average TREO recovery to concentrate	%	74.10
Average yearly flotation concentrate feed to hydrometallurgical plant	kt	74.06
Average NdPr oxide hydrometallurgical recovery to carbonate	%	85.26
Average Ce oxide hydrometallurgical recovery to carbonate	%	20.88
Average yearly TREOs in carbonate product	t	4,633.56
Average carbonate TREO grade	%	55.00
Average yearly carbonate production (dry basis)	t	8,424.65

Table 1.13: Summary of Mining and Processing Inputs and Results – Total LOO

Item	Unit	Value
Mining		
Total LOO ore production	kt	18,147.8
Waste mined	kt	40,553.9
Strip ratio (waste:ore)		2.2
Total LOO plant feed	kt	18,127.0
Average yearly plant feed	kt	982.0
Processing		
Tonnes to hydrometallurgical plant	kt	1,341.4
Contained REOs in carbonate product	kt	83.4
Total carbonate production (dry basis)	t	151,644

1.11.1 Capital and Operating Costs

The capital and operating cost inputs to the financial model are summarised in Table 1.14 to Table 1.16.

Table 1.14: Capital Costs

Item	Unit	Value
Total real development capital	US$ million	277.4
Contingency	US$ million	33.8
Total Real Development Capital Including Contingency	**US$ million**	**311.2**
Sustaining capital and reclamation	US$ million	77.6
Total Real Capital Expenditure	**US$ million**	**388.8**

Table 1.15: Operating Costs – Average over First Five Years

Item	Unit	Value
Mining	US$/kg TREO	4.8
Beneficiation – Milling and Flotation	US$/kg TREO	7.9
Hydrometallurgical Plant	US$/kg TREO	10.8
G&A and Other	US$/kg TREO	1.8
Total Operating Costs	**US$/kg TREO**	**25.3**

Table 1.16: Operating Costs – Average over LOO

Item	Unit	Value
Mining	US$/kg TREO	3.9
Beneficiation – Milling and Flotation	US$/kg TREO	10.2
Hydrometallurgical Plant	US$/kg TREO	13.8
G&A and Other	US$/kg TREO	2.2
Total Operating Costs	**US$/kg TREO**	**30.1**

1.11.2 Discounted Cash Flow Valuation Analysis

Based on the preceding assumptions, the discounted cash flow valuation analysis for the base case gave the following results:

- NPV at 10 % (nominal) (7.3 % real) of US$559 million as at 1 July 2022
- IRR of 31.47 % (nominal) (28.26 % real)

Table 1.17 and Table 1.18 summarise selected financial inputs and the corresponding results. All costs are quoted in real June 2022 United States dollars (US$).

Table 1.17: Summary of Selected Financial Inputs and Corresponding Results – Post-Tax Valuation

Item	Unit	Value
Project cash flow post-tax (nominal) (including royalty)	US$ million	2,083.3
Payback period from project start	Years	5.0
Payback period from start of production	Years	2.5
Post-tax NPV at 10 % (nominal) discount rate	US$ million	559.0
Post-tax IRR (nominal)	%	31.47

Table 1.18: NPVs of Songwe Hill Project[1]

Financial Evaluation	Nominal Discount Rate (%)	Real Discount Rate (%)	Adamas Intelligence Base Case Post-Tax NPV (US$ million)	Adamas Intelligence Upside Case Post-Tax NPV (US$ million)	Adamas Intelligence Downside Case Post-Tax NPV (US$ million)
	8.0	5.37	719.3	1,007.2	431.6
Base Case	**10.0**	7.32	559.0	801.4	316.5
	12.0	9.27	435.0	641.1	228.5
Nominal IRR			31.47 %	39.20 %	22.70 %
Real IRR			28.26 %	35.80 %	19.71 %

[1] As at 1 July 2022

1.11.3 Sensitivity Analysis

The sensitivity chart (see Figure 1.15) shows the nominal NPV at a 10 % variation for the base case due to changes in revenue, capital and operating costs, holding all other inputs constant. The project is most sensitive to the metal prices and more sensitive to OPEX than to CAPEX. The revenue sensitivity assumes that all rare earth metal prices change by the same percentage and that the tolling rate does not change with rare earth prices.

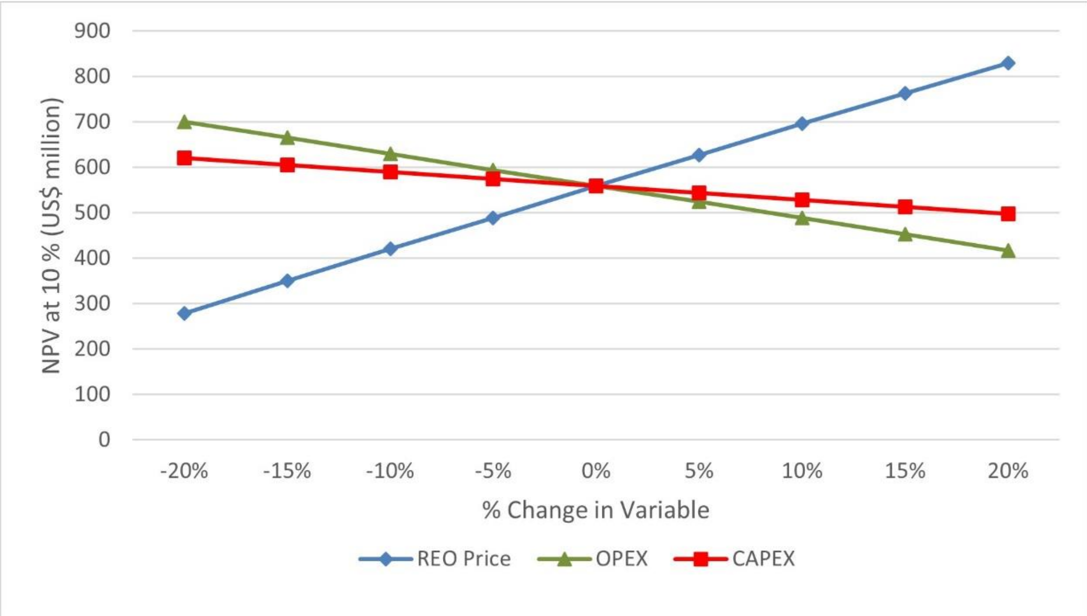


Figure 1.15: NPV at 10 % Nominal Sensitivity Analysis

Figure 1.16 shows the nominal annual cash flows over the life of the project.

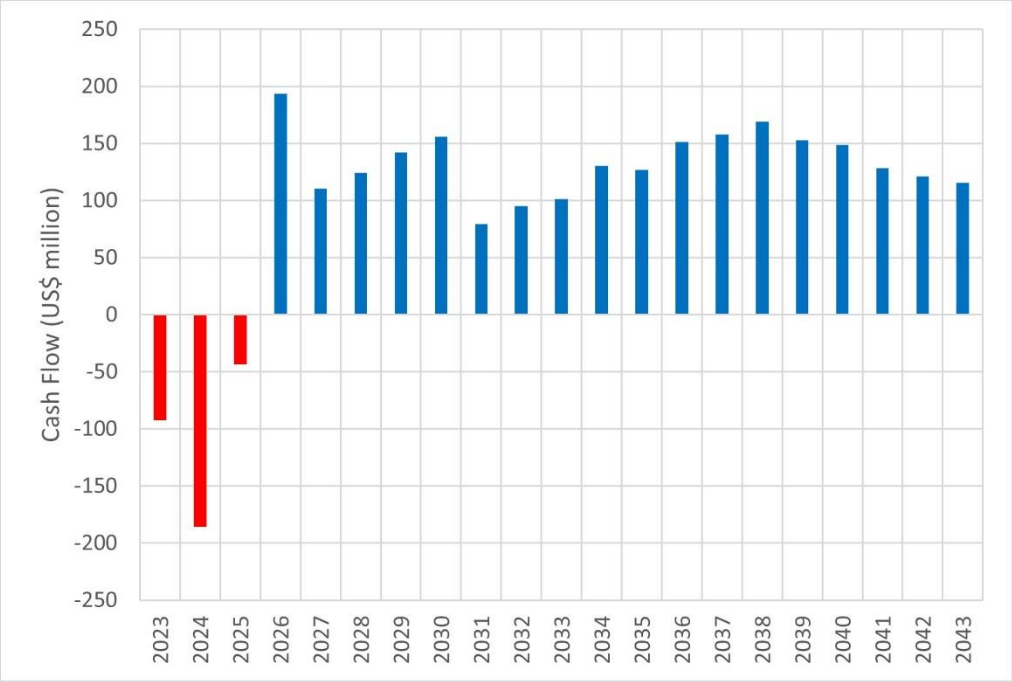


Figure 1.16: Annual Cash Flow (Nominal)

The maximum negative cash flow of US$186 million (nominal) occurs in 2024 as shown in the cumulative cash flow graph (see Figure 1.17).

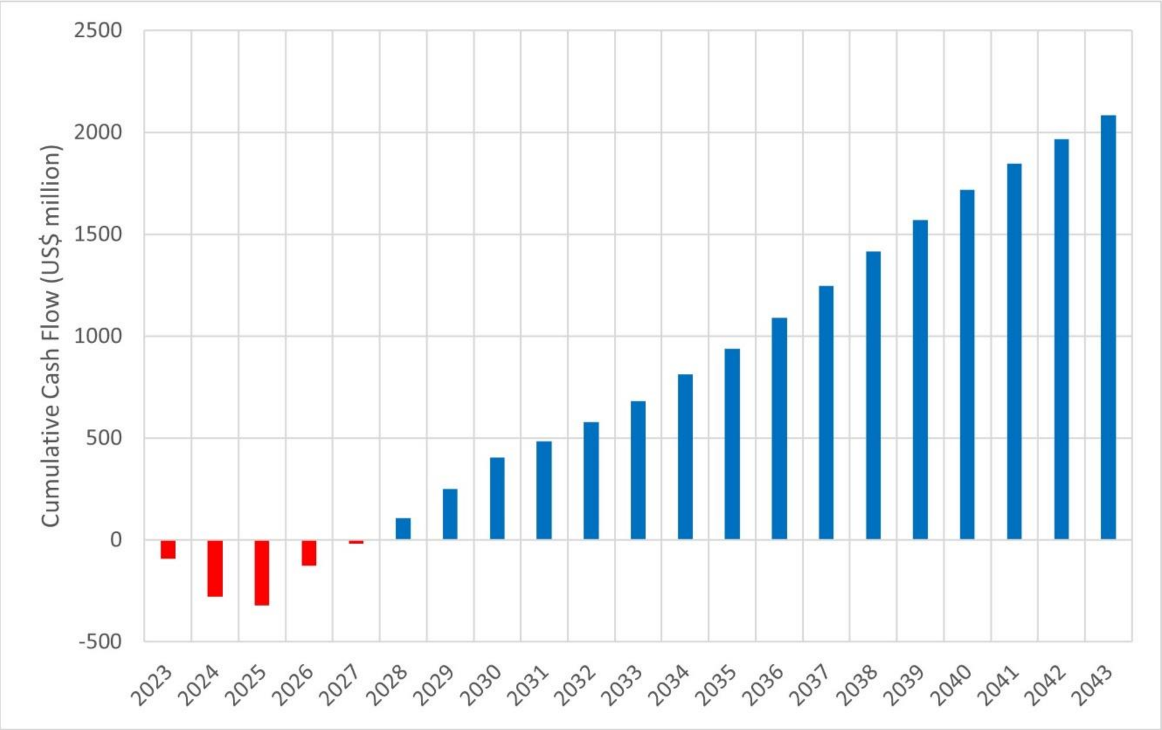


Figure 1.17: Cumulative Annual Cash Flow (Nominal)

1.12 CONCLUSIONS

Since Mkango has become involved in the Songwe Hill Project, considerable effort has been made and expenditure has been incurred to certify what is now a significant rare earth resource and reserve at Songwe Hill. This report confirms the extensive amount of exploration, tests and study work carried out on the project. It is believed that the level of accuracy used herein is sufficient to consider this report to be definitive with its demonstration of a viable rare earth resource at Songwe Hill that will exploit the current reserve over an 18-year life of operations.

The Mineral Resource Estimates for Songwe Hill are reported at a cut-off grade of 1.0 % TREO and classified into the Measured, Indicated and Inferred categories as summarised in Table 1.19.

Table 1.19: Mineral Resource Estimates

Category	Tonnage (Mt)	TREO %	TREO (kt)
Measured	8.81	1.50	131.9
Indicated	12.22	1.35	165.5
Measured & Indicated	**21.03**	**1.41**	**297.4**
Inferred	27.54	1.33	366.2
NOTE: TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3 in situ – no geological losses applied.			

Table 1.20 shows a summary of the total Mineral Reserves Estimate.

Table 1.20: Mineral Reserve Estimate

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

This report has demonstrated that based on the operating and pricing outlook assumed in the DFS, the Songwe Hill REE deposits can be economically mined using the open-pit method and processed using flotation and hydrometallurgy processes at an annual rate of approximately 1 Mt/a with a view to producing an average of 5,954 t of TREO in mixed rare earth carbonate (MREC) per year for the first five years and 4,081 t of TREO in MREC per year in Years 6 to 18.

The DFS is based on selling the MREC rather than the separate products. As a result, a 27 % discount was applied to the forecasted value of the rare earths contained in the MREC (discount equivalent to approximately US$22.07/kg (real 2022 US dollars) of TREO in MREC for the first full five years of production to reflect the discount that would be applied for the MREC product versus the value of the underlying separate rare earth oxides.

This report indicates a US$559.0 million post-tax NPV, using a 10 % nominal discount rate, and a 31.5 % post-tax IRR for 100% of Songwe.

1.13 RECOMMENDATIONS

SENET recommends the execution of a front-end engineering design (FEED) study prior to project execution stage. The estimated FEED duration is seven months, and through a well-defined and executed FEED phase, the following can be achieved:

- Reduced technical, schedule and cost risks
- Faster time to achieve plant/process start-up, commissioning and handover
- Reduced EHS and compliance risks
- Improved risk identification and mitigation
- Orders of long-lead items can be finalised
- Vendor drawings and data can be demanded, taking the detailed design to the next level of accuracy

The following early works activities should be completed before the site construction activities start in order to minimise potential delays:

- Complete additional geotechnical studies as per the Zutari recommendation.
- Commission sufficient water boreholes in the wellfield to supply water to the accommodation camp, site offices and facilities as well as the water required for construction purposes.
- Construct the accommodation camp and facilities prior to construction start date.
- Identify aggregate source.

The following are recommendations related to the environmental and social aspects of the project for Mkango to integrate throughout the project:

- Ensure continuous engagement and two-way dialogue with communities in the vicinity of the project and other key stakeholders, including government and administrative authorities, traditional authorities, group village heads, local chiefs, and community-based organisations, as well as international and local non-governmental organisations.
- Ensure management of waste by engineering and constructing waste facilities in compliance with good international industry practice. Infrastructure has been sited and designed to mitigate against potential negative impacts from dust, radiation, noise and water pollution. Design measures to manage contaminants and waste include clean and dirty water diversion berms, trenches, dams, HDPE lining of the TSF, and other technological measures that together contribute to the reduction of potential negative impacts. Monitoring of these measures through the ESMP must be undertaken throughout the project lifecycle to ensure that they are fit for purpose and appropriately manage any potential negative environmental and social risk.
- Design a wellfield in the alluvial material around the project for water provisioning for the project. Surface water runoff and precipitation during the wet season will also be

captured, stored and used to contribute to the mine's water demands. This alongside the project's aim to achieve high recycling rates will alleviate the potential impacts on groundwater abstraction.
- Ensure that the resettlement activities as a result of the physical and economic displacement of communities required by the project will follow the IFC PS5 through the development of a Resettlement Action Plan and concurrent stakeholder engagement.
- Ensure that the relocation of cultural heritage resources and graveyards will follow the IFC PS8.

The radiation protection programme assessed and presented radiological baseline and safety assessment findings consistent with the International Atomic Energy Agency (IAEA) Safety Standards, the IFC PSs, as well as the available Malawi Atomic Energy Regulations of 2012 promulgated by the Atomic Energy Regulatory Authority (AERA) in terms of the Atomic Energy Bill (Act 16 of 2011).

The following TSF recommendations are proposed:

- Prior to the commencement of the detailed design, a geotechnical engineer should be appointed to retrieve appropriate samples from test pits on site for the triaxial test work of the in-situ material.
- For consideration and evaluation during the detailed design of the TSF,
    - The possible further optimisation of the TSF drainage system should be assessed.
    - The validity of the basin geotextile should be assessed.
    - A more comprehensive detailed dam break analysis should be undertaken to more accurately define the potential inundation extent of the TSF.

It is recommended that opportunities to reduce reagent consumptions and negotiate prices with reliable reagent suppliers or distributors with long-term contracts be investigated in order to optimise the OPEX and mitigate price fluctuations.

It is also recommended that a detailed energy yield analysis and uncertainty assessment be conducted to further optimise the energy requirements.

2 INTRODUCTION

SENET, a DRA Global Group Company, was commissioned by Mkango Resources Limited to prepare an independent National Instrument 43-101 (NI 43-101) Technical Report on the Songwe Hill Rare Earth Element Project in Malawi, as per the requirements of applicable Canadian securities laws.

Table 2.1 indicates the details of the Qualified Persons for this technical report and their contributions.

Table 2.1: Qualified Persons and Their Contributions

Qualified Person	Company	Contribution
Nicholas Dempers	SENET	Metallurgical test work interpretation Processing plant and project infrastructure Economic evaluation Coordination and compilation of report
Jeremy Charles Witley	The MSA Group	Mineral Resource estimate Data verification
Scott Swinden	Swinden Geoscience Consultants Ltd	Geology and exploration
Graham Errol Trusler	Digby Wells Environmental	Environmental studies, permitting and social or community impact
Clive Wyndham Brown	Bara Consulting (Pty) Ltd	Mineral Reserves and mine design
Guy John Wiid	Epoch Resources (Pty) Ltd	Tailings storage facility

2.1 QUALIFICATIONS OF QUALIFIED PERSONS

The relevant sections of this NI 43-101 Technical Report were compiled by the Qualified Persons, as this term is defined in NI 43-101. The certificates of the Qualified Persons (QPs) are set out after the Date and Signature Page of this report. A summary of their qualifications and responsible sections, and whether they conducted site visits or not, is given in Table 2.2.

Table 2.2: Summary of the Qualifications and Responsibilities of the QPs

QP	Qualification	Site Visit	Responsibility (Section of Report)
Nicholas Dempers	MSc Eng (Chem), BSc Eng (Chem), BCom (Man), Pr Eng (RSA), Reg. No. 20150196, FSAIMM (RSA)	Yes	6, 13, 17, 18, 19, 21, 22, 23 and parts of 1, 2, 3, 4, 24, 25 and 26
Jeremy Charles Witley	BSc Hons, MSc (Eng) Pr Sci Nat, FGSSA	Yes	1.5, 12, 14, 24.2.2, 25.1 and parts of 1, 2 and 27
Scott Swinden	BSc (Hons), MSc, PhD, P Geo	Yes	7, 8, 9, 10, 11, and parts of 1 and 2
Graham Errol Trusler	MSc Eng (Chemical), BCom, ECSA (RSA)	Yes	20 and parts of 1, 2, 3, 4, 5, 21, 24, 25 and 26
Clive Wyndham Brown	BSc Eng (Mining), Pr Eng (RSA), FSAIMM (RSA)	Yes	15, 16 and parts of 1, 2, 3, 18, 21, 24, 25 and 26
Guy John Wiid	BSc Eng (Civil), MSc Eng (Civil),	No	18.4 and parts of 1, 2, 3, 21, 25 and 26

2.2 TERMS OF REFERENCE AND PURPOSE OF THE REPORT

SENET was commissioned by Mkango Resources to compile an NI 43-101 Technical Report on the Songwe Hill Rare Earth Project by coordinating the contributions from SENET's QP and the QPs from the other consultants. The report is compiled in accordance with National Instrument 43-101 (NI 43-101) and Form 43-101F.

2.3 SOURCES OF INFORMATION AND DATA CONTAINED IN THE REPORT

Most of the information in this NI 43-101 report was sourced from the Songwe Hill Rare Earth Project DFS completed in July 2022

SENET would like to acknowledge that the information in Sections 6, 20 and 23 was provided by Mkango Resources.

For further details on references, please refer to Section 27.

2.4 QUALIFIED PERSONS' PERSONAL INSPECTION OF THE PROPERTY

A summary of the QP's qualifications and responsibilities is given below.

Mr Nicholas Dempers, MSc Eng (Chem), BSc Eng (Chem), BCom (Man), Pr Eng (RSA), Reg. No. 20150196, FSAIMM (RSA), a principal process engineer at SENET, is the QP for the mineral processing, metal recoveries and metallurgical testing sections and oversaw the compilation of the project infrastructure and the capital and operating costs as per the SENET quality management system. Mr Dempers visited the project area on 19 May 2014 and 28 June 2022. By virtue of his education, as well as relevant work experience and membership of recognised professional associations, he is a QP as defined by the NI 43-101 guidelines.

Mr Jeremy Charles Witley BSc (Hons) MSc (Eng), Pr Sci Nat, FGSSA, is a principal mineral resource consultant at the MSA Group (Pty) Ltd. He is the QP responsible for the data verification and Mineral Resource estimation at Songwe Hill. He has worked as a geologist for a total of 33 years in a number of roles, including consulting, senior management, in mine geology, exploration projects and Mineral Resource management. He has conducted Mineral Resource estimates, audits and reviews for a wide range of commodities and styles of mineralisation including complex mixed distribution multi-element deposits as is the case at Songwe Hill. Specific REE experience includes deposits in Burundi, Mauritania, Namibia and South Africa as well as the Songwe Hill in Malawi. He visited the Songwe Hill property for four days from 25 to 28 July 2018 and for three days from 24 to 26 September 2018. By virtue of his education, relevant work experience and membership of recognised professional associations, he is a QP as defined by NI 43-101.

Dr Scott Swinden PhD PGeo is the principal consultant with Swinden Geoscience Consultants Ltd. He is a registered Professional Geoscientist with the Association of Professional Geoscientists of Nova Scotia, Dr Swinden has practised as a geoscientist since 1970 in mineral exploration where he has experience in base and precious metals, rare metals and industrial minerals. He has also worked as a research scientist and executive for provincial and federal geological surveys in Canada. As a researcher and teacher, he specialised in the geological setting of a variety of mineral deposit types. Since 2010, he has specialised in rare earth and critical metal geoscience and has studied and explored rare earth and carbonatite properties in southern Africa, Canada and the United States. He has co-authored seven NI 43-101 reports. By virtue of his education, as well as relevant work experience and membership of recognised professional associations, he is a QP as defined by the NI 43-101 guidelines.

Mr Graham Errol Trusler is one of the founding partners and CEO of Digby Wells Environmental. He holds an MSc (Engineering) and a BCom. Degree. He is a registered Professional Engineer with the Engineering Council of South Africa. He is also registered as a Chartered Chemical Engineer with the Institution of Chemical Engineers, is a member of the Water Institute of South Africa, and is a lifetime member of the American Society of Mining and Reclamation. Mr Trusler has 30 years of experience within the mining industry in metallurgical production, research, and environmental issues. He is the QP for the environmental and social sections and oversaw the compilation of the Environmental, Social and Health Impact Assessment (ESHIA) submitted to the Malawi Environment Protection Authority (MEPA) in July 2022. By virtue of his education, as well as relevant work experience and membership of recognised professional associations, he is a QP as defined by the NI 43-101 guidelines.

Mr Clive Wyndham Brown, BSc Eng (Mining), Pr Eng (RSA), FSAIMM (RSA), a principal engineer at Bara Consulting (Pty) Ltd, is the QP for the mining and Mineral Reserves sections of this report. Mr Brown has visited the project area on two previous occasions, the most recent of which was on 28 June 2022. During the site visits, Mr Brown observed the general site conditions, proposed sites for infrastructure, and proposed mining area, and he also made observations about the diamond drill core used in the Mineral Resource estimate and geotechnical studies. By virtue of his education, as well as relevant work experience and membership of recognised professional associations, he is a QP as defined by the NI 43-101 guidelines.

Mr Guy John Wiid is a co-founder and director of Epoch Resources (Pty) Ltd. He is registered as a Professional Engineer with the South African Council for Professional Engineers (Registration No. 940269) and as a Chartered Engineer with the American Society of Civil Engineers (Membership No. 9945778) and has worked in the mining waste and environmental management field since 1990. His work experience includes the conceptual, feasibility and detailed design of tailings storage facilities, rehabilitation and closure design, and project management and the calculation of mine closure liabilities. He has also completed a number of technical reviews and due diligence investigations. His experience spans a range of commodities including gold, platinum, uranium, diamonds, iron ore, fluorspar, coal, copper, nickel and rare earths. By virtue of his education, as well as relevant work experience and membership of recognised professional associations, he is a QP as defined by the NI 43-101 guidelines.

3 RELIANCE ON OTHER EXPERTS

The information, conclusions, opinions, and estimates contained in this report are based on the following:

- Information available at the time of preparation of this report
- Assumptions, conditions, and qualifications as set forth in this report
- Data, reports, and other information as supplied by Mkango and other third-party sources

For this report, the authors have relied on ownership information provided by Mkango. In the consideration of all the legal aspects relating to the Songwe Hill REE Project, the authors have relied on Mkango and assumed that the information relating to the legal aspects and the status of surface and mineral rights is accurate.

Property information in this report has been sourced from previous reports supplied by Mkango. The authors are not responsible for the accuracy of any property data, and do not make any claim or state any opinion as to the validity of the property disposition described herein.

For the preparation of this report, the authors relied on maps, documents, and electronic files generated by the current and past exploration crews on behalf of Mkango. To the extent possible under the mandate of an NI 43-101 compliant report, the data has been verified relating to the material facts.

Any use of this report by any third party is at that party's sole risk.

According to Mkango, there are no known litigations potentially affecting the Songwe Hill REE Project.

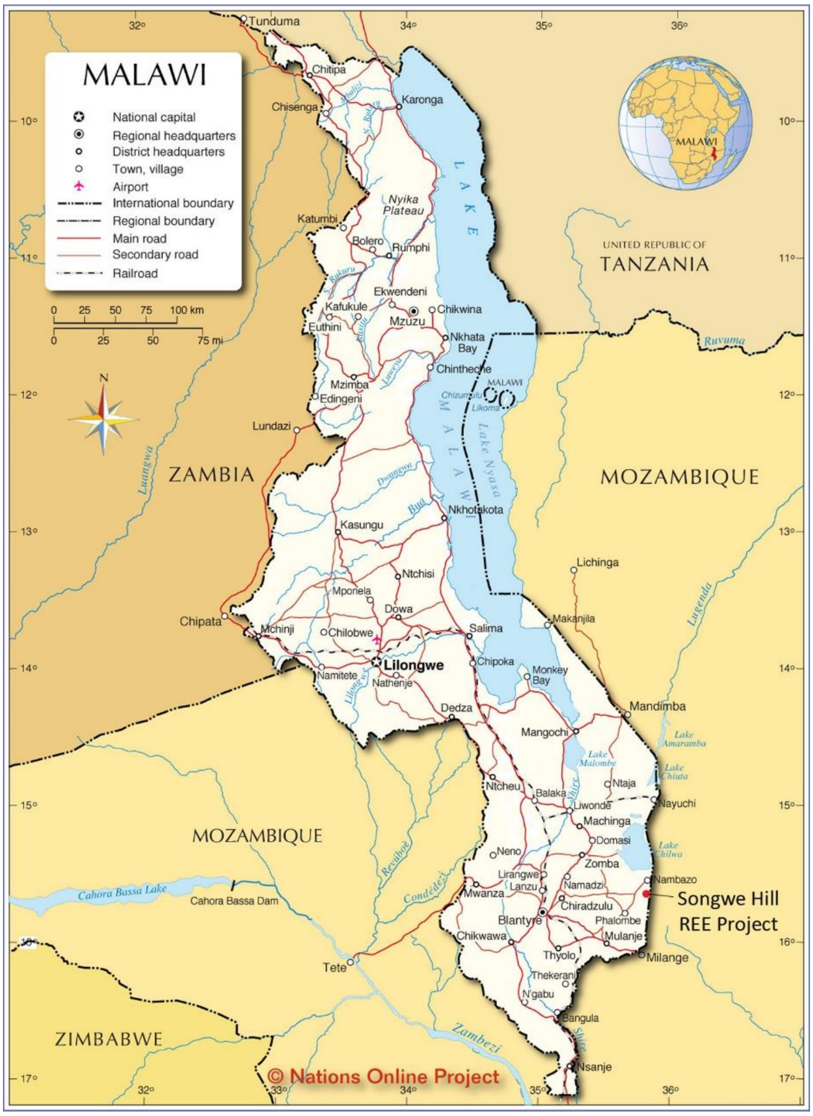
Digby Wells undertook the ESHIA with input from the following experts:

- AquiSim Consulting (Pty) Ltd undertook the radiation surveys, analysis, assessment and compilation of the pre-operational radiological baseline site characterisation report and the prospective radiological public safety assessment.
- IT^2P undertook the traffic and safety analysis and reporting component.
- Local content Malawian specialists undertook the baseline socio-economic, heritage, flora, fauna, avifauna and hydrology fieldwork in collaboration with the Digby Wells' specialists. Their specialised experience in-country as well as with the local languages facilitated the collection and analysis of data in Malawi.

4 PROPERTY DESCRIPTION AND LOCATION

4.1 LOCATION

Songwe Hill is located in south-eastern Malawi, between Lake Chilwa and the Mulanje Massif, and close to the eastern border of Malawi with Mozambique (see Figure 4.1). It lies within Retention Licence (RTL) 0001/21, which is one of a block of 11 retention licences (RTL 0001/21 to RTL 0011/21) that Mkango refers to as the "Phalombe Licences".



Source: Modified from UN Map of Malawi (2012)

Figure 4.1: Location of Songwe Hill in Malawi

RTL 0001/21 lies entirely within the Southern Region of Malawi, and Songwe Hill is within the Phalombe administrative district. It lies approximately 70 km in a straight line southeast from Zomba (the former capital of Malawi) and approximately 90 km in a straight line east-northeast of the commercial centre of Blantyre. Songwe Hill can be reached from these centres via national highways S144 and S145, respectively. At Migowi, the S145 passes within 15 km of Songwe Hill. Along that distance from Migowi to the Maoni village, the Malawi Roads Authority is currently widening the government road from a single-width dirt track to an all-weather graded and gravelled mine road with new reinforced concrete bridges and culverts.

4.2 MINERAL TENURE, PERMITTING, RIGHTS AND AGREEMENTS

4.2.1 Retention Licences in Malawi

The search for, the mining of, and the disposal of minerals in Malawi is currently governed by the Mines and Minerals Act (Act No. 8 of 2019; the “Act”).

It is the stated objective of Malawi’s mining policy to maximise the economic benefits to the nation and empower local communities by exploiting the nation’s mineral resources whilst managing environmental impacts. The Government encourages investors to explore, delineate, evaluate, and where viable, exploit the country’s mineral resources.

The rights to carry out a programme of prospecting operations for specified minerals over an area are conveyed by way of an exploration licence (EL), which replaces the former Exclusive Prospecting Licence (EPL). On application for an EL, a detailed programme of exploration and expected expenditures is presented by the applicant together with a proposal for the training and employment of Malawian citizens.

When exploration has been completed and a mineral deposit of commercial significance can be demonstrated, the holder of an EL or a Retention Licence (RTL) has the exclusive right to apply for a mining licence. The area of each RTL must not exceed 25 km^2, must fall entirely within a valid EL held by the applicant, and on successful mining licence application ceases to be part of that EL. An RTL may be granted for a non-extendable term of five years. Land that was not part of an RTL at the time the licence was granted shall not be added to the RTL at a later date.

4.2.2 Retention Licence RTL 0001/21

Retention Licence RTL 0001/21 (the “Licence Area”) covers an area of 25 km^2 and is one of a contiguous block of 11 RTLs with a total area of 250 km^2. The block falls within the former EPL 0284/10 that had an area of 849.1 km^2 and was originally granted to Lancaster Exploration Ltd (Lancaster), a 100 % subsidiary company of Mkango, on 21 January 2010 with a three-year term. It was renewed successively for two-year periods until 20 January 2015, 19 January 2017, 21 January 2019, and 21 January 2021 by the Minister of Natural Resources, Mines and Energy under the Act. The EPL was then converted to an EL on 19 January 2021 to comply with the Act. Most recently, a block of 11 RTLs was applied for and granted on 1 June 2021 (see Table 4.1), and the Songwe Hill REE Project falls within one of these licences, RTL 0001/21.

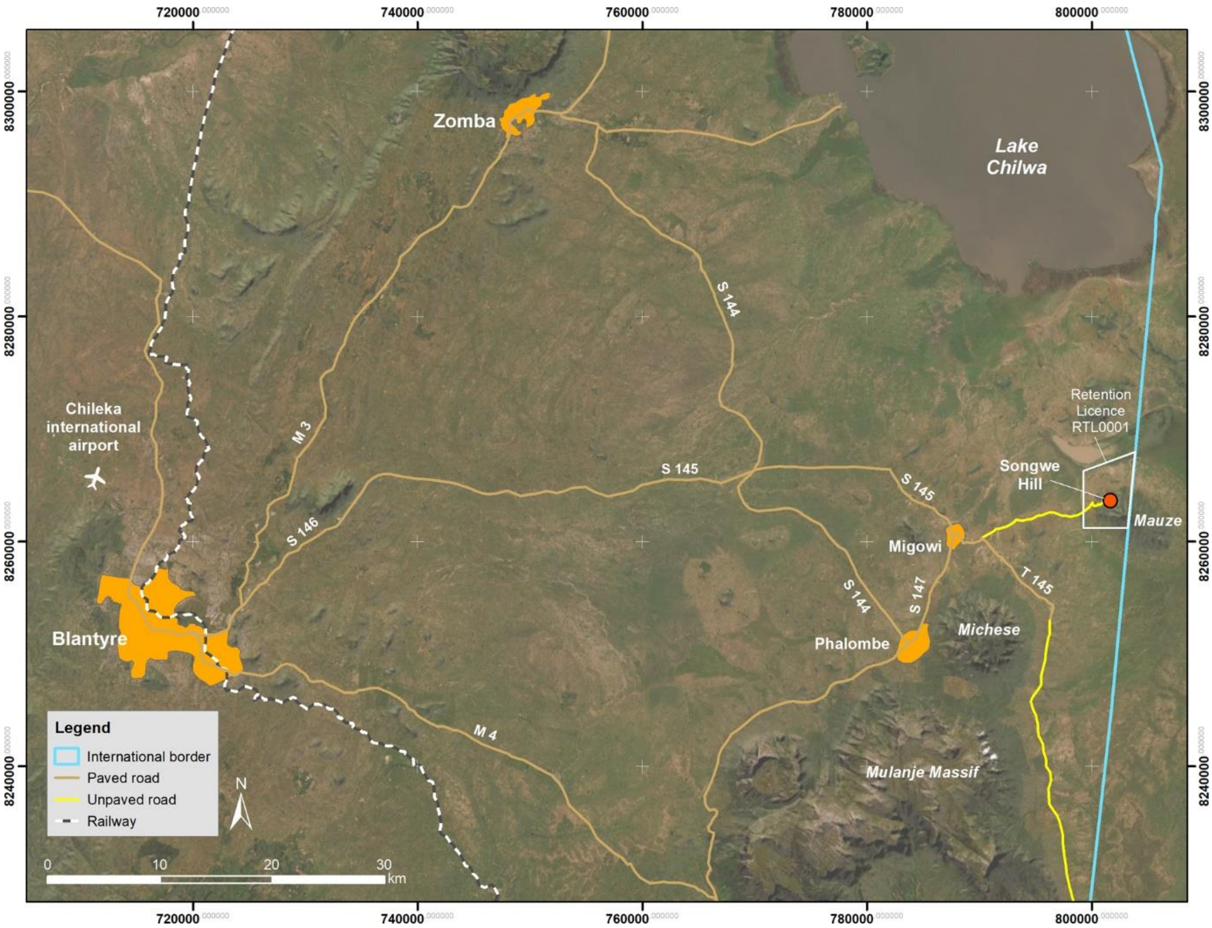
Mkango is in receipt of a legal opinion from Blantyre law firm, Gustave and Company, that its 100 % owned subsidiary, Lancaster, is the legal holder of 100 % interest in RTL 0001/21, which is valid and existing as of the date of this opinion, 19 May 2022. The opinion further states that the RTL is unencumbered and in good standing.

The RTL grants Mkango the right to retain part of its previous exploration area for the following mineral(s) of primary interest: all 17 rare earth elements including yttrium, additionally strontium, niobium, iron ore, manganese, gold, silver, copper, bauxite, fluorite, phosphate, uranium, thorium, monazite, nepheline syenite, zircon, tantalum, clay, kaolinite and all associated minerals.

The boundaries of the RTL are determined by reference to the Universal Transverse Mercator (UTM) Grid using the ARC1950 Datum in Zone 36 (Southern Hemisphere). The location of the RTL is shown in Figure 4.2.

Table 4.1: History of Tenure of EPL 0284/10 and RTL0001/21

Application	Granted	Validity
Original EPL	21 Jan. 2010	20 Jan. 2013
1st Renewal	9 Jan. 2013	20 Jan. 2015
2nd Renewal	5 Jan. 2015	19 Jan. 2017
3rd Renewal	13 Oct. 2017	19 Jan. 2019
4th Renewal	28 Nov. 2018	21 Jan. 2021
Conversion to Exploration Licence	19 Jan. 2019	19 Jan. 2021
Award of Retention Licence	1 Jun. 2021	1 Jun. 2026



Source: Mkango (2021)

NOTES: The Songwe Hill carbonatite abuts against Mauze Hill on its north-western flank and is entirely within the Republic of Malawi. UTM Zone 36S and WGS84 Datum.

Figure 4.2: Location of RTL 0001/21 and Access Roads

The current RTL document states: "The annual expenditure of the licensee in accordance with the approved plan shall not be less than the forecast amount of K30,000,000.00" (in Malawian kwacha, equivalent to approximately US$28,950).

4.2.3 General Provisions

Except for the general rights of the local communities to graze livestock or to cultivate the land, which rights may not interfere with the prospecting operations, there are no restrictions on surface access to the area pertaining to the Licence Area. Where a mineral tenement holder is denied access to any area that is the subject of such tenement by a lawful occupier or owner of that land, the holder, after a reasonable effort to negotiate access, may provide the Commissioner with written details of the land access problem and request a land access order pursuant to Section 230 of the Act.

Under the existing legislation, the holder of an RTL cannot renew the licence, and the Government of Malawi has no rights or options to acquire any interest in the Licence Area.

The Government would be entitled to cancel or suspend RTL 0001/21 if Lancaster fails to

- Conduct its activities in accordance with its approved plan, the conditions of its licence, the Act and applicable law, in a professional manner consistent with good practice in the mining industry.
- Expend annually the minimum amount specified in its licence to implement its approved plan.
- Prepare, implement and update the community engagement plan required under Section 300 of the Act.
- Notify the Commissioner when there is change in the control of the company that holds the licence, such as a sale of a majority ownership interest or a majority of its shares, as required under Section 63 of the Act.
- Provide any attachment required or agreed under Section 42 of the Act.

As far as is known, there has been no commercial exploitation of minerals within the Licence Area; therefore, there are no existing mine workings, tailing ponds or waste dumps. There are no known legal encumbrances to the Songwe Hill RTL and no environmental liabilities, apart from the obligations of Lancaster outlined in the Terms and Conditions of the RTL.

All necessary permits, approvals, consent, endorsements and permissions have been obtained in order to permit Lancaster to conduct exploration work of the type contemplated by the RTL, including geochemical sampling, geophysical surveying, diamond drilling, core sampling, and geotechnical ground investigations in the Licence Area.

There are no known significant factors or risks that may affect access, title, or the right or ability to perform work on the property as contemplated by the RTL.

4.2.4 Overlapping Licences

There are no overlapping licences of any kind governed by the Act, or other factors or risks known to the authors that might affect the right or ability to perform work on the Licence Area.

4.3 ENVIRONMENTAL LIABILITIES

Currently, the environmental liabilities on the site are minimal as only exploration has taken place, and it is a greenfield project. Should the project not proceed to construction, the site will need to be closed and rehabilitated. Current liabilities include

- Demolition, or handover to the community, of the exploration office, kitchen and toilet facilities
- Demolition of the concrete platforms constructed for the tented exploration accommodation
- Removal of the core shed and containers to store the core
- Rehabilitation of the access and drilling roads on Songwe Hill

The weather station currently on site has already been donated to the Malawi meteorological department.

5 ACCESSIBILITY, CLIMATE, LOCAL RESOURCES, INFRASTRUCTURE AND PHYSIOGRAPHY

Songwe Hill is located in south-eastern Malawi, between Lake Chilwa and the Mulanje Massif and close to the eastern border of Malawi with Mozambique. All-weather roads connect Migowi and Phalombe to Zomba, and Blantyre which are both approximately 90 km by road from Migowi. Local gravel roads provide access from Migowi to the base of Songwe Hill. The total travel time to the project area from Zomba or Blantyre is approximately 2 h.

Songwe Hill lies within the Southern Region of Malawi, in the Phalombe administrative district. Mpoto Lagoon is approximately 1.3 km from the edge of the project infrastructure and Lake Chilwa is approximately 22 km from the project site. It is located approximately 70 km in a straight line southeast of Zomba. Phalombe is one of 12 districts in the Southern Region of Malawi and is the largest nearby town, approximately 25 km from Songwe Hill. The project area is bordered by unformed gravel roads which traverse towards paved roads which will be used during the construction and operational stages for the movement of development-generated traffic.

5.1 CLIMATE AND METEOROLOGICAL OVERVIEW

Malawi is located between two climatic mega-zones, equatorial Africa and southern Africa. The climate is largely dictated by the oscillations of the Intertropical Convergence Zone (ITCZ), i.e. the converging of, and interaction between, the zonal Congo air mass and the meridional south-eastern trade winds and monsoonal north-eastern winds. The wet season stretches from November to April, and records 95 % of the annual precipitation. The dry season is subdivided into the cool dry season from May to August and hot dry season in September and October.

Malawi’s climate is moderated by a high percentage of surface water and by the fact that it possesses an altitudinal range from 500 metres above mean sea level (mamsl) (Lake Malawi and Liwonde) to peaks over 3,000 mamsl high (Mount Mulanje). In August 2014, a weather station was installed on site. The on-site data collected is used to understand the meteorology of the project area as presented below.

5.1.1 Wind Speed and Direction

Data from the on-site meteorological station from August 2014 to April 2021 shows the predominant wind direction as south-southwest and south, with the frequencies of occurrence of 14.9 % and 12.6 %. Secondary contributions are observed from southwest, northeast and north-northeast (see Figure 5.1), with frequencies of occurrence of 7.9 %, 6.8 % and 6.1 %, respectively. Calm conditions (wind speeds < 0.5 m/s) occurred for 0.9 % of the time. The average wind speed during the period was 2.17 m/s. Based on the data from the on-site meteorological station, the south-southwest winds dominate the overall regime for the area.

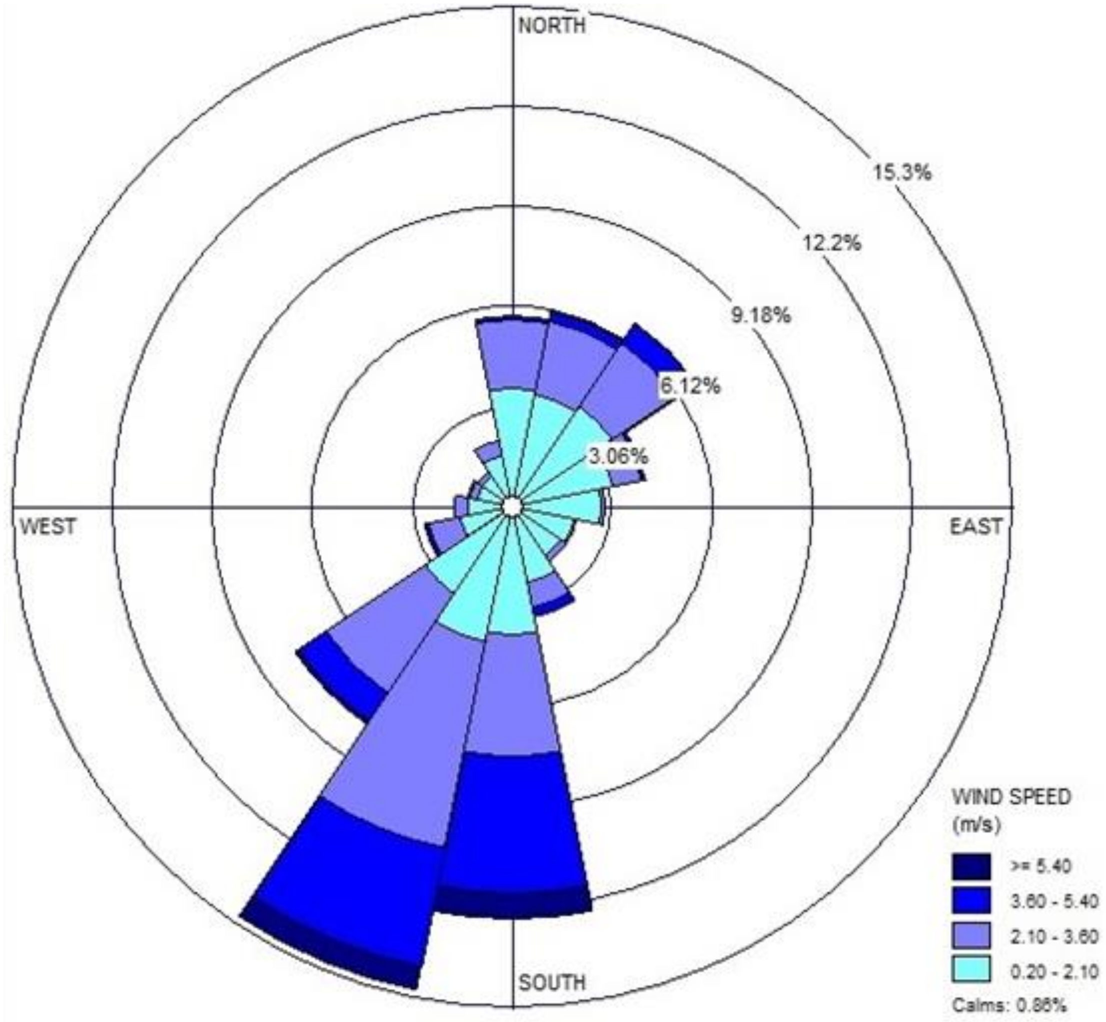
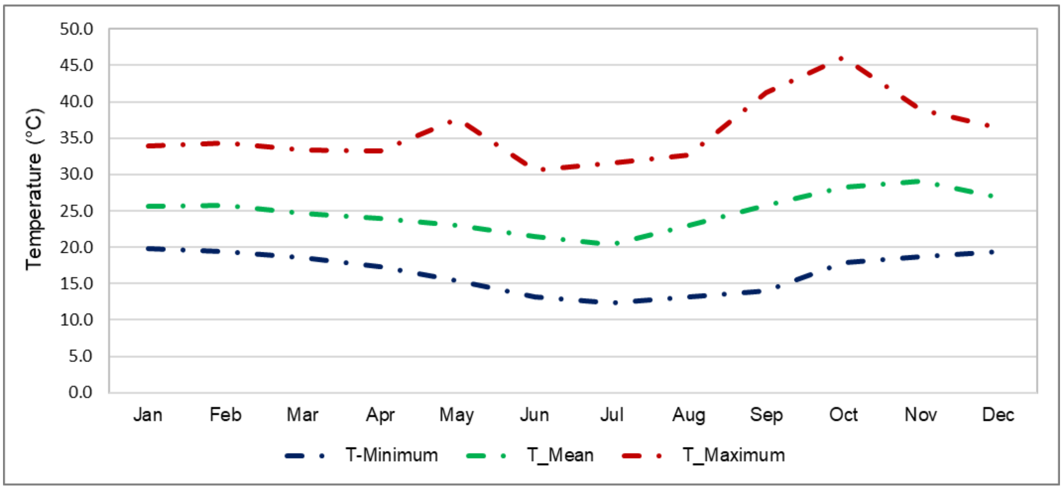


Figure 5.1: Wind Rose for Songwe Hill

Wind speeds of greater than 5.4 m/s, which can generate fugitive dust from open areas such as the WRD and the TSF, occurred for 1.8 % of the time. Diurnal variability in the wind fields was also assessed. During the night, wind field conditions from the south prevailed for 18 % of the time, 16.9 % from the south-southwest and 8.1 % from the east-northeast. Wind speeds greater than 5.4 m/s occurred for 2.8 % of the time. The morning is dominated by wind fields from the north-northeast (11.6 %), northeast (10.4 %), and south-southwest (9.8 %). Wind speeds greater than 5.4 m/s occurred for 0.7 % of the time.

5.1.2 Temperature

As seen in Figure 5.2, the monthly mean temperature during 2014 to 2021 (site data) was between 20.3 °C and 29.0 °C. The annual average ranged between 25.3 °C and 27.7 °C. The monthly maximum temperatures ranged from a low of 30.6 °C in June to a high of 46.1 °C in October.

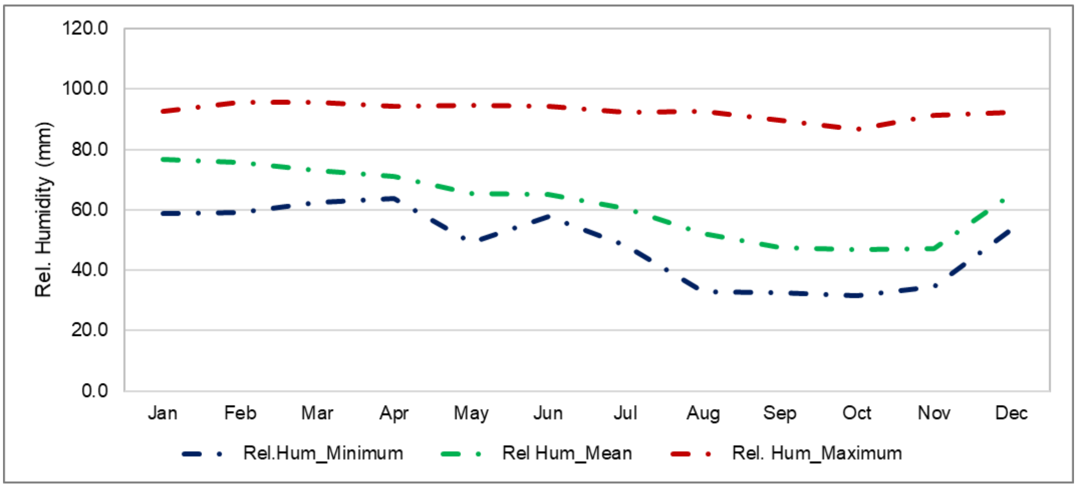


Source: Songwe Hill Meteorological Station (2014-2021)

Figure 5.2: Monthly Temperature for Songwe Hill

5.1.3 Relative Humidity

The average monthly relative humidity (see Figure 5.3) ranges from 46.7 % in October to 76.7 % in January.

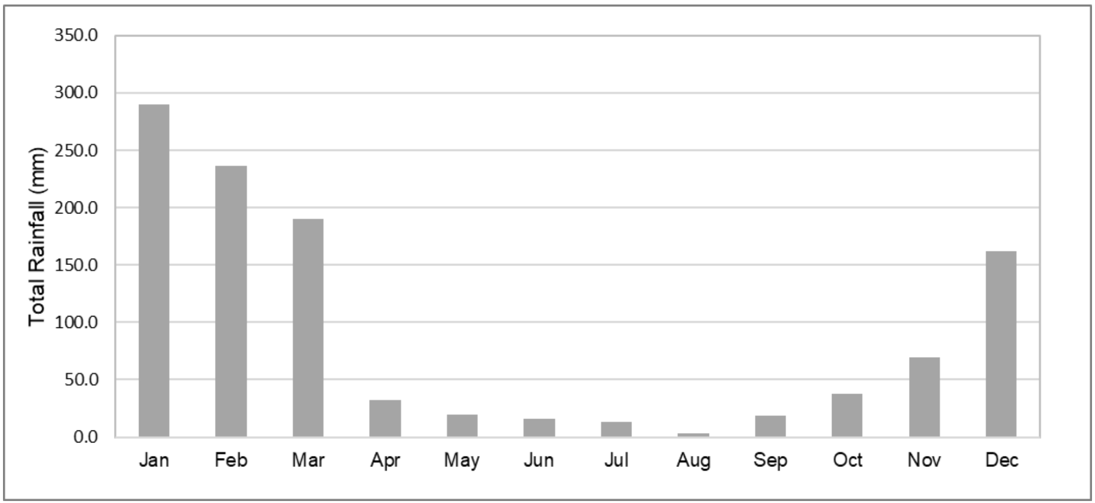


Source: Songwe Hill Meteorological Station (2014-2021)

Figure 5.3: Average Monthly Relative Humidity

5.1.4 Precipitation

The rainy season is from November to April, with the mean monthly rainfall peak in January, with 289.7 mm of rain measured. Much of the project area receives little to no rainfall from May to October (see Figure 5.4). Heavy rainfall occurs in January and February with the potential to cause flooding. The annual total rainfall measured from 2014 to 2021 varied between 946.7 mm and 1,292.5 mm.



Source: Songwe Hill Meteorological Station (2014-2021)

Figure 5.4: Total Monthly Rainfall

5.2 PHYSIOGRAPHY

To the north of Songwe Hill, the physiography comprises an alluvial plain immediately south of Lake Chilwa, which passes southwards into a more elevated region characterised by numerous hills and mountains. Some mountains are marked by steep cliffs and areas of bare rock, while other hills are completely wooded, varying from dense tropical forest to a more open forest comprised of the *Vachellia* species.

The vegetation changes significantly between the rainy and dry seasons. Following the rainy season, the higher ground is covered by a dense growth of elephant grass, which can reach 3 m in height in open areas. In the dry season, the grass cover withers and is commonly burnt to expose bare ground and rock. The lower lying areas, apart from a zone adjacent to Lake Chilwa, are prone to flooding in the rainy season and support occasional villages, with the land intensively farmed for tobacco, maize, cassava, and sweet potatoes.

The Songwe Hill carbonatite-fenite complex forms a moderate- to steep-sided conical hill with a diameter of approximately 800 m and a summit elevation of 990 m. On the south-eastern side, Songwe Hill abuts against the higher Mauze Mountain, which rises to an elevation of 1,592 m. The wetlands in the project area are associated within the larger Lake Chilwa catchment, with ephemeral streams and seasonal, temporary and permanent wetlands draining into the Mpoto Lagoon. Large portions of the wetlands have been heavily impacted and cleared for agricultural activities.

The project area falls under the tropical and subtropical grasslands, savannahs, and shrublands terrestrial biome and belongs to the Southern Miombo Ecoregion. Floristically, this ecoregion forms part of a wide belt of the Miombo woodland. There are no biodiversity hotspots, key biodiversity areas, or protected areas within the project area.

5.3 LOCAL RESOURCES AND INFRASTRUCTURE

The dominant tribe is the Lhomwe tribe, with Lhomwe being the dominant language spoken among the inhabitants. Most households use three separate structures including the primary sleeping area, kitchen and pit latrine. There are a few instances of households having four structures with the fourth being used as a business unit. The inhabitants live in extreme poverty, relying on subsistence agricultural and fishing in the project area. Access to education is limited, there are 11 primary schools in the project area and the closest secondary or tertiary schools are in the towns of Migowi and Phalombe. A new secondary school is being constructed in the Namalima village.

Access to potable water is reasonable in the project area. Communities rely on water from boreholes, six of which (fitted with handpumps) were drilled by Mkango and an additional five boreholes have been maintained by Mkango. The majority of households (80 %) have a pit latrine. Phalombe lies in a basin where cholera, malaria, and drought often occur. Surface water is mainly used for irrigation and livestock watering.

6 HISTORY

6.1 OWNERSHIP HISTORY

There are no public records documenting the history of mineral tenure in the project area. The Geological Survey Department of Malawi (GSDM) has no record of any exploration being carried out in the project area prior to the late 1980s.

6.2 HISTORICAL EXPLORATION

Historical work referenced below to Dixey et al. (1937), Garson (1962, 1965), Garson and Walshaw (1969), and Hunting Geology and Geophysics Limited (1985) was regional in nature and included work outside the boundaries of the current Phalombe Licences. Work referenced to Lewis (1953) and the Japan International Cooperation Agency and Metal Mining Agency of Japan (1989) was conducted within the boundaries of the current Phalombe Licences.

6.2.1 Pre-1981 Programmes

The geological sequence in the southern Chilwa Province was originally defined and referred to as “The Chilwa Series” by Dixey et al. (1937) in a monograph that is notably important for identifying and describing carbonatites in Africa for the first time. Dixey et al. (1937) recognised eleven occurrences of carbonatite in Malawi, which at that time more than doubled the global total of known carbonatites. Two localities in the Phalombe District, Songwe Hill and Tundulu, were investigated by Dixey et al. (1937), who described the Songwe Hill occurrence as a volcanic vent comprising limestone, feldspar rock and agglomerate. The authors produced a simple sketch map, along with photographs of hand specimens of agglomerate and feldspathic breccia, and concluded that the limestone found at Songwe Hill and other localities in the Chilwa Province was of magmatic origin and comparable to the carbonatites of the Fen complex in Norway.

The Songwe Hill Ring Structure was the subject of a brief unpublished report for the Nyasaland Mining Corporation Ltd in 1953 (Lewis, 1953).

Significant new work on the carbonatites of Malawi was conducted in the early 1950s. Of particular interest is Garson’s work with the Nyasaland Geological Survey. Building on earlier descriptions of specific occurrences in the area (e.g. Garson, 1962), he provided a comprehensive account of the carbonatites of Malawi including a detailed description of Songwe Hill (Garson, 1965) with a geological map indicating a volcanic vent filled with feldspathic breccia and agglomerate, and cut by arcuate sheets of carbonatite. He showed that rocks of the Precambrian basement were fenitised in the vicinity of the vent and interpreted the calcite-silicate rocks on the eastern margin to be the product of the reaction between carbonatite and nepheline syenite. Garson (1965) also noted that the agglomeritic rocks at Songwe Hill resembled feldspathic fenites of the Nkalonje vent and the Tundulu carbonatite complex, both in the Phalombe District. He provided mineralogical descriptions of the latter occurrences and noted the presence of accessory minerals including apatite, pyrochlore, synchysite, bastnäsite and fluorite.

In a later publication, Garson and Walshaw (1969) outlined the geology of the Mulanje area, including a description of the “Songwe Hill Carbonatite Vent”. The authors noted the presence of REE-bearing minerals at Tundulu but did not describe them.

6.2.2 Post-1981 Programmes

6.2.2.1 Geophysical Surveys

Airborne geophysical surveys covering the whole of Malawi were carried out in 1984 by Hunting Geology and Geophysics Ltd (Hunting) under contract to the United Nations (Project MLW/ 80/030) (Hunting Geology and Geophysics Limited, 1985). The data was obtained, dependent on the terrain, from fixed wing and helicopter surveys flown with a flight line spacing of 1,000 m at mean sensor elevations of 120 m and 50 m, respectively. Using the data collected by Hunting, the GSDM published a series of aeromagnetic, gravity, and radiometric maps with scales of 1:250,000, 1:100,000 and 1:50,000.

The GSDM compiled 1:100,000 map sheets of the interpreted anomaly coverage from electromagnetic (EM) survey data acquired in 1984 and 1985 by Hunting. The data was obtained using a Geonics EM33-3 helicopter-based EM system with a nominal sensor elevation of 30 m and a flight line spacing of 1,000 m. The anomalies were selected from the analogue profiles in the field and interpreted using either vertical thin dyke or uniform half-space models, as appropriate.

In the Phalombe District, the resolution of the geophysical maps is lower than that in most of Malawi due to the extreme relief caused by mountains rising steeply from the surrounding plain, forcing flight specifications to be altered.

6.2.2.2 Japan International Cooperation Agency and Metal Mining Agency of Japan (1986 to 1988)

In response to a request from the Government of the Republic of Malawi, the Government of Japan conducted a mineral exploration programme in the Chilwa Alkaline Province from 1986 to 1988. The work was overseen by the Japan International Cooperation Agency (JICA) and operated by the Metal Mining Agency of Japan (MMAJ) working together with the GSDM. JICA and MMAJ completed a detailed investigation of the potential for REE mineralisation in southern Malawi including the Songwe Hill deposit. Following the first phase of the programme, which comprised geological and geochemical surveys, JICA and MMAJ concluded that Songwe Hill, as well as other occurrences within and adjacent to the present Phalombe Licences, had a “high potentiality” for a “carbonatite deposit”.

The programme was divided into three phases corresponding to the work carried out from 1986 to 1988, and the results have been compiled in the “JICA and MMAJ Report on the Cooperative Mineral Exploration in the Chilwa Alkaline Area, Republic of Malawi, Phases I, II and III, Consolidated Report, 1989”.

The first phase involved a route survey (geological field survey) of 13 km, the collection of 89 geochemical samples, the completion of a single whole-rock chemical analysis, and a single thin section for mineralogical purposes. The sampling programme largely focused on carbonatite and related rocks with analyses for REE comprising lanthanum, cerium, neodymium, samarium, europium, terbium, dysprosium, ytterbium and yttrium as well as strontium, niobium and thorium. The grade range in the samples was 0.3–2.9 % TREO at an average of 1.2 % TREO. The reports contain no information on the method of REE analysis or any quality assurance and quality control (QA/QC) protocols that may have been implemented.

Following the positive Phase 1 results, the work programme proceeded to Phases 2 and 3 in 1987 and 1988, respectively. Phases 2 and 3 were more comprehensive and included the drawing of a detailed geological map over an area of 3.2 km^2, a route survey of a further 9 km, excavation of 600 m of trenches, collection and assay of 151 surface geochemical samples, preparation of 13 thin sections and 20 polished sections, 14 X-ray diffraction (XRD) analyses, one electron probe microanalysis, and two drilling programmes.

The geological map distinguishes carbonatite and agglomerate/feldspathic breccia and in this respect does not differ from Garson's 1965 map. However, it does show a more complex distribution of the carbonatite and notably indicates the presence of two large, continuous areas of carbonatite on the northern slope and a somewhat smaller occurrence on the lower north-eastern side of the hill.

The 1987 Phase 2 drilling programme comprised 11 diamond drillholes totalling 558 m and defined a number of mineralised zones. The average core recovery, excluding the unconsolidated soils, was 94 %.

The subsequent Phase 3 drilling programme in 1988 was aimed at better defining the extent and grade of the mineralised zone intersected in Phase 2 on the northern side of Songwe Hill. Two rigs were used to drill eight holes totalling 401.2 m with a maximum vertical drillhole depth of 55 m. The drilling followed the same procedures as in Phase 2, and the average core recovery (excluding soils) was 95 % during Phase 3.

There is no information on the sampling methods used in the JICA and MMAJ drilling programmes, other than that the drillhole core was halved prior to chemical analyses of 191 core samples. A total of 109 core samples with an average length of 2.3 m were analysed from the first phase of drilling, while the samples from the second phase had an average length of 4.6 m. The reports do not detail the analytical methods or any QA/QC protocols that JICA and MMAJ may have adopted for the sample preparation or chemical analyses. It has not proved possible to identify the locations of any of these drillhole collars in the field.

The Phase 2 and 3 drillhole core samples in 5 m lengths were assayed for seven rare earth elements, namely lanthanum, cerium, neodymium, samarium, europium, terbium and yttrium as well as strontium, niobium and phosphorous. The geological logs of the drillhole cores indicate broad intersections of carbonatite in a number of drillholes, including JMS 14 (46 m at 1.3 % REO), JMS 16 (50 m at 1.5 % REO) and JMS 18 (50 m at 3.1 % REO) and were used to assess the three-dimensional distribution of the individual carbonatite bodies to a vertical drillhole depth of 50 m. The holes were drilled with a nominal length of 50 m, but the collars were positioned at various elevations near the top of Songwe Hill and northwards down the slope with the result that only the outer shell of the deposit was drill-tested.

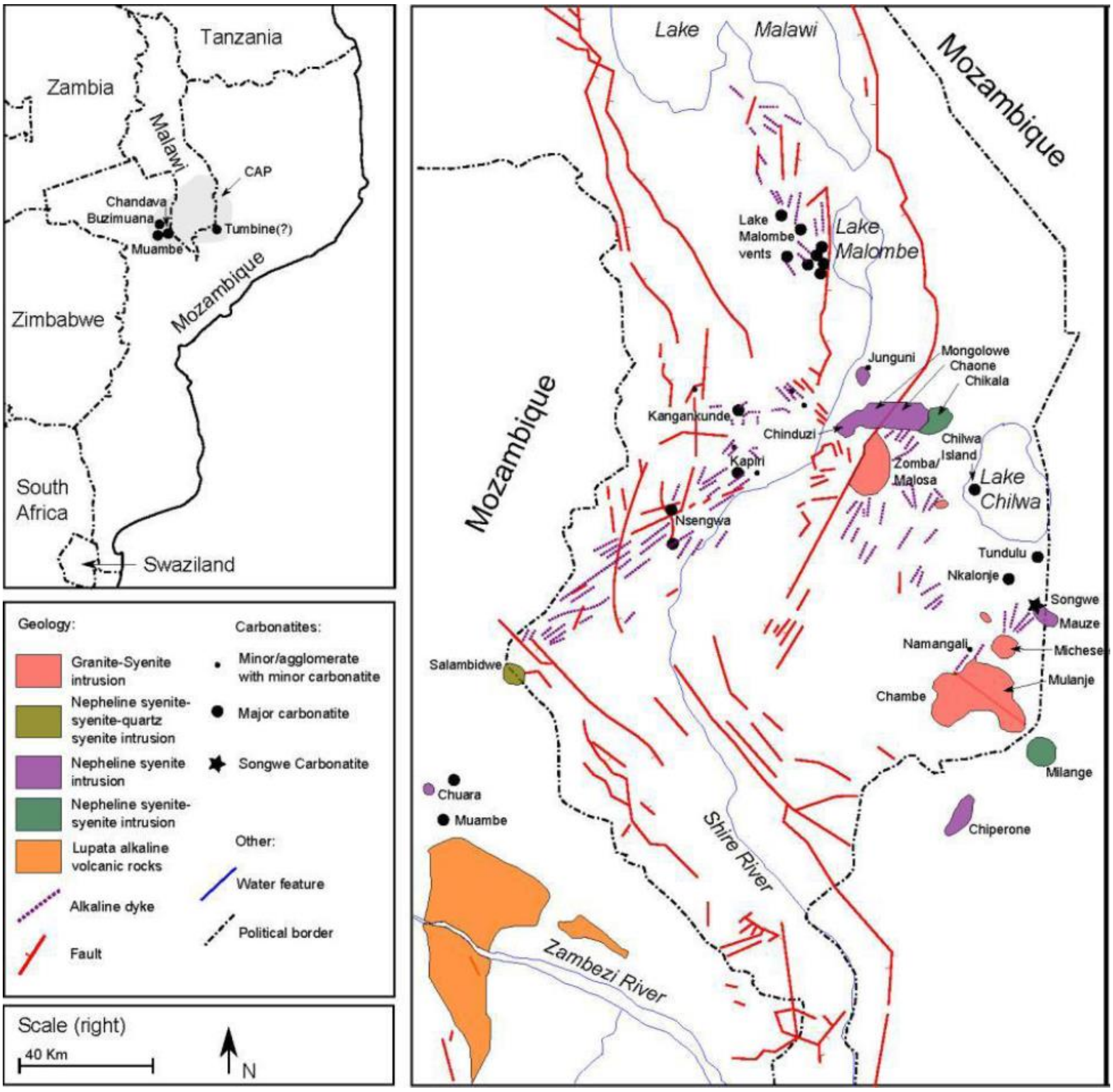
The principal REE-bearing minerals identified by JICA and MMAJ, using thin section, polished section, X-ray fluorescence (XRF) and electron probe microanalysis, included synchysite, bastnäsite, parisite, strontianite, monazite, pyrochlore and apatite.

JICA and MMAJ noted (Phase 3 Report, page 53, 1989) that "samples from Songwe Hill sector are more enriched in medium REE than those from Tundulu, Kangankunde and Chilwa Island sectors [in Malawi]". JICA and MMAJ defined the medium REE as samarium, europium and terbium.

7 GEOLOGICAL SETTING AND MINERALISATION

7.1 REGIONAL GEOLOGY

The Songwe Hill Project is located within the Chilwa Alkaline Province, which is centred in southern Malawi and extends into adjacent areas of Mozambique (see Figure 7.1).



Source: Broom-Fendley (2017) modified after Woolley (2001)

Figure 7.1: Distribution of Chilwa Province Alkaline Intrusions in Southern Malawi and Mozambique

Rocks in southern Malawi range in age from Precambrian to Cretaceous and are in many areas covered by Tertiary to Recent lacustrine sediments. A comprehensive description of all rock units can be found in Garson and Walshaw (1969). The oldest rocks in the area are assigned to a Precambrian Basement Complex that consists of charnockitic granulites and gneiss. The gneiss around the Songwe Hill area is typically paragneiss but orthogneiss is found elsewhere in the region. The Basement Complex was intruded during the Jurassic by a dolerite dyke swarm of the Stormberg Series. The latter are genetically linked to the basaltic lavas of the Karoo Supergroup which occur throughout southern Africa.

The geological units of significance with respect to REE mineralisation in the Songwe Hill area are intrusions and lavas of the Jurassic/Cretaceous Chilwa Alkaline Province. The Chilwa Alkaline Province is comprised of large alkaline intrusions ranging from Mulanje, which is a massif that covers approximately 640 km^2 and rises some 3,000 m above the Phalombe Plain (750 m), to the Michese intrusion with a diameter of 8 km, to the smaller Machemba intrusions and minor plugs and dykes measuring only a few tens of metres in length. These intrusive centres, mainly early Jurassic in age, comprise a variety of alkaline silica-saturated and silica undersaturated lithologies locally associated with carbonatites and are unrelated to the modern rift system. A general account of the tectonic setting has been given by Woolley and Garson (1970).

Although the Chilwa Alkaline Province is dominantly intrusive at the present level of exposure, there are local minor remnants of extrusive rocks. A comparison with alkaline provinces along the East African Rift to the north suggests that volcanic rocks at Chilwa Island may have originally been very extensive. The Chilwa Alkaline Province is remarkable for the diversity of rock types which include granites, quartz syenites, syenites and trachytes, nepheline syenites and phonolites, ijolites and nephelinites, and a plethora of dykes and carbonatites with associated fenites. Three principal lithological associations have been identified based on field relationships (Woolley, 1987), geochemistry (Woolley and Jones, 1987), and K-Ar age dating (Eby et al., 1995):

- Nephelinitic lavas and nepheline syenite coeval with carbonatite (133 million years old (Ma))
- Nepheline syenite and syenite (126 Ma)
- Syenite and peralkaline granite (123 Ma)

Carbonatites are widely present throughout the Chilwa Alkaline Province. There are 17 documented carbonatites in southern Malawi and adjacent Mozambique at the junction of the north-south-trending fault system of the East African Rift and east-west-trending fault system of the Zambezi Rift (Garson, 1965, 1966). In addition to the large carbonatitic intrusion at Songwe Hill, there are three other substantial carbonatite complexes within the Province: Chilwa Island, Kangankunde and Tundulu. Numerous smaller carbonatites occur throughout the Province and include dykes, sheets, small plugs and a carbonatitic volcanic vent at Nkalonje. Igneous silicate rocks comprise only a few small dykes and sheets of nephelinite, ijolite, trachyte and alnöite at the Chilwa Island carbonatite centre whilst there are no igneous silicate rocks associated with the Kangankunde carbonatites. However, there are significant intrusions of nepheline syenite, ijolite and feldspathoid-bearing carbonate-silicate rocks associated with the carbonatite at Tundulu. The four large carbonatite complexes have metasomatic aureoles characterised by the presence of fenites, which extend up to 2 km from the margins of the carbonatite. The fenites are mostly sodium-rich and comprised essentially of sodic pyroxenes and amphiboles. In addition, there are domains of potassic fenite which are intimately associated with the carbonatite, consisting mainly of K-feldspar reflecting a potassium rather than sodium metasomatism.

The largest intrusions of the Chilwa Alkaline Province in Malawi, notably Mulanje and Zomba, are comprised of peralkaline granite and quartz syenite similar to the large intrusion of Michese, which occurs immediately north of Mulanje. Some of the nepheline syenite and syenite intrusions have a considerable size. For instance, the four overlapping nepheline syenites north of Zomba extend nearly 40 km in an east-west line. Most of the igneous centres include swarms of dykes, and there are several volcanic vents including the six that make up the Malombe vents in the north of the Chilwa Alkaline Province (see Figure 7.1). In the Phalombe licence area, the vent in the Nkalonje complex is filled with breccia and agglomerate while the Namangale occurrence contains feldspathic and phonolitic breccias. The Songwe Hill centre comprises both carbonatite and phonolite intrusions, and their brecciated equivalents.

Intrusions in the northern part of the Chilwa Alkaline Province span ages from about 98 Ma to 137 Ma, making it the oldest igneous province associated with the eastern branch of the East African Rift. This relatively old age, in terms of the general rift volcanism, explains the typically intrusive nature of the province and paucity of extrusive rocks. Reviews of the general geology are provided by Woolley and Garson (1970) and Woolley (1991), while Woolley (2001) presents brief accounts of all the individual carbonatite occurrences.

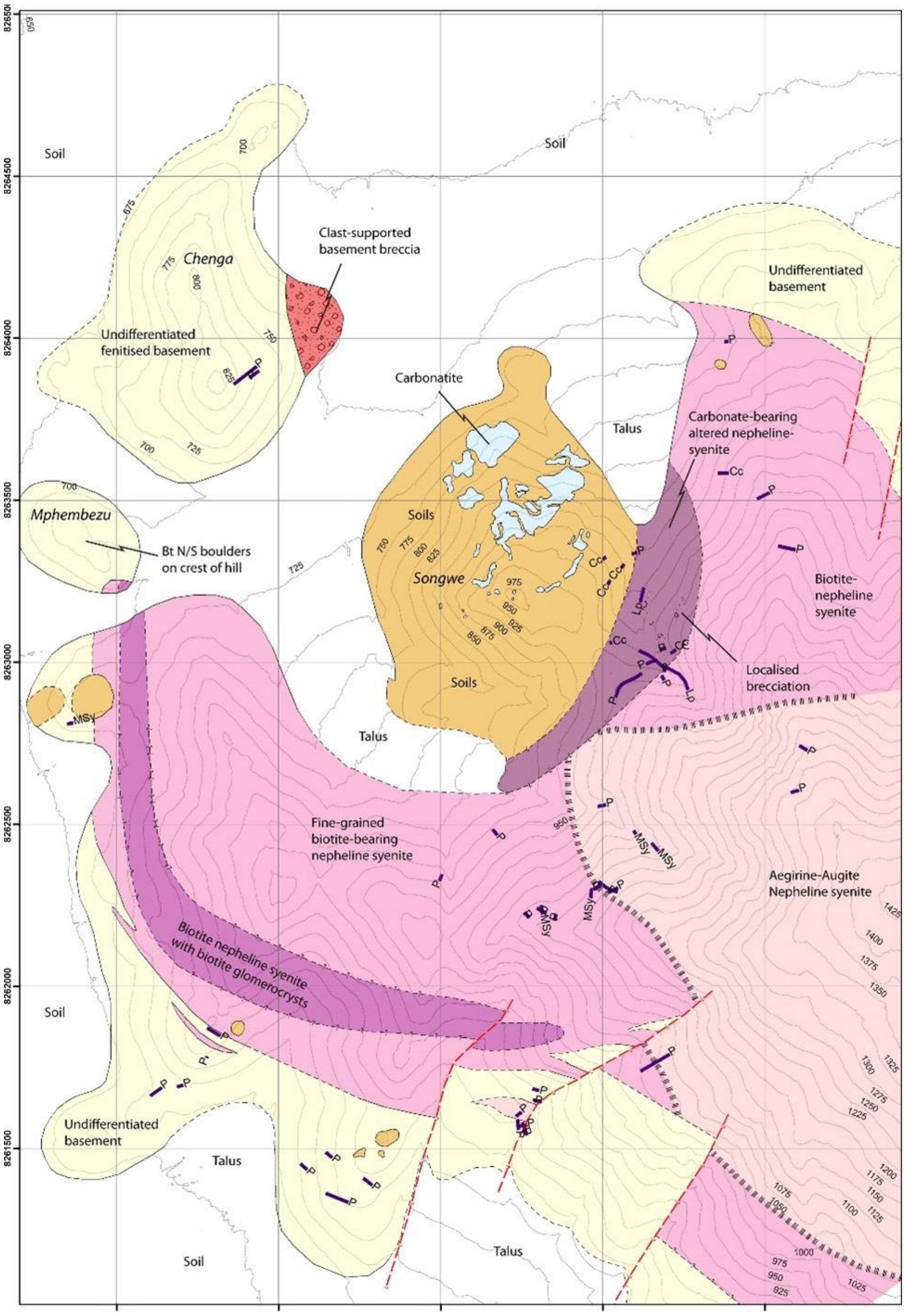
7.2 GEOLOGY OF THE SONGWE HILL CARBONATITE COMPLEX

Songwe Hill is interpreted as a carbonatite intrusion–breccia complex expressed as a steep-sided hill with a diameter of approximately 800 m. The general geology of the complex was described by Broom-Fendley et al. (2017). Information from surface mapping and drill core indicates that the complex consists of a multi-phase intrusion characterised by early intrusion of nepheline syenite (the Mauze nepheline syenite) and phonolite cut by diverse carbonatites and breccias exhibiting a range of alteration from potassic fenitisation to low-temperature hydrothermal/carbohydrothermal overprinting (see Figure 7.2). The entire complex is cut by phonolite dykes, which appear to represent either a continuous event or multiple pulses during and after carbonatite emplacement.

Source: Photos by Mkango Resources Ltd (2012)

Figure 7.2: Outcrops of the Major Rock Types at Songwe Hill

The intrusive/breccia complex abuts the western slope of the large Mauze nepheline syenite intrusion, but the contacts on the northern sides of the vent are hidden beneath recent surficial deposits (see Figure 7.3). It is possible that the carbonatite complex is in contact with Precambrian gneisses in this area because Chenga Hill, which is located less than 200 m west of the probable western margin of the Songwe Hill intrusion, includes fenitised gneisses and breccias. A nearby remnant of Precambrian gneiss north and northwest of the complex is also fenitised, although a screen of nepheline syenite intervenes between the gneiss and the intrusion. The fenitisation is interpreted to be the result of carbonatite intrusion, although it is also possible that the Mauze nepheline syenite had some role in the fenitisation process. The occurrence of carbonate-silicate rocks along the eastern margin of Songwe Hill was interpreted by Garson (1965) to be the product of metamorphism of the nepheline syenite by the Songwe Hill carbonatite.



Source: Map by Dr Sam Broom-Fendley (2018, unpublished)

NOTE: Colours refer to rock units and are labelled.

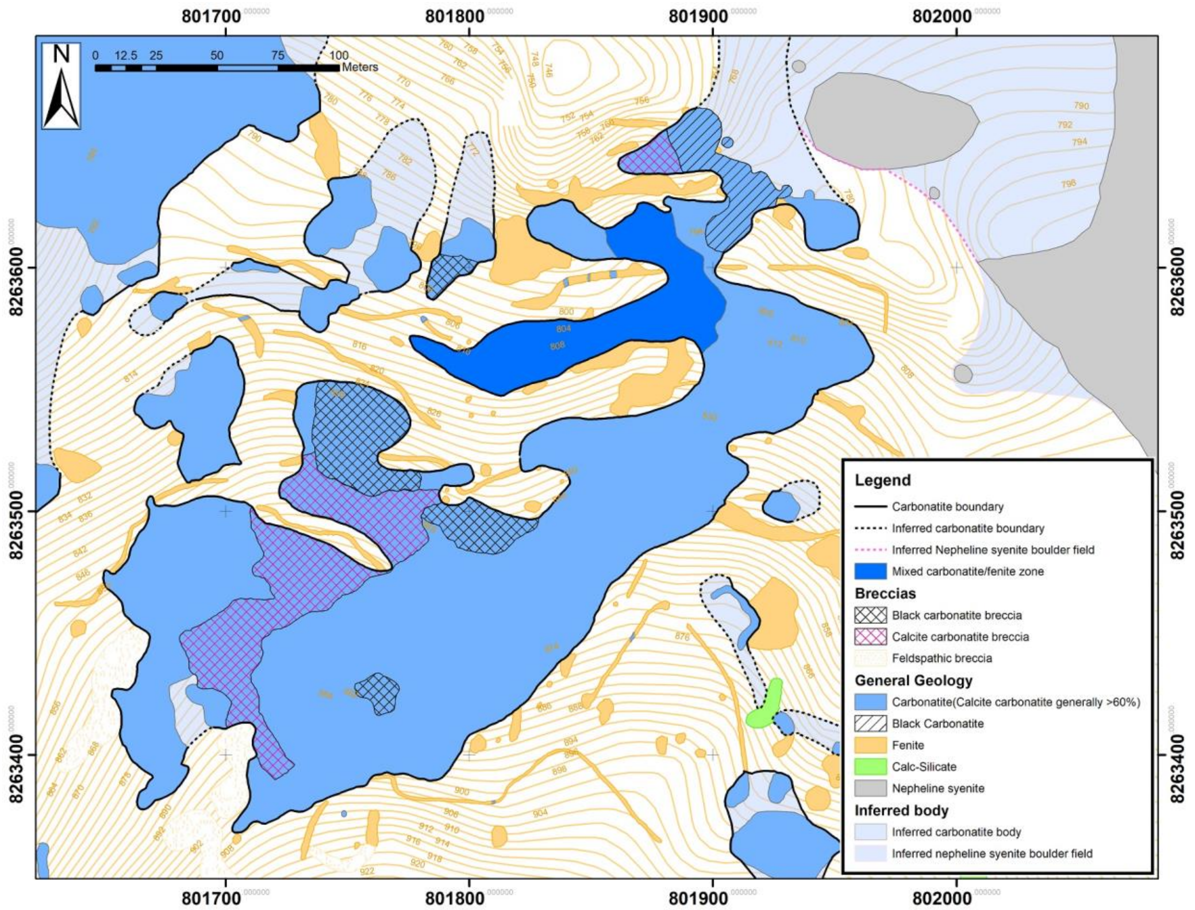
Figure 7.3: Geology of Songwe Hill and Environs

Broom-Fendley et al. (2017) reported U-Pb (zircon) ages of 132.9 Ma ± 6.7 Ma and 135.6 Ma +2.5 Ma −3.8 Ma for Songwe Hill carbonatite and of 134.6 Ma ± 4.4 Ma for Mauze syenite. The two lithologies are therefore indistinguishable in age, and although field evidence indicates that the Mauze silicate intrusions are older than the carbonatites, they are considered to be part of a single, broadly continuous magmatic event.

7.2.1 Carbonatite

The carbonatites are best exposed along the northwest facing slopes of Songwe Hill (see Figure 7.4). Broom-Fendley et al. (2017) identified three recognisable carbonatite phases in the Songwe Hill complex: coarse-grained calcite carbonatite (C1), fine-grained calcite carbonatite (C2), and iron-enriched ferroan calcite carbonatite (C3) (see Figure 7.5).

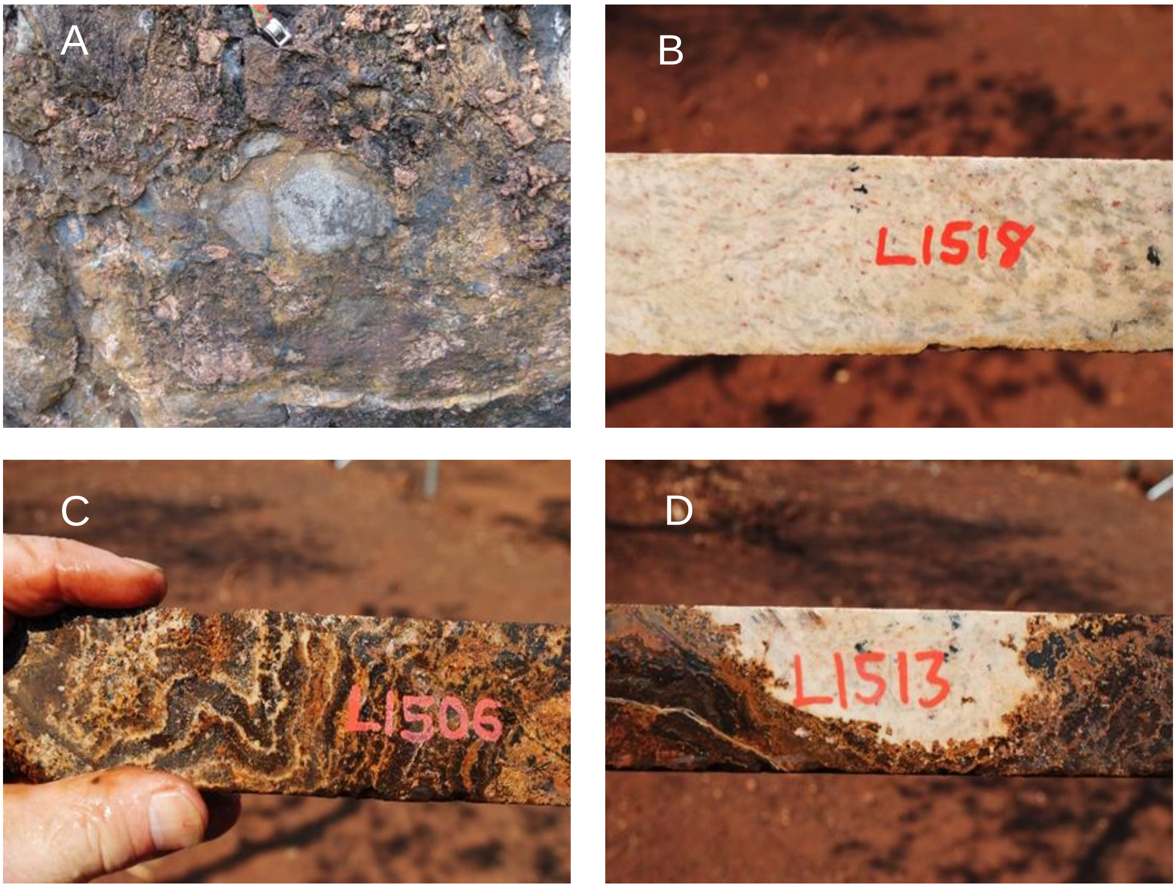
All carbonatite lithologies at Songwe Hill are mineralised with REE but the tenor of the mineralisation is variable. Broom-Fendley et al. (2017) summarised analytical data from the 2011 and 2012 drilling campaigns indicating that, on average, the ferroan (C3) carbonatites and Mn-Fe veins are more intensely mineralised than the grey calcic carbonatites (C1 and C2).



Source: Mkango Resources Ltd internal map (2012)

NOTE: UTM Zone 36S and WGS84 Datum, contour lines at 2 m intervals

Figure 7.4: Surface Geological Map of Songwe Hill



Source: Photographs by Dr Scott Swinden (2018)

A – A fragment of coarse C1 calcite carbonatite in fenite breccia
B – White fine-grained C2 calcite carbonatite
C – Laminated and veined black to orange C3 carbonatite
D – Enclave of C2 carbonatite surrounded by C3 carbonatite

Figure 7.5: Principal Carbonatite Lithologies in the Songwe Hill Complex

7.2.1.1 Coarse-Grained Calcite Carbonatite (C1)

C1 carbonatite is the least common carbonatite phase at Songwe Hill. It is only seen as rare, rounded clasts in other carbonatite types in outcrop and has rarely if ever been observed in drillhole core. Broom-Fendley et al. (2017) described it as comprising mainly anhedral, medium-grained calcite with minor ankerite, relatively coarse-grained apatite and zircon, and accessory pyrite, pyrochlore and K-feldspar. C1 carbonatites contain euhedral to subhedral zoned zircon which are interpreted as magmatic. Broom-Fendley et al. (2017) suggested that C1 carbonatites may represent a cumulate originating in a deeper level of the intrusion.

7.2.1.2 Fine-Grained Calcite Carbonatite (C2)

C2 carbonatite constitutes by far the most abundant carbonatite at Songwe Hill. It forms irregular, massive bodies and occurs as clasts and/or matrix in breccias. It is a dominantly white, calcite-rich carbonatite but includes a range of compositions that include more iron-rich compositions. C2 carbonatite is mineralogically and chemically similar to C1 carbonatite and may closely approach the primary carbonatite liquid composition. Petrographic studies have shown that C2 carbonatite consists predominantly of Fe- and Mn-rich calcite, with varying proportions of Mn-bearing ankerite apatite. Broom-Fendley et al. (2017) identified xenocrystic pyrite, zircon and K-feldspar and localised synchysite (Ce), barite and strontianite.

C2 Carbonatite is typically fine-grained and light grey to pinkish white in colour. Sulphides, mainly pyrite, are abundant and occur as disseminations, patches and veins. Fluorite is present as locally abundant patches or blebs and can impart a purple hue to the rock. Mineralisation is fine-grained and widely dispersed in these rocks and is not typically seen in hand specimen or outcrop. Narrow ferro-carbonatite veins are common along with occasional late-stage calcite veining.

7.2.1.3 Ferroan Calcite Carbonatite (C3)

C3 carbonatite is more heterogeneous than C2, typically dark brown or black to orange and red in colour, and intensely veined by black Fe- and Mn-rich veins. It typically displays laminated veining textures indicating that it has been extensively altered. It occurs as veins, breccia clasts and/or matrix, and large irregular masses. C3 carbonatites typically weather dark grey to black, and texturally are dominated by laminated vein textures containing alternating ferroan calcite and apatite. It contains Fe- and Mn-rich calcite, and Fe- and Mn-oxides, apatite and minor amounts of alkali (K) feldspar and zircon.

There are systematic but relatively minor compositional differences between C2 and C3 carbonatites. C3 carbonatites are enriched in iron, manganese and phosphorous and depleted in calcium and potassium relative to C2 carbonatites (Broom-Fendley et al., 2017) and generally contain higher concentrations of REE.

Mineralisation can often be recognised in the dark Mn-Fe-rich carbonatite by the pervasive streaks of orange pink to white rare earth fluorocarbonate minerals and apatite.

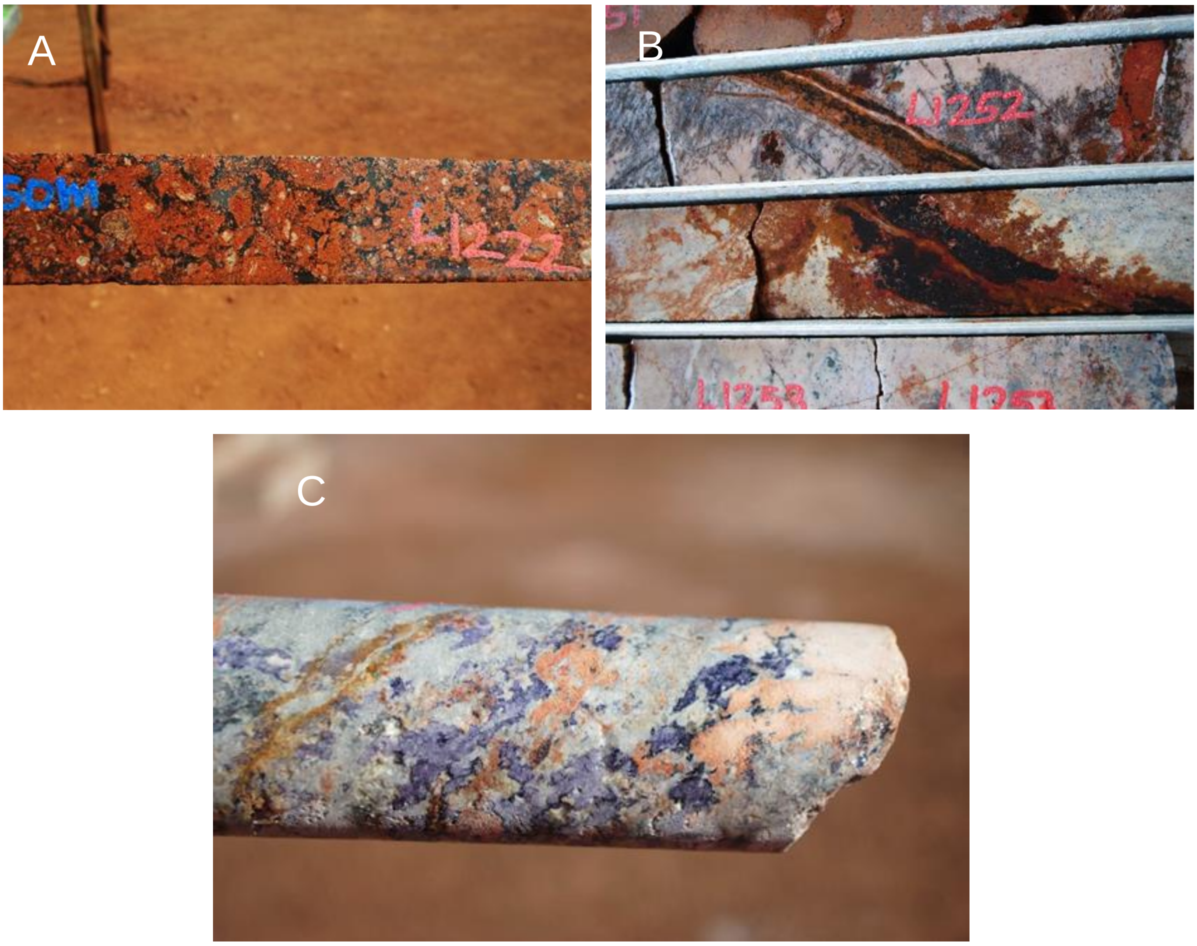
A variety of the C3 carbonatites, locally termed “black carbonatite”, outcrops in the north-eastern part of the deposit and contains the consistently highest REE grades of any lithology in the deposit. It can be traced at surface for approximately 50 m in an east-west direction and to a depth of approximately 60 m beneath the surface of the hill. The black carbonatite is texturally complex, heterogeneous on the local scale, ranging in colour from black to light grey with a highly variable fabric comprising various late-stage cross-cutting Fe-carbonatite veins. The higher TREO content in the black carbonatite does not reflect differences in REE mineralogy compared to the calcite carbonatite but a greater abundance of the REE-bearing minerals.

7.2.1.4 Late Veins

Black Mn-Fe veins (see Figure 7.6A and B) are abundant throughout the complex and cross-cut all lithologies, although they are most abundant in the fenites, fenite breccias and the C3 carbonatites. Veins typically range in size from less than 1 cm to several metres and occur as the matrix to late-stage breccias comprising a mixture of Fe-bearing carbonatites (calcite and ankerite) and Fe- and Mn-oxides. The veins exhibit a wide range of Mn-Fe ratios and are typically mineralised with synchysite (Ce) and apatite, particularly when relatively Mn-rich. Locally, veins of almost pure Fe-oxide are found; these are typically unmineralised.

The Mn-Fe veins are typically highly calcic and contribute significantly to the grade of REE in rocks where they are abundant. In breccias, where the REE are already present in carbonatite breccia fragments or matrix, they result in an upgrading of the concentration of REE. In fenites, where there is little REE in the rock, they can locally result in narrow higher-grade intersections.

The Songwe Hill complex is also cut by a wide variety of late apatite-fluorite veins seen locally in both outcrop and drill core. These veins are widely dispersed and contain fluorite, apatite, calcite and barite and elevated concentrations of REE (Broom-Fendley et al., 2017) (see Figure 7.6C).



Source: Photographs by Dr Scott Swinden (2018)

A – Black Mn-Fe veining as the matrix to a fenite breccia
B – Black Mn-Fe veins cutting C2 carbonatite
C – Fluorite-apatite veins containing REE fluorocarbonate (light brown)

Figure 7.6: Examples of Mn Veining and Apatite in Drill Cores

7.2.2 Fenite

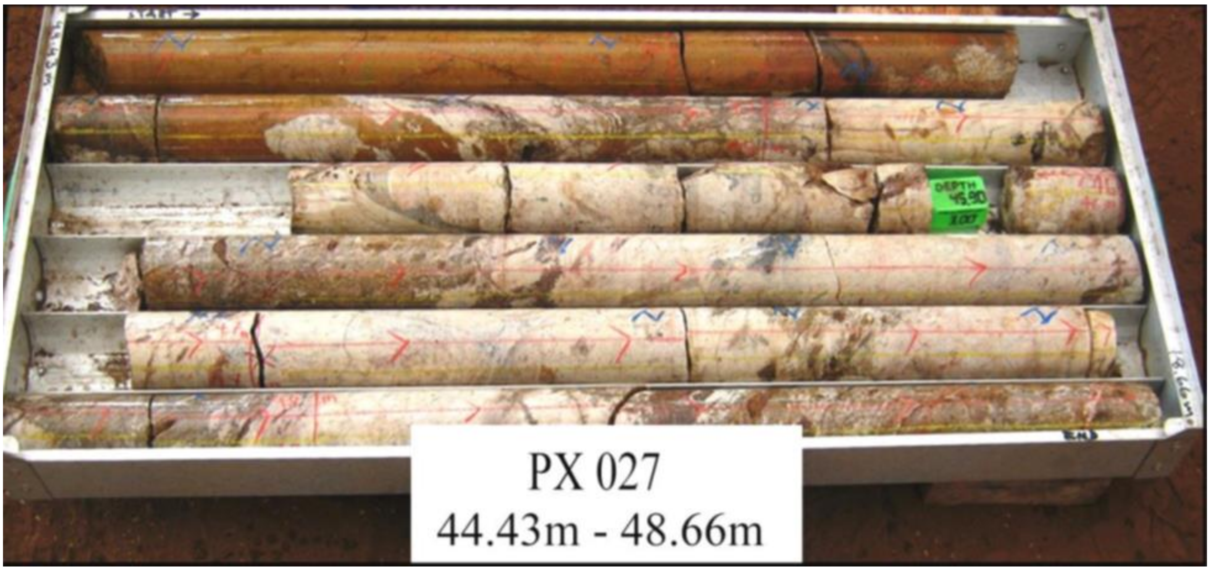
Potassium fenite surrounds the mineralised carbonatite body at surface and is present in virtually all drillholes where it is typically intimately intermixed with the carbonatite. The fenites are characteristically light red in colour (see Figure 7.2 and Figure 7.7) and composed essentially of alkali (K) feldspar with minor aegirine and accessory apatite, zircon and iron oxides. The fenites display a wide range of alteration intensity, from lightly discoloured phonolites and syenites in which much of the original mineralogy and textures are preserved, to completely altered rocks composed essentially of K-feldspar in which no original textures are preserved.

No vertical zonation of fenitisation has been observed in the drillhole core at Songwe Hill, and potassic fenites extend from surface to deeper levels. However, the fenites that occur on Chenga Hill, north of Songwe Hill, are sodic in nature. Garson (1965) described them as containing aegirine, aegirine-augite, a blue sodic amphibole and albite. This is consistent with the fenitisation pattern at other carbonatite complexes in Malawi, where potassic fenites are intimately associated with carbonatite while sodic fenites occur at some distance from the carbonatite margin.

The fenite on Songwe Hill occurs both as in-situ mass forming large irregular bodies that mantle the carbonatite intrusion, and as blocks and small fragments in breccias (see Figure 7.6A). On the upper reaches of the hill, fenite appears to mantle the carbonatite and black Fe- and Mn-rich carbonate veins, which are believed to originate in the carbonatite, locally intrude the fenite. The Songwe Hill complex is interpreted to represent a complex carbonatite-silicate intrusive, and many of the fenite blocks are interpreted to be dismembered, originally phonolite, blocks, some of which may have been emplaced along late, intrusion-related faults.

Fenite is variably mineralised, and the degree of mineralisation is a function of the degree of carbonatisation and/or intensity of late-stage veining of the fenite. Along the north-western and eastern side of Songwe Hill, the fenite is relatively uncarbonatised, geochemically characterised by consistently low CaO (~ 7 wt%) and high SiO_2 and K_2O concentrations (averages of 17 wt% and 7 wt%, respectively), and can be traced in drillholes from surface to depth with values of consistently less than 0.5 % TREO.

Well-defined lithological and geochemical contacts are observed between the fenite and carbonatite at the north-western side of Songwe Hill (see Figure 7.7). Further south, the fenite becomes more intimately associated with the carbonatite and is variably carbonatised and cross-cut by multiple generations of late-stage Mn-Fe-rich carbonatite veins. In these areas, the fenite contains lower concentrations of SiO_2 and K_2O but higher concentrations of CaO and consequently REE concentrations may exceed 1 % TREO.



Source: Photo with annotation by Mkango Resources Ltd (2012)

Figure 7.7: Example of Contact Between Fenite and C2 Calcite Carbonatite

7.2.3 Breccia

The Songwe Hill complex includes breccias that range from clearly abraded pebble-sized fragments (pebble dykes) to metre-sized angular blocks as well as significant volumes of breccias in which the fragments appear to have undergone little or no movement. The breccias are variably mineralised and the degree of mineralisation is a function of the proportion of carbonatite. The breccias can essentially be divided into two types: C2 carbonatite-rich breccias and C3 feldspar-rich breccias.

7.2.3.1 C2 Carbonatite-Rich Breccia

Carbonatite-rich breccias contain an abundance of light grey, fine-grained calcite carbonatite clasts, with subordinate fenite clasts in a similarly fine-grained carbonate-rich matrix (see Figure 7.2). The calcite carbonatite breccias are light grey to orange-red in colour depending on the proportions of calcite carbonatite and fenite fragments. Typically, carbonatite breccias contain abundant angular to sub-angular calcite carbonatite fragments in a fine-grained grey carbonatitic to feldspathic matrix. Similar to the main calcite carbonatite lithology, fluorite and sulphides are abundant and occur as disseminations, patches and veins.

Gradational relationships can be observed from one variety of breccia into another, indicating a complex process of intrusion, fragmentation and continuous movement of a carbonatite-breccia mixture. The breccias, regardless of type, are invariably cross-cut by numerous late-stage black Fe- and Mn-rich carbonate veins.

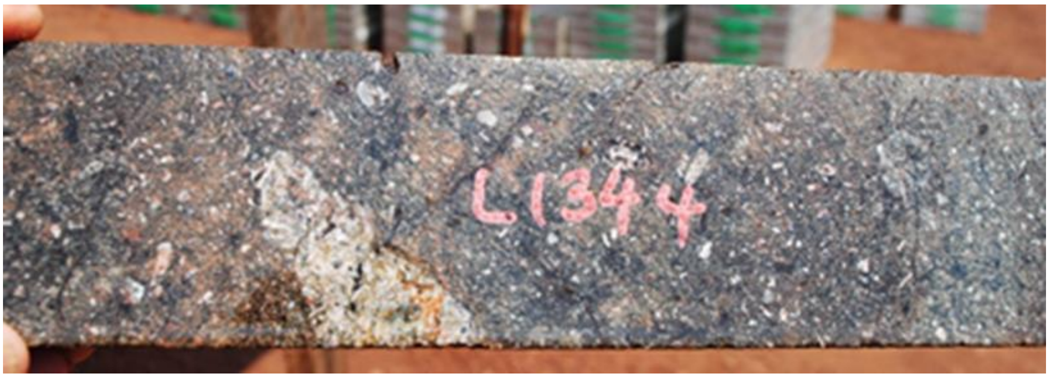
7.2.3.2 C3 Feldspar-Rich Breccia

C3 carbonatite breccias consist of a mixture of fenite and carbonatite fragments with varying shapes from rounded to angular and typically have spotted, striped and patchy late-stage textures. The feldspar-rich breccias consist mainly of light red alkali-feldspar-rich (orthoclase or sanidine; Garson, 1965) fenite clasts and fragments, partially fenitised phonolite and nepheline syenite and minor clasts of calcite carbonatite (see Figure 7.6A). The matrix is fine-grained, carbonatitic in nature and composed of abundant Fe- and Mn-oxides, Fe-rich carbonates and alkali feldspar with occasional pyrochlore. In some cases, the matrix can have a relatively high silica content reflecting the comminution of fenite during formation of the breccias.

The level of rare earth mineralisation in the breccias is more variable than in the carbonatites and directly related to the proportion of carbonatite to fenite fragments and the amount of carbonatitic matrix.

7.2.4 Silicate Dykes

Late-stage silicate dykes have been identified in abundance in drillhole core and at surface. The dykes are mainly phonolitic in composition, aphanitic or porphyritic in texture, and exhibit a wide degree of alteration ranging from minimal modification to extensive alteration and fenitisation (see Figure 7.8). Subrounded to subangular xenoliths of relatively unaltered nepheline syenite are very common in the dykes (see Figure 7.9). Syn-intrusion and post-intrusion faulting of the dykes are evident across Songwe Hill although displacements appear to be relatively small. In general, however, dykes occur in a wide spectrum of deformation: from virtually undeformed and internally pristine, through extensively disrupted but still recognisable dykes, to dispersed fragments (see Figure 7.10). The ubiquitous clasts that characterise the 'mixed rock' are now considered to be fragments of early syn-carbonatite phonolite dykes torn up by the continually intruding or pulsing carbonatite magma (see top right photograph in Figure 7.2).



Source: Photo by Dr Scott Swinden (2018)

Figure 7.8: Phonolite Dyke in Drill Core, Lightly Fenitised with Phenocrysts of K-Feldspar and Nepheline and a Xenolith of Coarse-Grained Nepheline Syenite

Source: Photo by Dr Paul Armitage (2018)

Note reddish colour typical of fenitised dykes

Figure 7.9: Phonolite Dyke with Syenite Xenoliths in Dark Carbonatite Breccia

Source: Photo by Dr Paul Armitage (2018)

Figure 7.10: Wall of Calcite Carbonatite with Syn-Intrusive Dykes and Locally Cross-Cutting and Fragmented Dykes

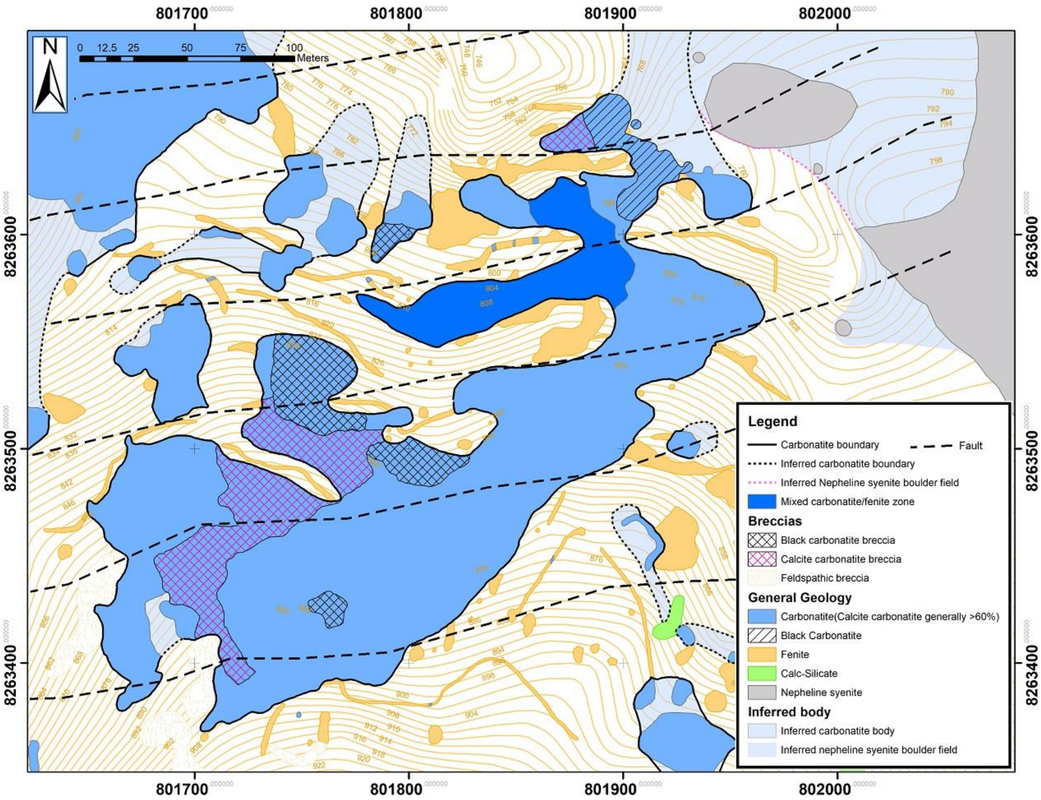
7.2.5 Structural Geology

The Songwe Hill complex is irregular in shape. Some of this irregularity reflects the intrusive nature of the carbonatite. However, there is evidence for structural deformation in some parts of the complex. There is a consistent igneous foliation in the carbonatite that typically strikes NNE-SSW, dipping steeply to vertically (see Figure 7.11). There are sharp lithological breaks that appear to correspond with faults as well as breaks in the ground magnetics that also seem to correspond to the position of faults. Figure 7.12 illustrates several faults interpreted from ground magnetics. The fault traces should be regarded as approximations, as the resolution of the magnetic image is low at the scale of the geological map. However, the interpreted faults do appear to explain some of the patterns in the map, particularly the “fingers” and “neck” in the carbonatite and an apparent offset of a breccia body. The faulting is not unexpected, given the active tectonic environment, and although it appears to disrupt the geology on outcrop scale, it is not believed that structural disruption has occurred on a large scale.

Source: Photograph by Dr Paul Armitage (2018)

Note entrainment and alignment of small phonolite fragments in the foliation.

Figure 7.11: Igneous Foliation in Calcite Carbonatite



Source: Mkango Resources Ltd internal map (2019)

Figure 7.12: Geological Map with Faults (Long Dashed Lines) Interpreted from a Ground Magnetic Survey

7.3 GEOLOGICAL/GEOCHEMICAL MODELLING OF THE SONGWE HILL COMPLEX

7.3.1 Rationale

Early geological models for the Songwe Hill complex envisaged a vertically dipping intrusive carbonatite plug, the dimensions of which were defined by mapped contacts at surface and projected downward. In very simplified terms, the plug was modelled as a central plug, enveloped by fenite and breccia. However, this simple model had some significant drawbacks. Few if any drillholes penetrated the contacts of the carbonatite intrusive so the contacts were virtually unconstrained in the subsurface. The drilling also demonstrated that the internal structure of the complex was intricate, and that fenites and breccias occurred throughout the area that was modelled as carbonatite intrusive. Finally, the model did not easily account for late-stage alteration and veining that cuts not only the carbonatites and breccias but also the fenites, and which locally carries economically interesting grades. The lithological and geochemical variation occurs on such fine scales that core logging becomes a complex exercise and the correlation of lithologies between holes (which were relatively wide-spaced) became problematic.

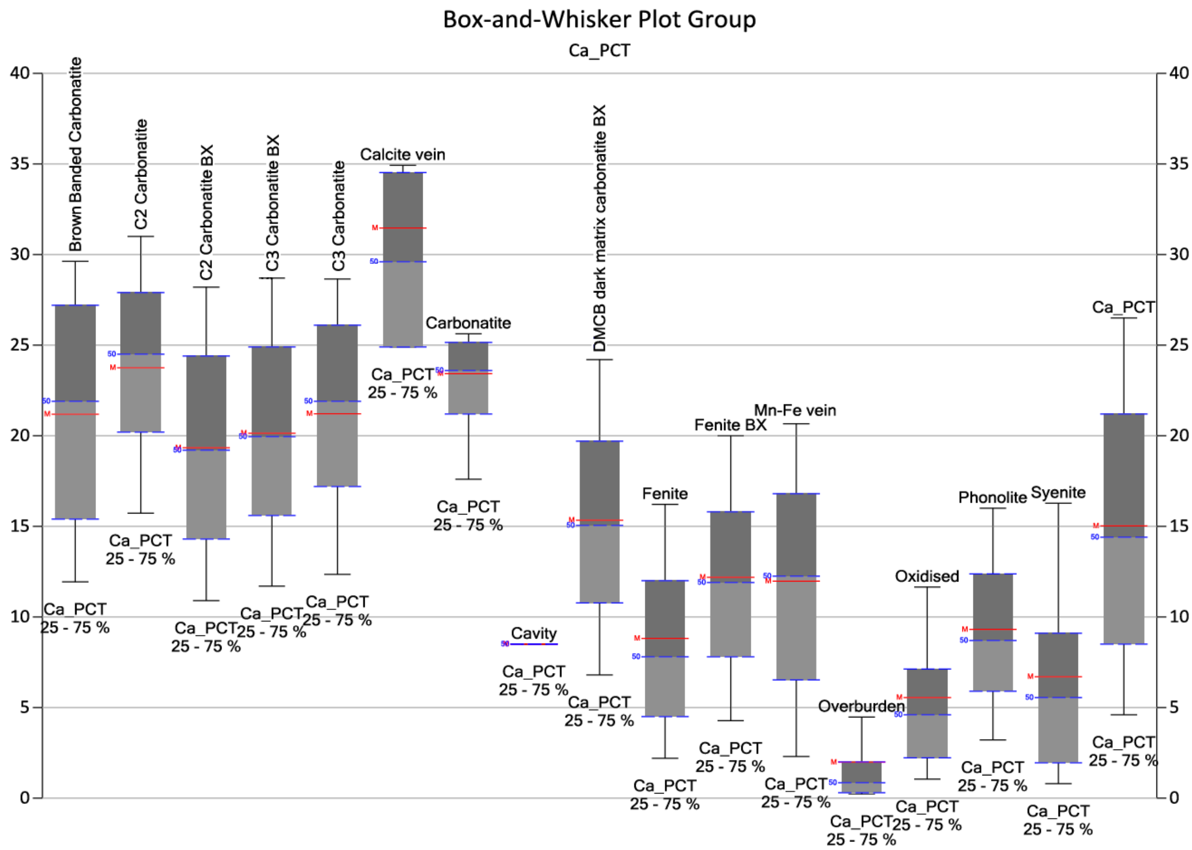
Because all holes were sampled and assayed from top to bottom, the geochemical information provides a potentially powerful tool to model the lithological variation if clear correlations can be demonstrated between the geochemistry and the lithology. Accordingly, a modelling exercise was undertaken in which geochemical indicators were tested as discriminants of carbonatites and non-carbonatite lithologies.

The objective of this exercise was to produce a model based on geochemical coding that is reflective of the main mineralisation, and that is objective, repeatable, and provides a consistent and meaningful illustration of the distribution of REE mineralisation in the context of the geological setting.

7.3.2 Modelling Methodology

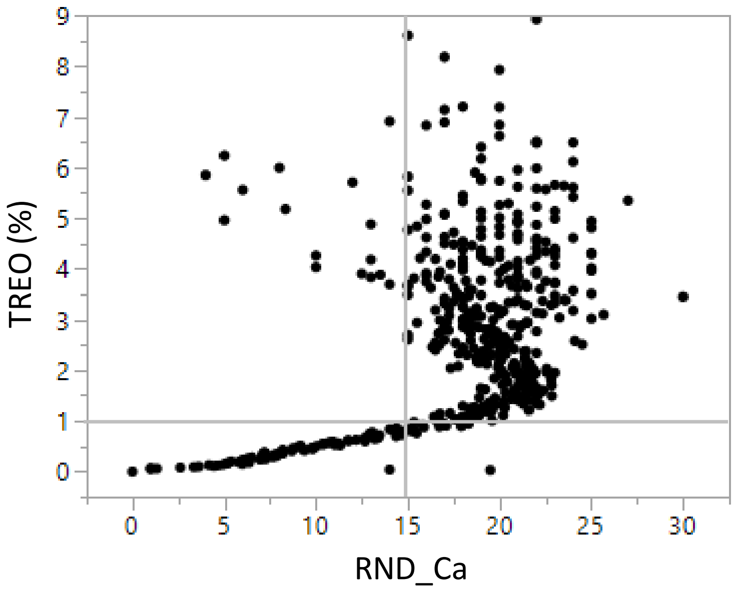
The modelling was carried out using Leapfrog software. The principal geochemical discriminators of the lithological variation were found to be Al, Si, K, and Ca. Ca was used as the final indicator, because it gave a good separation with the same accuracy and resolution as if all four discriminators were used.

The use of the 15 % Ca threshold is validated by the box and whisker plot in Figure 7.13, which shows that, apart from dark matrix carbonatite breccia, the samples described as carbonatite contain above 15 % Ca and those described as other rock types largely contain less than 15 % Ca. The scatter plot shows that samples with more than 15 % Ca also tend to have the highest TREO grade (see Figure 7.14). The points with low Ca and high TREO values are likely to be manganese-iron veins that can have an elevated TREO grade. The linear portion observed in the lower portion of the scatterplot is likely a result of the TREO grade increasing in mixed units with increasing carbonatite content.



Source: The MSA Group (2020)

Figure 7.13: Box and Whisker Plots of Lithology Versus Ca Grade at Songwe Hill



Source: The MSA Group (2020)

Figure 7.14: Scatterplot of Binned Ca Grade Versus TREO Grade at Songwe Hill

7.3.3 Modelling Results

The raw drillhole data, coded as carbonatite or non-carbonatite by separation of a 15 % Ca threshold, was modelled using Leapfrog Geo in order to create a carbonatite volume that constrains the higher-grade mineralisation (see Figure 7.15).

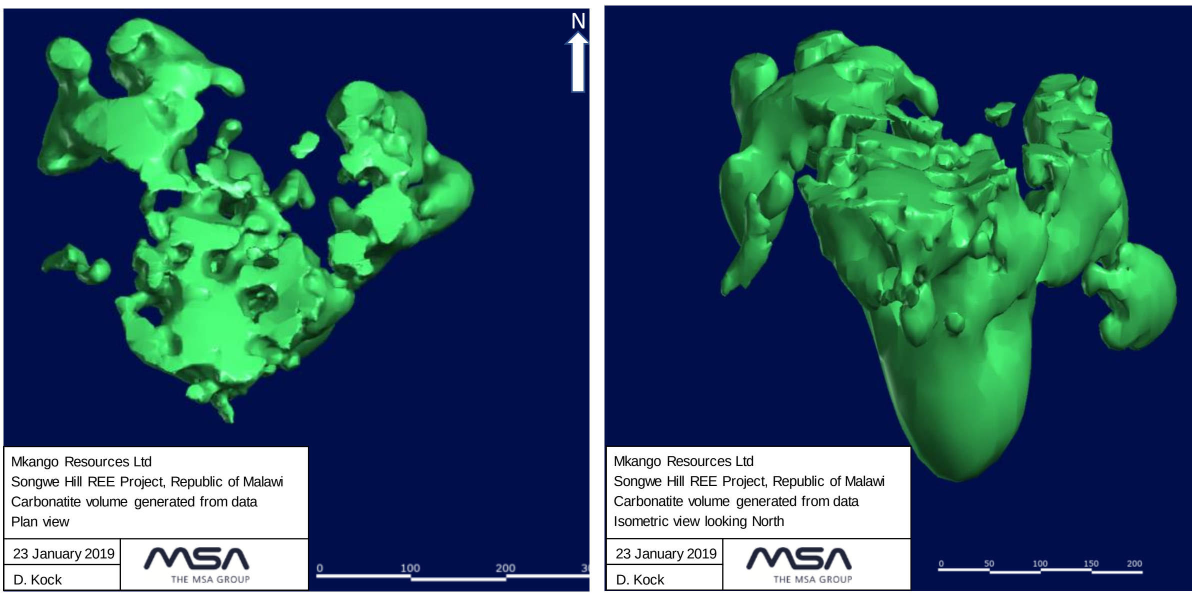


Figure 7.15: Carbonatite Volume Modelled at Songwe Hill

The model gave a reasonable estimate of the shape and extent of the carbonatite. On querying the drillhole data within the model, it was found that 75 % of the data was carbonatite coded and the other 25 % was non-carbonatite coded material. This created a mixed REE statistical distribution and was therefore not considered a valid framework within which to discriminate higher- from lower-REE grade zones. The model is considered a useful tool to describe the shape of the carbonatite and was used to validate the indicator approach that was finally chosen to estimate the carbonatite proportion in each cell of the block model.

An indicator approach was taken whereby the samples coded as carbonatite were assigned an indicator value of 1 and non-carbonatite samples were assigned an indicator value of 0. The indicators were estimated into a block model using ordinary kriging. Each cell in the block model contains a proportion (probability) of carbonatite and non-carbonatite, i.e. if a block has an indicator estimate of 1 then the entire block is made up of carbonatite. The indicator model generally fitted well with the Leapfrog Geo generated carbonatite volume (see Figure 7.16), and the proportional approach to assigning the domain to each block was used for estimation.

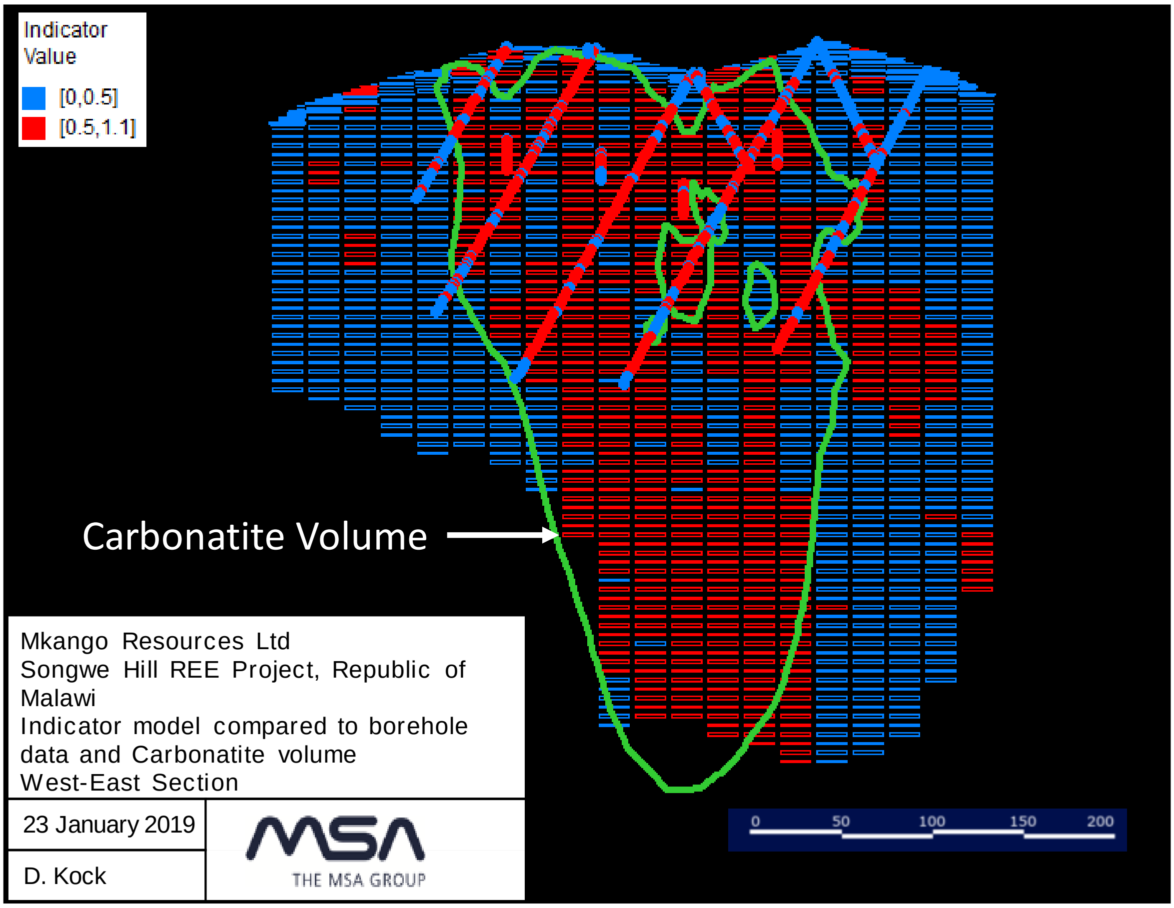


Figure 7.16: Cross Section of the Indicator Block Model, Drillhole Data and the Modelled Carbonatite Volume (Green Perimeter)

7.3.4 Geometry of the Complex

The geological model constructed from the geochemistry provides a good framework within which to interpret the geology of the deposit. This is a rather chaotic geological environment that is not easily interpreted from lithological observations of drillhole core and outcrop alone.

The model confirms previous interpretations of the Songwe Hill complex as comprising, in simplified terms, a central carbonatite intrusion, enveloped by carbonatite-rich breccias and altered lithologies, and passing outwards into a halo of fenitised phonolite and nepheline syenite. The model clearly outlines the carbonatite core to the deposit and shows the many outlying carbonatite bodies and the generally irregular distribution of carbonatite outside the main body. The central core carbonatite is modelled as a steep intrusion with steeply dipping but irregular contacts, surrounded by mixed lithologies that logging shows are mainly a combination of breccias and carbonatite-altered fenites. The mixed lithologies pass outward into silicate rocks, dominantly fenite but including less altered phonolite and nepheline syenite.

In general, the thick sections of carbonatite logged in the core correspond well with carbonatites identified geochemically by their Ca content. The identification of a central core of carbonatite to the intrusive complex seems to be well supported by the data, and the grades are consistent throughout this lithology. The geometry of the central carbonatite body is well constrained by the geochemical/geochemical modelling and ties in well with the mapped outcrops at Songwe Hill. The carbonatites are consistently mineralised with REE, arising mainly from REE minerals as an essential accessory in the carbonatite, locally supplemented by REE in cross-cutting carbonatite and Mn-Fe veins. Grades are relatively consistent in carbonatites in the core of the deposit and across most geological sections.

The mixed lithologies are the most complicated lithologies to deal with and are likely to be the most variable in terms of tracing lithologies and grades between drillholes. The mixed lithologies include various types of breccias and carbonate-altered rocks that reflect the complex nature of the intrusive environment. They may include carbonatite magma contaminated by blocks of country rock that have detached and sunk into the magma, intrusion breccias, where carbonatite has surrounded and stoped earlier fenitised rocks, and explosion breccias where hydrothermal overpressuring has brecciated the rocks and allowed a matrix of carbonatite to be introduced. They also may include dominantly fenite that has been veined and altered by later carbonate-rich veins/dykes. All of these are likely to be irregular in shape and size, and difficult to define geometrically. The mixed lithologies are usually, but not always, mineralised with REE, and the grades are more variable than in the carbonatites. REE grades in these rocks depend on the proportion of carbonatite in the breccias as well as the intensity and tenor of the veins cutting the rocks. These grades are likely to vary considerably on a small scale and to be difficult to correlate between drillholes.

The silicate lithologies (fenite and phonolite/syenite) are clearly identified by their low Ca contents. There is little practical benefit in attempting to separate the fenites from unaltered rocks as they are typically unmineralised and do not contribute to the Mineral Resource. Locally, isolated pockets of fenites return economically interesting grades – this is invariably the result of late Mn-Fe veining that is not readily traced between drillholes.

7.4 MINERALISATION

Mineralisation in the Songwe Hill complex occurs in all three geological domains, but the highest grades and most consistent mineralisation are found in the carbonatites. The mixed lithologies locally carry a high enough grade over significant widths to be included in the Mineral Resource but are not consistently mineralised throughout their full extent. Fenites only locally contain economically interesting concentrations of REE, and seldom over economic widths.

7.4.1 Mineralogy

Mineralogical studies carried out on Songwe Hill samples were reported in detail by The MSA Group (2015) and are summarised here, supplemented by recently published data. Mineralogical studies using a scanning electron microscope (SEM), electron microprobe (EMP) and laser ablation, inductively coupled plasma, mass spectrometry (LA-ICP-MS) showed that the REE mineral assemblage at Songwe Hill, regardless of lithology, is dominated by fluorocarbonates, principally synchysite with minor parisite, apatite and occasional florencite. Average REO concentrations in synchysites from several drillholes are presented in Table 7.1. The synchysite crystals are homogeneous, typically occurring as randomly oriented laths or tabular crystals and/or fibro-radial to plumose aggregates (see Figure 7.17). Crystal size varies, but laths typically range in length from 10 μm to 60 μm, and crystal aggregates can reach up to 400 μm.

Synchysite is invariably associated with strontianite and/or baryte either as inclusions and/or intergrowths, and together they form distinctive vein-like aggregates or segregations (see Figure 7.17). In addition to these two phases, synchysite is locally associated with calcite, fluorite, alkali (K) feldspar, pyrochlore and titanite. The mineral association of synchysite with strontianite and baryte in the Songwe Hill carbonatites and their textural relationships was described by Broom-Fendley et al. (2017) and interpreted on the basis of paragenesis with various states of apatite as representing hydrothermal redistribution of the REE during early hydrothermal activity at 250 °C to 300 °C.

Fluorapatite in the Songwe Hill carbonatites has a complex history and paragenesis. Broom-Fendley et al. (2017) showed that there are five recognisable stages of apatite crystallisation: two early stages representative of crystallisation from a carbonatite magma, and three stages that are texturally atypical of magmatic apatite and progressively enriched in the heavy rare earth oxides (HREO). The HREO enrichment factor of Songwe Hill apatite, defined here as the sum of all HREO from Eu_2O_3 to Lu_2O_3 and Y_2O_3/TREO, ranges from 40 % to 85 % compared to 2 % to 11 % in apatite from other carbonatites (Hornig-Kjarsgaard, 1998). It is rare for apatite in carbonatite deposits to display heavy rare earth enrichment.

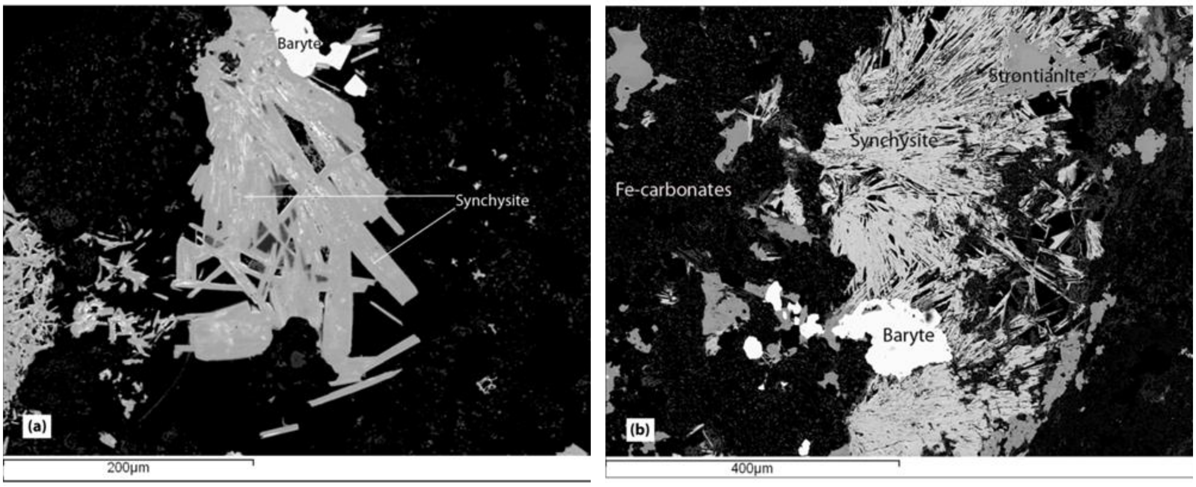
Fluorapatite in the Songwe Hill carbonatite lithologies is often visibly recrystallised and occurs as stringers and groundmass anhedral crystals, or as large bands (see Figure 7.18A) and veins which frequently contain entrained groundmass material, typically carbonate. In samples from the black carbonatite, apatite invariably forms large bands and veins (see Figure 7.18B) and is closely associated with the Fe-carbonate.

Florencite is particularly abundant in the groundmass of the carbonatite breccias forming narrow acicular crystals (< 20 μm in width) and is associated with various Fe- and Mn-bearing oxides (see Figure 7.19). Occasionally, florencite is also found as small anhedral crystals along the edges of entrained carbonate crystals in apatite veins and most likely formed as a replacement/alteration product of apatite.

Figure 7.20 compares representative analyses of the Songwe Hill late-stage apatite to typical light rare earth element (LREE) enriched unaltered magmatic carbonatite from other carbonatite complexes, Oka in Canada and Jacupiranga in Brazil (Hornig-Kjarsgaard, 1998), clearly illustrating the anomalous enrichment of heavy rare earth element (HREE)+Y in the Songwe Hill apatites. Broom-Fendley et al. (2016, 2017) presented evidence that the HREE enrichment in apatite at Songwe Hill resulted from late-stage hydrothermal activity and, in the latter stages of activity, is associated with minor xenotime (Y) and HREE-enriched fluorite. In this model, subsolidus, carbonatite-derived fluids remobilised and fractionated the REE. The rapid crystallisation of apatite resulted in destabilisation of the HREE and their incorporation in the apatite structure. More soluble LREE stayed in solution and subsequently precipitated as synchysite (Ce).

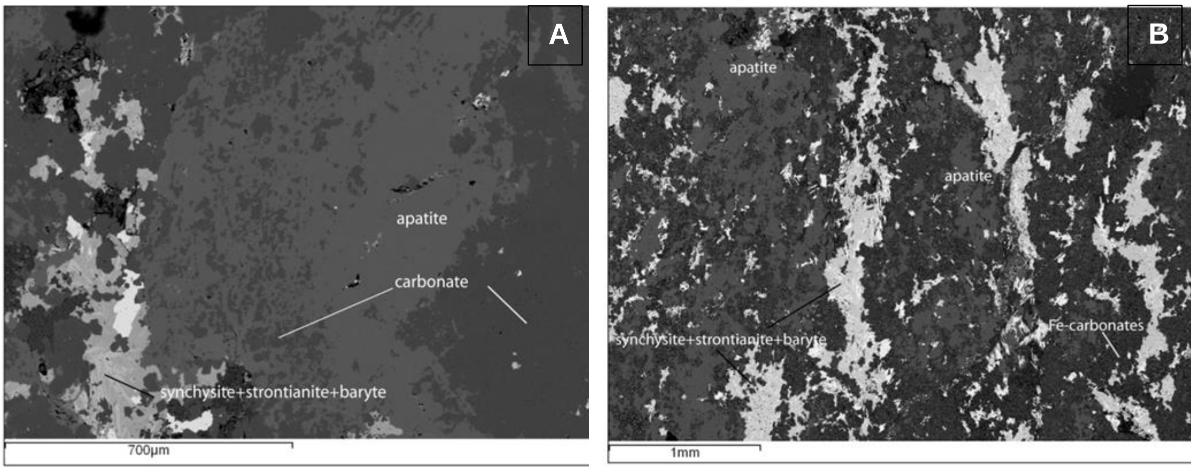
Table 7.1: Average REO Distribution of Synchysite, Analysed by EMP, in Songwe Hill Carbonatites (Excluding Outliers)

Drillhole	La_2O_3 wt%	Ce_2O_3 wt%	Pr_2O_3 wt%	Nd_2O_3 wt%	Sm_2O_3 wt%	Eu_2O_3 wt%	Gd_2O_3 wt%	Dy_2O_3 wt%	Y_2O_3 wt%	REO[1] wt%
PX001										
Median	14.50	23.39	2.16	7.45	1.04	0.26	0.63	0.21	0.54	50.18
Average	14.39	23.11	2.13	7.38	1.03	0.25	0.60	0.22	0.55	49.66
PX003										
Median	15.84	26.52	2.39	7.45	0.58	0.04	0.00	0.06	0.24	53.12
Average	16.13	26.78	2.40	7.17	0.55	0.05	0.01	0.07	0.27	53.43
PX005										
Median	11.42	24.70	2.72	9.42	0.99	0.10	0.17	0.14	0.50	50.16
Average	10.98	24.19	2.55	8.94	0.98	0.12	0.20	0.14	0.61	48.71
PX011										
Median	13.65	24.43	2.38	6.63	0.65	0.11	0.16	0.21	0.84	49.06
Average	13.73	23.99	2.31	6.57	0.64	0.11	0.17	0.24	0.92	48.68
Drillhole	**La_2O_3 %**	**Ce_2O_3 %**	**Pr_2O_3 %**	**Nd_2O_3 %**	**Sm_2O_3 %**	**Eu_2O_3 %**	**Gd_2O_3 %**	**Dy_2O_3 %**	**Y_2O_3 %**	**REO[1] %**
PX001										
Median	28.92	46.44	4.32	15.10	2.11	0.51	1.23	0.43	1.07	100.0
Average	28.97	46.53	4.29	14.86	2.08	0.50	1.21	0.44	1.12	100.0
PX003										
Median	29.88	49.65	4.58	13.81	1.09	0.08	0.00	0.11	0.45	100.0
Average	30.23	50.12	4.50	13.39	1.02	0.09	0.01	0.13	0.51	100.0
PX005										
Median	22.75	49.21	5.36	18.65	1.93	0.24	0.38	0.28	1.17	100.0
Average	22.45	49.80	5.21	18.33	2.00	0.25	0.41	0.29	1.26	100.0
PX011										
Median	28.66	49.09	4.78	13.55	1.30	0.23	0.32	0.45	1.78	100.0
Average	28.20	49.30	4.75	13.50	1.31	0.23	0.33	0.48	1.87	100.0
REO[1] = La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Dy_2O_3 and Y_2O_3										
Source: Tables from NHM and Dr Aoife Brady (2012)										



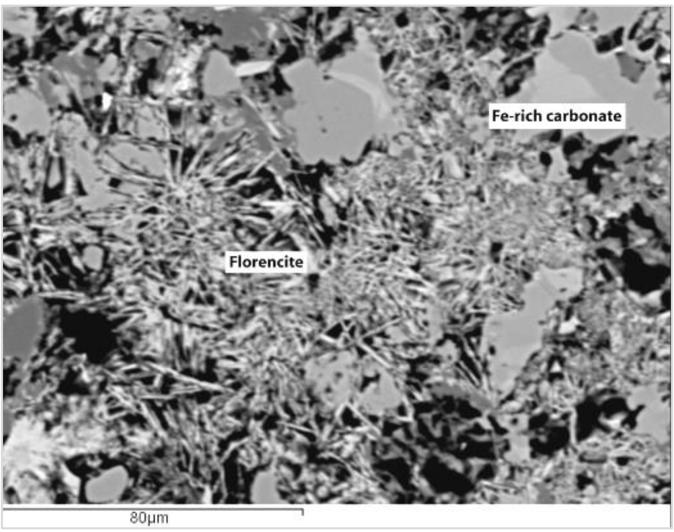
Source: Images from NHM and Dr Aoife Brady (2012)

Figure 7.17: SEM Images of Synchysite in the Songwe Hill Carbonatite



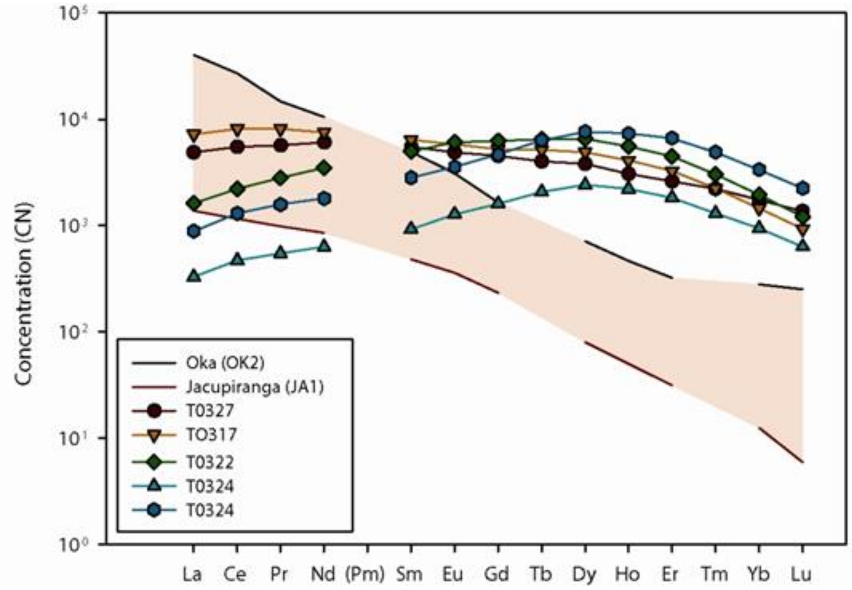
Source: Images from NHM and Dr Aoife Brady (2012)

Figure 7.18: SEM Images of Apatite in the Songwe Hill Carbonatite



Source: Images from NHM and Dr Aoife Brady (2012)

Figure 7.19: Florencite-Rich Groundmass of Carbonatite Breccia



Source: Chart by Dr Sam Broom-Fendley (2012)

NOTE: Typical LREE-enriched unaltered magmatic carbonatite from the Oka and Jacupiranga carbonatites are shown in the coloured field.

Figure 7.20: Chondrite-Normalised Late-Stage Apatite from Songwe Hill Carbonatites

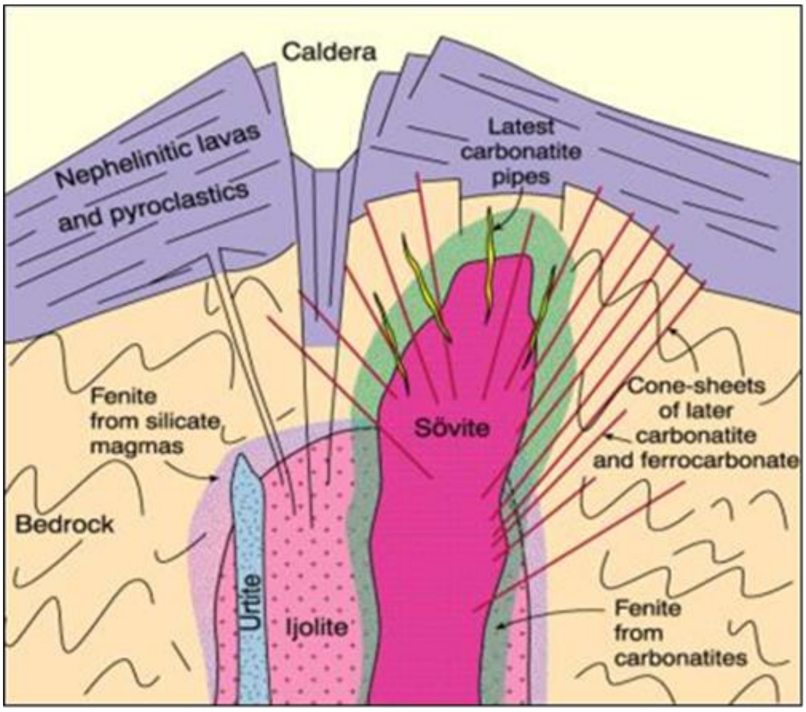
7.4.2 Genetic Model for REE Mineralisation

The Songwe Hill complex records a short-lived but complicated history of intrusion, hydrothermal activity, and REE mineralisation. The igneous history of the complex began with intrusion of the Mauze nepheline syenites and phonolites. This is characteristic of complex silicate/carbonatite intrusions where the silicates typically intrude first, followed by the carbonatite. The intrusion of the carbonatite plug closely followed intrusion of the Mauze nepheline syenites – sufficiently close that the U/Pb isotopic ages of the two are identical within analytical uncertainty. The carbonatite plug closely resembled the composition of the C2 calcite carbonatites and had probably undergone at least some fractionation in the subsurface, evidenced by the cumulate C1 carbonatites that occur as fragments. During intrusion, fluid exsolution from the C2 carbonatite metasomatised the surrounding silicate rocks producing fenites, and these fenites were then incorporated in the carbonatite by stoping or in explosion breccias related to continued fluid overpressuring of the magma chamber. Phonolite dykes intruded the carbonatite in a single continuous event or multiple pulses, evidenced by the highly variable degree of fragmentation and entrainment of the dykes, which were fenitised by exsolving fluids from the C2 carbonatite. The latest dykes remain virtually intact and at least internally unfenitised.

As the carbonatite system evolved, an extensive and intense hydro (carbo)thermal system developed which resulted in widespread redistribution of mobile elements in the system. The mineral association of REE-rich fluorocarbonates and apatite with strontianite, baryte, ankerite and fluorite at Songwe Hill strongly suggests that the REE mineralisation formed by re-equilibration and recrystallisation of primary (early-crystallised) minerals (e.g. calcite) in the various carbonatite lithologies. The alteration resulted in the remobilisation of the REE into fluorocarbonates in the C2 carbonatite, and more intense alteration produced veined and laminated black to orange Mn-Fe-rich C3 carbonatites (C3). In the later stages of alteration, the REE were somewhat partitioned with an HREE-rich fraction entering apatite, while the LREE-rich fraction continued to enter fluorocarbonates. The higher intensity of alteration recorded by the C3 carbonatites is reflected in their overall higher REE contents. The fluid system, besides producing pervasively altered rocks, also produced Mn-Fe calcic veins which persisted until late in the evolution of the system and invaded all lithologies, although the intensity was greatest in the core of the system (i.e. close to the carbonatite plug). The alteration veins are locally seen cutting and modifying the C2 carbonatites. Late-stage Mn-Fe veins are enriched in REE, similar to the C3 carbonatites, and where they cut relatively unmineralised lithologies, they locally bring the grades up to economically interesting values.

8 DEPOSIT TYPES

The target deposit type at Songwe Hill is a high-level, REE-enriched carbonatite intrusive complex. Carbonatites are traditionally defined as intrusive and extrusive igneous rocks that contain in excess of 50 % modal carbonate minerals (Woolley and Kempe, 1989). Mitchell (2005) defines carbonatites as “containing greater than an arbitrary 30 % by volume of primary igneous carbonate regardless of silica content”. Carbonatites can be named according to their carbonate mineralogy (e.g. calcite carbonatite, dolomite carbonatite and ankerite carbonatite), and chemically they can be divided into the three main varieties: calcio-, magnesio- and ferro-carbonatite. Figure 8.1 is a generalised and widely accepted schematic illustration of the intrusion of a carbonatite complex.



Source: Le Bas (1987)

Figure 8.1: General Model for an Alkali Silicate-Carbonate Intrusive Complex

Carbonatites usually occur as plugs or pipe-like bodies within zoned alkalic intrusive complexes, or as dykes, sills, breccias, and veins, and are almost exclusively associated with continental rift-related tectonic settings. They are characterised by an aureole of metasomatically altered country rocks which are usually referred to as fenites. Carbonatite magmas are typically low-viscosity and volatile-rich, and when intruded at a high crustal level, produce widespread intrusion- and explosion-breccias incorporating country rocks, carbonatites and associated fenites. Carbonatites are typically associated with silicate rocks of which the seven key carbonatite-silicate rock associations are, in decreasing order of abundance, 1) nephelinite-ijolite, 2) phonolite-feldspathoidal syenite, 3) trachyte-syenite, 4) melilitite-melilitolite, 5) lamprophyre, 6) kimberlite, and 7) basanite-alkali gabbro (Woolley & Kjarsgaard, 2008). The carbonatite deposit at Songwe Hill is spatially associated with the large nepheline syenite intrusion of Mauze, and the Songwe Hill carbonatite is intimately associated with intrusive phonolites and their fenitised equivalents. It is therefore interpreted to belong to the phonolite-feldspathoidal syenite association.

Carbonatites can be generated by

- A low degree of partial melting in the mantle (e.g. Wallace & Green, 1988)
- Extreme crystal fractionation (e.g. Watkinson and Wyllie, 1971)
- Liquid immiscibility (e.g. Kjarsgaard and Hamilton, 1989) from carbonated silicate magma

It is possible that all three mechanisms may play a part in carbonate magma evolution. Low degrees of partial melting in the mantle produce a magma that is anomalously enriched in the incompatible elements such as the REE. Carbonatites typically consist of multiple phases of intrusions and characteristically evolve, by crystal fractionation within the intrusion, from early magmatic calcite-rich carbonatite to magnesium-rich dolomite carbonatites and finally with decreasing temperature to late-stage iron-rich carbonatite phases. As a result of their petrogenesis, carbonatites tend to be anomalously enriched in the highly incompatible REE and high field strength elements (HFSE), and such enrichment can lead to economic concentrations of REE (Chakhmouradian and Zaitsev, 2012).

The REE profile of carbonatite-associated mineralisation is typically LREE-dominated. Concentrations of REE tend to increase with fractionation from calcio- to magnesio- to ferro-carbonatites, and the REE distribution and profile in carbonatites is typically modified by late-stage hydrothermal activity (Mariano, 1989; Giere, 1996; Wall and Mariano, 1996; Doroshkevich et. al., 2009). Carbonatite deposits may also contain economic or anomalous concentrations of magnetite, apatite, baryte, sulphides and vermiculite and are characterised by elevated concentrations of some or all phosphorous, niobium, tantalum, uranium, thorium, copper, iron, titanium, vanadium, barium, fluorine, zirconium, and other rare or incompatible elements.

REE-enriched carbonatite hosted deposits may be divided into three types: magmatic, hydrothermal, and residual/supergene (Mariano, 1989). Rare earth mineral deposits produced by primary crystallisation from carbonatite magma are very rare, and at the present time, the Mountain Pass deposit in the USA is the only well documented example (Castor, 2008). Late-stage rare earth mineralisation produced by magmatic hydrothermal fluids is much more common, resulting in the precipitation of rare earth minerals, such as bastnäsite-(Ce), parisite-(Ce), synchysite-(Ce) and monazite-(Ce) in fractures or voids in the host carbonatite rock, often associated with enriched mobile elements such as strontium (strontianite) and barium (baryte). Alternatively, hydrothermal mineralisation may be present as disseminated, fine grained, polycrystalline aggregates of rare earth minerals overprinting or replacing earlier-formed minerals. Examples of hydrothermal deposits include Bayan Obo in China (Chao et al., 1992; Smith and Henderson, 2000) and Karonge/Gakara in Burundi (Lehmann et al., 1994).

Laterites, overlying deeply weathered carbonatites and alkaline rocks, are also an important source of REE enrichment, and examples of supergene mineralisation include the Mount Weld deposit in Western Australia. However, the rare earth deposit at Songwe Hill is not a laterite and is best described as a magmatic/hydrothermal REE deposit.

The target at Songwe Hill is a large body of intrusive calcic carbonatite with related breccias and fenites that appears to represent a high-level intrusion with an extensive history of metasomatism and high-level fluid exsolution. The REE mineralisation is lithologically controlled, and the highest concentrations and greatest volumes of mineralisation occur specifically within the carbonatites.

The carbonatites are believed to have been REE-enriched when they were intruded, and the REE are interpreted to have been redistributed and enhanced by late-stage hydrothermal and carbohydrothermal activity and now principally reside in synchysite (with minor florencite) and apatite.

Associated breccias are also variably mineralised locally to potentially economic grades, and the level of REE concentrations is a function of the relative abundance of carbonatite fragments and REE-enriched hydrothermal veins.

Adjacent fenites are also variably mineralised, although typically at lower volumes and concentrations than carbonatites, and the intensity of mineralisation is related to the degree of overprinting carbonate alteration and veining, suggesting that these rocks have also been mineralised by late-stage hydrothermal activity.

9 EXPLORATION

Mkango has been exploring and evaluating the Songwe Hill deposit since January 2010. Following confirmation of the enriched zones, previously investigated by the Japan International Cooperation Agency and Metal Mining Agency of Japan (JICA and MMAJ, 1989), exploration focused on identifying the nature and extent of the REE-mineralised carbonatites and related rocks. Mkango's exploration activities consisted of litho-geochemical sampling, soil sampling, channel sampling, geological mapping, ground magnetic, density and radiometric surveys, and petrographic/mineralogical analyses and culminated in diamond drilling campaigns in 2011, 2012 and 2018, the results of which are described in The MSA Group (2015, 2020), and taking of a bulk sample in 2018. Geological observations and interpretations and procedures related to exploration methodology were implemented and overseen by the Mkango geological team in Malawi.

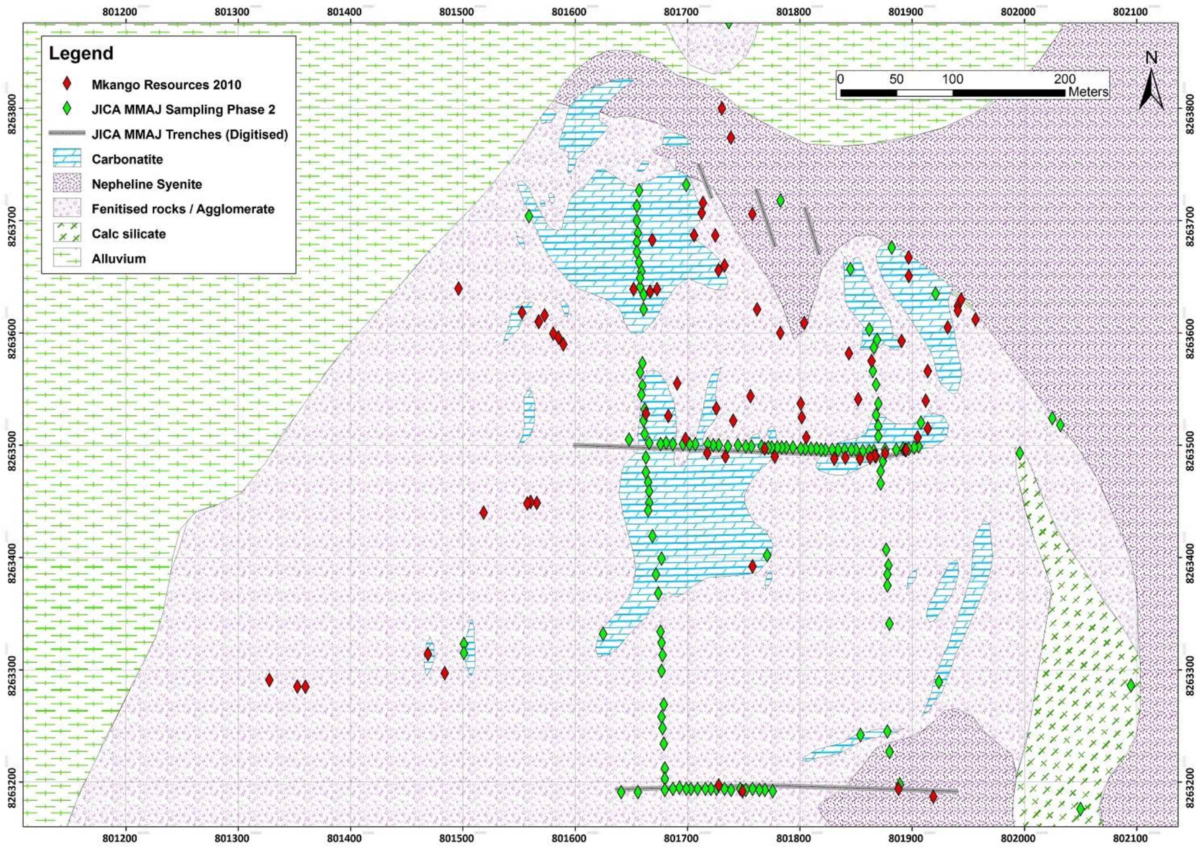
9.1 LITHO-GEOCHEMICAL SAMPLING

Fieldwork undertaken by Mkango at Songwe Hill during March 2010 and May 2010 consisted primarily of litho-geochemical sampling to confirm the nature and extent of the mineralisation identified by JICA and MMAJ. Outcrops were systematically scanned with a Thermo-Scientific Niton® XLp handheld X-ray fluorescence analyser calibrated for the semi-quantitative analysis of REE. This work indicated that all lithologies at Songwe Hill contain anomalous amounts of REE and that there are variations between the different lithologies. In general, the contents of the total REE in the fenites were found to be lower than the carbonatites.

Two principal types of carbonatite were identified: a relatively homogeneous, medium grey rock, which appeared flow banded in places and a much blacker type, which was characteristically heterogeneous. The black carbonatite appeared to form zones of various widths that cut or replace the grey homogeneous carbonatite. A total of 88 grab samples were taken from the outcrop (62 carbonatite, 14 fenite, 11 Fe-rich and related rocks) and assayed for a full suite of rare earth and related elements. The sample locations are shown in Figure 9.1, and the assay results for the various rock types are presented in Table 9.1 and Figure 9.2. The samples were representative of the outcrop distribution of the mineralisation; however, they are not considered to be of sufficient quality for use in a Mineral Resource estimate. Care was taken to take samples from visually fresh rock, although there may have been minor modification of the concentration of REE in some samples by near-surface effects.

The new results generally compared well with the data from JICA and MMAJ and confirmed broad zones of carbonatite at surface. The 62 carbonatite grab samples produced TREO concentrations between 0.4 % and 5.3 % TREO with an average of 1.5 % TREO. The proportion of HREO, defined as the sum of oxides of Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y, for these samples averaged 8 % of TREO. The average TREO concentration of samples exceeding 1 % TREO is 1.84 % TREO.

The results of this work confirmed the REE enrichment initially identified by JICA and MMAJ and suggested that the mineralised carbonatites are more widespread than originally identified. This led to a broadening of the exploration focus to include most of the north-facing slopes of Songwe Hill.



Source: Mkango Resources Ltd after JICA/MMAJ (1989).

NOTE: UTM Zone 36S and WGS84 Datum

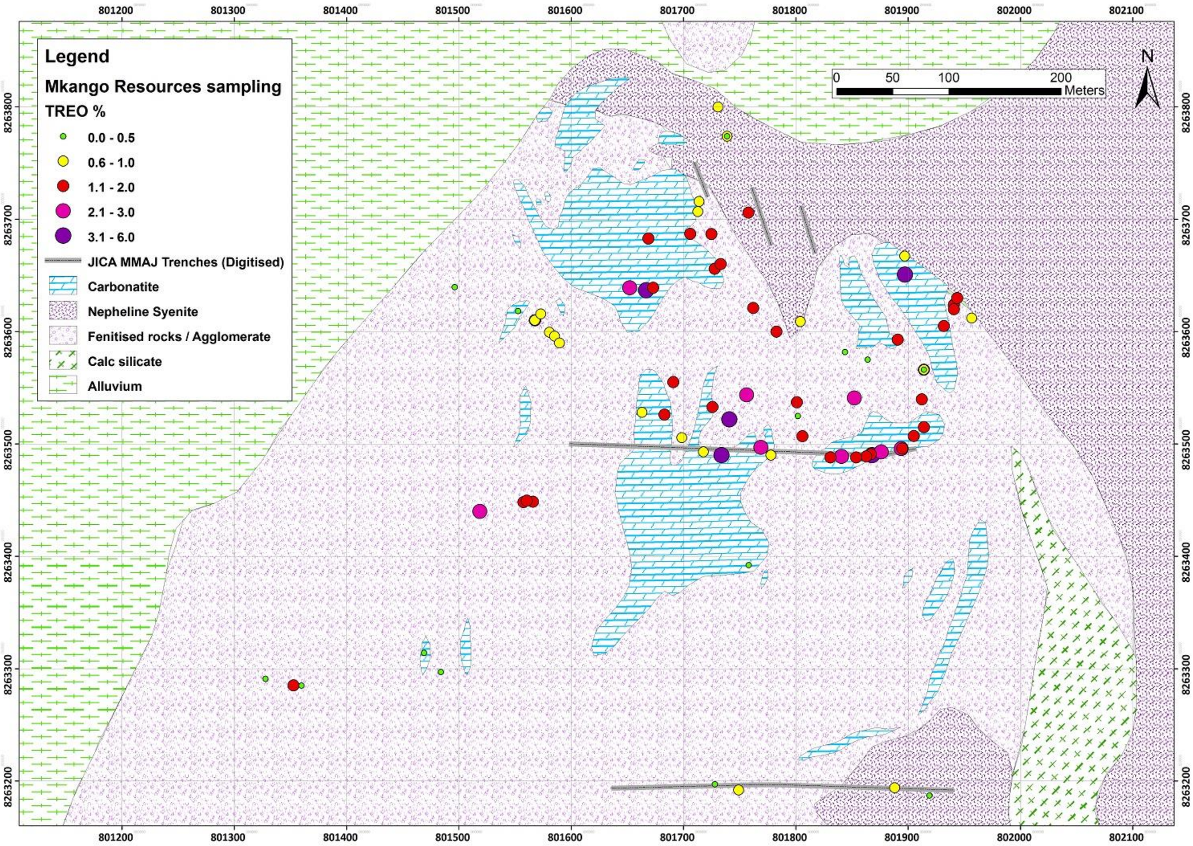
Figure 9.1: Geological Map of Songwe Hill with Sample Localities of JICA (1988) and Mkango (2010) Samples

Table 9.1: Average REO Distribution of Apatite, analysed by LA-ICP-MS, in Songwe Hill Carbonatites (Excluding Outliers)

Drillhole	Rock Type	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	Eu_2O_3	Gd_2O_3	Tb_2O_3	Dy_2O_3	Y_2O_3	Other[1]	TREO[2]
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
H0101	Carbonatite	8,704	13,232	1,126	3,218	343	85	238	23	102	385	66	2.75
H0102	Carbonatite	2,100	4,661	569	1,866	269	75	183	24	116	547	104	1.05
H0103	Carbonatite	10,135	15,691	1,310	3,626	326	77	228	20	88	370	76	3.19
H0117	Carbonatite	2,721	6,277	715	2,600	364	95	225	24	103	428	112	1.37
H0118	Carbonatite	10,979	16,043	1,369	3,999	448	108	309	30	142	749	155	3.43
H0119	Carbonatite	4,481	9,309	1,013	3,696	592	160	380	41	171	635	128	2.06
H0125	Carbonatite	2,064	4,754	517	1,842	261	68	166	22	118	655	130	1.06
H0126	Carbonatite	2,933	6,663	766	2,775	416	117	292	34	135	466	91	1.47
H0127	Carbonatite	11,343	16,511	1,369	3,731	458	122	326	39	180	720	131	3.49
H0917	Carbonatite	5,396	10,047	1,062	3,964	686	167	395	47	200	711	131	2.28
H0003	Fenite	1,408	3,244	314	1,259	264	68	146	13	46	183	41	0.70
H0004	Fenite	1,021	1,792	185	749	152	38	75	6	22	112	26	0.42
H0901	Fenite	903	1,265	228	1,056	220	62	137	15	63	271	57	0.43
H0902	Fenite	1,325	1,405	298	1,178	182	48	105	12	56	262	57	0.49
H0134	Fenite	745	1,522	199	802	200	61	156	19	88	395	68	0.43
H0909	Fe-rich rock	2,018	4,625	524	2,110	281	63	130	11	35	121	23	0.99
H0911	Fe-rich rock	1,279	2,916	339	1,411	213	52	118	13	49	179	30	0.66
H0913	Fe-rich rock	3,202	7,834	940	3,790	488	103	211	15	51	174	26	1.68
H0109	Fe-rich rock	5,501	8,115	741	1,912	216	66	203	27	119	538	95	1.75
H0002	Fe-rich rock	555	2,764	496	3,090	1,070	299	641	67	228	598	102	0.99

Other[1] = Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3 and Lu_2O_3
TREO[2] = Total rare earth oxides including yttrium

Source: Mkango Resources Ltd (2012)



Source: Mkango Resources Ltd after JICA/MMAJ (1989)

NOTE: UTM Zone 36S and WGS84 Datum

Figure 9.2: Geological Map of Songwe Hill with Assay Results for Mkango Samples

9.2 GROUND GEOPHYSICAL PROGRAMME

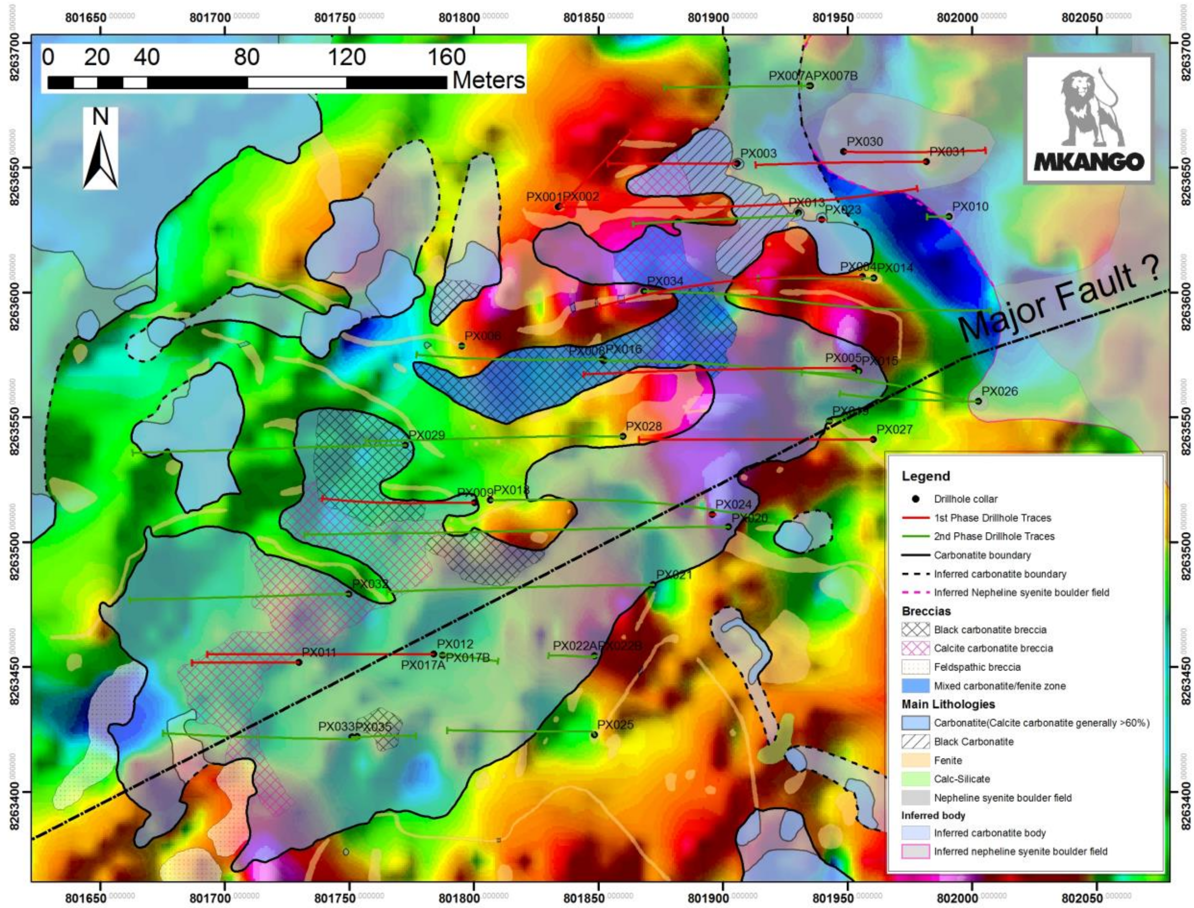
In October 2010 and January 2011, Remote Exploration Services (Pty) Ltd (RES) from South Africa conducted magnetic, radiometric and gravity surveys over Songwe Hill. The objective of the geophysical programme was to determine the geophysical characteristics of the geological units as an aid to mapping the extent of the carbonatite over Songwe Hill (Remote Exploration Services Ltd, 2010). A digital terrain model (DTM) was prepared as part of the geophysical programme. All data was processed by RES.

More recently, following flotation test results of the Songwe Hill samples in September 2019, it was decided that an induced polarity (IP) geophysical survey might assist in identifying iron oxide/hydroxide-rich zones in the Songwe resource area that had proven to be deleterious in the flotation process. An extra benefit to this main objective was identifying possible extensions of the orebody (both laterally and at depth) outside the present resource/drilling zone. It was felt that the IP survey data would be best understood in a wider and deeper context, so a natural source audio-frequency magnetotelluric (NSAMT) survey was drawn up to collect geophysical data for the wider setting of Songwe Hill to complement the limited geological mapping. Both the NSAMT and IP geophysical methods were carried out by geophysicists from Terratec Geophysical Services (Terratec) under the HiTech AlkCarb project (https://www2.bgs.ac.uk/HiTechAlkCarb) funded by the European Union's Horizon

2020 Research and Innovation programme (https://ec.europa.eu/programmes/horizon2020/en/home).

9.2.1 Magnetic Survey

The ground-magnetic survey was conducted using GEM Overhauser Magnetometers. Magnetic data was collected in "Walk Mode" at 1 s intervals along 1 km long lines spaced 50 m apart, while a fixed GEM base magnetometer enabled each day's magnetic data to be corrected for diurnal variations by recording magnetic field readings at 10 s intervals. Field data spatial positioning was accomplished with the use of a Garmin handheld GPS. The magnetic data defines the vent aureole as a zone of demagnetisation around the mapped fenite and depicts the vent as magnetically zoned. An interpreted NE-trending major fault cross-cutting the centre of the vent could be the cause for this magnetic zoning. The data showed no clear correlation between magnetic anomalies and the mapped carbonatite outcrops. The magnetic survey also identified several faults/lineaments which could have played an important role in carbonatite emplacement as well as radioelement mobility (see Figure 9.3).



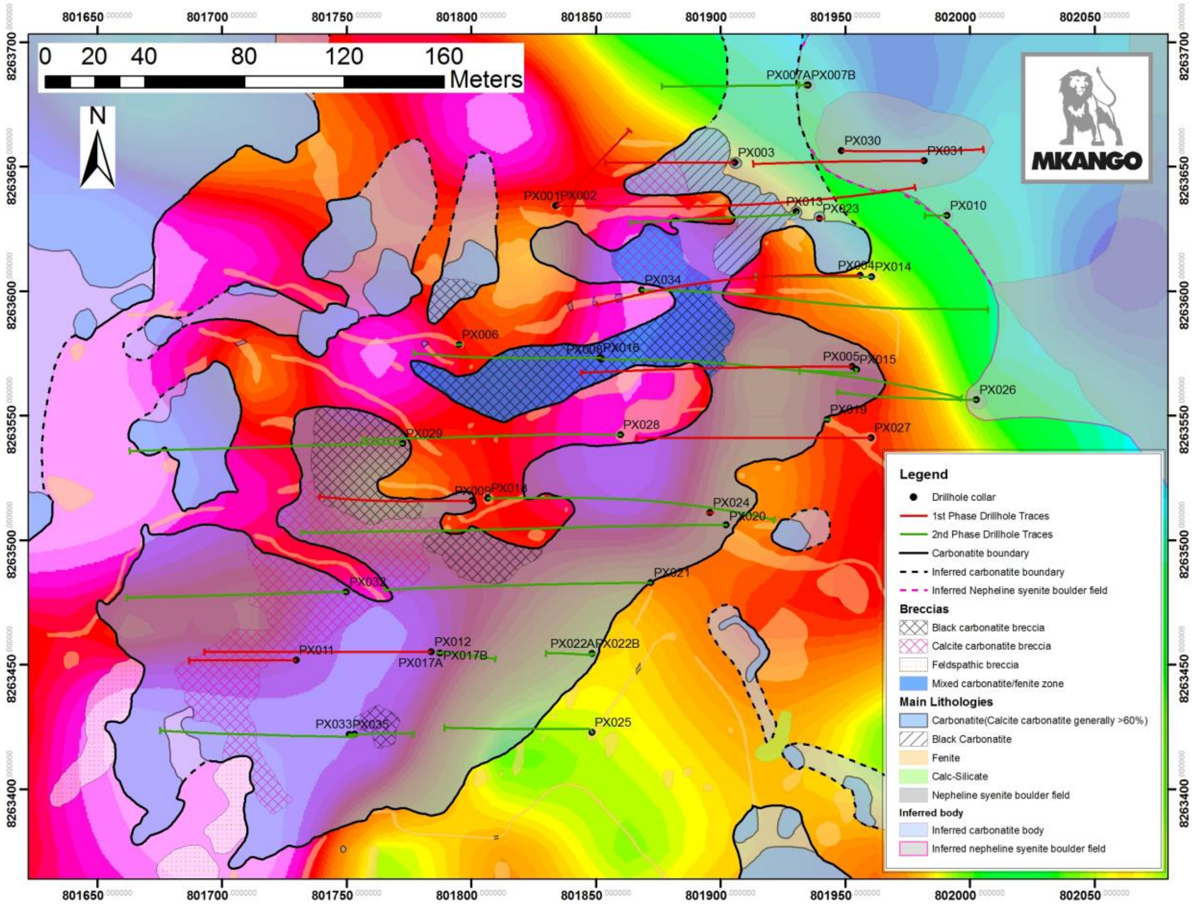
Source: Mkango Resources Ltd internal geological map (2011) on total magnetic intensity map by RES (2011)

NOTE: Analytical signal showing magnetic zone and structures; geological map, drillhole collars and traces are superimposed. UTM Zone 36S and WGS84 Datum.

Figure 9.3: Modified Analytical Signal of Total Magnetic Intensity over Songwe Hill

9.2.2 Radiometric Survey

A calibrated four-channel spectrometer was used for the radiometric survey. Total count of potassium (K), thorium (Th) and uranium (U) and differentiated counts of these three elements were recorded for 60 s at 50 m station intervals along 1 km long lines spaced 50 m apart. An additional infill survey was conducted over part of the survey area with a known carbonatite occurrence. The radiometric survey data showed the existence of significant thorium and potassium anomalies and demonstrated a good correlation between the Th response and the mapped carbonatite (see Figure 9.4).



Source: Mkango Resources Ltd internal geological map (2011) on RES thorium map (2011)

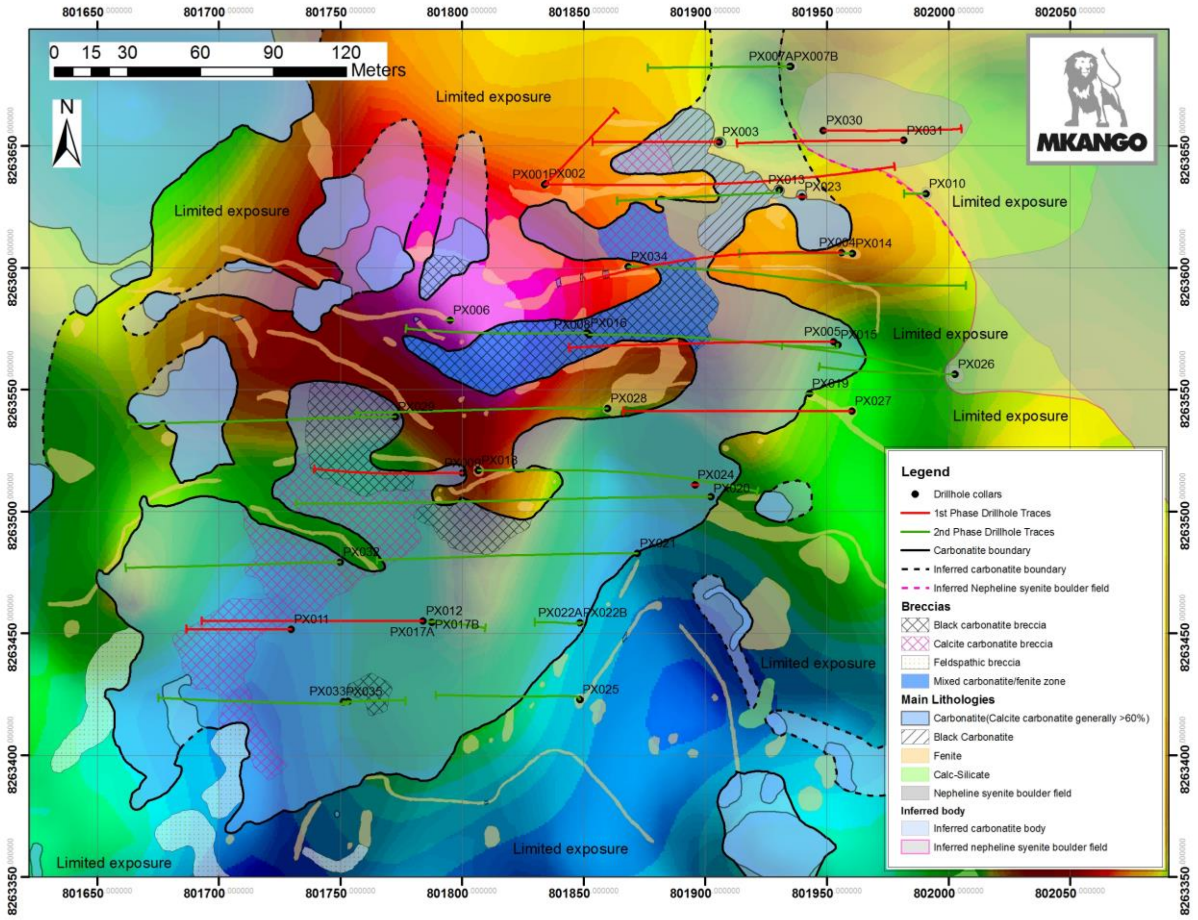
NOTE: Thorium radiometric survey; geological map, drill collars and drillhole traces are superimposed. UTM Zone 36S and WGS84 Datum.

Figure 9.4: Thorium Radiometric Survey over Songwe Hill

9.2.3 Gravity Survey

The ground gravity survey was conducted using a Scintrex CG3 micro-gravimeter, capable of taking readings with an accuracy of ± 0.001 mGal. Gravimetric measurements were made at 50 m station intervals along 1 km long lines spaced 50 m apart. Readings were stacked for 60 s and averaged at each station so as to minimise random noise and were also kept within a standard deviation of ± 0.050 mGal. Base readings were taken at the “gravity base” at the beginning and end of each survey day in order to correct field measurements for instrument drift. Elevation and positional control were accomplished initially with the use of a Trimble differential global positioning system (DGPS) unit. This had to be abandoned due to a technical fault within the DGPS system and a Garmin 60CSX handheld GPS unit was adopted for the remainder of the survey. The hill was resurveyed in January 2011 (Remote Exploration Services Ltd, 2011) in order to better constrain the DTM, and the gravity survey data was reinterpreted based on the revised DTM. Interpretation of the gravity data, based on in-field observations undertaken on hand specimen grab samples, assumed a high-density contrast between the carbonatites and the surrounding rocks.

Due to inherent errors in the gravity data emanating from imprecise elevation measurements using a handheld GPS, as well as the coarse nature of the data, it is likely that an accurate assessment of the density distribution within the vent has not been achieved. A central gravity high was identified (see Figure 9.5), which later proved to correlate with the relatively magnesium-rich carbonatite in the drill core.



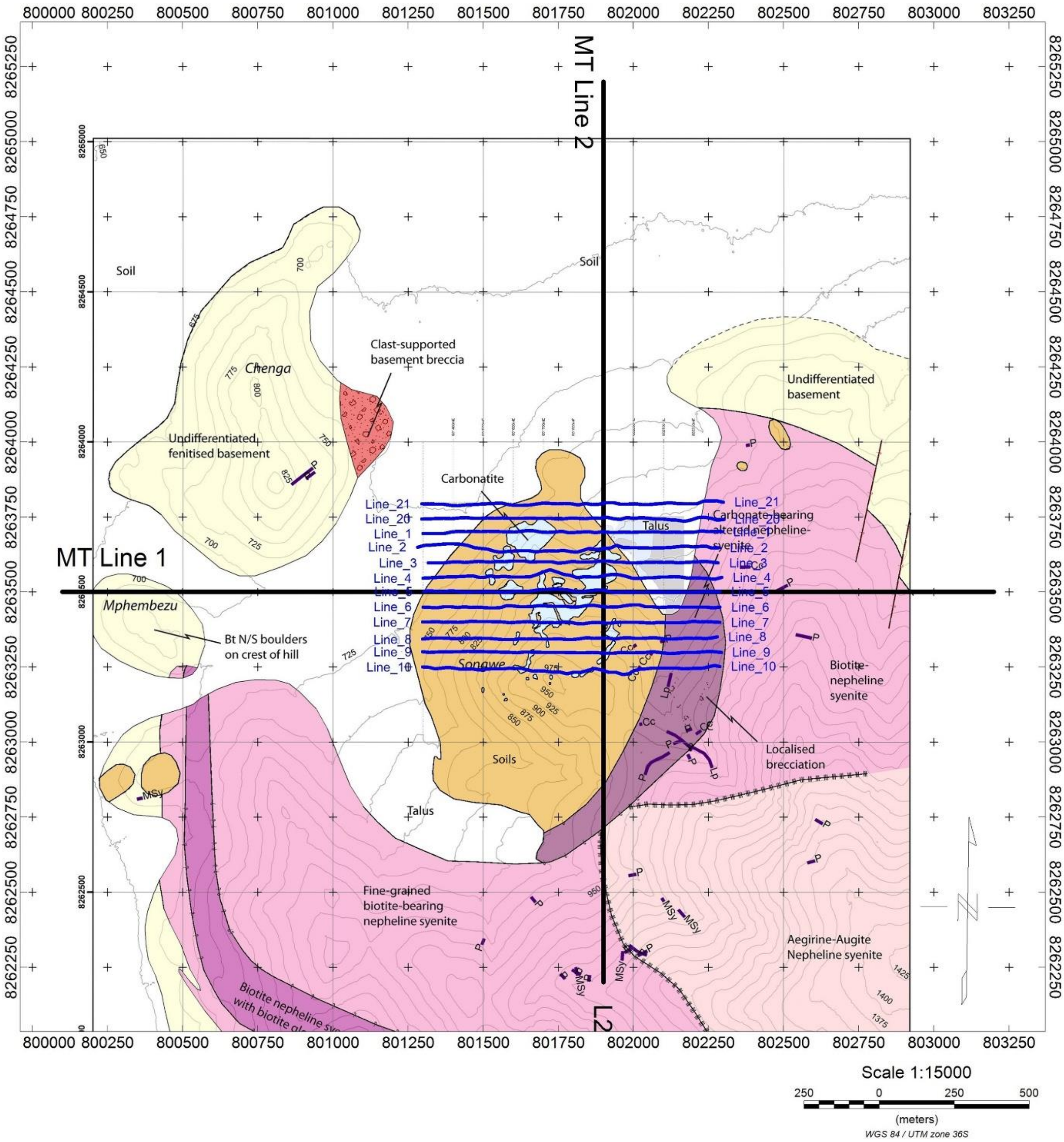
Source: Mkango Resources Ltd internal geological map (2011) on gravity map by RES (2011)

NOTE: Ground gravity survey over Songwe Hill showing a central gravity high; geological map, drill collars and drillhole traces are superimposed. UTM Zone 36S and WGS84 Datum.

Figure 9.5: Ground Gravity Survey over Songwe Hill

9.2.4 NSAMT Survey

The NSAMT survey was carried out in the period 29 November to 9 December 2019 by Terratec geophysicists with the aid of Lancaster geologists and local helpers. Data was acquired on two lines, one oriented west-east and the other north-south, each 3 km long (see Figure 9.6). The lines intersect on Songwe Hill at the point approximately central to a zone where the 3D geological model, based on geochemical analyses of drill core samples, indicates the possible main "pipe" of the Songwe Hill carbonatite.



NOTE: Geological map of Songwe Hill and surrounding hills (by Dr Sam Broom-Fendley 2018, unpublished). UTM Zone 36S and WGS84 Datum.

Figure 9.6: NSAMT Survey Lines (Black) and IP Survey Lines (Blue)

At every 50 m station along the lines Ex and Ey (non-polarisable electrode) and Hx and Hy (induction coil), measurements were made using a Zonge GDP 32 II 24-bit Receiver and two ANT-6 magnetic field sensors. Ex and Ey dipole spacing was 50 m (see Figure 9.7). The electrodes were buried to a depth of approximately 5 cm, in holes with a diameter of approximately 5 cm. These holes were watered 1 d before occupation unless rain had moistened the ground sufficiently. The different electrical and magnetic measurements are grouped into Te = Ey/Hx components (perpendicular to the survey line) and Tm = Ex/Hy components (parallel to the line).

The positions were recorded with a Trimble Geo7X DGPS receiver and recorded in UTM Zone 36S in the WGS84 Datum. Zonge proprietary software was used to read the time series data, calculate averages, edit and invert the data. The inversion products are the following: Te component (Ey and Hx) 2D inversion, Tm component (Ex and Hy) 2D inversion, and the vector component (Te and Tm data) 2D inversion.

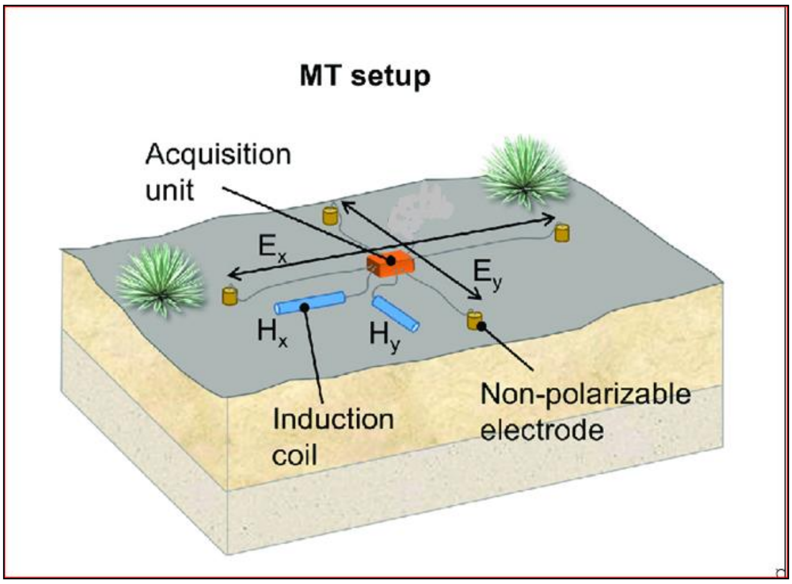
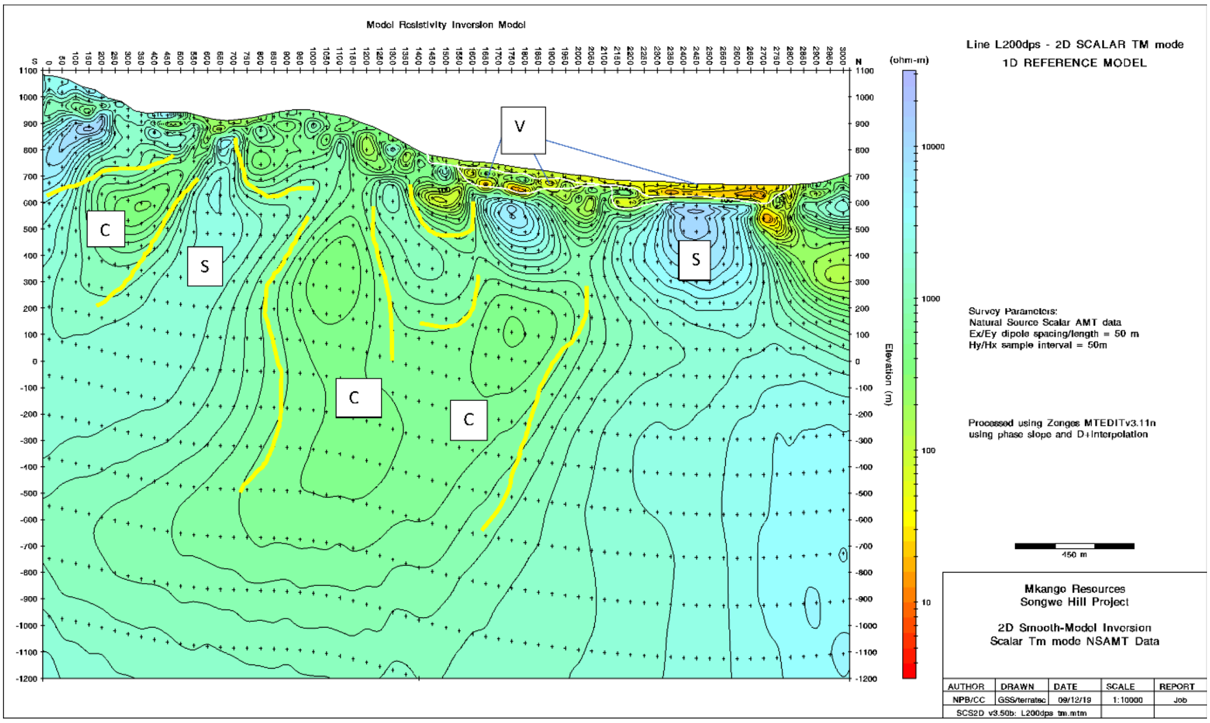


Figure 9.7: Diagram of the Field Station Setup in the NSAMT Survey

The NSAMT survey has revealed a possible continuation of the carbonatite to depth, probable geological boundaries that cannot be observed at surface, and the approximate depth of recent cover between the exposed hills (see Figure 9.8). The survey also reflects the observable and mapped geology, specifically the carbonatite-fenite complex of Songwe Hill, the syenite complex of Mauze, and the basement gneisses.



NOTE: North-south survey line with geological interpretation: C = Carbonatite, S = Syenite, V = Valley Fill (Sediments)

Figure 9.8: Example of the Inversion Products of the NSAMT Survey

9.2.5 IP Survey

A dipole-dipole electrical resistivity tomography (ERT)/time domain induced polarisation (TDIP) survey – together referred to as an IP survey – was carried out by Terratec geophysicists with the aid of Lancaster geologists and local helpers in the period 5 to 27 January 2020.

The ERT and TDIP methods were selected to detect the resistivity and chargeability distribution in depth sections, derived from a 3D volume, to support the detailed geological interpretation. In this survey, measurements were taken along 12 lines (see Figure 9.6) between 1,015 m and 1,125 m in length and at a 50 m separation. The survey zone was designed to cover the entire drilled area of Songwe Hill but extended far beyond it to the west and east. It was also extended slightly to the north with two lines (Lines 20 and 21) additional to the originally planned ten lines (Lines 1 to 10). The spatial relationship between the IP and NSAMT survey lines is shown in Figure 9.6.

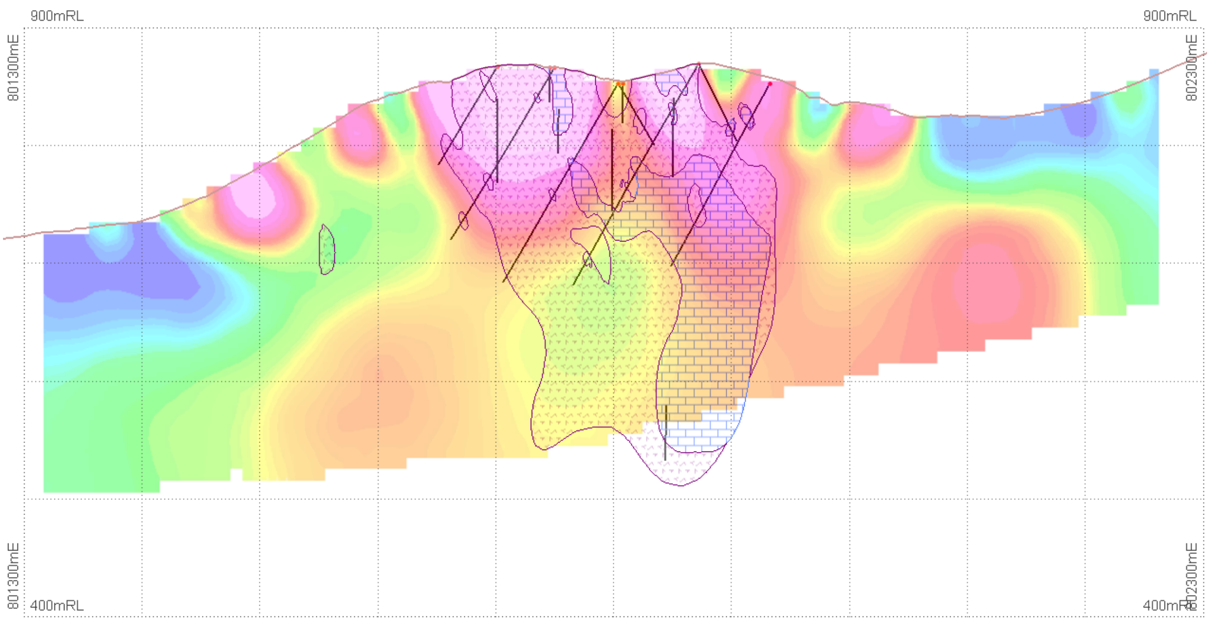
The system consists of a 400 m long cable for the receiver positions (Rx) and two transmitter electrodes (Tx). The transmitter electrodes were located at −50 m and −25 m, relative to the reference position at Rx 0 m, behind the receiver line.

The transmitter dipole had a fixed length of 25 m and an offset distance of 25 m from the receiver line. The receiver dipoles had lengths of 50 m evenly distributed over the 400 m long cable. Additional shorter dipoles were measured close to the transmitter dipole to detect near-surface structures at high resolution. Also, multiples of the 50 m dipoles (100 m and 200 m) were measured on the far side of the receiver cable, away from the transmitter dipole, to improve signal quality for deeper structures. The connection to the ground was established with stainless steel electrodes.

The transmitter was an IRIS instruments TIPIX 3000 3 kW Transmitter (3,600 V). The data receiver was a GDD instruments GDDX16 16-channel IP full-wave receiver allowing for advanced post-processing for noise reduction, if necessary. The transmitter/receiver settings were as follows: time domain cycle = 2 s, delay time = 240 ms, width of partial window = 80 ms.

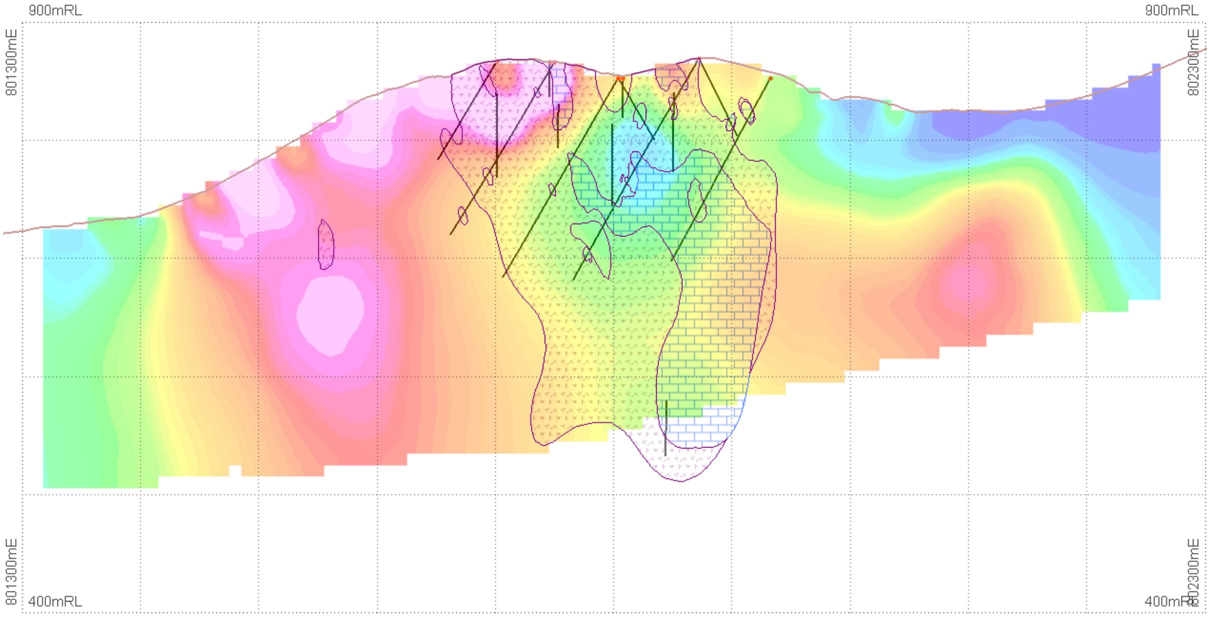
The receiver cable with 13 receiver electrodes and 2 injection electrodes was laid along the ground. Injection was carried out with an external transmitter (TIPIX 3000). To improve the contact resistivity at each injection point, 3 electrodes were arranged in a triangle with a side length of approximately 40 cm, and the injection ground points were saturated with salt water. The receiver electrodes were prepared with unsalted fresh water. After completion of a reading, both the receiver and the transmitter cable systems were moved 25 m to the next stations along the line. At each station, the position of the reference point (Rx = 0 m) was taken with a Trimble Geo7X DGPS receiver and recorded in UTM Zone 36S in the WGS84 Datum. Field data was processed in software packages Prosys II, ZondRes2D, and Geosoft.

The IP survey has provided a detailed geophysical picture of Songwe Hill itself to a depth of several tens of metres (see Figure 9.9 and Figure 9.10). In addition to the research value of the geophysical data and interpretation, the geophysics has revealed new drill targets; this is elaborated on in Section 24.3 (Opportunities). Furthermore, of particular economic significance, the geophysics has aided the identification of weathered iron-rich zones that have proven to be deleterious in flotation tests. Such zones are known from the drilling, but their extent could only be guessed before the IP survey.



NOTE: Geological model on a 100 m grid; brick pattern = carbonatite, chevron pattern = mixed carbonatite and fenite. Resistivity scale from blue (low) to purple (high). Drill traces in 20 m envelope (10 m toward and 10 m away from the west-east plane of view).

Figure 9.9: Example of an IP Resistivity Profile through Songwe Hill



NOTE: Geological model on a 100 m grid; brick pattern = carbonatite, chevron pattern = mixed carbonatite and fenite. Chargeability scale from blue (low) to purple (high). Drill traces in 20 m envelope (10 m toward and 10 m away from the west-east plane of view).

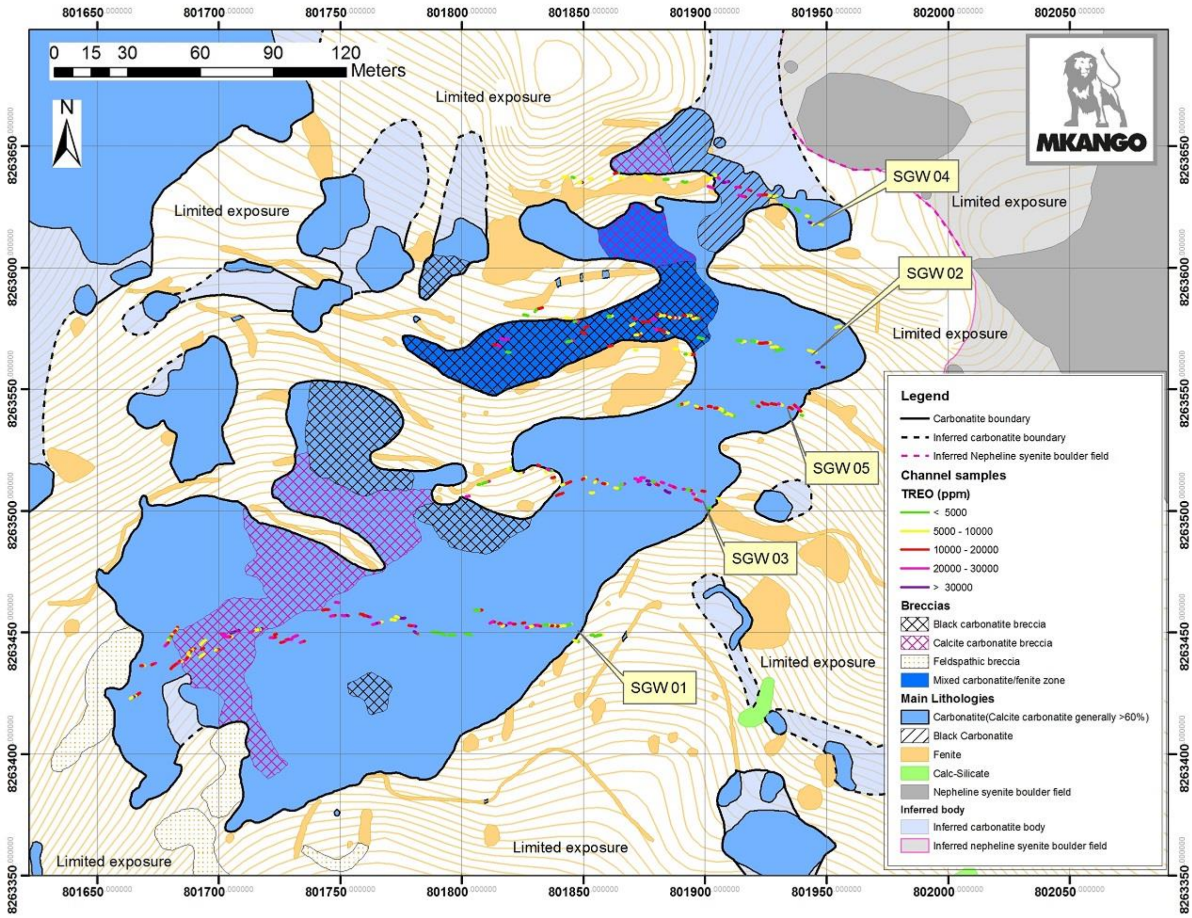
Figure 9.10: Example of an IP Chargeability Profile through Songwe Hill

9.3 GEOLOGICAL MAPPING

Detailed geological mapping of Songwe Hill was carried out during March 2010 in conjunction with the surface litho-geochemical sampling programme, and between May and July 2011 with refinements and revisions in October and November 2011. All outcrops on the north-facing slopes of Songwe Hill were systematically recorded, and their locations determined with a handheld GPS (Garmin 60CSX). Mapping was aimed to provide better detail on the distribution of carbonatite, fenite and breccia across Songwe Hill and to delineate the zones of rare earth mineralisation (see Figure 7.2). The mapping programme demonstrated that carbonatite outcrops over a significantly larger area than had previously been recognised by JICA and MMAJ. Mapping further achieved a more precise delineation of the distribution of breccia and fenite. The mapping broadened the surface area of known rare earth mineralisation significantly beyond the areas identified in previous exploration and identified new areas of rare earth enriched carbonatite on the western slope of the hill.

9.4 SURFACE CHANNEL SAMPLING

A channel sampling programme was undertaken during November and December 2011 following the Stage 1 drilling campaign. The objective was to guide the geological model and provide continuous surface sampling along the drillhole section lines in order to assist in constraining the Mineral Resource estimate. Outcrops were exposed by cleaning off overburden and soil as continuously as possible along five lines with an east-west orientation that followed the approximate surface projections of existing and planned drillholes. In detail, the location of the channel sampling lines was dictated by the availability of outcrop along each E-W line. Where outcrop could not be exposed directly on the line, sampling was offset to the outcrop nearest to the line, irrespective of lithology (see Figure 9.11). To the extent possible, continuous channel samples were cut along each of these lines.



Source: Mkango Resources Ltd internal map (2012).

NOTE: UTM Zone 36S and WGS84 Datum

Figure 9.11: Geological Map with Location and TREO of the Five Channel Sample Lines

Channels were cut in the exposed outcrop using a Stihl TS 700 saw fitted with a diamond saw blade (see Figure 9.12) and connected to a Stihl 10 L pressurised water tank. All channels were cut to widths of between approximately 4 cm and 5 cm and a depth of between approximately 10 cm and 12 cm. A single channel was defined by the start and end of a continuous cut. There were many breaks in the cutting due to the uneven topography and distribution of outcrop and overburden. As a result, although the channels follow the planned surface lines as closely as possible, they are not continuous and locally deviate from the line.

Source: Photographs by Paul Armitage (2011)

Figure 9.12: Example of Channel Sampling Programme on Songwe Hill

On completion of cutting, the channels and an area approximately 50 cm to either side of the channels were cleaned of sludge using water and a stiff brush if necessary. When the rock surface had dried after cleaning, metre marks across the channels were painted, together with unique sample numbers (sample ticket book number) adjacent to the metre marks, on the left side of the channel, viewed in the direction of sequential sampling.

Samples were broken and chipped out of the channels using a tapered masonry chisel and a club hammer. As slabs and chips of rock were liberated, they were placed immediately into pre-prepared sampling bags containing sample tickets and marked with sample numbers on the outside. Before sampling each metre, the geologist checked that the sample number of the bag corresponded to the number spray-painted alongside the channel. Channels were sampled at 1 m intervals, and if there was a change of lithology within the sampling interval, then each lithology was sampled separately, using a channel length with a minimum of 20 cm and a maximum of 130 cm.

On completion of sampling, all channels were photographed, viewed in the direction of sequential sample numbering, and clearly showing the sample numbers.

The channel sampling logging and sampling technique employed during the channel sampling programme followed strict internal QA/QC procedures. Each channel sample line was geologically logged and sampled observing the same procedures used during the drilling programmes. Sample preparation and analytical work was carried out by Intertek-Genalysis Laboratory Services (Johannesburg, South Africa and Perth, Australia) employing ICP-MS analytical procedures and following strict internal QA/QC procedures, including the insertion of duplicates, blanks and certified standards. Detailed information on logging, sampling and geochemical analysis is presented in The MSA Group (2020).

A summary of the results of the channel sampling programme is presented in Table 9.2. Given the irregular surface and potential near-surface modification of the TREO grade, the channel samples were not considered of sufficient reliability for use in Mineral Resource estimation. However, the results are broadly consistent with the geological mapping, litho-geochemical sampling and portable XRF sampling results and further confirm the continuity of rare earth mineralisation at surface in carbonatite, carbonatite breccia, and fenite on Songwe Hill.

Table 9.2: Summary of Assay Results for the Five Channel Sample Lines

E-W Line (Approximate Length)	Aggregated Length of Channel Samples	Aggregated Length of Carbonatite[1] in Channel Samples	Weighted Average TREO[2] in Carbonatite[1]	Aggregated Length of Fenite in Channel Samples	Weighted Average TREO[2] in Fenite
m	m	m	% TREO[2]	m	% TREO
SGW-01 (200 m)	152	119	1.75	33	0.73
SGW-02 (150 m)	106	79	1.44	27	1.20
SGW-03 (110 m)	66	53	1.70	14	0.67
SGW-04 (120 m)	63	33	2.83	31	0.94
SGW-05 (55 m)	37	31	1.37	6	1.28

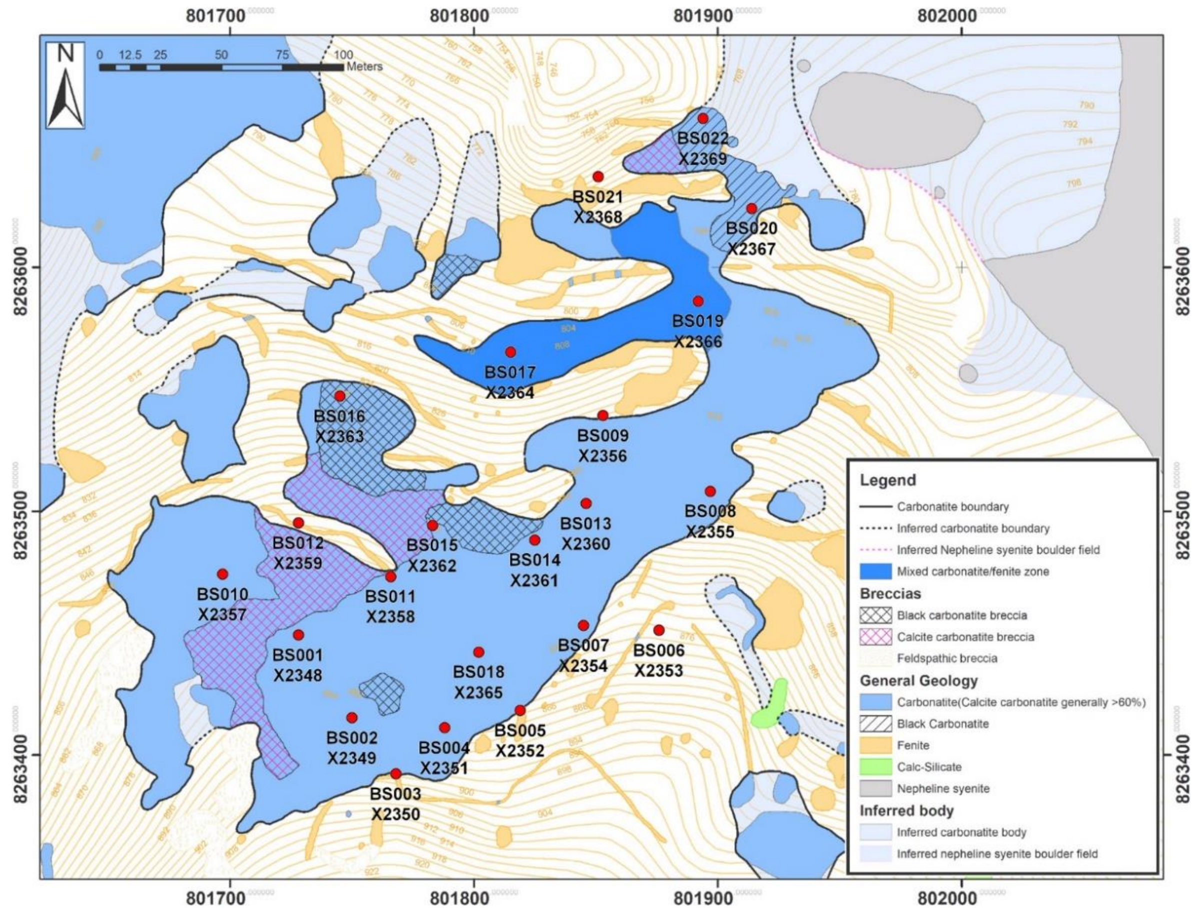
[1] Includes both carbonatite and carbonatite breccia
[2] TREO = Total Rare Earth Oxides including yttrium

Source: Mkango Resources Ltd (2012)

9.5 BULK SAMPLING

A bulk sample was collected from outcrops to provide better information on the consistency of REE grades in the deposit and to provide material for metallurgical testing. Twenty-two locations (BS001-BS022) were identified where the carbonatite and “mixed rock” were well exposed and with minimal surface weathering, with exposure sufficiently prominent and next to roads/pads to allow access by a JCB tracked excavator equipped with a hammer (see Figure 9.13 and Figure 9.14). Approximately 2.7 t of rock were hammered out and collected at each location to make up a total of approximately 60 t. Only blocks of fresh rock were collected; any pieces with weathering rind or cavity walls were rejected. Blocks of rock were gathered in rice bags, labelled by sampling location, and manually loaded onto a Land Cruiser, driven to camp and placed into bags containing approximately 1 t each for transport on a low loader to Blantyre for air freight to Perth, Australia.

Smaller representative rock chips were collected at each location for assay.



Source: Mkango Resources Ltd internal map (2019).

NOTE: Prefix BS- indicates field location ID, prefix X- indicates laboratory ID. UTM Zone 36S and WGS84 Datum

Figure 9.13: Location of Sites where the Bulk Sample was Taken

Source: Photograph by Bill Levene (2018)

Figure 9.14: Bulk Sampling in Progress by JCB Tracked Excavator with Hydraulic Hammer Attachment

9.6 RESEARCH PROGRAMMES

Post-graduate studies on the middle and heavy REE (HREE) mineralisation at Songwe Hill have been completed at Camborne School Mines (CSM), University of Exeter, UK in conjunction with the British Geological Survey (BGS). This project investigated HREE concentration levels in alkaline and carbonatite complexes, which are typically light rare earth dominated.

This research was focused on two principal questions:

- Under what conditions are the HREE preferentially removed from a carbonatite and deposited in hydrothermal veins?
- How does the REE distribution evolve through the carbonatite intrusion phases and into late-stage hydrothermal remobilisation?

This work was carried out at the mineralogical laboratories at CSM using cathodoluminescence, electron microscopy and an electron microprobe, and at the BGS utilising LA-ICP-MS and a fluid inclusion heating and cooling stage.

The study has been completed, and the results have been published. It has resulted in a better understanding of the geological and age relationships of the vent complex (Broom-Fendley et al., 2016), and the mineralogy and fluid history of the intrusion (Broom-Fendley et al., 2017a, b).

Mkango continues to encourage and participate in research at Songwe Hill by serving as a project partner in the HiTech AlkCarb project, funded under the European Union’s Horizon 2020 Research and Innovation programme, to develop new geomodels and sustainable exploration methods for alkaline igneous rocks and carbonatites. This project brings the expertise of a wide variety of specialists to bear on problems related to the understanding and effective exploration of critical metal deposits, through examination of a number of “natural laboratories”, including the Chilwa Alkaline Province, and specifically the Songwe Hill deposit. The project members visited the Songwe Hill site in October 2016.

10 DRILLING

10.1 HISTORICAL DIAMOND DRILLING (1988)

Historical drilling from the JICA and MMAJ programme is described in JICA and MMAJ (1989). The historical drilling does not have adequate geodetic or procedural information to be incorporated in the evaluation of the Songwe Hill deposit and does not form part of the database for the current Mineral Resource estimate.

10.2 PHASE 1 (2011), PHASE 2 (2012) AND PHASE 3 (2018) DIAMOND DRILLING

Mkango undertook three diamond drilling campaigns at Songwe Hill: two totalling 38 drillholes during 2011 (Stage 1) and 2012 (Stage 2), and a third totalling 91 holes (Phase 3) in 2018. The drilling programmes were undertaken following strict, industry standard protocols, which were part of a comprehensive set of standard operating procedures (SOPs). The implementation of all the protocols was independently monitored by The MSA Group (MSA).

10.2.1 Phases 1 and 2

The objectives of the Phases 1 and 2 drilling were to evaluate the REE potential of the Songwe Hill deposit and develop a Mineral Resource estimate. These two phases of drilling resulted in the initial Mineral Resource estimate for Songwe Hill (The MSA Group, 2015) and are summarised below from the 2015 NI 43-101.

The Phase 1 drilling programme, from April 2011 to June 2011, was conducted to confirm the extent and grade of the mineralisation that had previously been identified during the JICA and MMAJ drilling campaigns and to test whether the mineralisation extends beyond the boundaries of the previously established mineralised areas.

The programme totalled 13 drillholes, comprising 2 vertical holes and 11 inclined holes drilled on 90° and 270° azimuths at inclinations of −60° and −70°, and 1 hole (PX002) drilled at 045° azimuth at −70° inclination. Drillhole depths ranged from a minimum of 86 m to a maximum of 302.2 m. A total of 1,987.38 m was drilled, and 2,118 samples were collected for geochemical analyses.

The Phase 2 diamond core drilling programme was carried out between January 2012 and May 2012, and focused on infill drilling and expanding the area of known mineralisation identified during Phase 1, particularly at depth.

The programme totalled 25 holes, comprising 4 vertical holes and 21 inclined holes drilled on 90° and 270° azimuths at inclinations of −60°, −65°, −70° or −80°. Drillhole depths ranged from a minimum of 21 m to a maximum of 363 m. A total of 4,864.90 m was drilled, and 5,116 samples were collected for assays.

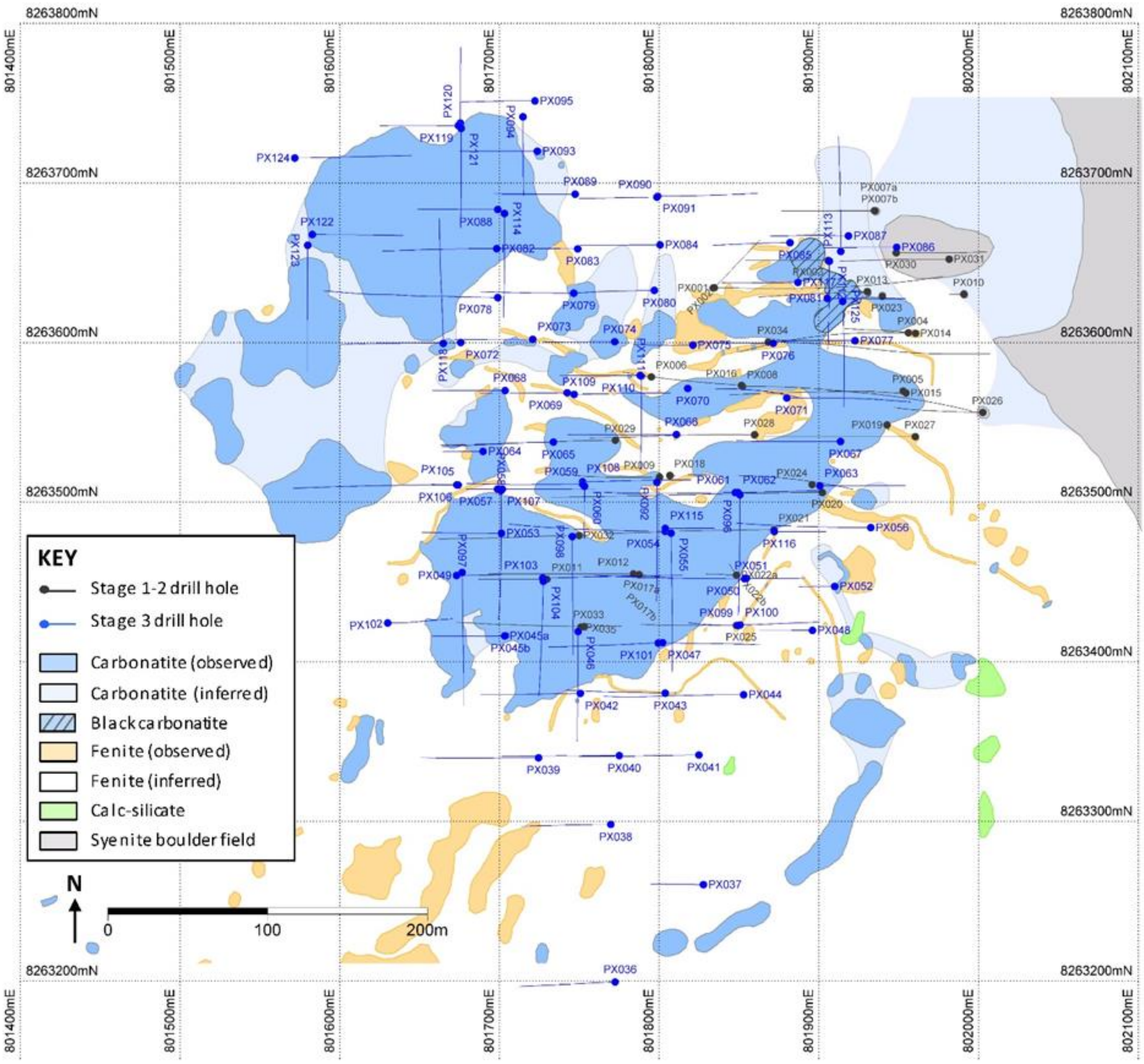
As a result of the first two phases of drilling, Mineral Resource and Mineral Reserve estimates were reported in an NI 43-101 Technical Report in 2015 (The MSA Group, 2015). The Inferred Mineral Resource at a 1 % cut-off for TREO was quoted as 18.59 Mt grading 1.38 % TREO. The estimated Mineral Reserve was quoted as Probable Mineral Reserves of 8,482,603 Mt, grading 1.60 % TREO. These estimates are superseded by the Mineral Resource estimate reported in the DFS report, and Mkango is not treating this prior estimate as the current Mineral Resources or Mineral Reserves.

10.2.2 Phase 3

The Phase 3 diamond drilling programme at Songwe Hill was carried out between June and September 2018. The objectives were to revise and upgrade the existing Indicated and Inferred Mineral Resource estimates, test extensions to the mineralisation outside the previously defined resource area, and provide geotechnical information to contribute to the mining plan. The prime objective was to provide a revised Mineral Resource estimate for the project.

The Stage 3 drilling programme was conducted by Cartwright Drilling Inc. of Goose Bay, Canada, using two skid-mounted proprietary CDI-500 drill rigs capable of drilling to a depth of 700 m. The rigs accessed the drill pads via purpose-built roads on Songwe Hill and were moved into place using two JCB tracked excavators. The drilling utilised HQ/NQ core barrels. The locations of the holes and their surface traces are illustrated in Figure 10.1.

The programme totalled 91 drillholes. All except one are inclined holes. Most (84 holes) were drilled at −60°. Of the remaining holes, one was drilled at −65°, two at −70°, one at 75°, two at 80°, five at 50° and one vertically. A total of 54 holes were drilled at an azimuth of 270°, 16 at an azimuth of 180°, 18 at an azimuth of 090°, and 3 at an azimuth of 000°. Drillhole depths ranged from a minimum of 42.7 m to a maximum of 219.6 m. A total of 10,897.33 m was drilled, and 5,725 samples (not including certified reference materials or duplicates) were collected for geochemical analyses.



Source: Mkango Resources Ltd (2018)

Figure 10.1: Geological Map Showing Drillhole Collars and Traces

10.3 CORE RECOVERY

In all the phases of drilling, core recovery was determined prior to logging and sampling, and standard core recovery forms, prepared by MSA, were completed for each hole by the geologist at the drilling site. Core recovery was typically very good, usually > 90 % within the carbonatite, carbonatite breccia and fenite lithologies. However, in zones that contained significant void space/cavities, recoveries were locally very poor (< 50 %), and in a few cases, little material (< 10 %) was returned to the surface. The cavities/void spaces are the likely result of the karst-type dissolution of matrix carbonate in the host carbonatite.

Large cavity/void areas were not included in the assay intervals but were tabulated as voids.

10.4 COLLAR SURVEYS

The 2011 Phase 1 drillhole collars were surveyed by Digital Surveying based in South Africa. The 2012 Stage 2 channel sample lines and drillhole collars were surveyed by a licensed land surveyor, Land Management Consultants, of Blantyre, Malawi using a real-time kinematic (RTK) DGPS with sub-centimetre accuracy. The Stage 1 drillhole collars were also re-surveyed by Land Management Consultants for verification purposes, and all collar locations are reported using the Land Management Consultants survey data.

The Phase 3 drill collars were surveyed by Terratec using a Trimble R2 DGPS with RTX correction signal (see Figure 10.2). No base station was required because the RTX signal allows coordinates to be derived to an accuracy of 2 cm in X and Y and 4 cm in Z.

All Phase 3 collars were surveyed in the period 18 to 20 September 2018. On each of the three days, a checkpoint inside the weather station enclosure in camp was surveyed in the morning (prior to work) and in the afternoon (after work). An attempt was made to access government survey beacons, but the two beacons within reasonable distance of Songwe Hill were found to have been destroyed.

Eleven drill collars surveyed in 2012 were re-surveyed in 2018, and the surveys were compared. The coordinates obtained in 2018 and those obtained in 2012 by Land Management Consultants agreed well in X and Y; however, the previously surveyed elevations were on average 1.734 m higher than the 2018 geoid elevations. It was decided that the 2018 data should be brought in line with the 2012 data, as the 2012 survey elevations agreed well with the LiDAR (light detection and ranging) survey of Songwe Hill completed in 2016.

Source: Photograph by Terratec Geophysical Services (2018)

NOTE: A plank was placed across the collar pit to ensure that the intersection between ground level and the top side of the casing in the drillhole could be measured.

Figure 10.2: DGPS Survey of a Drillhole Collar

10.5 DOWNHOLE SURVEYS

10.5.1 Phase 1

The 2011 Phase 1 drillholes were surveyed by Digital Surveying based in South Africa using a Reflex GYRO tool with station readings every 5 m. The surveys were carried out using a winch inside plastic casing placed down the hole to ensure hole integrity.

10.5.2 Phase 2

During the Phase 2 programme, 14 holes (PX007a, PX008, PX014, PX015, PX016, PX018, PX020, PX021, PX026, PX028, PX029, PX032, PX034, and PX035) were surveyed using a Reflex GYRO tool, with station readings every 5 m. The Reflex GYRO tool has an integrated azimuth pointing system (APS) that indicates the true north azimuth, a GPS position, and the degree of inclination. The APS is not affected by magnetic interference, and thus during the Stage 2 programme, the surveys were carried out inside the drill rods. The Reflex GYRO was set up and controlled by the site geologist using the Toughbook field PC supplied with the system. Several parameters, including temperature, were continuously recorded in the on-board memory throughout the survey to track the path of the drillhole. Once the survey was finished and the instrument brought to the surface, the data was transferred from the Reflex GYRO's onboard memory to the Toughbook.

The remaining 10 holes of the Phase 2 programme were surveyed using a Reflex EZ-AQ instrument with station readings every 5 m. The EZ-AQ surveys were carried out using a hand winch inside plastic casing placed down the hole to ensure hole integrity. The EZ-AQ instrument, which is sensitive to magnetic interference, measured the inclination and direction of the drillhole, together with magnetic and gravity field components. A handheld device was used to communicate with the instrument, which allowed the site geologist to view the orientation of the drillhole path immediately. The survey data was transferred from the EZ-AQ instrument via an infrared data link. Both the Reflex GYRO and the EZ-AQ tools worked effectively.

In general, very minor dip deflections were recorded in both the Stage 1 and Stage 2 drillholes. The azimuth deviation was typically less than 5° for all holes, but for a number of deep holes deviation could range up to 10° over 300 m.

10.5.3 Phase 3

The Phase 3 drillholes were surveyed using a Reflex GYRO probe (serial no. 508) to establish the inclination and azimuth for each hole. The probe is set up and controlled using a field PC supplied with the system. Twelve parameters are continuously recorded in the probe's memory throughout the survey to track the path of the drillhole. The power is provided by a rechargeable internal battery pack, and all the data is stored on the 512 MB onboard memory of the probe. The Reflex GYRO probe provides accurate directional data (azimuth and dip) at any interval, its accuracy is not affected by magnetic interference, and it can be used inside all types of drill rods or in magnetically disturbed ground. Once the probe has been brought to the surface, the data can be transferred from the probe's onboard memory to the field PC via Bluetooth.

All the drillholes were surveyed using a known start direction. These azimuth values were supplied by Mkango. For QA/QC purposes, all the holes were surveyed in both upward and downward directions to provide two sets of data. For further processing, the upward direction data set was used. Most of the data was recorded at 5 m station spacing, but for shorter holes (20 m to 50 m), the spacing was decreased and could be as small as 2 m depending on the depth of the holes.

The Phase 3 holes exhibited very minor deflections. Dip deviation was generally less than 5° for all holes. The azimuth deviation was typically less than 3.5° for all holes, except for hole PX070, which showed a final deviation of 13.3°.

10.6 DRILLHOLE PROGRAMME MANAGEMENT

Access to drilling sites on Songwe Hill was via a network of roads constructed for that purpose. Water for drilling was supplied from two boreholes: one within the Songwe Hill exploration camp perimeter, and one outside, close to the driveway into the camp. Water was pumped from the boreholes into a 30,000 L aqua dam at the base of Songwe Hill and then pumped through heavy-duty pipes to 30,000 L aqua dams approximately halfway up and at the top of the hill and then gravity fed to the drill rigs. For Phase 3, water was pumped from two aqua dams in the camp to two separate sets of five 5,000 L plastic tanks: one at the top of the hill next to PX036, and one about a third of the way down the hill near PX044; the upper set of tanks was moved to the PX072 pad later in the programme when drilling was taking place below the PX072 elevation.

All the drillhole positions were sited by a geologist from Mkango's exploration team with a handheld GARMIN GPS unit using UTM Zone 36S projection and WGS84 Datum. The planned collar positions were marked with wooden pegs, and the azimuth was outlined using spray paint. Prior to drilling, the alignment of the rig was checked by the site geologist to ensure correct rig setup. The inclination was measured on the derrick using a Brunton compass. The azimuths were checked by the geologist using a compass clinometer corrected for local magnetic declination. After the completion of each drilling programme, all the hole collars were re-surveyed using DGPS equipment (refer to Section 10.4).

Drilling was monitored on a continuous basis by Mkango geologists to ensure maximum recovery. Cores were obtained using wire-line methods and were washed by a member of the drill crew prior to placement in a steel core tray. Core trays were labelled in advance with the drillhole name and box number and placed near the drill rig. Drillhole cores were consistently packed left to right, pointing down hole, in each tray. Plastic depth marker blocks were inserted at the end of every run, and the actual drill depth, according to the number of rods in the ground, and the length of the recovered core were recorded on the depth blocks. Detailed core recovery measurements were completed by the site geologist before the trays were transferred to the exploration camp.

Filled core trays were removed from the drill site twice a day under the supervision of the site geologist. Trays were covered with blankets and then secured by straps with ratchets in Mkango's pick-up truck and transported to the exploration camp site.

Following completion of the Phase 1 and 2 drillholes, all the collars were capped and marked with a concrete slab with the relevant information recorded on a metal plate.

Following completion of the Phase 3 drillholes, all the collars were capped with a concrete plinth and labelled with an embossed galvanised steel plate. The top of the plastic casing was cut, capped, and covered in concrete. A short length of dummy plastic casing was set in the ground away from the plinth as a distractive measure to prevent further theft of plastic casing from the drillholes (see Figure 10.3).

Source: Mkango Resources Ltd (2018)

Figure 10.3: Examples of Plinths Marking Drillhole Locations

10.7 RESULTS OF THE DRILLING PROGRAMMES

10.7.1 Objectives

10.7.1.1 Phases 1 and 2

The Phase 1 drilling programme was successful in confirming the presence of REE mineralisation first outlined by the JICA and MMAJ work. Eleven of the thirteen holes intersected significant zones of rare earth mineralisation. Having confirmed the presence of the mineralisation, the Phase 1 drilling was expanded to areas not previously tested and demonstrated the extension of rare earth mineralisation both laterally and vertically.

The Phase 2 drilling focused on expanding the area of known mineralisation, infilling between existing holes, and testing the mineralisation at depth. All the drillholes intersected REE mineralisation and the maximum depth at which REE mineralisation was encountered was 350 m below the surface of the hill.

10.7.1.2 Phase 3

Approximately 60 % of the Phase 3 drillholes were infill holes aimed at better defining the geology and geometry of the mineralised body, to permit better understanding of the geological characteristics and setting of the mineralisation, and to refine the geological model as a prelude to redefining the Mineral Resource. As a result of the Phase 3 drilling, the Mineral Resource has now been drilled at a maximum collar spacing of 50 m in the east-west direction and between 30 m and 40 m in the north-south direction (approximately 30 m in the infill drilling zone and 40 m in the step-out areas). All infill holes intersected significant widths of mineralised carbonatite and breccia. Modelling of the lithologies based on geochemistry reported in The MSA Group (2020) confirms that the core of the deposit is a more or less uniformly mineralised carbonatite intrusive with steep sides. Within the carbonatite and mantling it on all sides and above are various breccias containing variable amounts of carbonatite that are variably mineralised.

Approximately 30 % of the Phase 3 drillholes were step-out holes, aimed at expanding the known Mineral Resource by identifying or better delineating mineralisation that is outside the volume of the previously defined Mineral Resource. Most of these holes contained mineralised intersections although not all reached their targeted depth. These holes have resulted in the expansion of the estimated Mineral Resources by identifying new areas of mineralised carbonatite beyond the limits of the previous drilling.

Sixteen of the holes were drilled to provide geotechnical information within the Mineral Resource. In these holes, oriented cores were recovered.

10.7.2 Mineralised Lithologies

The drilling demonstrated that the mineralised body at Songwe Hill is geologically complex. The drilling also revealed that the core of the system is a carbonatite plug of highly irregular geometry that is more or less uniformly mineralised. The carbonatite intrudes and is intruded by more or less coeval phonolitic intrusions that are typically variably fenitised and brecciated. The fenitised rocks and associated breccias are intimately associated with the carbonatite and, at a large scale, form a halo around the carbonatite intrusion. The explosive and fluid-rich nature of the intrusion is demonstrated by the widespread occurrence of carbonatite and fenite breccias. The following three lithological domains were used to guide the documentation of the lithologies in the drillhole core:

- Carbonatite
- Fenite
- Mixed lithologies

10.7.2.1 Carbonatite

Carbonatite is the dominant lithology, ranges from grey to black in colour, and typically hosts REE mineralisation. Assay data shows that the carbonatite is widely and uniformly mineralised. Mineralogical observations suggest that the mineralisation is dominantly hosted by synchysite and apatite. The latter is generally anomalously rich in heavy rare earths compared to apatites in many other carbonatite complexes. This feature is interpreted to be the result of sub-solidus hydrothermal redistribution of the REE during the final stages of the evolution of the carbonatite body.

10.7.2.2 Fenite

Fenite is present throughout the carbonatite body and is intimately intermixed with the carbonatite. The fenites comprise dominantly potassium feldspar and are interpreted to have formed through metasomatism related to the intrusion of the carbonatite. The protolith to most of the fenites seems to be phonolitic intrusions, which were intruded both before, during and after carbonatite intrusion. At least some of the fenites are interpreted to be blocks stoped into the carbonatite magma, while others seem to be fault-bounded and may be structurally emplaced in their present position. The fenites are variably carbonatised and locally enriched in REE. Mineralisation in the fenite appears to be related to the degree of carbonatisation and the intensity of carbonatite and Mn-Fe veining. Relatively pure fenites typically do not contain significant REE concentrations, while increasingly carbonatised fenites carry anomalous quantities of REE.

10.7.2.3 Mixed Lithologies

The mixed lithologies are intimately associated with both carbonatites and fenites. They include breccias with carbonatite and fenite components, as well as finely intermixed carbonatite and fenite that cannot be separated into distinct units and correlated at the scale of mapping. The mixed lithologies are typically mineralised and are a significant contributor to the REE Mineral Resource. The concentration of REE is a function of the amount of carbonatite in the unit and the intensity of Mn-Fe veining.

10.7.3 Orientation and Spatial Distribution of Mineralisation

The Phase 3 drilling has resulted in a better understanding of the geometry and orientation of mineralisation at Songwe Hill. The mineralised body is a carbonatite plug, which is part of a larger system of intrusion and brecciation incorporating variable amounts of the surrounding lithologies. The mineralisation appears to be the result of hydrothermal processes that acted within the carbonatite, as well as in the related lithologies (fenite, breccia), and produced a relatively uniformly mineralised body. As such, the mineralisation does not have a well-defined strike or geometric shape although the drilling suggests that, in plan view, it is elongated in a NE-SW direction, and this is consistent with the presence of a persistent NE-SW striking, steeply dipping foliation observed in some of the carbonatite outcrops. The outline of the carbonatite plug is well defined by the drilling although there are isolated distal occurrences of carbonatite that cannot be connected to the main body at the present level of detail. It seems likely that there are additional carbonatite dykes and pods that remain untested by drilling beyond the NW and SW extent of the current drill sections (see Figure 10.1) as well as at depth. Structural observations in the drillhole core suggest that contacts and other fabrics are very steep, and this supports the interpretation that the overall contacts of the body may be sub-vertical, and the carbonatite body may, therefore, extend to considerable depths below the surface. The apparently isolated northwest body is an exception, in that contacts are observed in several places to be moderately to gently dipping. However, the overall geometry is not well enough constrained to allow a determination of the extent to which intersections represent true width.

11 SAMPLE PREPARATION, ANALYSES AND SECURITY

Channel sampling and core drilling programmes were carried out in accordance with written SOPs developed by MSA and reviewed during site visits. All core cutting, sampling, bagging and dispatch procedures were undertaken at the Songwe Hill exploration camp by Mkango personnel.

SOPs for geological and geotechnical logging, core splitting and sampling were compiled by MSA and reviewed with Mkango's Chief Geologist to ensure that the various activities are carried out in a consistent, transparent, auditable and appropriate manner in accordance with industry standards.

11.1 SAMPLE PREPARATION

11.1.1 Core Handling

Drillhole cores were placed by the drill crew in pre-labelled steel core trays, together with plastic depth blocks indicating the start and end of each run. A down hole orientation line was then marked on the core immediately with a china marker by the site geologist.

Geotechnical logging was carried out at the drill site by a geologist who measured the core from each run to determine the accuracy of the drillers' recoveries. The core was marked incrementally every metre with a red china marker perpendicular to the core axis.

Oriented core for geotechnical studies was recovered from 16 drillholes:

- A Reflex III orientation tool was placed in the hole prior to removal of the core from the core barrel.
- Upon removal of the core, a geologist carefully marked the core according to its placement in the orientation tool.
- The down hole orientation line was drawn on the core using the mark made by the orientation tool.

Core trays were transported twice daily under the supervision of the site geologist to the core logging and sampling facility at the exploration camp. The core trays were laid out at the camp, and the tray labels and the metre markings were checked for accuracy by a geologist.

11.1.2 Core Logging

Geological logging of the core was carried out using customised logging sheets designed by Mkango geologists and approved by MSA. In Phases 1 and 2, the cores were logged on paper forms, and the logs were subsequently captured in project-specific MS Excel spreadsheets. All original paper drill logs are kept on file. In Phase 3, the cores were logged directly on digital forms on a tablet computer, and the logs were subsequently exported to MS Excel spreadsheets. Digital drill logs are kept on file as part of the project database.

Semi-quantitative geochemical analyses were undertaken by the logging geologist using a handheld Thermo-Scientific Niton® XLP Analyzer. This was used as a guide to areas of mineralisation that are not always easily identified visually.

The magnetic susceptibility and gamma radiation (average reading over 30 s) for each metre of core were measured using a handheld magnetic susceptibility meter (SM30) and a RadEye personal radiation detector (PRD).

After core observations and measurements were completed, and prior to splitting, the core was photographed dry and wet (see Figure 11.1) on a tray stand in a fixed position, using a digital camera on a tripod also in a fixed position. The drillhole number and interval of each core tray are clearly marked, and each tray was photographed separately.

Source: Mkango Resources Ltd (2018)

Figure 11.1: Examples of Drillhole Core Marking before Splitting

11.1.3 Core Sampling

The entire length of each drillhole was sampled for chemical analyses. In Phases 1 and 2, cores were generally sampled in 1 m intervals. In Phase 3, cores were generally sampled in 2 m intervals. Where a change of lithology occurred within the sampling interval, then each lithology was sampled separately, using a minimum and maximum core length of 20 cm and 130 cm, respectively. A black line marked the start and end of each sample interval.

The sampling interval and a unique, sequential sample number (from a sample ticket book) were clearly marked by the logging geologist above the red orientation line and below the core cutting line. The core cutting line (yellow china marker) was marked on the core below and parallel to the red core orientation line. Sample numbers were marked with blue permanent marker on each individual piece of core.

The sample ticket number for each interval was recorded in the sampling sheet prior to sampling. The drillhole number and the sampled interval were also recorded on the stub of the sample ticket book.

The cores were cut in half using a commercial core cutter with a 2.2 mm wide diamond cutting blade. If any part of the core was friable or difficult to handle, it was taped with masking tape prior to cutting. Once sawn, both halves of the core were returned to the core tray. After each sample, the saw blade was cleaned with water. The upper half of the core was used for sampling, and the lower half of the core was retained in the core tray for future reference or additional test work. Sample numbers and metre marks were transcribed with a china marker onto the cut core faces prior to storage.

Each sample was double bagged with two sample number tags in extra-strength plastic sample bags. The sample was first placed in a pre-labelled sample bag and securely sealed with a cable tie. This bag was then placed in a second plastic bag, along with the corresponding sample number tag, and closed with a stapler. A second sample number tag was embedded in the stapled opening of the bag.

Sealed bags of samples were placed in a container which was always locked when not in use. The bags were laid out in sample number sequence and certified reference material (CRM), duplicate and blank samples were inserted. The samples were then assembled in approximately 25 kg batches. The assembled samples for each bag were photographed, placed in the rice bags, and the bag was sealed with tape.

Cores that have been logged, cut and sampled are stored in locked and secure, company-owned, storage containers at the Songwe Hill exploration camp (see Figure 11.2).

Source: Photographs by Mkango Resources Ltd (2012) and Dr Scott Swinden (2018)

Figure 11.2: Core Logging and Core Tray Storage Facilities

11.1.4 Density Measurements

Rock density measurements using the Archimedes principle (weight in air versus weight in water) were taken for every sample of core, after splitting and sampling. Each sample was approximately 15 cm to 20 cm long. The density device comprised a 3 kg electronic scale, below which a water container was placed. Attached to the scale was a core sample holder used to immerse the core in water in the container. The density method proceeded as follows:

- The scale was always reset to 0.00 g before each reading.
- A dry length of core was placed in the core holder, and the mass of the core in air was recorded.
- During Phase 3, permeable dry core was dipped in hot wax so that it was fully coated with a thin wax layer, and the waxed core was placed in the scale to record the mass of the core plus the wax.
- The container was filled with water to submerge the sample, and the mass of the core (plus the wax in the Phase 3 permeable samples) was determined in water.

The following formula was used to calculate the density (specific gravity = SG):

$$SG = \frac{\text{Mass in Air}}{\text{Mass in Air} - \text{Mass in Water}} \quad \begin{array}{l} = W \\ = V \end{array}$$

During Phase 3, a correction of 0.9*mass of wax was applied to waxed samples to account for the presence of the wax coating during measurement. All the information was recorded on density measurement sheets for the core.

The sampling database was maintained at the camp site and systematically backed up and incorporated in the project database.

The average density for the carbonatite and non-carbonatite rocks is 2.76 g/cm^3 and 2.64 g/cm^3, respectively.

11.2 SAMPLE ANALYSES

11.2.1 Primary Laboratory

Intertek Genalysis (Genalysis) in Perth, Australia, was the primary laboratory for the sample preparation and analysis of drillhole core and channel samples. Genalysis is an independent laboratory that performs geochemical analyses on a commercial basis. Genalysis has no relationship with Mkango other than the provision of analytical services for a fee.

Genalysis is accredited by The National Association of Testing Authorities Australia (NATA) to operate in accordance with ISO/IEC 17025, which includes the management requirements of ISO 9001. The Perth facility is accredited in the field of chemical testing for the tests shown in the scope of accreditation issued by NATA (date of accreditation: 20 September 1991).

During Phases 1 and 2, the samples were prepared at Genalysis in Johannesburg prior to chemical analyses in Perth; procedures were the same as the procedures followed during the Phase 3 analysis.

During Phase 3, samples were prepared at Genalysis in Perth, using the following procedures:

- The samples were weighed, checked, and job registered on the laboratory information management system (LIMS). Any discrepancies between the samples received and the sample submission sheets were conveyed to Mkango and resolved immediately.
- After weighing the samples, if required, the material was dried in a drying oven at 110 °C for 8 h.
- The samples were crushed in a jaw crusher to ~ 10 mm. If a sample was > 3 kg, it was split through a riffle splitter to provide a 1.5 kg sub-sample. If the material was < 3 kg, then the entire sample was used.
- The samples were milled and pulverised in a swing mill to 85 % passing 75 µm.
- A portion of 150 g was split from the pulp material and submitted for assay.

The samples were analysed in Perth, using digestion method FP6 and inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES). The FP6 fusion digest ensures complete dissolution of the sample including the refractory mineral component. Each sample was weighed at 0.25 g, mixed with an alkaline flux (Na_2O_2), and placed in a nickel crucible. This was fused in a muffle with precautions to retain sulphur, and the fusion product was dissolved in hydrogen chloride (HCl). Once digestion was accomplished, the sample was diluted appropriately and analysed with an ICP-MS, ideally suited to the analysis of trace elements in the parts-per-million or parts-per-billion range.

For major element analysis, once digestion is accomplished, the sample was diluted appropriately and read on the ICP-OES. Calibration was effected using standard solutions of known concentration.

Corrections were made, where applicable, for emission line overlaps and scattered light, and the overall dilution and catch weights used in the digestion process. Internal standards were used to correct for drift, viscosity effects, and plasma fluctuations.

The analytical results were emailed to Mkango in an MS Excel comma-separated values (.csv) file format, followed by the issuing of signed assay certificates in PDF format.

11.2.2 Verification (Umpire) Laboratory

Activation Laboratories Ltd (Actlabs) in Ancaster, Ontario, Canada, was selected as the umpire laboratory. Actlabs is an independent laboratory that performs geochemical analyses on a commercial basis. Actlabs has no relationship with Mkango other than the provision of analytical services for a fee.

Pulps split from the original samples were provided to Actlabs directly from Genalysis. Actlabs' digestion involved a lithium metaborate/tetraborate fusion with subsequent analysis by ICP and ICP-MS (Code 8-REE Assay Package Major Elements Fusion ICP (WRA)/Trace Elements Fusion ICP-MS (WRA4B2/OE)). A mass balance was required as an additional quality control technique to ensure elemental totals of the oxides between 98 % and 101 %. If samples contained > 0.3 % Nb_2O_5, then the ICP-MS technique was replaced by fusion XRF for Nb_2O_5 because ICP-MS results tend to be very low as a result of the Nb falling out of solution.

Actlabs' quality system is accredited to international quality standards through ISO/IEC 17025, which includes ISO 9001 and ISO 9002, with CAN-P-1758 (Forensics), CAN-P-1579 (Mineral Analysis) and CAN-P-1585 (Environmental) for specific registered tests by the Standards Council of Canada (SCC). Actlabs is also accredited by the National Environmental Laboratory Accreditation Conference (NELAC) program and Health Canada.

The analytical results were emailed to Mkango in MS Excel format, followed by the issuing of signed assay certificates in PDF format.

11.3 SAMPLE SECURITY AND DISPATCH

Strict security protocols were employed for the handling of samples. All the samples were prepared and transported in such a manner that a secure and auditable chain of custody from the field to the laboratory was ensured.

Once an entire hole was sampled, the bagged and securely closed samples were placed in woven PVC bags, approximately 25 kg per bag. The drillhole number and corresponding sample numbers were recorded on the exterior of each bag. The bags were then stored inside locked and secured, company-owned, storage containers at the exploration camp until dispatch.

During Phases 1 and 2, samples were dispatched from the camp to Zomba for shipping to Johannesburg. Detailed procedures were documented in the 2015 NI 43-101 Technical report (The MSA Group, 2015) and are summarised as follows:

- All the samples submitted for analysis were accompanied by standard sample submission documents carrying sample details and analytical instructions.
- Woven bags containing the samples were transported by road using a contract commercial carrier to the company office in Zomba. Samples were physically accompanied from the exploration camp to Zomba by a senior geologist from Mkango's exploration team.
- Upon receipt at Mkango's office in Zomba, samples were inspected, weighed, and sealed by a senior geologist of the Malawian Geological Survey Department. A certificate of inspection, which was signed by the Director of the Malawian Geological Survey or his representative, was prepared and issued. The certificate of inspection contained the name of the rocks, exploration licence number, total number and weight of the samples inspected, estimated sample value, port of exit, and the name and address of the consignee.
- Samples were then delivered by a senior Mkango geologist to SDV Malawi Ltd (SDV) in Blantyre for shipment by commercial carrier South African Airlines (SAA) to Genalysis in Johannesburg. Samples were weighed by SDV and compared with the weights supplied by Mkango. In most cases, sample transport was timed so that samples proceeded directly from camp to Zomba and then to the carrier. In rare instances, where SDV was unable to receive the samples the same day, the bags were stored in a secure, locked room at Mkango's offices in Zomba until they could be delivered to SDV.
- SDV was responsible for the shipment and tracking of the samples from Malawi to Genalysis in Johannesburg. All the shipping paperwork was sent to Mkango personnel,

and once shipment was confirmed by SDV, notification along with sample submission sheets were emailed to Genalysis.

- When the sample batches were received by Genalysis, the sample numbers were checked and recorded, and a job number was assigned on the LIMS. Sample receipt verification was then emailed to Mkango staff, including the Chief Geologist. Following sample preparation, the samples were couriered by Genalysis to their analytical facilities in Perth.

During Phase 3, samples were dispatched whole to Perth for sample preparation according to the following protocols:

- All the samples submitted for analysis were accompanied by standard sample submission documents carrying sample details and analytical instructions.
- Approximately every two weeks, samples were expedited to the Bolloré Transport and Logistics Malawi Ltd (BTLM) company offices in Blantyre via a contracted truck. Each shipment was accompanied by a senior geologist, who supervised the transport and unloading of the samples in Blantyre. BTLM, supervised by a Mkango geologist, loaded the samples on pallets and wrapped them securely in plastic wrap for shipment to the laboratory in Perth.
- Upon receipt at the BTLM warehouse in Blantyre, samples were inspected, weighed and sealed by a senior geologist of the Malawian Geological Survey Department. A certificate of inspection, which was signed by the Director of the Malawian Geological Survey or his representative, was prepared and issued. The certificate of inspection contains the name of the rocks, exploration licence number, total weight of the samples inspected, estimated sample value, port of exit, and the name and address of the consignee.
- BTLM was responsible for the shipment and tracking of the samples from Malawi to Genalysis in Perth. All the shipping paperwork was sent to Mkango personnel, and once shipment was confirmed by BTLM, notification along with sample submission sheets were emailed to Genalysis.
- When the sample batches were received by Genalysis, the sample numbers were checked and recorded, and a job number was assigned on the LIMS. Sample receipt verification was then emailed to Mkango staff, including the Chief Geologist.

11.4 QUALITY ASSURANCE AND QUALITY CONTROL

Appropriate QA/QC monitoring is a critical aspect of the sampling and assaying process in any exploration programme. Monitoring the quality of laboratory analyses is fundamental to ensuring the highest degree of confidence in the analytical data and providing the necessary confidence to make informed decisions when interpreting all the available information. Quality assurance (QA) may be defined as information collected to demonstrate that the data used further in the project is valid. Quality control (QC) comprises procedures designed to maintain a desired level of quality in the assay database. Effectively applied, QC leads to the identification and corrections of errors or to changes in the procedures that improve the overall data quality. Appropriate documentation of QC measures and regular scrutiny of QC data are important as a safeguard for project data and form the basis for the QA programme implemented during exploration.

In order to ensure that quality standards are met and maintained, planning and implementation of a range of external QC measures are required. Such measures are essential for minimising uncertainty and improving the integrity of the assay database, and are aimed to provide the following:

- An integrity check on the reliability of the data
- Quantification of accuracy and precision
- Confidence in the sample and assay database
- The necessary documentation to support database validation

Mkango adopted an industry standard QA/QC programme and inserted CRM and blanks each at a frequency of 1 in 20 (5 %) into the batches prior to submission to Genalysis. These control samples were inserted as part of a continuous sample number sequence, and the QA/QC samples were not obviously different from routine samples after the pulverisation process.

In order to create the required 5 % duplicate samples, two protocols were followed. For approximately two in three sample duplicates, Genalysis was requested in the sample submission sheet to split the pulp of predetermined samples and insert the material into empty and pre-numbered bags, supplied by Mkango, together with the other samples. For approximately one in three sample duplicates, the core was quartered, and the two quarters were treated as field duplicates. This allowed for monitoring of the sample geological variation as well as the sample preparation procedure and the precision of the analyses.

An additional 3 % of the total samples was couriered by Genalysis to the umpire laboratory Actlabs. Hence, the overall number of control samples constituted approximately 21 % of the samples analysed, which is in line with best practice procedures to ensure the integrity of the data and is independent from the internal QA/QC methods applied by the laboratory.

Gaps in the sample sequence were left for CRMs, blanks and duplicates in the course of the sampling and bagging process conducted at the Songwe Hill camp. The CRMs and blanks were only packed after the main sampling process was completed to minimise the possibility that sample numbers would be inadvertently swapped between the routine and control samples.

The results of the QA/QC programme for Phases 1 and 2 are detailed in the 2015 NI 43-101 Technical Report on Songwe Hill (The MSA Group, 2015) and demonstrated that the data quality was acceptable for Mineral Resource estimation. Short summaries of the Phase 1, Phase 2 and Phase 3 QA/QC are given below.

11.4.1 Phase 1 and Phase 2 Blank Samples

The blank sample material used during the Phase 1 drilling programme was REE-barren Magaliesberg quartzite chips. During the Phase 2 campaign, AMIS0305 from African Mineral Standards (AMIS) and Magaliesberg quartzite were used. The blanks were inserted into the sample stream with a normal, sequential sample number. Slightly elevated REE concentrations in four blank samples from four separate batches were queried with Genalysis, which re-analysed the samples with acceptable results. No further action was taken or required, and the results of the blank analyses are interpreted to indicate that there was no contamination or systematic analytical issues during the period of sample submission and analyses.

11.4.2 Phase 1 and Phase 2 Certified Reference Material

For independent assessment of the accuracy of laboratory analyses, CRMs were inserted using a frequency of 5 % (1 in 20). CRMs comprised AMIS0185 and SARM 40 during the Phase 1 programme and AMIS0185 and Geostats GRE-04 during the Phase 2 campaign. The performance of the CRMs during the two phases was acceptable, and occasional values outside the recommended range have no material effect on the overall data quality. Rare earth elements Tb, Dy, Gd and Y showed a systematic under-reporting for AMIS0185, which is not considered critical due to their very low concentration levels in this light rare earth standard.

11.4.3 Phase 1 and Phase 2 Duplicates

Duplicate samples were not used during the Phase 1 drilling programme. However, they were inserted during the channel sampling and Phase 2 drilling programmes at a rate of 1 in every 20 samples (5 % frequency) to assess the precision of the analyses. Duplicates were placed as an empty numbered bag into the sample stream. Samples were split at the laboratory following pulverisation, and the pulp of the sub-sample was inserted in the empty sample bag. The instructions on the sample submission sheet to Genalysis specified which samples were to be split for duplicates.

The duplicates indicate a very high level of precision except for three duplicate pairs where the problem was traced to a sample number issue at the laboratory. Genalysis re-analysed these samples with acceptable results, and no further action was taken or deemed necessary.

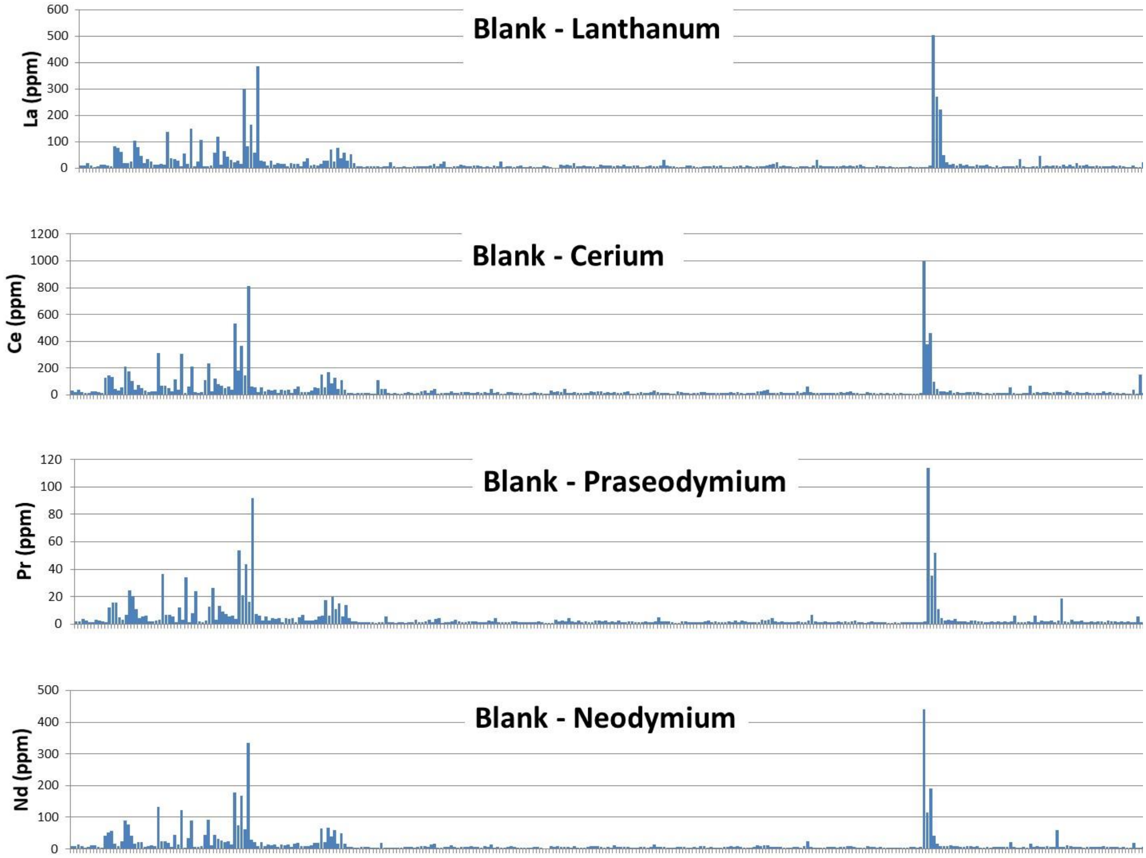
11.4.4 Phase 1 and Phase 2 Umpire Laboratory samples

In order to check the quality of the analyses from the primary laboratory, a duplicate of the pulps was sent by Genalysis to Actlabs. Umpire samples were sent at a frequency of approximately 5 % (1 in 20). The results of these analyses were plotted graphically against the original analysis. In two cases, the umpire results differed substantially from the primary data. This problem was subsequently rectified through re-analysis and attributed to a sample mix-up. The vast majority of the samples show a discrepancy between the two laboratories of less than 10 %, and less than 1 % of the 405 sample pairs exceeded 20 %.

11.4.5 Phase 3 Blank Samples

To monitor any contamination of the samples, a blank sample containing negligible REE concentrations was included in every 20 samples. The blank sample material was REE-barren Magaliesberg quartzite. The blanks were inserted into the sample stream with a normal, sequential sample number.

Significantly elevated REE concentrations were observed in a number of blank samples from four separate batches. These were queried with Genalysis, and 85 samples from a hole with highly anomalous blanks were re-pulverised and re-analysed. The results were identical to the original analyses, suggesting that any contamination was not sufficient to affect the assays of the core samples. No further action was taken or required, and the results of the blank analyses are interpreted to indicate that any contamination that may have occurred was not significant enough to affect the analysis of the samples. Examples of the four elements are shown in Figure 11.3.

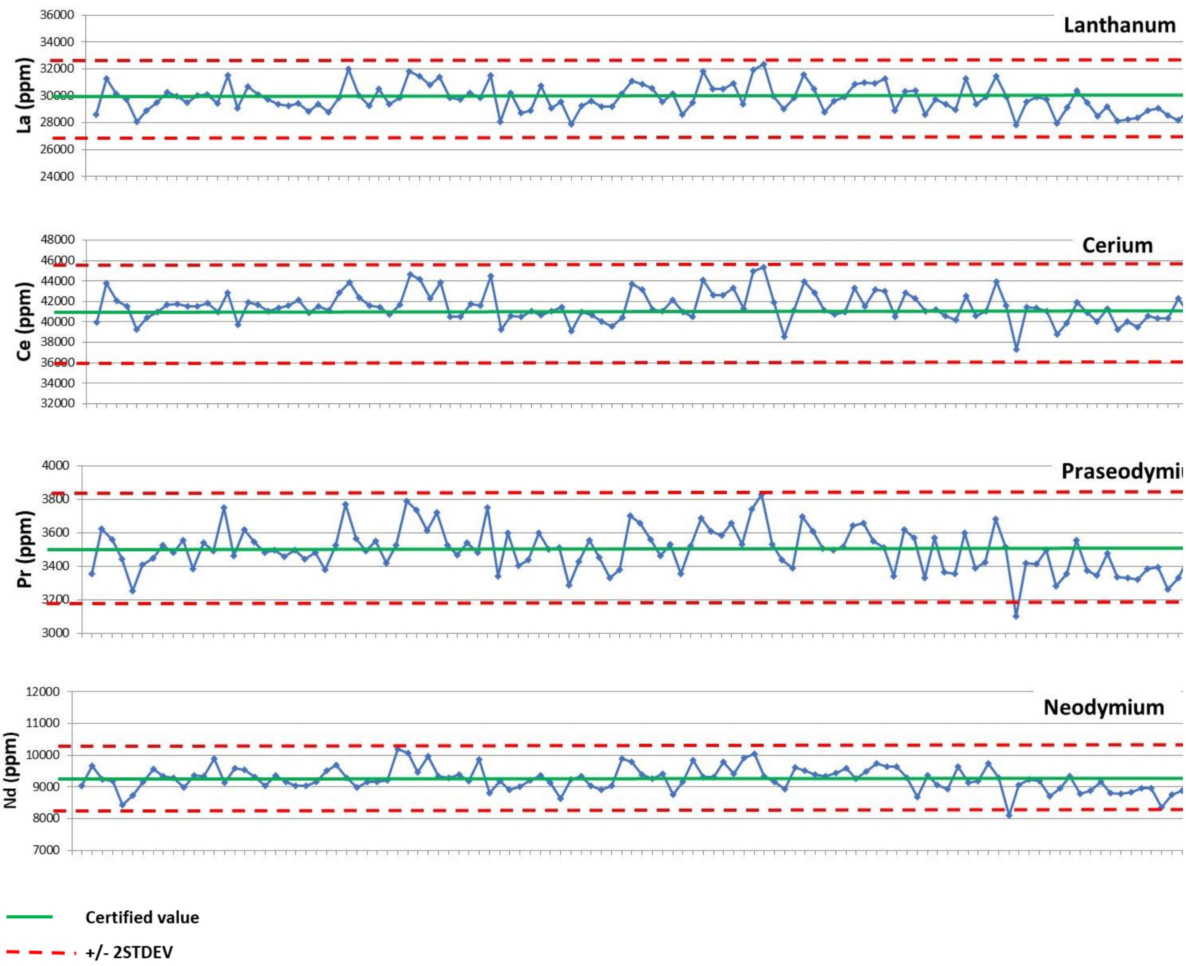


Source: Charts by Dr Scott Swinden (2018)

Figure 11.3: Performance of Selected Rare Earth Elements in 329 Blank Analyses

11.4.6 Phase 3 Certified Reference Materials

For independent assessment of the accuracy of laboratory analyses, CRMs were inserted at a frequency of 1 in 20 (5 % frequency). Each CRM was assigned a sample number within the normal sample sequence. CRMs comprised AMIS0185, AMIS0275 and AMIS0356. The performance of the CRMs was acceptable, and occasional values slightly outside the recommended range have no material effect on the overall data quality. Examples of four elements are shown in Figure 11.4 for one of the CRMs used.

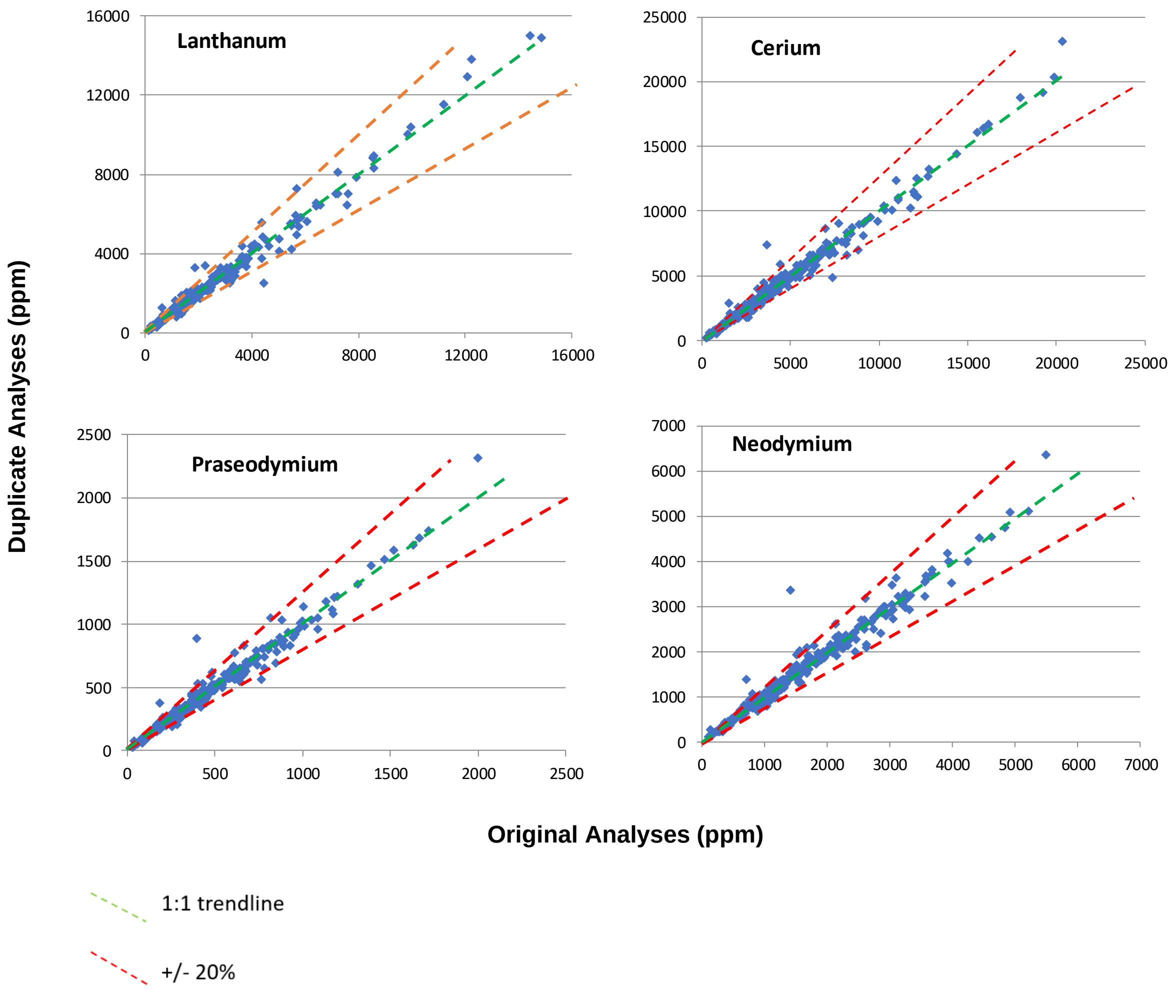


Source: Charts by Dr Scott Swinden (2018)

Figure 11.4: Accuracy of Selected Light Rare Earth Elements in 112 Samples of CRM AMIS0185

11.4.7 Phase 3 Duplicate Samples

The duplicates indicate a very high level of precision except for one duplicate pair in an early batch of analyses. Examples of the four elements are shown in Figure 11.5.

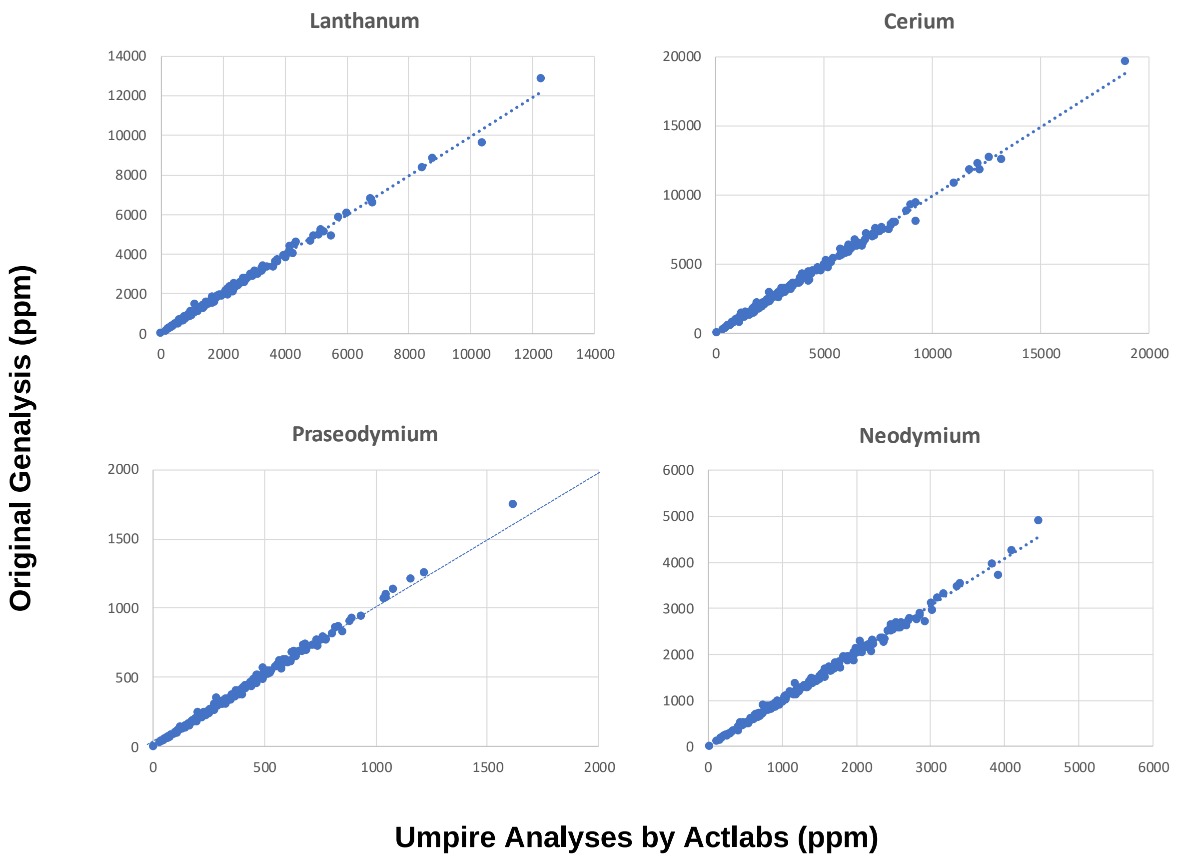


Source: Charts by Dr Scott Swinden (2018)

Figure 11.5: Repeatability of Selected Light and Heavy Rare Earth Elements in 337 Duplicate Sample Pairs (ppm)

11.4.8 Phase 3 Umpire Sample Assays

Check samples were sent to Actlabs to conduct analyses on 219 samples. The analyses of the umpire duplicate pairs were plotted graphically. The vast majority of the samples showed a discrepancy between the two laboratories of less than 10 %. Examples of the four elements are shown in Figure 11.6.



Source: Charts by Dr Scott Swinden (2018)

Figure 11.6: Repeatability of Selected Light and Heavy Rare Earth Elements Umpire vs Original Assay

11.5 ADEQUACY OF SAMPLE PREPARATION, SECURITY AND ANALYTICAL PROCEDURES

All aspects of core handling, marking, logging, cutting, bagging, labelling and sample submission to the Genalysis preparation facilities in Johannesburg are covered by well-designed protocols to ensure that all the routine activities are conducted with maximum consistency and follow industry standards.

Mkango followed an auditable chain of custody, which ensured security and integrity of the results. Dr Scott Swinden (the Qualified Person contracted by Mkango), is satisfied that there was little or no opportunity for an outside agent to tamper with the sample material, and that the sampling and analytical procedures and number of QA/QC samples inserted into the sample stream were appropriate. The CRMs and blanks show acceptable performance for the elements analysed over the period of the sampling campaign. The duplicate samples reported acceptable precision for all the relevant concentration levels.

The analytical results from the primary and the umpire laboratories show a very good correlation and therefore confirm the element concentrations determined by the primary laboratory.

The QC procedures have been effective in demonstrating the quality of the analytical results, and any issues that were identified were quickly dealt with and resolved.

Based on these results, it is the QP's opinion that the sampling and assay data from the drilling and channel sampling programmes is acceptable for use in a Mineral Resource estimate.

12 DATA VERIFICATION

The data verification processes that were completed for Songwe Hill are as follows:

- The site was visited by the QP from 25 to 28 July 2018 and from 24 to 26 September 2018.
- The data from more than 10 % of the assay certificates from the laboratory was checked against the database output. No errors were found.
- The drilling locations were observed at the site.
- The logging was examined in a selection of the Phase 3 drillholes and verified against observations made on the cores. In general, the logging was found to be reasonable. A recommendation was made to re-examine the logging with respect to the geochemistry in situations where the lithology is uncertain.
- The mineralisation in the cores for a selection of the Phase 3 holes was examined, and comparisons between the core observations and the sample assays were made. Clear relationships were noted between the assays and observations of the rock type and alteration.
- Readings on the cores were taken using a handheld XRF. Although the results of this exercise are not definitive, the results served to verify the magnitude of the assayed grades.
- The assays completed by the primary laboratory (Genalysis) were verified by re-assaying approximately 3 % of the pulp rejects at the umpire laboratory (Actlabs). The assays received from the two laboratories compared within reasonable limits.

In the opinion of the QP, the data verification processes demonstrate that the database is adequate for the purpose of Mineral Resource estimation.

13 MINERAL PROCESSING AND METALLURGICAL TESTING

Test work started on the Songwe Hill project in 2010. Large amounts of test work have been completed over various test work campaigns, ensuring that the orebody and optimal processing routes are well understood. Surface grab samples, drill core samples from drilling campaigns, and bulk samples have been collected in the decade since 2010 and used to determine the optimal beneficiation and recovery processes for the Songwe Hill ore. Mineralogical analyses have indicated that the ore largely comprises carbonaceous gangue minerals, containing synchysite, apatite and florencite as main rare earth bearing minerals. The understanding of the ore has been of cardinal importance in developing optimised flowsheets for the beneficiation and recovery of rare earths.

This section gives a review of the test work done to date, as well as the major aims and findings that influenced decisions in the process design.

13.1 EARLY TEST WORK (2010 TO 2018)

Extensive test work was completed prior to the commencement of the DFS as disclosed in the PFS report (150177-0000-30RA-0001 Mkango Rare Earths PFS Report Rev 00_12-02-2015) and other announcements.

13.2 TEST WORK USED FOR THE DFS

Subsequent to the PFS, further test work was conducted by Mkango to optimise and prove the process design. This test work is described in the sections below.

13.2.1 ALS

13.2.1.1 Mineralogy

In May 2018, ALS Minerals Division (ALS) reported on a series of mineralogical tests done on the run of mine (ROM) material at the request of KYSPYmet, a consultant approached by Mkango to assist with the flotation flowsheet development.

The ROM ore sample received by ALS was labelled “Comp4” (Composite 4) and was supplied at a P_{80} of 53 µm, and it was divided into the following four size fractions:

- +53 µm
- 53 µm to 38 µm
- 38 µm to 20 µm
- −20 µm

The test work aimed to determine the following:

- Minerals and their concentrations in the ROM ore sample
- Grain size distribution data
- Elemental distributions
- Liberation information
- Particle images

The test work indicated that there was no significant difference in mineral abundances between the size fractions. The mineral distributions are shown in Figure 13.1. The results given by ALS correlate well with prior analyses done by Mintek in 2012.

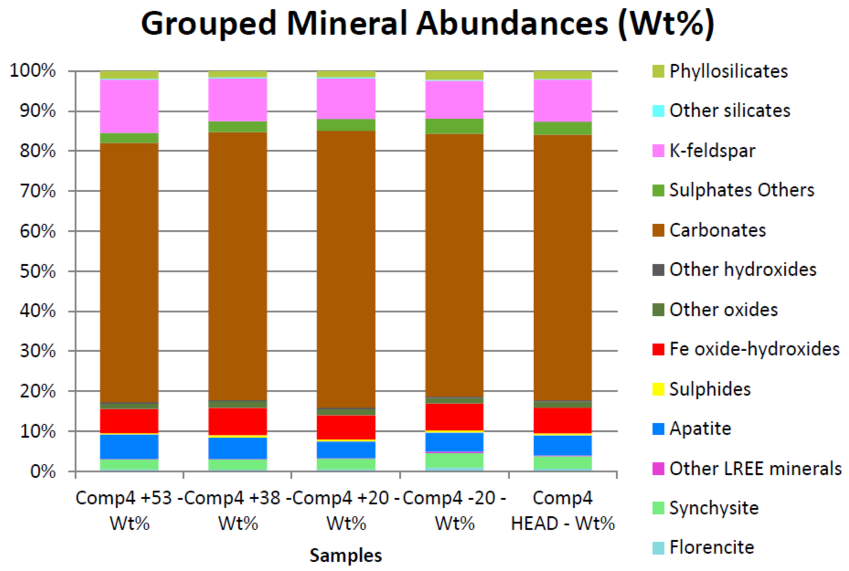


Figure 13.1: Mineral Abundances (ALS, 2018)

The significant rare earth bearing minerals and their abundance in the ROM sample were identified to be florencite (0.73 wt%), synchysite (3.05 wt%), and apatite (5.05 wt%). Other light rare earth bearing minerals were identified but were only present in 0.19 wt% of the bulk sample.

Rare earth mineral liberation was found to be the best for the −20 µm size fraction, reaching approximately 80 % liberation versus 23 % to 62 % liberation in the 38 µm to 20 µm size fraction. The degree to which liberation decreases in particle sizes larger than 20 µm indicated that optimal flotation and hydrometallurgical recovery of rare earths would only occur if particles were finely ground before processing.

13.2.1.2 KYSPYmet Flotation (2018 to 2020)

From the initial drilling campaign in the area of the Measured resource, various ore composites were generated for flotation testing and the development of a flotation regime for successfully upgrading the rare earth minerals.

KYSPYmet performed many tests on the composite samples. The tests were used to establish the favourable flotation parameters such as grind size, pulp density, pH, temperature, conditioning time and reagent suites, in addition to determining the optimal arrangement of pre-float/rougher/cleaner/scavenger flotation stages.

A combination of fine grinding and conditioning with collectors at elevated temperatures was shown to be effective in upgrading the primary ore type, Type 1 mineralisation, as discussed below.

13.2.1.3 Geochemical, XRD and Flotation (2019 to 2020)

Bulk sampling on site was concluded in October 2018 and produced 22 bulk samples totalling 60 t, taken from the Measured and Indicated resource areas. The samples were labelled BS001 to BS022.

The bulk samples were collected from outcrops to provide better information on the consistency of REE grades in the deposit and to provide material for metallurgical testing. The locations (BS01 to BS22) were identified where the carbonatite and “mixed rock” were well exposed and with minimal surface weathering, with exposure sufficiently prominent and next to roads/pads to allow access by a JCB tracked excavator. Approximately 2.7 t of rock was hammered out and collected at each location to make up a total of approximately 60 t. Only blocks of fresh rock were collected; any pieces with weathering rind or cavity walls were rejected.

Prior to the generation of the bulk samples, KYSPYmet had successfully developed a flotation regime for the Composite 4 and Composite 5 samples, both created from the drill core samples. The flotation concentrate achieved TREO grades of ~20 wt%. KYSPYmet completed initial test work on Composite 6, which was also generated from drill core samples, and the initial results from Composite 6 were poor. KYSPYmet proposed that this was due to the presence of iron oxides, such as hematite and magnetite, consuming the collector.

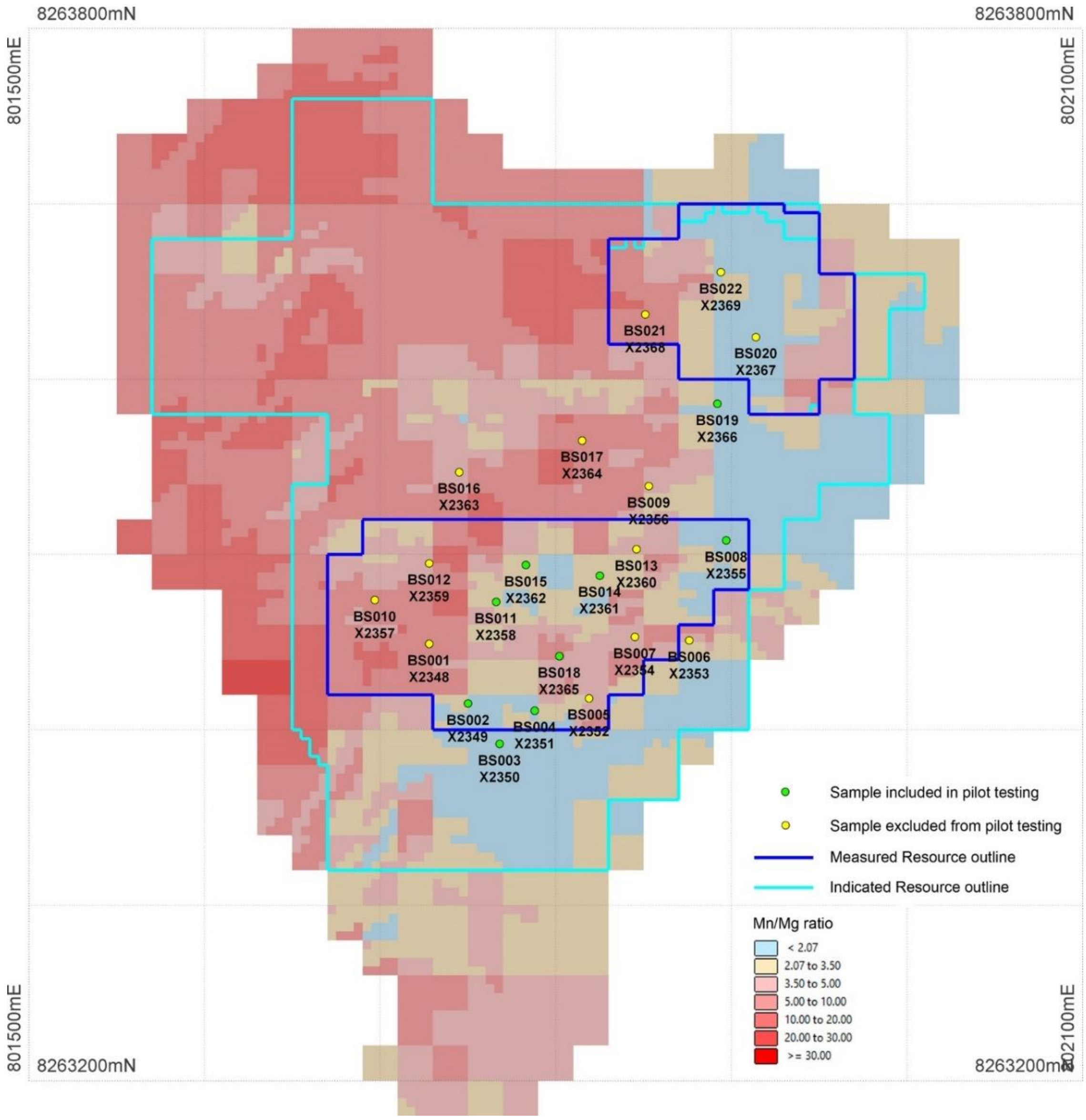
Further composites were made up from 20 of the 22 bulk samples sent from Malawi, categorised into grades (< 1 % TREO, 1 % to 1.5 % TREO, 1.5 % to 2 % TREO, > 2 % TREO) for the purposes of initial variability test work. Two low-grade samples were excluded because they were significantly below the likely cut-off grade of 1 % TREO (BS05 0.5 % TREO and BS07 0.64 % TREO).

The same issue experienced with Composite 6 was encountered in some of the other composite samples where the flotation performance for the 1.5 % to 2 % TREO and > 2 % TREO composites was significantly impacted potentially by iron oxides.

It was found that ore types could be generally grouped as ore with higher or lower Mn:Mg and Fe:Mg ratios. The ore was classified as Type 1 and Type 2 material. Type 1 ore had a lower Mn:Mg and Fe:Mg ratio, and performed better in flotation testing. Type 2 material contained less magnesium and was more difficult to upgrade in flotation. Composites 4 and 5 correlated well with what was deemed to be Type 1 ore whereas Composite 6 correlated with the Type 2 material mineralogical profile.

Magnesium was incorporated into the block model, and sections and plans were generated to see if there was a coherent and continuous distribution of the Type 1 ore using the Mn:Mg ratio. This indicated a clear zone of such mineralisation along the western portion of the Songwe Hill deposit and overlying the lower Mn:Mg mineralisation in the south, illustrated in Figure 13.2.

The bulk samples are shown on the block model in Figure 13.2. The samples for the pilot scale test work largely correspond to the Type 1 ore zones, taking the TREO grade (> 1 %) and the Mn:Mg ratio into account, and are indicated as green points in Figure 13.2.



Source: Paul Armitage, Mkango Resources (paul@mkango.ca)

Figure 13.2: Bulk Sample Locations including Mn:Mg Ratios

13.2.1.4 Ore Variability Test Work (ALS, 2022)

ALS performed ore variability test work on 27 samples in addition to the composite sample that was used as feed for the pilot plant. Variability samples were generated from drill core samples in and around the area that is currently targeted by the mine plan. Samples were analysed for TREO, Mn, Mg and Fe concentrations. The majority of the samples were characterised as Type 1 ore samples, with only 7 samples out of 27 being characterised as Type 2 or “almost” Type 2 (within 20 %).

The variability samples were all subjected to bench-scale flotation tests. The flotation circuit comprised a circuit representative of the current flotation design, starting with a sulphide pre-float and sulphide pre-float cleaner, followed by REO rougher flotation, REO cleaner flotation, and REO cleaner scavenger flotation to produce a final concentrate in the form of REO cleaner concentrate and REO cleaner scavenger concentrate. Samples were taken from the REO rougher cells and each of the REO cleaner cells, as well as the REO cleaner scavenger cell. Each intermediate sample was analysed for rare earth grade and recovery to construct sample grade/recovery curves. Sample grade and recovery data was used in conjunction with sample head compositions in order to evaluate the sample flotation performance as a function of sample compositions and elemental ratios.

Figure 13.3 shows the combined grade/recovery curves for all the ore variability samples. It is evident that the Type 2 material performs poorly but the Type 1 ore samples that fall close to the Mn:Mg threshold ratio of 3.5 achieve a wide range of grades and recoveries. This indicates that there could be as yet undiscovered factors influencing performance, not only the Mn:Mg ratio.

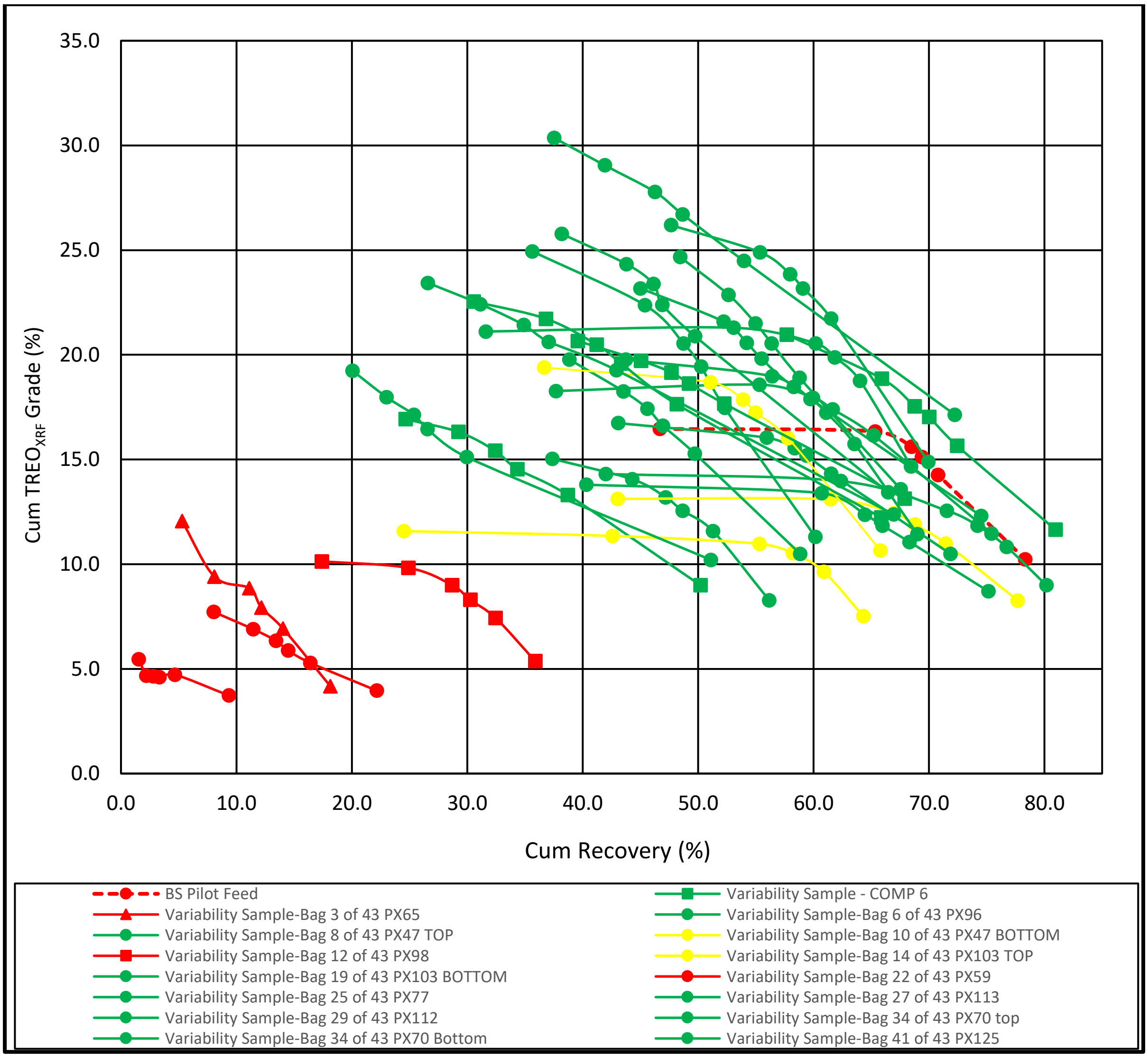


Figure 13.3: Variability Test Work Campaign – Combined Grade/Recovery Curves

Figure 13.3 shows that a 70 % TREO recovery and 15 % w/w grade in the flotation concentrate were achieved by the composite pilot plant feed sample and several other variability samples during the bench-scale tests that followed a pilot plant equivalent process flow. There could be several reasons for the variability in performance. The variability samples were all subjected to bench-scale flotation tests and not optimised. Flotation performances could improve significantly if the flotation regime was optimised for a more varied sample, for example,

- Drill core samples classified as Type 1 could also have intersected areas identified as Type 2, which would have negatively impacted the overall flotation performance of that sample.
- The large-scale plant feed would be more homogenously blended, and the flotation regime could be optimised with relative ease to achieve the target flotation performance.

13.2.2 Grinding Solutions (2019) – IsaMill vs SMD Signature Plots

Grinding Solutions performed sample preparation, crushing and rod milling to produce fine grinding feed material.

The material was milled in a horizontal fine grinding mill (IsaMill) and also in a vertical stirred media detritor (SMD). Both tests were conducted in an open-circuit arrangement to better compare performance. The feed material was milled to the target product size P_{90} of 20 µm.

The results showed that the SMD consumed significantly less power than the IsaMill to produce all the product size classes.

The power requirements for the IsaMill were 20.96 kWh/t and the SMD were 7.77 kWh/t.

13.2.3 Keramos (2020)

Keramos Metallurgical Services conducted test work in their CeramoStar ultra-fine grinding (UFG) metallurgical laboratory on ROM material with a P_{80} of 52.4 µm. Keramos performed batch testing in their small-scale SMD, which yielded results that correlated very well with earlier results produced by Grinding Solutions. For a target P_{80} of 20 µm, the specific grinding energy was 7.59 kWh/t.

13.2.4 ALS Comminution and Flotation Piloting

13.2.4.1 Comminution

ALS conducted test work to determine the following for each of the 22 bulk samples:

- Unconfined Compressive Strength (UCS)
- Crushing Work Index (CWi)
- Abrasion Index (Ai)
- Bond Rod Work Index (BRWi)
- Bond Ball Work Index (BBWi)

Table 13.1 shows the test work results for the composite sample used for flotation and hydrometallurgical piloting.

Table 13.1: Composite Pilot Feed Sample Characteristics

Description	UCS (MPa)	CWi (kWh/t)		Ai	BRWi		BBWi	
		Average	Standard Deviation		Bulk Density (t/m³)	kWh/t	Bulk Density (t/m³)	kWh/t
Average of all samples	45.56	12.42	3.64	0.0218	1.86	17.38	1.92	13.49

13.2.4.2 Bench-Scale Flotation Test Work

KYSPYmet supplied ALS with an optimised flotation flowsheet including reagent regimes, and conditioning and flotation conditions. Samples of the reagents were also provided to ALS for use in piloting.

ALS performed several bench-scale tests to confirm the process parameters and adjust certain conditions if deemed appropriate. A modified flowsheet was developed for the flotation pilot plant, decreasing the number of flotation cells and reagent dosing points, but retaining the conditioning and elevated temperature downstream of the sulphide pre-float. A comparison of the ALS bench-scale results and the KYSPYmet results is shown in Figure 13.4, and it is evident that the results are similar.

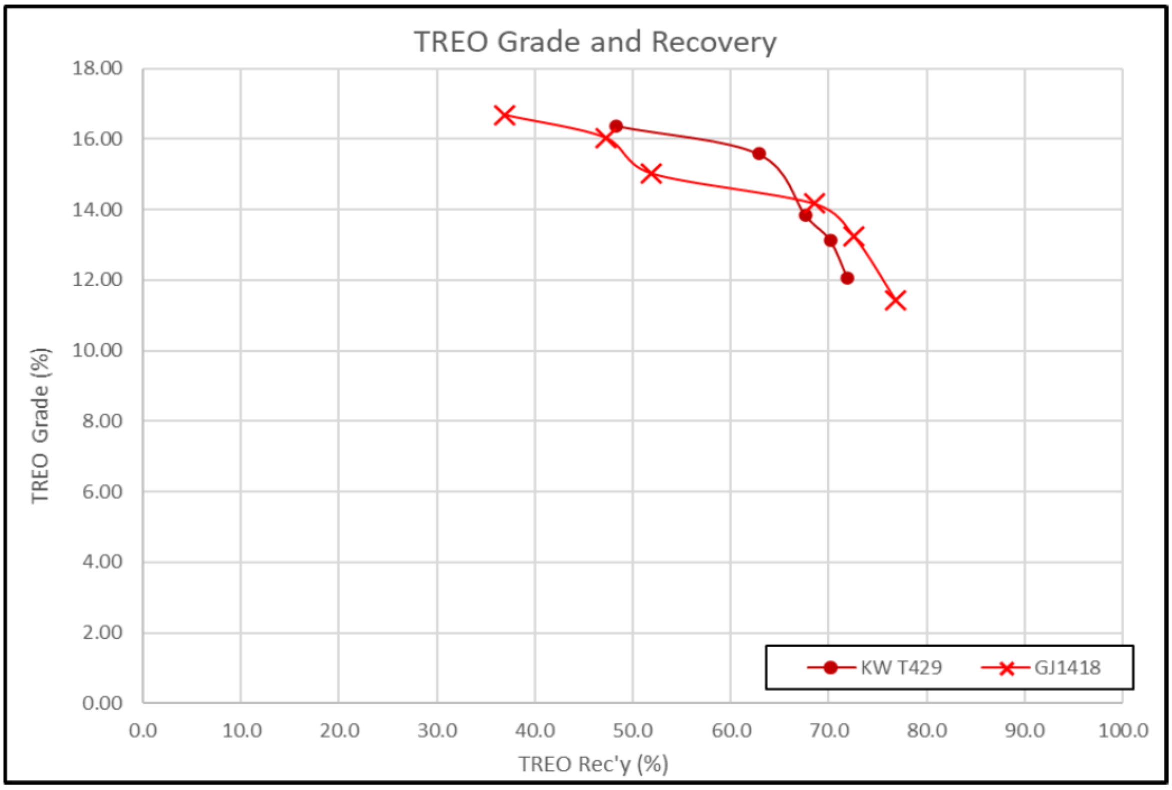


Figure 13.4: Modified Bench-Scale Test vs Optimised KYSPY Test

It was demonstrated that ALS could replicate and improve the optimised flotation performance developed by KYSPYmet's bench-scale test work campaigns.

13.2.4.3 Pilot Plant Test Work

The pilot plant was constructed by ALS in Perth and initially aimed to stabilise grinding and regrinding circuits in order to consistently provide target feed size material to the flotation circuit. The float feed particle size achieved showed a good consistency around the target P_{80} of 20 µm.

The process comprised a sulphide pre-float, REO rougher flotation, REO scavenger flotation, REO cleaner flotation, and REO cleaner scavenger flotation.

The pilot plant was run for approximately 5 d, the first 2 d of which served as process stabilisation and tweaking of reagent dosages to obtain the optimal steady-state operation. After that, three surveys were performed to collect the performance data on the pilot plant for reporting.

During continuous piloting runs, the reagent addition was adjusted as required to achieve optimal grade and recovery, based on observations from the pilot plant.

Overall, the flotation piloting was successful in achieving and exceeding target recovery and grade for the composite sample fed into the flotation plant. There were process fluctuations of higher or lower than the target recovery and grade, but the overall mass balance indicates that the target of > 70 % recovery and 15 % grade is realistically achievable, with the 74.1 % recovery and 15 % grade achieved in piloting exceeding the bench-scale test work. The overall Survey 1 to Survey 3 grades and recoveries are shown in Figure 13.5. There is a slight difference between measured and estimated grade/recovery values, as in certain cases the measured data had to be adjusted to achieve a better overall balance. For Surveys 1 and 3, this was deemed to be insignificant, but slightly larger adjustments were required for Survey 2.

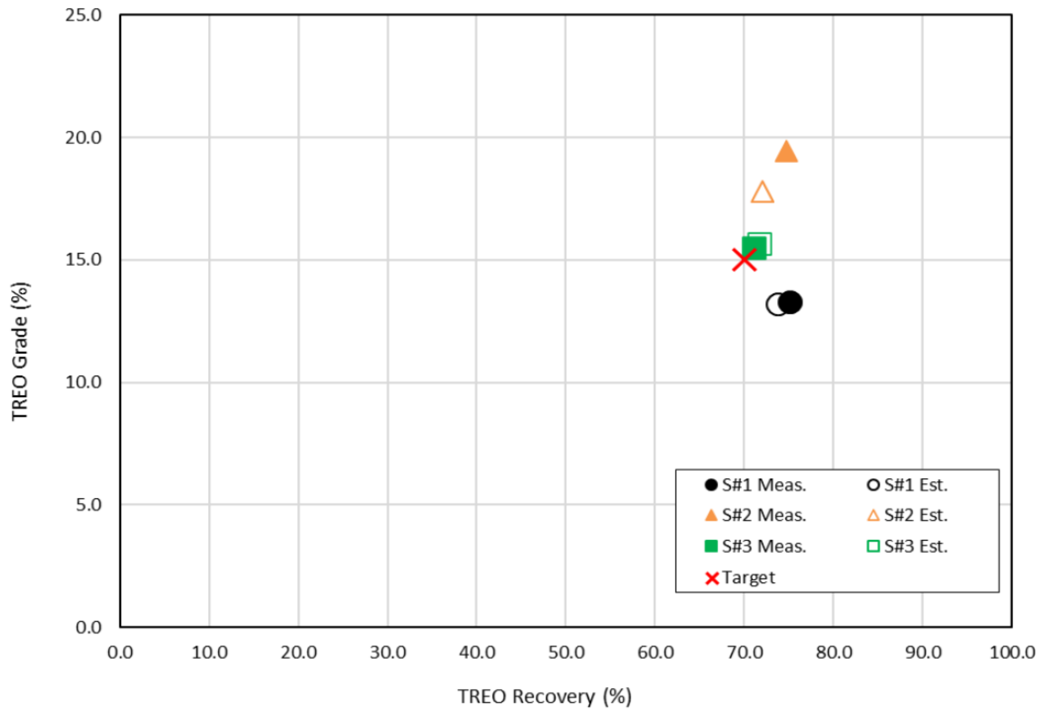


Figure 13.5: Overall Survey Grade-Recovery Plot (ALS, 2021)

13.2.4.4 Site Water Testing

In addition to comminution and flotation piloting, ALS tested the site water quality and the effect of site water on flotation performance. It was found that the use of site water impacted on the flotation, but the impact can be mitigated by modified process parameters.

13.2.5 ANSTO Hydrometallurgical Test Work

13.2.5.1 Bench-Scale, Pre-Pilot and Piloting

Since mid-2019, ANSTO has conducted test work on the flotation concentrate produced by KYSPYmet while developing a flotation flowsheet. This section contains a brief description of the process that ANSTO refined and ultimately piloted. Numerous tests were done over a two-year span, optimising conditions for each unit operation in the hydrometallurgical plant.

Bench-scale test work was conducted to establish the optimal process parameters, focusing largely on the optimal extraction of rare earths and effective rejection of impurities that might impact rare earth recovery. Bench-scale test work was often conducted with synthetic liquors. After the bench-scale test work, step-through tests were conducted on consecutive processing operations using material from the previous test in the next, and so forth. This further refined the conditions and target reagent consumptions, rare earth extractions, and impurity levels.

Following the step-through tests, the pilot plant design criteria were generated to upscale the process to continuous piloting. In many cases, bench-scale test work, step-through test work and piloting overlapped, as various unit operations were tested in parallel.

13.2.5.2 Gangue Leach

Gangue leach was found to perform optimally at an elevated temperature and a pH of 4. This led to maximum impurity removal and mass loss whilst retaining rare earths in the residue and minimising acid consumption. Gangue leach and hydrochloric acid regeneration are integrally connected, and conditions were optimised to produce an HCl stream of 10 wt% to 12 wt%.

The extraction of elements associated with gangue minerals is a good indicator for the success of the gangue leach. At the pH, temperature and residence time used in gangue leach, the dissolution of rare earth elements has been shown to be almost zero. Extraction of rare earth elements during the pilot run was shown to remain below 0.5 %, and the overall mass loss was approximately 37 %.

13.2.5.3 Gangue Leach Liquor Neutralisation

Gangue leach liquor is high in calcium and chloride, along with other impurities. The gangue leach liquor stream is sent to HCl regeneration, but impurity build-up in the recycle loop would be detrimental to the leaching performance. Therefore, gangue leach liquor is dosed with hydrated lime slurry, increasing the pH and decreasing the solubility of impurity metal salts, which precipitate and are filtered out. Lime addition in the pilot plant was controlled to maintain the pH of the slurry at 10.

During the piloting run, the neutralised and filtered gangue leach liquor was shown to have assays for Fe, Mg and Mn of below 5 mg/L and below 6 g/L for Sr. Lime consumption appeared to level off at approximately 17 kg $Ca(OH)_2/m^3$ of feed solution.

13.2.5.4 Hydrochloric Acid Regeneration

The optimal regeneration of hydrochloric acid is imperative to the performance of the gangue and rare earth leaches and to the OPEX of the project. Acid regeneration must be operated such that acid is not lost to the gypsum filter cake but is also of high enough concentration and purity to be used in the leaches. Sulphuric acid is added stoichiometrically to ensure sufficient acid production for the gangue and rare earth leaches. Calcium chloride is added to minimise the residual calcium and sulphate in solution by precipitating the maximum amount of gypsum.

The pilot plant data showed that a combined liquor (filtrate and wash) acid concentration of 14 wt% HCl to 16 wt% HCl could be achieved. This is a good result, albeit a slight deviation from the target. This shows that regenerating acid is effective, and a higher concentration than the design concentration could potentially be produced which could be decreased by dilution, the preferred alternative to evaporation for an acid solution of too low concentration. Residual calcium in the regenerated acid stabilised at below 5 g/L and was trending downward by the end of the piloting run.

13.2.5.5 Caustic Conversion

Gangue leach residue is contacted with concentrated NaOH solution at a high temperature in order to convert rare earth fluorides and phosphates to hydroxides that are amenable to leaching with hydrochloric acid in the downstream rare earth leach. Hot caustic solution resulting from the caustic conversion is diluted with hot water to prevent the precipitation of sodium salts before filtration as entrained sodium salts in the conversion cake are deleterious to cerium oxidation and rare earth leach. Precipitation of sodium salts after conversion also removes sodium from the NaOH regeneration circuit, leading to increased fresh NaOH requirement. The performance of the caustic conversion and dilution stage is measured by the rare earth extraction in the rare earth leach.

With synthetically regenerated acid in the rare earth leach, extractions of neodymium appeared stable at approximately 90 %, but with the switch to acid regenerated from the gangue leach pilot liquor, the recoveries decreased. This is an area for optimisation, as ANSTO has reported that the mechanism for decreased extraction is not well understood. The decrease in neodymium extraction also coincided with the recycling of regenerated NaOH to the caustic conversion process, which may also be responsible for the decrease in Nd recovery in the rare earth leach, as it is suggested that less pure NaOH might not offer optimal conversion of the rare earth minerals in caustic conversion.

13.2.5.6 Caustic Conversion Repulp Wash

To aid in the water balance and maximise washing of the caustic conversion residue, the conversion residue is repulped with overflow solution and filtrate from the final repulp wash in a countercurrent wash circuit. The conversion residue is repulped and filtered twice: first with overflow solution from the subsequent repulp stage, thickened and filtered, and then repulped a second time with hot wash water, at which time air is sparged through the slurry. The air oxidises cerium to an optimal degree for rejection during the rare earth leach. As with caustic conversion, the performance of the cerium oxidation is measured by cerium extraction in the rare earth leach.

13.2.5.7 Rare Earth Leach

The rare earth leach is more acidic than the gangue leach, with the goal of dissolving rare earth minerals that are naturally amenable to leaching, and also those that have been converted in the caustic conversion process. The pH is held at 2 under ambient temperature. During the test work, a sulphuric acid leach was considered and tested but rejected as an option because additional downstream processing was required to achieve the same rare earth recoveries as the HCl process.

Using synthetic sodium hydroxide solution versus plant-recycled sodium hydroxide solution in the caustic conversion appeared to have a significant impact on the extraction of rare earth elements in the leach. This has been identified as an area that can be optimised.

13.2.5.8 Caustic Evaporation

Diluted caustic conversion liquor is fed to an evaporator to increase the concentration of sodium hydroxide from approximately 14 wt% to 33 wt% NaOH. In the full-scale plant, a multiple-effect evaporator plant run on saturated steam with mechanical vapour recompression has been costed. On the pilot plant, two pan boilers were used, alternating every 8 h. The solution was heated up in batch mode. The feed and discharge NaOH concentrations were monitored by titration. After evaporation, the solution was cooled down to drive the precipitation of sodium fluoride and sodium carbonate salts from the available fluoride and carbonate in solution. The residue was filtered and treated in a causticisation circuit to recover the sodium and regenerated sodium hydroxide.

The pilot plant data showed successful evaporation of moisture to reach > 33 wt% NaOH in solution and produce a hot solution with 1 wt% to 1.5 wt% dissolved Na_2CO_3. After cooling and filtration, approximately 90 % of the sodium carbonate was rejected from the solution, as well as > 90 % of the fluoride and sulphur, indicating the formation of sulphide salts as well.

13.2.5.9 Causticisation

Solids precipitated in caustic evaporation were digested with water and contacted with hydrated lime slurry to produce calcium salts and NaOH. The precipitated solids were filtered and washed before being discarded as waste, and the resulting filtrate and wash liquor were returned to the caustic evaporator. Water balance in the caustic circuit is critical, as any excess water will inevitably end up in the evaporator and consume large amounts of energy to be evaporated. Bench-scale test work indicated that the NaOH, F and Na_2CO_3 targets in the filtrate should be approximately 14 wt%, 5 wt% and 1.5 g/L, respectively.

During the pilot run, concentrations of sodium hydroxide, sodium carbonate and fluoride were erratic but appeared to stabilise at slightly below-target values. This is advantageous from an impurity perspective but means that the evaporator will consume more energy due to the lower NaOH than the design value. This is an area that can be optimised in conjunction with the rare earth leach to improve rare earth recoveries. Causticisation removed > 90 % of the fluoride, but struggled to reach the 70 % target for Na_2CO_3 removal, achieving only approximately 30 %.

13.2.5.10 Rare Earth Solution Purification

Uranium and thorium, present in the ore, follow the rare earth elements to the rare earth leach liquor, and must be removed to prevent them from being concentrated in the final product. Bench-scale and pilot-scale test work has been completed on the process, and a process design has been developed. Preliminary testing indicated a potential process for removing radium and other metals from the rare earth leach liquor. Radium is removed by adding barium chloride and sulphuric acid or calcium sulphate as a source of sulphate. Radium precipitates in the matrix of barium sulphate and can be removed.

Liquor from the radium removal tests still contained lead and zinc, and the addition of NaOH to slightly increase the pH to 4.7, along with the addition of 0.1 g Na_2S/L feed, precipitated > 59 % of the lead and > 91 % of the zinc still present in the solution.

Uranium was not precipitated with radium or lead and zinc, and must be removed from the solution with an ion-exchange process. As part of the DFS, solution properties were conveyed to the supplier of ion-exchange plants, and an ion-exchange plant was costed and included in the current design.

13.2.5.11 Rare Earth Carbonate Precipitation

ANSTO completed bench-scale test work on the precipitation of a rare earth carbonate product by the addition of ammonium bicarbonate to the purified PLS stream, increasing the pH to 6.7. Batch tests were completed to establish processing parameters. In the batch tests, 100 g/L NH_4HCO_3 solution was added to the PLS to incrementally increase the pH. Test work indicated that > 99 % of the rare earths could be precipitated with excellent rejection of Mn, Sr, Ca and Ba. This was used as the basis of design for the precipitation of the rare earth carbonate product, which is a straight-forward process if a pure enough feed solution is used.

Upon completion of bench-scale test work, four rare earth carbonate precipitation piloting runs were completed using ammonium bicarbonate. The precipitation of rare earths was greater than 99 %. Washed rare earth carbonate filter cake samples contained an average of 46.6 % w/w TRE+Y.

13.2.6 Solid-Liquid Separation Test Work

13.2.6.1 Concentrator Plant

During the flotation piloting, Metso-Outotec was commissioned to perform thickening and filtration test work on the flotation concentrate, and thickening test work on the flotation tails.

Outotec used a Larox® membrane filter press (MFP) to determine the filtration behaviour of the flotation concentrate.

13.2.6.2 Hydrometallurgical Thickening Test Work

ANSTO commissioned Fremantle Metallurgy to perform thickening test work on the hydrometallurgical slurry samples in May 2021. Cylinder settling tests were performed to determine the optimal thickening conditions, followed by dynamic thickening tests to obtain the data for equipment sizing.

13.2.6.3 Hydrometallurgical Filtration Test Work

ANSTO commissioned GBL Process Pty Ltd to perform filtration test work on the thickened samples supplied by Fremantle Metallurgy. The following eight slurries were tested (shown with their abbreviations as used in the report):

- Gangue Leach Slurry (GLS, G)
- Gangue Leach Neutralisation Slurry (GLN, N)
- Acid Regeneration Slurry (ARS, A) – Vacuum filtration was deemed to be more appropriate, and a vacuum belt filter was sized and costed.
- Caustic Conversion Slurry (CC, CC)
- Caustic Conversion Repulp Wash 1 and 2 Slurries (CCRW1/2, CR1,2)
- Evaporation Slurry (ES, E)
- Causticisation Slurry (CS, C)
- Rare Earth Leach Slurry (RE, RE)

13.2.6.4 Tailings Geotechnical Test Work

SENET contacted Western Geological Laboratory Services (WGLS) in February 2021 with a scope of work to geotechnically characterise the flotation and hydrometallurgical plant tailings streams. The purpose of this test work was to assist in the design of the TSF. The original scope of testing, as was received from the TSF contractor (Epoch), is given below:

- Drained and undrained settlement tests – at a tailings slurry solids content of 55 % w/w
- Particle size distribution
- Atterberg limits
- Specific gravity determinations
- Consolidation tests with oedometer
- Consolidated undrained triaxial tests, with pore water pressure measurements
- Flexible wall triaxial permeability tests

During the operation of the flotation and hydrometallurgical pilot plants in 2021, samples were generated, and the scope was further refined to include more detailed rheology test work for the purposes of finalising the design of the pumping and distribution system in the TSF. Correspondence between WGLS and Epoch amended the initial quotation and scope of work to include additional viscosity and yield stress characteristics as a function of slurry solids content, and also shear stress versus shear rate for a range of slurry solids concentrations. For the purposes of the additional rheology test work, a combined tailings sample was dried and repulped to three different solids concentrations: 45 % w/w, 55 % w/w and 65 % w/w.

Samples were provided to WGLS by ALS (flotation tails) and ANSTO (hydrometallurgical plant tails). These samples were mixed in the approximate mass ratios that they were produced in during piloting and predicted by the SENET mass balance.

The combined processing plant tailings stream comprised primarily flotation tails, mixed with relatively smaller quantities of hydrometallurgical plant impurity solids and residues. Samples used in the mixing and generation of a combined tails sample were the following:

- Gangue leach neutralisation precipitate

- Causticisation residue
- Rare earth leach residue
- Flotation tails

The other hydrometallurgical waste streams were not deemed to have a large enough relative production rate to influence the characteristics of the combined tailings slurry to a significant degree; therefore, they were excluded from the combined sample.

The combined sample was found to exhibit shear-thinning behaviour within the range of solids concentrations tested. The complete set of test work results can be found in the WGLS Tailings Geotechnical Characterisation Study.

13.2.6.5 Tailings Geochemical Characterisation

SENET contacted SGS in April 2021 to perform geochemical analyses on separate and combined waste samples from the Songwe Hill processing plant. The environmental consultant provided the desired outputs from the test campaign for each sample where applicable – some samples were in liquor form already. The outputs provided by the environmental consultant are given in Table 13.2.

Table 13.2: Geochemical Testing Parameters

General		
Paste pH		
ABA (Acid/Base Accounting)		
NAG (Net Acid Generation)		
Sulphur specification		
Mineral composition		
Reagent (Distilled Water) Extraction	**Total Element Analysis Using Aqua Regia (Total Digestion)**	**SPLP Leach Testing**
pH	pH	pH
EC (Electrical Conductivity)	EC	EC
Alkalinity	Alkalinity	Alkalinity
Sulphate	Sulphate	Sulphate
Chloride	Chloride	Chloride
Fluoride	Fluoride	Fluoride
Nitrate	Nitrate	Nitrate
ICP-OES metal scan	ICP-OES metal scan	ICP-OES metal scan

It became relevant to determine whether the Type 2 material should be classified as hazardous or non-hazardous in terms of acid generating capacity and radioactivity, and a sample of Type 2 material was received by SGS in Perth sent by KYSPYmet, which was still busy testing flotation regimes on the Type 2 material. The Type 2 material was tested, and the results were sent to the environmental consultant to interpret. The Type 2 material exhibited no hazardous leaching or geochemical behaviour and was classified as non-hazardous. Testing was also performed on the Type 1 ore, which led to the same conclusion. This indicated that both Type 1 and Type 2 material could be stockpiled without the need to make provision for hazardous leaching or weathering products.

After waste samples had been generated from the hydrometallurgical piloting campaigns, test work commenced at SGS. In April 2022, SGS started to report the first geochemical results. The following samples were tested:

- Gangue neutralisation precipitate
- Causticisation residue
- Rare earth leach residue
- Rare earth carbonate precipitation barren liquor
- Combined hydrometallurgical purification residue
- Combined front- and back-end hydrometallurgical tails
- Type 2 material sample
- Type 1 ore sample

The complete test work results and individual test work reports are provided in the SGS Tailings Geochemical Characterisation Report.

14 MINERAL RESOURCE ESTIMATES

Mr J.C. Witley (the QP for this Mineral Resource estimate) of MSA, an independent consulting company, visited the Songwe Hill project site in the periods 25 to 28 July 2018 and 24 to 26 September 2018. During the site visit, the drill cores were examined and the locations of the drillhole collars observed. Handheld XRF readings were taken to verify the magnitude of the REE grades in the cores.

The assay results received from the primary laboratory (Intertek Australia) were subjected to a QA/QC programme, and the assays were confirmed by check assays at a second laboratory. The original certificates were cross-checked against the drillhole database by MSA.

The QP considers that the exploration work conducted by Mkango was carried out using appropriate techniques for the style of mineralisation at Songwe Hill and that the resulting database is suitable for Mineral Resource estimation.

The Mineral Resource estimate was based on REE, thorium, uranium, iron, manganese, aluminium, silica, potassium and density measurements obtained from the cores of 129 diamond drillholes, which were completed in three phases of drilling (2011, 2012 and 2018).

For the purposes of Mineral Resource definition, three lithological domains were identified in the Songwe Hill deposit: a carbonatite domain, a fenite domain, and a “mixed” domain consisting of breccia and/or finely intermixed carbonatite and fenite. The carbonatite domain tends to contain the highest concentration of REE mineralisation with the lowest concentration being in the fenite, which grades to barren in places. A 15 % calcium threshold was used to distinguish between carbonatite and non-carbonatite rocks.

An indicator approach was used to estimate the proportion of carbonatite dominant to fenite dominant rocks in each of the 20 mX by 20 mY by 5 mZ cells in the block model. Ordinary kriging was used to estimate the attributes into the block model separately for carbonatite and non-carbonatite sample composites. The final grade assigned to the block model was proportioned for the two lithological domains using the proportions estimated by the indicator model.

The Mineral Resource forms an irregular, roughly circular surface expression with a diameter of approximately 450 m. The maximum depth of the Inferred Mineral Resource is 390 m below surface, with the Measured and Indicated Mineral Resource occurring to a maximum depth of 200 m, paralleling the topographic surface of the hill and surrounding plain. The majority of the Measured and Indicated Mineral Resource occurs to a depth of approximately 160 m. Extrapolation in the Inferred area was limited to a maximum of 50 m from the drilling area.

The Mineral Resource estimate was completed by Mr Daniel Kock (BSc Hons) under the supervision of Mr J.C. Witley (BSc Hons, MSc (Eng.)).

The Mineral Resource was estimated using the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Best Practice Guidelines (2003) and is reported in accordance with the 2014 CIM Definition Standards, which have been incorporated by reference into National Instrument 43-101 – *Standards of Disclosure for Mineral Projects* (NI 43-101). The Mineral

Resource is classified into the Measured, Indicated and Inferred categories as shown in Table 14.1.

The Mineral Resource is reported at a base-case TREO grade of 1.00 %, which the QP considers will satisfy reasonable prospects for eventual economic extraction.

Table 14.1: Songwe Hill Mineral Resource at 1.00 % TREO Cut-Off Grade, 23 January 2019

Category	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)	Th (ppm)	U (ppm)
Measured	8.81	1.50	131.9	343	13
Indicated	12.22	1.35	165.5	342	12
Total M&I	**21.03**	**1.41**	**297.4**	**339**	**13**
Inferred	27.54	1.33	366.2	302	12
NOTES: 1. All tabulated data has been rounded, and as a result minor computational errors may occur. 2. Mineral Resources, which are not Mineral Reserves, have no demonstrated economic viability.					
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3					

The Mineral Resource is tabulated using a number of cut-off grades as shown in Table 14.2 for the Measured and Indicated Mineral Resource and in Table 14.3 for the Inferred Mineral Resource. Table 14.4 shows the grades of the individual REEs for each class and domain.

Table 14.2: Songwe Hill, Measured and Indicated Mineral Resources Grade and Tonnage, 23 January 2019

Cut-Off Grade (TREO %)	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
0.50	37.64	1.13	425.67
0.75	30.45	1.25	379.90
1.00	**21.03**	**1.41**	**297.40**
1.25	12.44	1.62	201.20
1.50	6.80	1.83	124.08
1.75	3.27	2.05	2.05
2.00	1.12	2.35	26.32
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

Table 14.3: Songwe Hill, Inferred Mineral Resources Grade and Tonnage, 23 January 2019

Cut-Off Grade (TREO %)	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
0.50	59.65	1.02	608.19
0.75	43.74	1.16	507.12
1.00	**27.54**	**1.33**	**366.15**
1.25	14.35	1.52	218.44
1.50	5.92	1.75	103.41
1.75	2.23	2.00	44.44
2.00	0.92	2.21	20.28
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

Table 14.4: Songwe Hill, Individual REO Measured, Indicated and Inferred Mineral Resources above 1.00 % TREO Cut-Off Grade within the Different Domains, 23 January 2019

Domain	Class	Tonnage (Mt)	TREO (ppm)	La_2O_3 (ppm)	CeO_2 (ppm)	Pr_6O_{11} (ppm)	Nd_2O_3 (ppm)	Sm_2O_3 (ppm)	Eu_2O_3 (ppm)	Gd_2O_3 (ppm)	Tb_4O_7 (ppm)	Dy_2O_3 (ppm)	Ho_2O_3 (ppm)	Er_2O_3 (ppm)	Tm_2O_3 (ppm)	Yb_2O_3 (ppm)	Lu_2O_3 (ppm)	Y_2O_3 (ppm)	Th (ppm)	U (ppm)
Carbonatite	Measured	3.31	16,192	3,814	7,340	779	2,613	374	102	241	30	138	22	53	7	39	5	634	340	12
Carbonatite	Indicated	2.85	14,491	3,556	6,615	678	2,226	323	88	211	26	120	19	46	6	33	4	539	338	11
Mixed	Measured	4.75	14,398	3,471	6,530	684	2,282	328	90	211	26	119	19	45	6	33	4	549	332	13
Mixed	Indicated	6.97	13,432	3,375	6,150	626	2,051	297	80	189	22	101	16	38	5	27	4	451	340	13
Fenite	Measured	0.76	13,270	3,253	6,053	631	2,103	305	82	190	22	99	15	36	5	27	4	445	326	13
Fenite	Indicated	2.40	12,701	3,129	5,824	605	2,004	285	75	175	20	90	14	33	4	24	3	414	351	13
Total	**Measured**	**8.81**	**14,975**	**3,581**	**6,793**	**715**	**2,391**	**343**	**94**	**221**	**27**	**124**	**20**	**47**	**6**	**35**	**5**	**572**	**335**	**13**
Total	**Indicated**	**12.22**	**13,535**	**3,369**	**6,195**	**634**	**2,083**	**301**	**81**	**191**	**23**	**103**	**16**	**39**	**5**	**28**	**4**	**465**	**342**	**12**
Total	**M&I**	**21.03**	**14,138**	**3,458**	**6,446**	**668**	**2,212**	**319**	**86**	**204**	**25**	**112**	**18**	**42**	**5**	**31**	**4**	**509**	**339**	**13**
Carbonatite	Inferred	8.16	14,625	3,384	6,619	709	2,400	348	95	221	27	123	20	49	6	38	5	580	314	11
Mixed	Inferred	13.23	12,909	3,128	5,904	616	2,053	296	79	183	22	97	15	37	5	28	4	443	303	12
Fenite	Inferred	6.14	12,366	3,062	5,740	594	1,957	270	70	156	18	77	12	29	4	22	3	354	282	13
Total	**Inferred**	**27.54**	**13,296**	**3,189**	**6,079**	**639**	**2,134**	**306**	**82**	**188**	**22**	**100**	**16**	**39**	**5**	**29**	**4**	**464**	**302**	**12**

NOTES:
1. All tabulated data has been rounded, and as a result minor computational errors may occur.
2. Mineral Resources, which are not Mineral Reserves, have no demonstrated economic viability.

TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3

15 MINERAL RESERVE ESTIMATES

15.1 MINING LIMITS

Mining at Songwe Hill will be by open-pit mining methods. The orebody outcrops on surface and is well suited to open-pit mining. The mining design will consider all the ore types, and the limit of the mine design will be determined by a pit optimisation exercise.

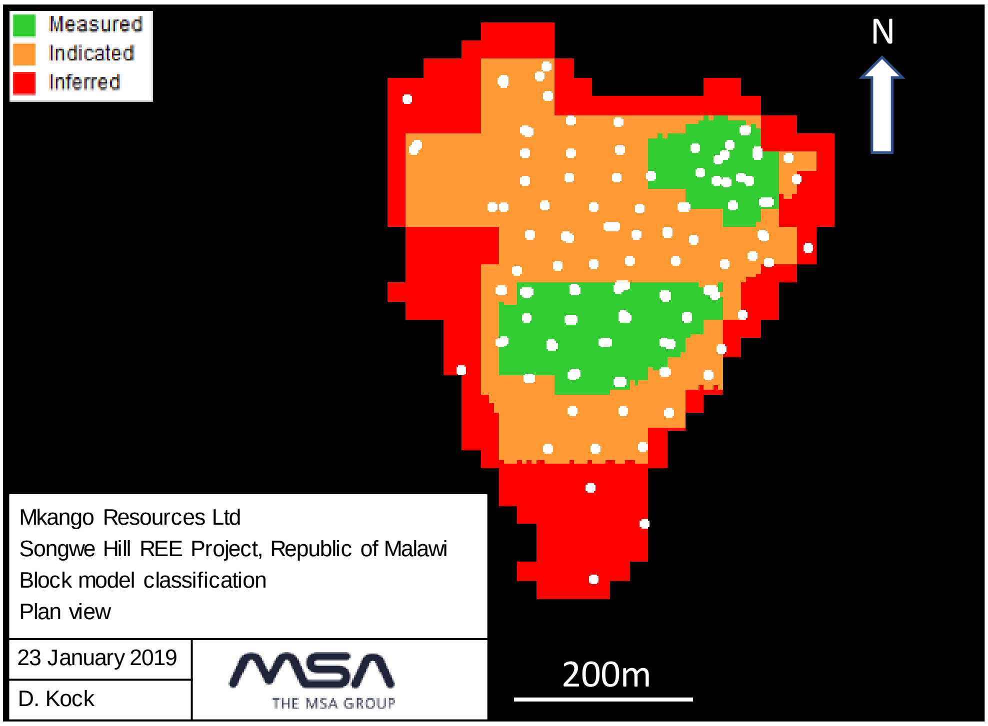
15.2 GEOLOGICAL DATA FOR MINE DESIGN

The geological data provided to Bara by MSA, for purposes of mine design, included a geological block model with the parameters given in Table 15.1.

Table 15.1: Block Model Prototype Parameters for Songwe Hill

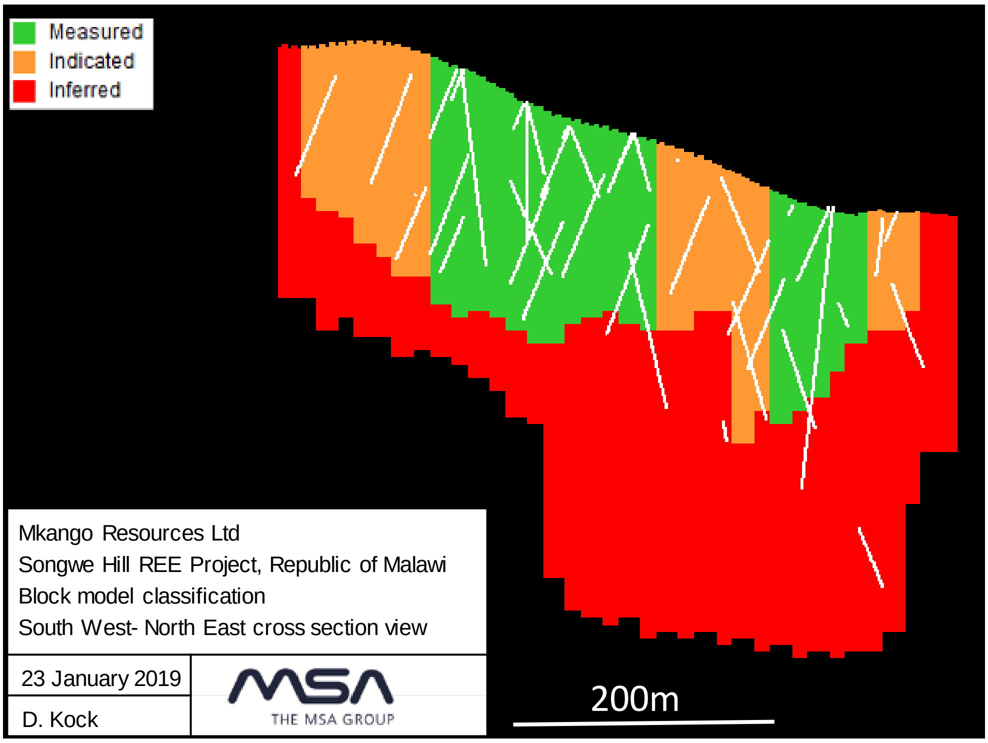
Block Size (m)			Model Origin			Rotation Angle			Rotation Axis			Number of Cells		
X	Y	Z	X	Y	Z	1	2	3	1	2	3	X	Y	Z
20	20	5	801530	8263120	300	0	0	0	-	-	-	30	35	150

Figure 15.1 and Figure 15.2 show a plan and cross section through the model, respectively, indicating the ore by resource class. The block model file used by Bara in the mine design is a Datamine format block model file entitled “mkango_mod_fin2”.



Source: MSA (2019)

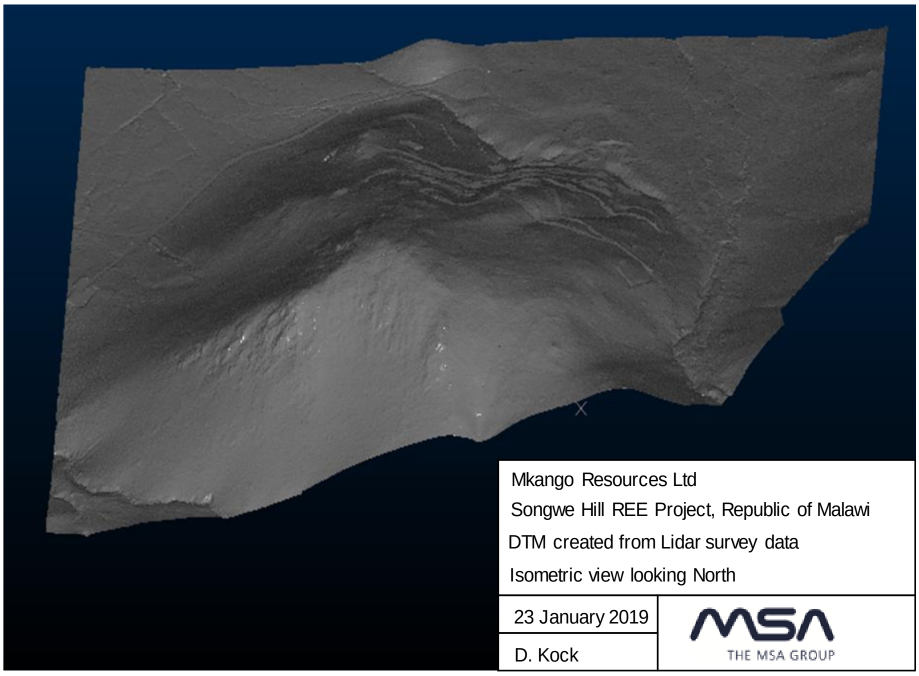
Figure 15.1: Mineral Resource Classification, Songwe Hill – Plan View from Top



Source: MSA (2019)

Figure 15.2: Mineral Resource Classification, Songwe Hill – Northeast Section View

Mkango completed a LiDAR survey, which provides an accurate model of the topography. The processed data was provided by Mkango as a DTM (see Figure 15.3).



Source: MSA (2019)

Figure 15.3: Isometric View of the DTM Created from the LiDAR Survey Data – View Is Approximately to the North

15.3 PIT OPTIMISATION

The pit optimisation objective was to determine the best case achievable to feed the plant at the highest grade of total rare earth oxide per cent (TREO_PCT) possible for the LOO based on the parameters described below. The initial optimisation was run with all the Type 1 ore considered as run of mine (ROM).

15.3.1 Material Definition

The geological resource model was separated into various material types to run the pit optimisation. These fields were class, ore type, and TREO_PCT grade cut-off.

The class has three categories:

1 = Measured
2 = Indicated
3 = Inferred

The ore type is defined by the ratio between manganese and magnesium (Mn:Mg):

- Type 1 ore is all the material with a ratio of Mn:Mg equal to or below 3.5
- Type 2 material is all the material with a ratio of Mn:Mg above 3.5

The grade cut-off was determined as follows: all the material with a TREO_PCT above 0.6 % was deemed to be ore. The ore was then split between high-grade and medium-grade material (grade bins):

- High-grade – TREO_PCT equal to and greater than 1.2 % (GRDTYPE=1)
- Medium-grade – TREO_PCT less than 1.2 % but greater than and equal to 0.6 % (GRDTYPE=2)
- Low grade – TREO_PCT less than 0.6 % (GRDTYPE=0)
- Waste – Host rock

In order to identify and report on the various material types, the material types were coded using a combination of numbers representing the ore type, class and grade bin.

15.3.1.1 Block Model Data

Table 15.2 summarises the block model statistics by material type. Figure 15.4 shows a grade tonnage curve of the Songwe Hill resource.

Table 15.2: Block Model Statistics by Material Type

CLASS	OTYPE	GRDTYPE	Volume	Density	Mass	TREO_PCT	Al_PCT	Ca_PCT	Fe_PCT	Mg_PCT	Mn_PCT	Mn:Mg Ratio
Total Model												
All	All	All	40,904,712	2.71	110,987,088	1.00	4.17	14.42	10.68	0.79	1.66	3.63
Class Split												
3	All	All	24,945,189	2.74	68,237,995	0.96	4.25	13.77	10.71	0.89	1.66	3.41
2	All	All	10,607,597	2.65	28,155,308	1.00	4.47	14.45	10.45	0.59	1.64	4.43
1	All	All	5,351,926	2.73	14,593,785	1.21	3.23	17.38	10.94	0.73	1.69	3.08
Class and Ore Type Split												
3	2	All	8,067,947	2.55	20,570,860	0.84	5.27	11.83	12.17	0.28	1.94	7.79
3	1	GRDTYPE	16,877,242	2.82	47,667,135	1.02	3.81	14.61	10.08	1.15	1.54	1.53
2	2	All	5,139,396	2.60	13,347,329	1.07	4.34	15.03	11.41	0.29	1.87	7.25
2	1	GRDTYPE	5,468,201	2.71	14,807,978	0.93	4.58	13.92	9.59	0.87	1.42	1.89
1	1	All	3,678,389	2.76	10,154,533	1.20	3.18	17.50	10.32	0.89	1.58	2.02
1	2	GRDTYPE	1,673,537	2.65	4,439,252	1.24	3.33	17.10	12.35	0.38	1.92	5.51
Class, Ore Type and Grade Cut-Off												
1	1	0	369,090	2.70	998,253	0.46	6.56	9.30	7.68	0.82	0.99	1.69
1	1	1	1,653,066	2.81	4,641,178	1.66	1.87	20.42	11.32	0.98	1.85	2.12
1	1	2	1,656,233	2.73	4,515,102	0.90	3.77	16.32	9.87	0.81	1.44	2.00
1	2	0	90,940	2.57	233,648	0.47	7.54	7.12	7.67	0.25	1.19	4.99
1	2	1	813,320	2.69	2,183,943	1.58	2.38	19.08	13.57	0.41	2.12	5.58
1	2	2	769,277	2.63	2,021,662	0.96	3.87	16.12	11.58	0.35	1.78	5.49
2	1	0	1,427,795	2.61	3,730,291	0.46	6.75	9.20	7.66	0.71	0.98	1.74
2	1	1	1,305,016	2.77	3,614,446	1.53	2.90	16.94	11.37	1.02	1.87	2.04
2	1	2	2,735,390	2.73	7,463,242	0.88	4.30	14.82	9.69	0.87	1.43	1.89

CLASS	OTYPE	GRDTYPE	Volume	Density	Mass	TREO_PCT	Al_PCT	Ca_PCT	Fe_PCT	Mg_PCT	Mn_PCT	Mn:Mg Ratio
2	2	0	423,957	2.55	1,082,623	0.49	7.16	8.23	8.38	0.24	1.24	5.60
2	2	1	1,533,684	2.63	4,027,574	1.52	3.03	17.71	13.23	0.34	2.24	7.59
2	2	2	3,181,754	2.59	8,237,132	0.92	4.62	14.61	10.92	0.27	1.77	7.30
3	1	0	2,919,655	2.61	7,620,157	0.45	6.71	8.59	7.70	0.76	1.01	1.68
3	1	1	5,186,030	2.94	15,226,571	1.49	2.26	17.92	11.09	1.33	1.78	1.43
3	1	2	8,771,557	2.83	24,820,407	0.90	3.86	14.42	10.19	1.16	1.55	1.54
3	2	0	1,563,349	2.49	3,900,408	0.50	7.04	7.44	10.38	0.26	1.51	6.16
3	2	1	807,521	2.61	2,105,307	1.44	3.55	15.29	13.96	0.32	2.40	9.06
3	2	2	5,697,077	2.56	14,565,145	0.85	5.04	12.51	12.39	0.28	1.98	8.04
Total			**40,904,712**	**2.71**	**110,987,088**	**1.00**	**4.17**	**14.42**	**10.68**	**0.79**	**1.66**	**3.63**

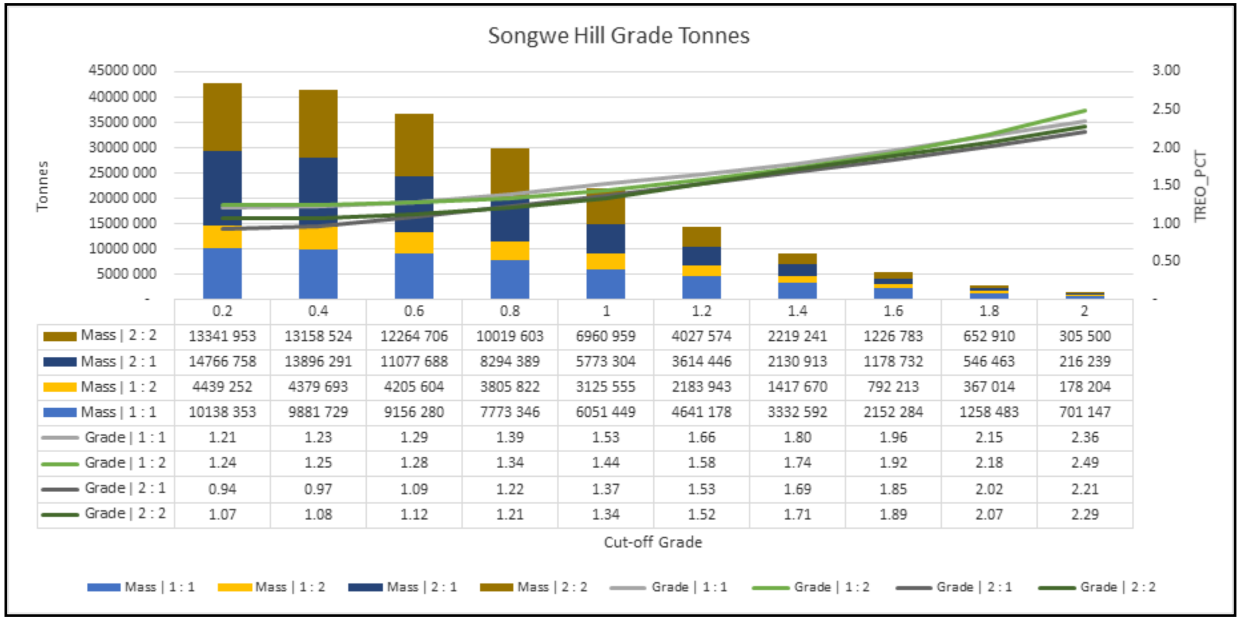


Figure 15.4: Grade Versus Tonnage Curve

15.3.2 Optimisation Parameters

A set of optimisation input parameters was prepared based on the data available at the time.

Mining costs were based on budget estimates obtained from a mining contractor. The processing cost was provided by SENET. The general and administrative costs were estimated by Bara.

The slope angles were based on the DFS geotechnical report.

Product prices and separation costs were provided by Mkango.

Table 15.3 shows the parameters used in the pit optimisation.

Table 15.3: Pit Optimisation Input Parameters

Item	Value	Unit	Comments/Source
Operating Cost			
Waste			
Mining Cost – Free Dig	2.51	US$/t mined	Mining contract submission (Digmin)
Mining Cost – Drill and Blast	3.53	US$/t mined	Mining contract submission (Digmin)
Ore			
Mining Cost – Free Dig	3.28	US$/t mined	Mining contract submission (Digmin)
Mining Cost – Drill and Blast	4.26	US$/t mined	Mining contract submission (Digmin)
Process Cost	106.65	US$/t milled	Provided by Senet
General and Administrative Cost	5.31	US$/t milled	Provided by Senet
Technical			
Slope Angles (Sector 1)	49	degrees	Geotechnical report
Slope Angles (Sector 2)	44	degrees	Geotechnical report
Slope Angles (Sectors 3 and 4)	40	degrees	Geotechnical report
Slope Angles (Sector 5)	43	degrees	Geotechnical report
Slope Angles (Sector 6)	46	degrees	Geotechnical report
Slope Angles (Sector 7)	36	degrees	Geotechnical report
Mining Dilution	5	%	Bara
Mining Loss	5	%	Bara
Bench Height	10	m	Bara
Metallurgical Recovery	44.5	%	Based on all metals, recovery to carbonate
To Carbonate	39.4	%	Recovery to carbonate
To Saleable Metal	98.0	%	Separation recovery from carbonate
Ore Production Rate	83,333	kt/month	Per month – **ORE** only, Mkango to advise
Ore Production Rate	1,000,000	kt/a	

Item	Value	Unit	Comments/Source
Economic			
Royalties	5	%	Covered in basket price calculation
TREO Price (Basket Price)	34.2	US$/kg	Value in carbonate pre-discounts
Separation Costs	2,500	US$/t TREO in carbonate	Based on Mkango separation costs
Discount Factor to Use	7.3	%	Assumed

Only Type 1 Ore Measured and Indicated resources were considered for processing in the pit optimisation model. In this report, no processing of Type 2 material is considered. Type 2 material will be treated as waste in the pit optimisation and future financial modelling exercises, but it will be stockpiled separately so that it can be accessed for processing in future should a viable processing solution be developed.

Inferred resources were not considered for processing and report to the waste material bin.

The pit optimisation was undertaken using Deswik Pseudoflow®, a module of the Deswik® suite of mine design and scheduling software.

15.3.3 Results of Pit Optimisation

The results of the optimisation exercise are presented in Figure 15.5 and Table 15.4.

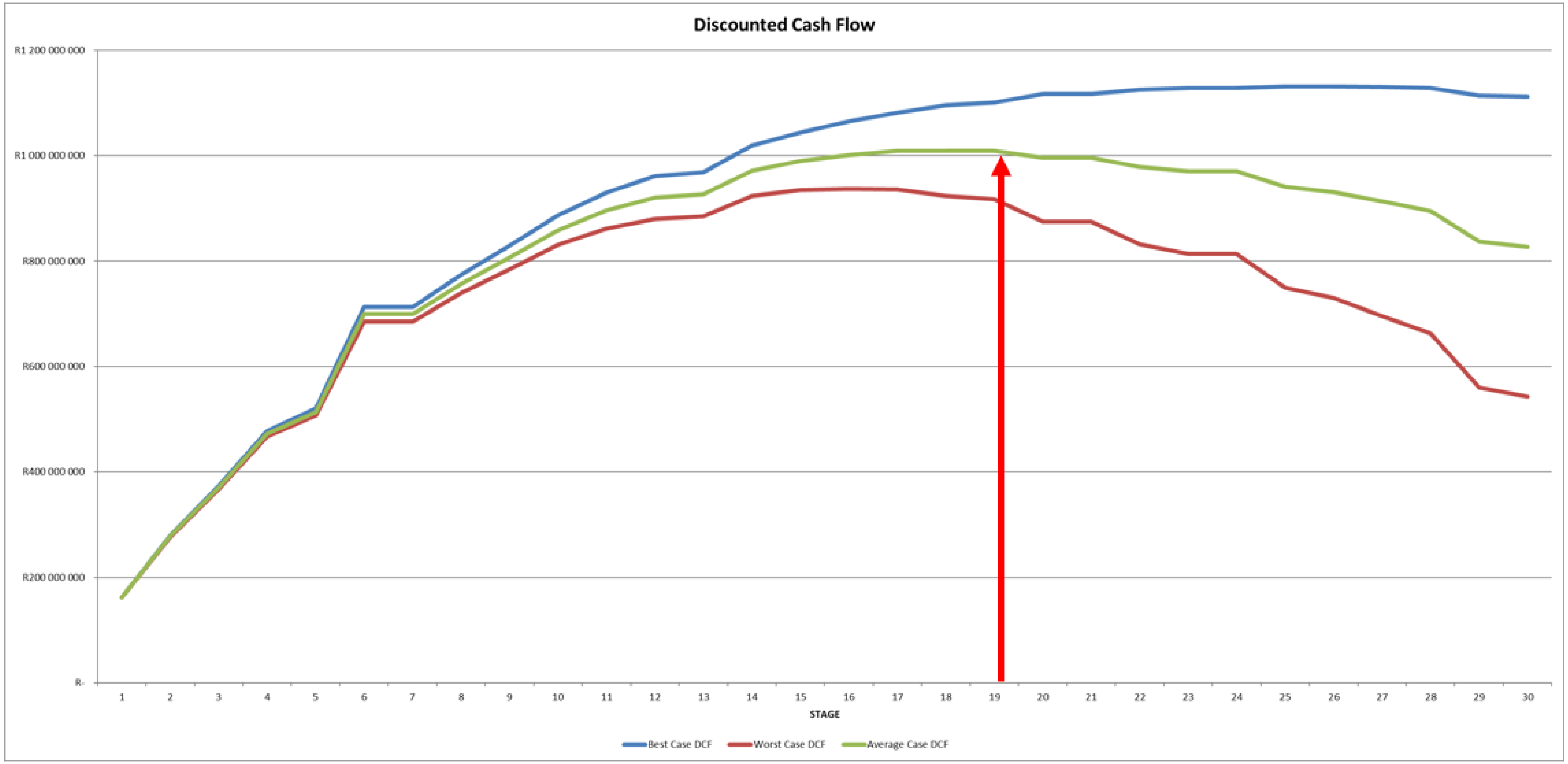


Figure 15.5: Discounted Cash Flow by Pit Shell

Based on the results presented in Figure 15.5, the optimum pit shell, where the net present value (NPV) is maximised, on the average case curve, is pit shell Number 19. The material contents and grade of Shell 19 are highlighted in Table 15.4.

Table 15.4: Material Contents of Pit Optimisation Shells

Stage	Total (t)	Waste (t)	Type 2 Material (t)	Type 1 Ore (t)
1	2,565,880	754,683	301,935	909,783
2	5,318,229	1,523,255	1,179,659	1,830,954
3	7,848,414	2,620,677	1,508,157	2,815,310
4	11,021,565	4,009,751	2,005,341	4,024,661
5	13,428,249	5,066,381	2,458,510	4,847,706
6	15,708,103	5,980,123	3,053,065	5,551,026
7	17,853,409	10,245,892	4,351,149	6,844,604
8	21,997,829	12,810,706	4,781,768	7,928,645
9	26,826,035	16,145,718	5,157,622	8,995,406
10	30,451,461	18,744,714	5,373,453	9,762,680
11	34,620,937	21,437,933	5,843,155	10,724,936
12	42,237,938	26,502,595	6,816,613	11,868,654
13	43,105,511	27,178,858	6,874,514	11,989,770
14	44,425,879	39,432,590	7,374,539	13,289,864
15	49,351,617	43,280,953	7,475,013	14,240,881
16	53,106,001	45,689,654	7,945,602	15,066,096
17	59,225,573	50,028,583	8,506,588	16,235,117
18	66,609,412	55,984,654	8,738,225	17,393,292
19	74,825,264	62,190,532	9,451,244	18,516,329
20	86,623,208	71,370,051	10,153,836	20,360,177
21	100,729,327	81,644,329	11,793,791	22,430,426
22	105,987,159	85,860,509	12,024,974	23,212,370
23	114,128,502	93,070,762	12,024,974	24,111,323
24	124,825,088	102,188,960	12,249,044	25,418,471
25	136,553,741	112,268,723	12,548,247	26,717,942
26	141,495,384	115,978,935	13,183,448	27,266,960

In order to maximise the NPV, while maintaining an acceptable LOO, a number of scenarios were tested applying the following:

- A cut-off grade varying from 0.6 % to 1.2 % TREO
- Varying cut-off grades over time

The scenarios given in Table 15.5 were tested.

Table 15.5: Cut-Off Grade Scenarios Tested

<table>
<tr><th>Cut-Off Grade Phase 1</th><th colspan="3">Period</th></tr>
<tr><td>0.6 % TREO</td><td colspan="3">LOO</td></tr>
<tr><td>0.8 % TREO</td><td colspan="3">LOO</td></tr>
<tr><td>1.0 % TREO</td><td colspan="3">LOO</td></tr>
<tr><td>1.2 % TREO</td><td colspan="3">LOO</td></tr>
<tr><td colspan="4">VARYING CUT-OFF GRADE</td></tr>
<tr><th>Cut-Off Grade Phase 1</th><th>Period</th><th>Cut-Off Grade Phase 2</th><th>Period</th></tr>
<tr><td rowspan="2">1.2 % TREO</td><td rowspan="2">5 years</td><td>0.6 % TREO</td><td rowspan="2">Remaining LOO</td></tr>
<tr><td>0.8 % TREO</td></tr>
</table>

A LOO of at least 15 years at a processing rate of 1.0 Mt/a was required by Mkango, provided that the schedule supported a viable financial result.

The results of the various scenarios tested are given in Table 15.6.

Table 15.6: Results of the Cut-Off Grade Scenarios Tested

Scenario	Cut-Off Grade	ROM Tonnes	ROM Grade (% TREO)	Waste Tonnes	Strip Ratio
1	0.60 %	18,213,194	1.15	35,320,013	1.94
2	0.80 %	14,246,194	1.27	34,003,657	2.39
3	1.00 %	11,341,066	1.39	42,506,076	3.75
4	1.20 %	7,850,222	1.53	38,183,838	4.86

The ore tonnes resulting from the 1.2 % and 1.0 % TREO cut-off grades were insufficient to support the required LOO at the targeted production rate of 1.0 Mt/a, so the pit optimisation was then rerun using the Type 1 ore Measured and Indicated cut-off grades of 0.6 % and 0.8 %, respectively. These options resulted in a lower grade to the plant, which proved unviable.

Options considering a varying cut-off grade over time were then considered. A higher cut-off grade was applied in the earlier years of the LOO, with the aim of maintaining a higher grade during the project payback period and then reducing the cut-off grade later in the LOO. Lower-grade ore, below the Stage 1 cut-off grade, mined in the earlier years will be stockpiled and processed later in the LOO. Table 15.7 shows the results for the options considered using a varying cut-off grade.

Table 15.7: Varying Cut-Off Grade Scenarios Tested

Scenario	Cut-Off Grade	ROM Tonnes	ROM Grade (% TREO)	Waste Tonnes	Strip Ratio
5	1.2 %, 0.6 %	18,261,011	1.22	46,236,506	2.53
6	1.2 %, 0.8 %	13,699,377	1.34	42,907,143	3.13

Option 5, a Phase 1 cut-off grade of 1.2 % TREO for a period of approximately five years, followed by a cut-off grade of 0.6 % thereafter, was selected as the preferred option, based on an acceptable early grade resulting in early cash flow and payback of capital and a suitably long and sustained LOO.

The combination of the two cut-off grades resulted in a two-phased pit. The contents of nested pit shells within each phase of the pit are given in Table 15.8.

Table 15.8: Results of Two-Phased Pit Optimisation

Stage	Total Tonnes	Waste Tonnes	SR	MAT2 Tonnes	MAT3 Tonnes	MAT4 Tonnes	MAT1 Tonnes	MAT1 ROM Tonnes	TREO_DIL MAT1	Mn_DIL MAT1	Mg_DIL MAT1	Fe_DIL MAT1	Ca_DIL MAT1	MngRT_DIL MAT1	MAT2 ROM Tonnes	TREO_DIL MAT2	Mn_DIL MAT2	Mg_DIL MAT2	Fe_DIL MAT2	Ca_DIL MAT2	Mn:Mg_DIL MAT2
Phase 1: 1.2 % Cut-off grade – Revenue factor: 0.00 to 0.49																					
1	1,481,412	873,669	1.95	61,031	99,522	-	447,190	446,072	2.00	1.86	1.21	9.86	20.62	1.54	60,878	1.60	1.74	0.35	11.85	15.25	4.97
2	2,743,002	1,370,944	1.90	503,235	146,120	-	722,703	720,896	1.60	1.83	0.91	10.59	18.73	2.02	501,977	1.62	2.12	0.37	13.25	16.57	5.80
3	4,607,969	2,353,249	1.77	820,100	102,269	-	1,332,351	1,329,021	1.49	1.76	0.80	10.88	17.64	2.20	818,050	1.60	2.15	0.41	13.28	16.77	5.20
4	2,920,728	1,472,588	2.18	306,925	466,929	13	674,274	672,588	1.54	1.79	0.93	10.52	17.64	1.92	306,157	1.50	2.16	0.40	13.37	17.39	5.40
5	5,556,400	3,188,498	2.69	851,049	318,514	14,647	1,183,692	1,180,733	1.49	1.78	0.93	11.12	18.17	1.92	848,922	1.42	2.09	0.38	14.09	18.09	5.47
6	5,427,302	3,298,644	3.16	570,611	482,054	30,744	1,045,249	1,042,636	1.50	1.75	1.01	11.04	16.98	1.74	569,185	1.46	2.07	0.37	13.99	16.85	5.55
Total	**22,736,812**	**12,557,592**	**2.32**	**3,112,951**	**1,615,407**	**45,404**	**5,405,458**	**5,391,945**	**1.56**	**1.78**	**0.93**	**10.79**	**18.02**	**1.93**	**3,105,169**	**1.52**	**2.11**	**0.39**	**13.61**	**17.15**	**5.45**
Phase 2: 0.6 % Cut-off grade – Revenue factor: 0.50 to 0.98																					
7	2,416,045	533,441	0	638,349	83,478	28,463	1,132,314	1,129,484	1.19	1.56	0.86	10.29	16.21	1.81	636,754	1.24	2.09	0.37	14.94	15.12	5.65
8	2,032,531	437,303	1	500,714	176,442	56,490	861,581	859,427	1.17	1.54	0.87	9.92	16.15	1.77	499,462	1.18	1.88	0.35	12.19	16.11	5.44
9	318,033	51,442	0	26,190	39,324	8,418	192,659	192,177	1.14	1.39	0.98	9.04	15.53	1.42	26,125	1.07	1.81	0.31	11.91	15.41	5.79
10	4,243,248	735,439	0	1,536,451	155,868	12,965	1,802,524	1,798,018	1.13	1.52	0.84	10.12	15.69	1.82	1,532,610	1.07	1.71	0.30	10.68	14.74	5.74
11	2,080,171	616,263	1	255,346	256,461	98,381	853,720	851,585	1.15	1.51	0.94	9.90	15.78	1.60	254,708	1.26	1.97	0.36	14.32	13.64	5.53
12	2,857,084	913,295	1	506,844	291,660	64,974	1,080,310	1,077,610	1.16	1.55	0.95	10.46	16.70	1.63	505,577	1.22	1.93	0.37	12.72	15.97	5.17
13	5,011,578	1,941,118	1	531,357	823,371	229,315	1,486,417	1,482,701	1.15	1.52	0.93	10.05	16.91	1.64	530,029	1.20	1.82	0.34	11.90	12.58	5.44
14	1,941,156	180,354	0	1,015,009	52,873	157,712	535,208	533,870	1.09	1.58	0.67	10.16	17.42	2.34	1,012,472	1.15	1.87	0.32	10.92	17.98	5.87
15	3,029,346	928,075	1	584,698	393,267	180,089	943,216	940,858	1.06	1.49	0.80	9.93	16.47	1.85	583,236	1.09	1.73	0.30	10.37	16.30	5.69
16	4,298,474	1,170,084	1	983,417	640,284	340,515	1,164,175	1,161,264	0.99	1.45	0.85	9.66	14.61	1.70	980,958	1.03	1.62	0.28	9.43	15.80	5.87
17	3,232,469	873,020	1	704,304	642,985	172,006	840,153	838,053	0.95	1.40	0.88	9.33	14.88	1.60	702,543	1.01	1.64	0.26	9.17	16.99	6.22
18	4,899,480	1,521,583	1	755,498	978,161	597,371	1,046,868	1,044,251	0.93	1.46	0.84	9.61	14.85	1.74	753,609	0.93	1.67	0.28	10.32	14.48	5.95
19	5,355,439	1,993,907	2	702,582	798,979	943,564	916,407	914,116	0.87	1.43	0.87	9.61	14.83	1.65	700,826	0.87	1.78	0.25	11.10	12.06	7.06
Total	**41,715,052**	**11,895,324**	**0.93**	**8,740,760**	**5,333,153**	**2,890,261**	**12,855,553**	**12,823,414**	**1.08**	**1.50**	**0.87**	**9.93**	**15.84**	**1.74**	**8,718,908**	**1.08**	**1.78**	**0.31**	**11.13**	**15.30**	**5.85**
TOTAL	**64,451,864**	**24,452,917**	**1.34**	**11,853,711**	**6,948,560**	**2,935,665**	**18,261,011**	**18,215,359**	**1.22**	**1.58**	**0.89**	**10.18**	**16.49**	**1.80**	**11,824,077**	**1.20**	**1.87**	**0.33**	**11.78**	**15.78**	**5.74**

Based on the results, the 0.6 % TREO_PCT cut-off grade produced the most favourable pit shells.

Phase 1 (1.2 % cut-off) is to Stage 6, and Phase 2 (0.6 % cut-off grade) is from Stage 7 to Stage 19.

The pit shells will be used as a guide for the final pit designs. Cross sections and plan views illustrating the pit shells are shown below (see Table 15.9 for the legend to the colours used in Figure 15.6 to Figure 15.9).

Table 15.9: Legend for the Pit Shells

Pit Shell	Colour
Phase 1	
Phase 2	
Material Type	**Colour (code)**
Measured, Type 1 Ore	1_1
Measured, Type 2 Material	1_2
Indicated, Type 1 Ore	2_1
Indicated, Type 2 Material	2_2
Inferred, Type 1 Ore	3_1
Inferred, Type 2 Material	3_2

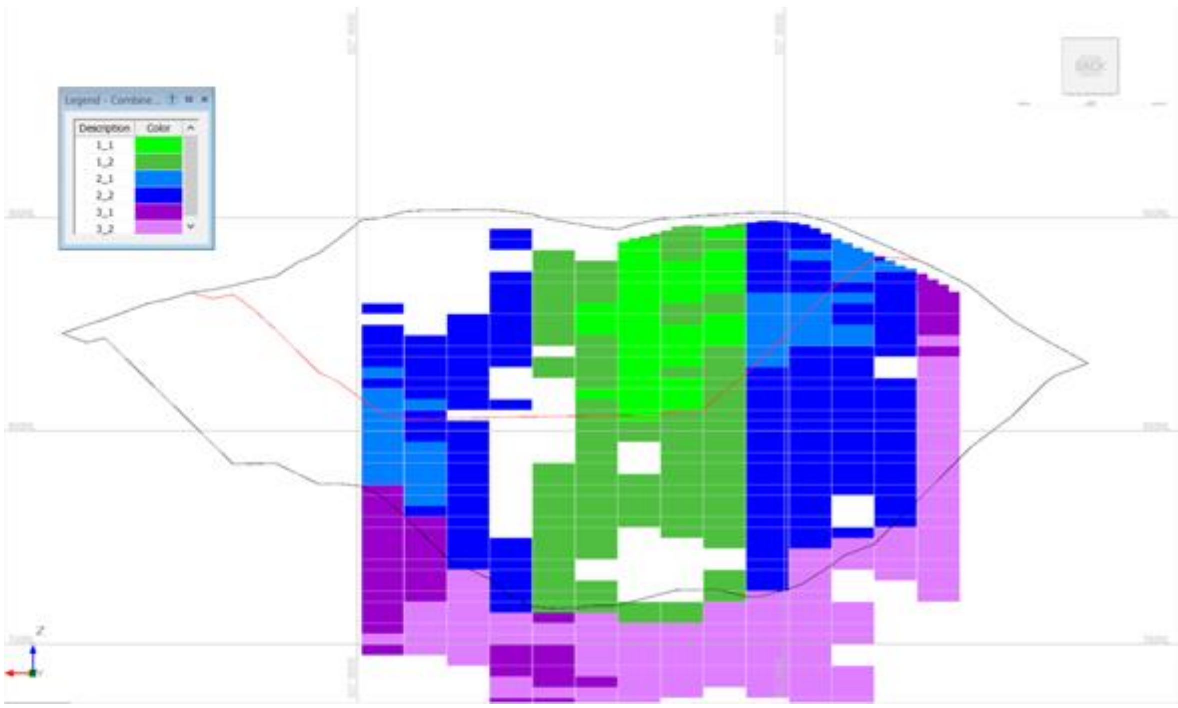


Figure 15.6: Phase 1 and 2 Pit Shells EW Section

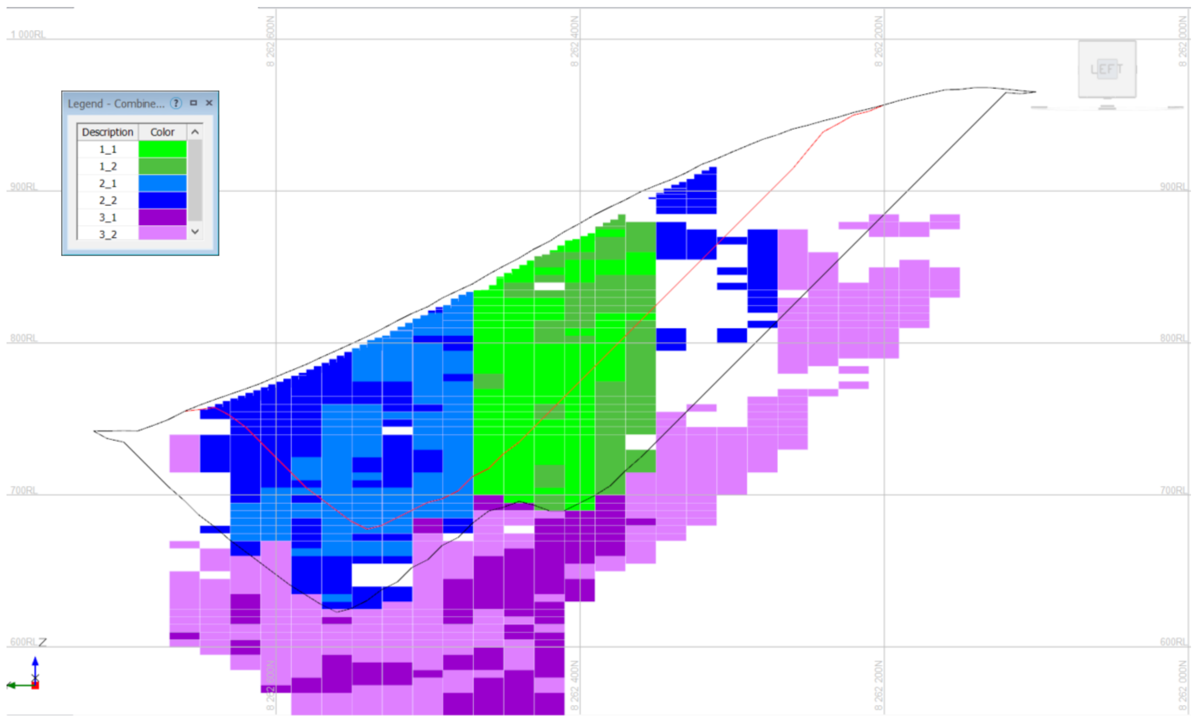


Figure 15.7: Phase 1 and 2 Pit Shells NS Section

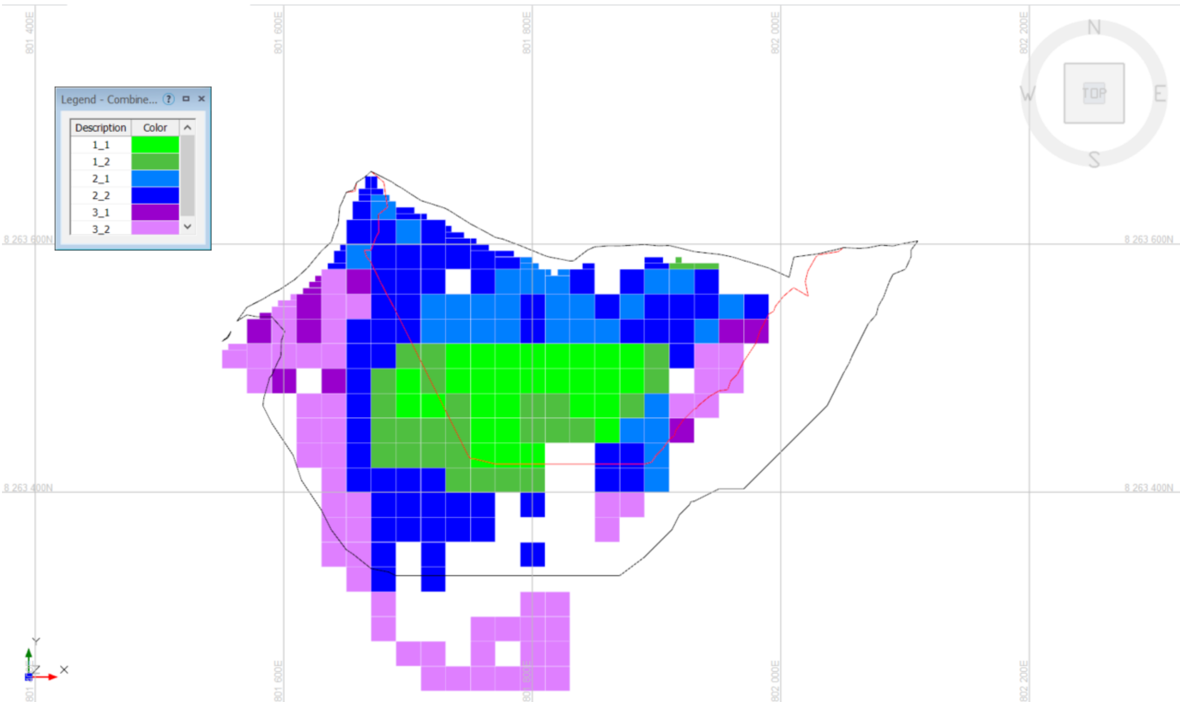


Figure 15.8: Phase 1 and 2 Pit Shells Plan View 800 m Elevation

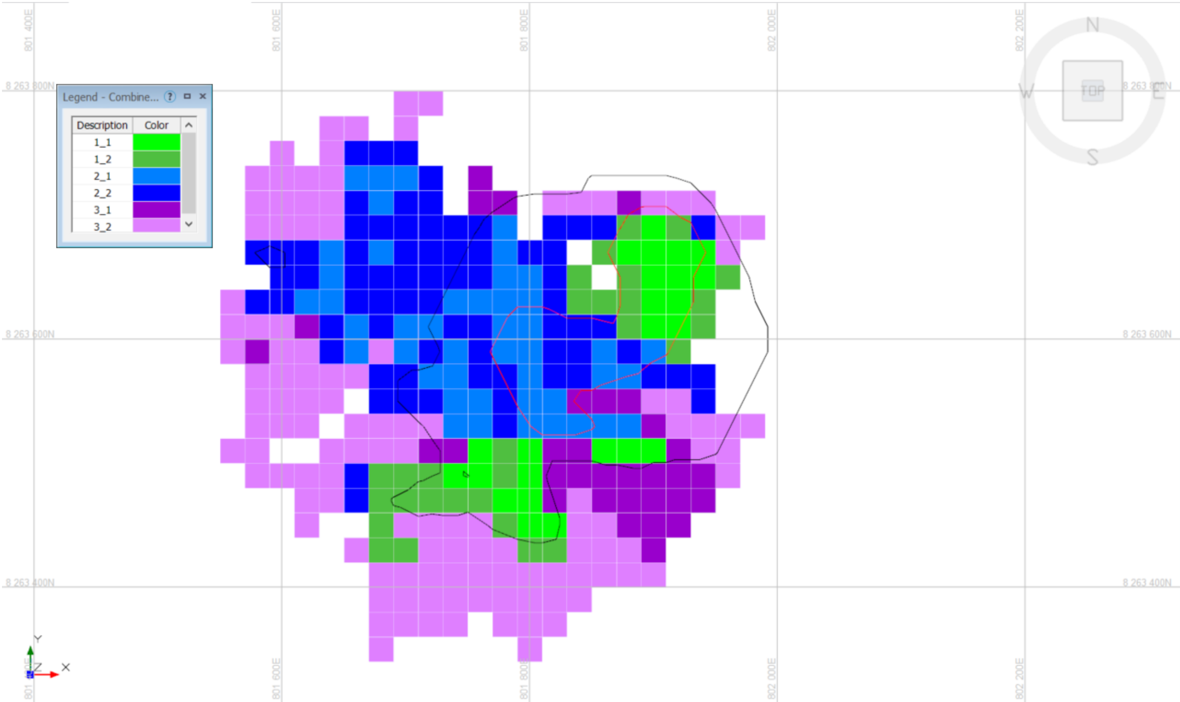


Figure 15.9: Phase 1 and 2 Plan View 700 m Elevation

15.4 PIT DESIGN

15.4.1 Pit Design Overview

The pit design was structured around the strategy of Phase 1 accessing high-grade Type 1 ore for the first five years and stockpiling any medium-grade Type 1 ore to feed as ROM at a later stage. The high-grade pit shell from the pit optimisation was used as a guide for the design of the first five-year pit.

The final pit pushback Phase 2 was then designed to the final pit limits, and the final pit shell from the pit optimisation was used as a guide. The designs also took into consideration the following:

- Mine design criteria
- Geotechnical slope designs
- Bench configuration
- Access

Figure 15.10 and Figure 15.11 show a general plan and cross section looking east of the final pit design.

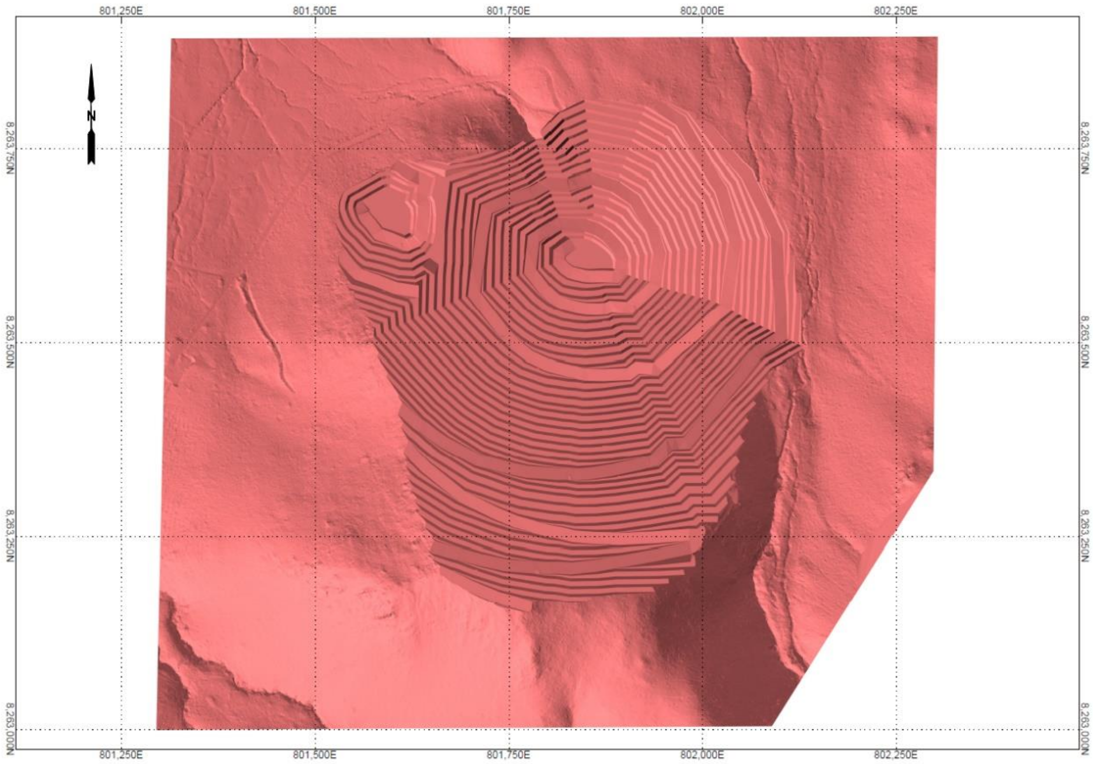


Figure 15.10: Plan View of Final Open Pit

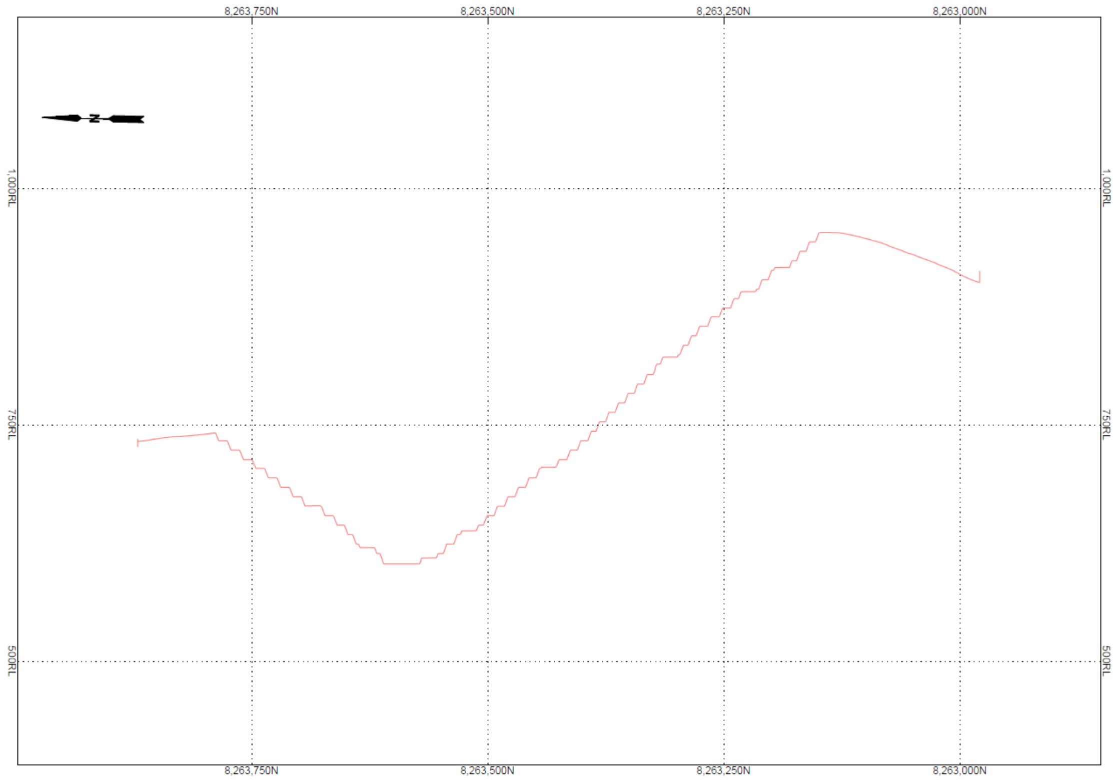


Figure 15.11: Cross Section Looking East of Final Open Pit

15.4.2 Design Criteria

The following pit design parameters were considered for the design of the open pit:

- Berm width – Varied based on geotechnical requirements
- Batter angle (bench face angle) – Varied based on geotechnical requirements
- Bench height – 10 m
- IRA limits – Varied based on geotechnical requirements
- OSA limits – Varied based on geotechnical requirements
- Ramp width – 15 m based on a 40 t articulated dump truck
- Ramp gradient – 10 %
- Switchback width and gradient – As per ramp width
- Minimum radius for curves – 30 m
- Minimum mining width (pit bottom, bench ends, stage cutback widths) – Minimum of 20 m by 20 m mining blocks were considered
- Preferred effective bench mining width – Not less than 20 m

15.4.2.1 Geotechnical Slope Design

The slope designs were based on the design criteria set out in the geotechnical report and discussed in Section 16.2.

The geotechnical domain minimum bench widths and stack angle were applied to each design sector to ensure that the berm width was within the geotechnical requirements.

The designed pit overall slope angles for each sector are all within the geotechnical design requirements and are given in Table 15.10.

Table 15.10: Pit Design Versus Specified Slope Angles

Design Sector	Overall Slope Angle Geotechnical Requirement (°)	Overall Slope Angle from Design (°)
1	47	40.5
2	44	43.4
3 and 4	40	39.8
5	42	40.0
6	43	41.6
7	39	36.8

15.4.2.2 Access Ramp

The access ramp was designed at a 15 m width and a slope of 10 %. The pit exit was determined by the flatter terrain to the east portion of the orebody on the 760 m elevation. This allowed for the ramp to access both the hill and the deeper section of the orebody from the same access point. The strategy to access early higher-grade Type 1 ore was also considered, and this access point also allowed for the pushback to the final pit to be from the same ramp position.

15.4.3 Final Pit Design Volumes

Figure 15.12 to Figure 15.14 illustrate the Phase 1 and 2 (final pit) designs and the pit optimisation shells on which the designs were based. Table 15.11 shows a comparison of the designed pit volumes and the pit optimisation shells.

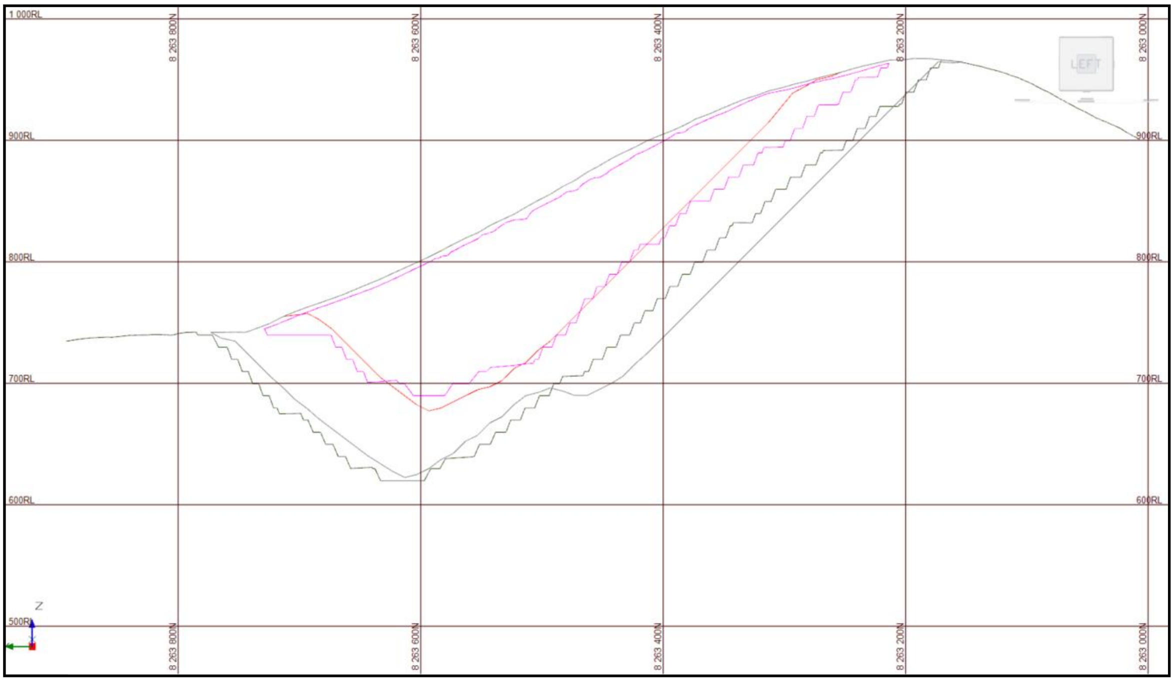


Figure 15.12: Cross Section (Looking East) Showing Pit Optimisation Shells and Pit Designs

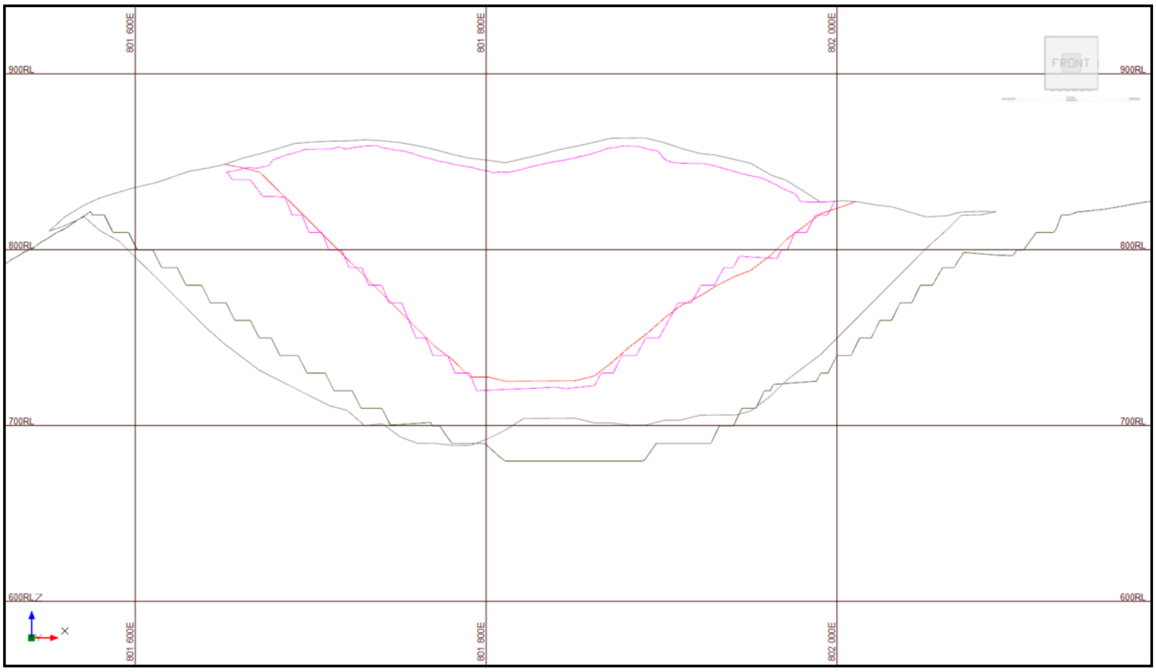


Figure 15.13: Cross Section (Looking South) Showing Pit Optimisation Shells and Pit Designs

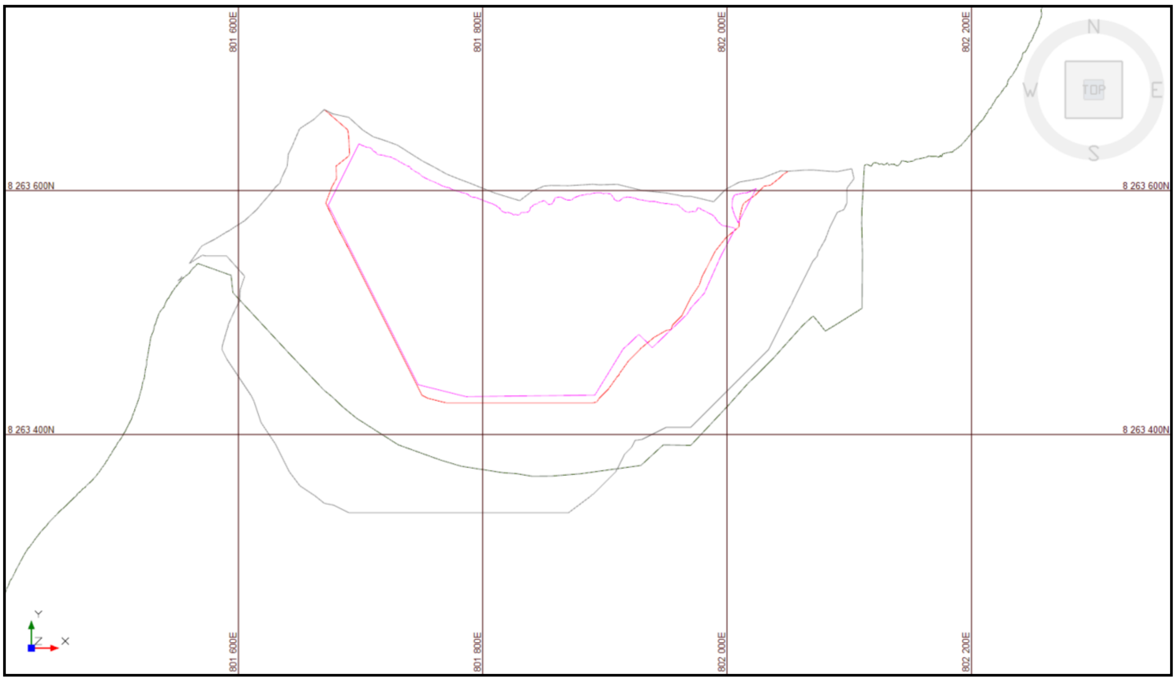


Figure 15.14: Plan on 800 RL Showing Pit Optimisation Shells and Pit Designs

Table 15.11: Pit Design Versus Pit Optimisation Shell Comparison

Description	Optimisation Pit Shell (19)	Pit Design
Waste Tonnes	46,190,853	40,553,931
Type 1 Ore Tonnes	18,261,011	18,147,781
TREO %	1.22	1.16
TREO (t)	222,641	210,984

The final designed pit contains 6 Mt less waste than the pit optimisation shell, resulting in a reduced stripping ratio from 2.53 to 2.17. This is due to the final ramp design against the hill being zigzagged with switchbacks outside of the optimised pit shell and the slope angle required for that geotechnical sector.

15.4.4 Mining Modifying Factors

Only Measured and Indicated mineral resources have been considered in the mine plan. Inferred resources were not considered as ore. Although Inferred resources were included in the block model, these were not included in the mine design and mining inventory.

Modifying factors have been applied to the mineral resource to emulate practical mining conditions and estimate the mining inventory that will be delivered to the plant as ROM production. Modifying factors that have been applied are as follows:

- Ore recovery of 95 %.

- External dilution of 3 % – This is waste at zero grade added to the ore volume to account for inaccuracies in mining.
- Internal dilution – This is dilution included in the mining blocks (minimum mining units) applied in the mine design. The mining block size applied at Songwe Hill was 20 m × 20 m × 10 m depth. Internal dilution amounts to 5 % at a grade of 0.68 TREO %. This internal dilution is made up of a combination of Inferred resources, Type 2 material, and waste, all of which are treated as waste material in the mine design but are included in the mining blocks selected as ore blocks.

The level of study which has been undertaken to generate the above schedule is at a DFS level. The ROM tonnages and grades reported in the above mining schedule can be considered as Mineral Reserves in terms of NI 43-101, provided that the project is shown to be viable by the financial analysis. A statement of ore reserves is included in Section 15.5.

15.5 ORE RESERVE STATEMENT

The work reported above has demonstrated that a portion of the resources stated in the Mineral Resource statement can be viably mined, processed and sold and will support a sustainable mining and processing operation.

Applying the mining modifying factors, process recovery, operating costs and product prices detailed in the sections above, the project is shown to be profitable and viable. This work supports the declaration of Mineral Reserves under NI 43-101.

Although the Qualified Person was not responsible for the completion of the processing, tailings storage, environmental and financial modelling sections of this report, the QP has relied on the specialists in these fields for completion of their respective sections. The QP has reviewed the sections completed by others and has found no reason not to accept their work. The results of the DFS have shown that the mining inventory included in the study, which is derived from only Measured and Indicated Mineral Resources, can be viably mined based on the techno-economic assumptions documented in this report.

In estimating the Mineral Reserves, only material from the Measured and Indicated Mineral Resources has been included in the inventory. Mineral Reserves resulting from Measured Mineral Resources have been considered as Proven Mineral Reserves while those generated from Indicated Mineral Resources are categorised as Probable Mineral Reserves. Table 15.12 shows the conversion from Mineral Resource to Mineral Reserves while Table 15.13 shows a summary of the total Mineral Reserves. The Mineral Reserve showing the grades of the individual rare earth elements is shown in Table 15.14.

Table 15.12: Summary of Resource-to-Reserve Conversion

Item	Factor (%)	Tonnage (t)	TREO %	TREO (t)
Resources within Pit Design				
Measured		7,913,142	1.34	106,165
Indicated		9,705,350	1.13	109,377
Mining Losses				
Measured	5	395,657	1.34	5,308
Indicated	5	485,267	1.13	5,469

Item	Factor (%)	Tonnage (t)	TREO %	TREO (t)
Dilution				
External:				
Measured	3	225,525		
Indicated	3	276,602		
Internal:				
Measured	6	416,700	0.80	3,326
Indicated	6	491,387	0.59	2,892
Total Mining Inventory (Mineral Reserves)				
Measured		8,159,710	1.28	104,183
Indicated		9,988,072	1.07	106,801
Total Mineral Reserves		**18,147,781**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.				

Table 15.13: Mineral Reserve Summary

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

Table 15.14: Mineral Reserve Summary Showing Rare Earth Element Grades

Category	Tonnage (Mt)	TREO %	CeO_2 (ppm)	Dy_2O_3 (ppm	Er_2O_3 (ppm)	Eu_2O_3 (ppm)	Gd_2O_3 (ppm)	Ho_2O_3 (ppm)	La_2O_3 (ppm)	Lu_2O_3 (ppm)	Nd_2O_3 (ppm)	Pr_6O_{11} (ppm)	Sm_2O_3 (ppm)	Tb_4O_7 (ppm)	Tm_2O_3 (ppm)	Y_2O_3 (ppm)	Yb_2O_3 (ppm)	Th (ppm)	U (ppm)
Proven Mineral Reserves	8.16	1.28	5,779	108	41	80	190	17	3,069	4	2,027	606	294	23	5	493	30	296	13
Probable Mineral Reserves	9.988	1.07	4,852	89	34	66	159	14	2,633	3	1,642	498	243	19	4	410	25	295	13
Total Ore Reserves	**18.147**	**1.16**	**5,269**	**98**	**37**	**72**	**173**	**16**	**2,829**	**4**	**1,815**	**547**	**266**	**21**	**5**	**448**	**27**	**295**	**13**
NOTE: Totals might not add up due to rounding.																			

Type 2 material, which is mineralised material with a grade above the cut-off grade but with an Mn:Mg ratio of greater then 3.5, is stockpiled on site for possible future processing. This material is excluded from both the ROM ore inventory and any Mineral Reserve estimate.

Inferred resources are not considered as ore in the mine plan and as such are treated as waste and not included in the ROM ore inventory.

Bara is not aware of any issues that materially affect the Mineral Reserve estimation for Songwe Hill. The Mineral Resource and Mineral Reserves are sensitive to cut-off grade as shown in the Mineral Resource grade tonnage curves from the Mineral Resource section (Section 14). The factors affecting the Mineral Reserve cut-off grade are as follows:

- Rare earth element prices
- Mining costs
- Processing recovery costs
- Processing costs
- Environmental closure costs

Other factors that can affect the Mineral Reserve estimate are the following:

- Environmental and social risks, including the timely completion of the relocation action plan required to allow the project to proceed
- Adherence to geotechnical design recommendations
- Production throughput, which directly influences the rate of depletion of the mineral reserve
- Achievement of the planned modifying factors, including ore loss and dilution.

16 MINING METHODS

16.1 MINING OVERVIEW

The mining method at Songwe Hill will be conventional open-pit mining, making use of relatively small-scale trucks and diesel-hydraulic excavators, selected to match the mining conditions and required production rates.

The procedure followed in arriving at the mine design was as follows:

- A geotechnical evaluation was completed including logging of core on site. The geotechnical data was collated into a database and used to inform a geotechnical design of the pit slope design parameters.
- Using the slope design parameters, mining costs obtained from mining contractors, modifying factors derived during the pre-feasibility mining study, and the product price data provided by Mkango, a pit optimisation was completed. The results of the pit optimisation were analysed, and a pit shell was selected on which to base the DFS pit design.
- Various scenarios of production rate, cut-off grade application, and stockpiling strategy were tested during the pit optimisation, which ultimately led to the selection of an option developed in more detail for the DFS pit design.
- Mine design criteria were developed for the pit design. A practical pit design was completed which included the design of haul roads and safety berms. The overall pit was split into two phases or cutbacks.
- A production schedule was developed, reporting all the material types produced from the pit over the life of operations (LOO). The material types reported include
    - Waste.
    - Type 1 ore – This is ore above the cut-off grade with an Mn:Mg ratio of less than 3.5. This ore can be processed in the current plant design proposed.
    - Type 2 material – This is material above the cut-off grade but with an Mn:Mg ratio of 3.5 or greater. This material cannot be handled by the current process but will be stockpiled for potential processing at a later stage.

The sections below describe the design and operation of the proposed open pit mining operation.

16.2 MINING GEOTECHNICAL EVALUATION

Bara subcontracted Middindi Consulting to carry out an open-pit slope design for the Songwe Hill Project at a DFS level of accuracy. The study addresses the geotechnical characteristics of the rock mass within the planned open-pit area, the methods used for the slope design, and the pit slope configurations obtained. A summary of the geotechnical findings and slope design, extracted from DFS Geotechnical Report (Middindi, 2019), is given below.

16.2.1 Geohydrology

The outcome of the geohydrological assessment conducted by Digby Wells to ensure stability of the slopes recommends the following:

- Periodical, long-term groundwater level monitoring in the surrounding areas of the proposed mine
- Placement of monitoring boreholes in the vicinity of the Songwe Hill pit to act as an early warning system
- Minimal pit dewatering, which may only be needed for the later years of mining, when mining of the pit nears the deepest part

The geotechnical pit design provided in 2019 for Songwe Hill is still valid and applicable as saturated conditions were incorporated into the open-pit slope design to account for surface water ingress or subsurface water within the slopes.

16.2.2 Seismicity

According to Chapola (2001), Malawi is within the most seismically active belt of the East African Rift System (EARS). The magnitudes of the earthquakes are categorised as moderate and may reach up to 6.3 on a Richter Scale. For a 50 to 100-year period, PGA values range from 80 cm/s^2 to 130 cm/s^2 (0.8 m/s^2 to 1.3 m/s^2) in cities such as Mzuzu, Lilongwe and Blantyre (Chapola, 2001).

The spatial distribution of earthquakes shows northern Malawi as highly active, followed by the centre, with sparse distribution to the south. The Salima event of 1989 and the Karonga event of 2009 were the largest recorded earthquakes in Malawi, with magnitudes of up to M6.2 and M6.0, respectively (Chindandali, 2016).

The pit slope design for Songwe Hill accounted for potential seismicity by including a seismic coefficient (k_s) in the limit equilibrium analysis models. The seismic coefficients are dimensionless coefficients which represent the PGA as a fraction of the acceleration due to gravity, or $k_s = a_c / g$.

Typical values are in the range of 0.1 to 0.3 (Rocscience Slide, 2017). PGA values of up to 1.3 m/s^2 (130 cm/s^2) for Malawi thus equate to a k_s of 0.13.

16.2.3 Geotechnical Data Acquisition

Geotechnical data was obtained from geotechnical logging of borehole core and from laboratory testing of core on selected rock samples.

16.2.3.1 Borehole Data

Eighteen boreholes were logged geotechnically, totalling 2,198 m of core. The core was selectively sampled for rock strength testing, and the results of the drill core logging informed the geotechnical characterisation for the project. The positions of the geotechnical boreholes in relation to the planned pit shell are shown in Figure 16.1.

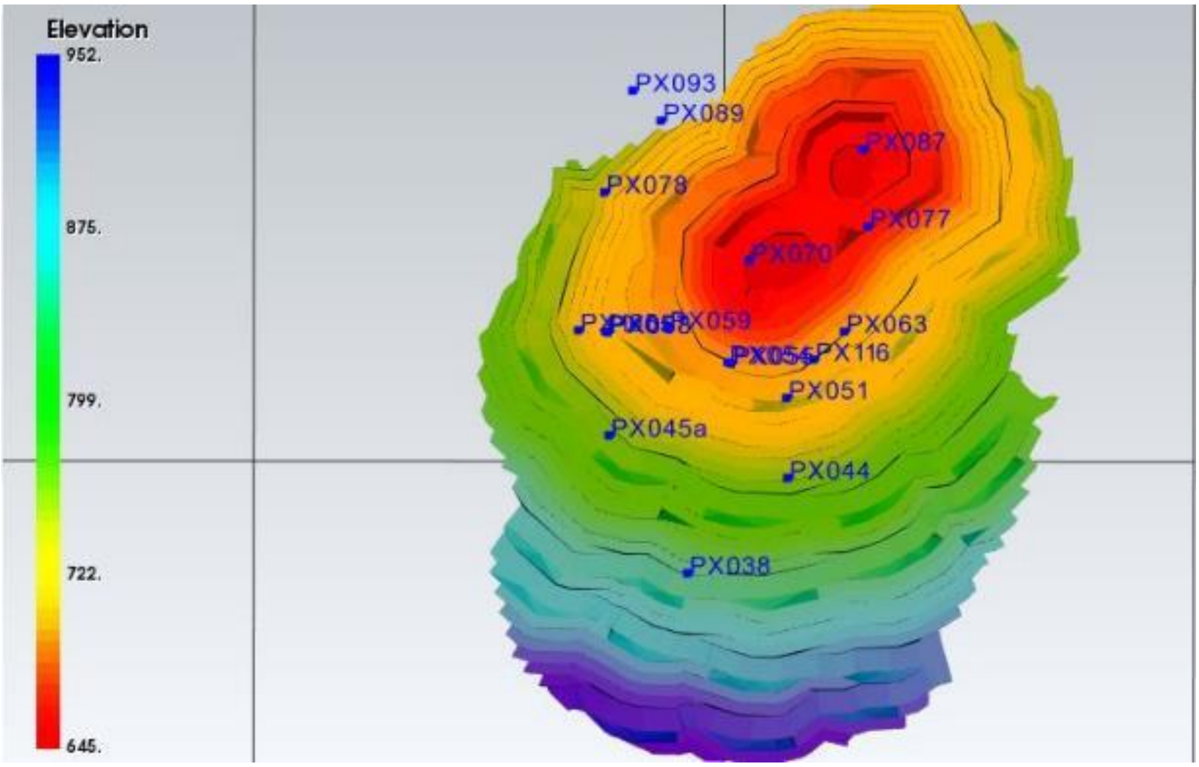


Figure 16.1: Locations of Geotechnical Boreholes

The core was logged per run within lithologies, recorded on a geotechnical log sheet, and then captured on a Microsoft (MS) Excel spreadsheet. All the boreholes were orientated, thereby enabling discontinuity orientations to be analysed. Discontinuity orientations are recorded by measuring alpha (α) and beta (β) angles, which are thereafter corrected into dip angles and dip directions, respectively.

For each borehole logged, the following parameters were recorded by Middindi Consulting using ISRM (International Society of Rock Mechanics) based SOPs for geotechnical logging:

- Drill run (from, to)
- Rock type
- Weathering of the rock mass
- Hardness of the rock mass (field estimate)
- Total core recovery (TCR)
- Solid core recovery (SCR)
- Rock quality designation (RQD)
- Number of joints per run
- Number of pieces per run
- Total number of cemented joints per run
- Depth of each individual open joint
- Dip angle (α-angle), i.e. angle of defects relative to the long axis of the core
- Dip direction (β-angle)
- Joint condition (roughness, infill type, infill thickness and joint alteration)

During core drilling, runs of core (approximately 1.5 m to 3.0 m lengths) are extracted from the core barrel and placed in core boxes. The extraction process rotates the core randomly so that once the core is laid out in core boxes its original orientation is lost, although the orientation of the core axis is generally still known. Unorientated core can thus not allow for a complete geotechnical analysis of the discontinuity orientations (dip and dip directions), and the identification of dominant discontinuity sets is also limited.

The logging data was transformed into rock quality parameters such as RMR and geological strength index (GSI), which, together with weathering and hardness properties, enabled the derivation of geotechnical domains within the rock mass.

16.2.3.2 Rock Testing

A series of rock samples were selected from the boreholes during the data acquisition phase, in line with the ISRM's guideline for sample selection for different rock tests. Uniaxial compressive strength with elastic moduli (UCM), triaxial compressive strength (TCS), indirect tensile strength (UTB) and direct shear on saw-cut surface (base friction angle (BFA)) tests were delivered and performed at the Rocklab Laboratory in South Africa. Samples of only the rock types which were dominant in the rock mass (i.e. fenite, phonolite, C2-carbonatite/breccia and C3-carbonatite) were selected. All the variations of breccias and carbonatites could not be sampled, such as brown banded carbonatite and dark matrix carbonatite, due to their sparsity. A brief description of the tests is presented in the subsections below.

16.2.3.2.1 Uniaxial Compressive Strength with Elastic Moduli (UCM)

Twenty-one UCM tests were carried out by Rocklab Laboratory. The UCM test allows for rock samples to be assessed and categorised by their unconfined strengths and is the most commonly used strength test. The elastic modulus and Poisson's Ratio are also obtained from the UCM tests.

16.2.3.2.2 Triaxial Compressive Strength (TCS)

Twenty-two TCS tests were carried out by Rocklab Laboratory to determine the effect of confining stress on the strength of rock samples. The TCS test results allow for the derivation of mechanical rock properties such as Hoek-Brown and equivalent Mohr-Coulomb parameters, which are important in describing the behaviour of the rock mass in numerical models. This is achieved using the Rocscience RocData software.

16.2.3.2.3 Indirect Tensile Strength (UTB)

Twelve indirect tensile tests of rock, also known as the Brazilian Disc Test, were carried out to provide an alternative to direct tensile testing. The Brazilian tests produce tensile failure in the end faces of cylindrical rock samples by subjecting these specimens to a compressive force along their length. Specimens usually have a height-to-diameter ratio of at least 0.5:1.0, and a typical diameter of 54.0 mm. The specimens were placed horizontally and loaded in compression until the flat ends split, revealing the tensile strength data.

16.2.3.2.4 Base Friction Angle (BFA)

Direct shear tests of saw-cut surfaces on nine core specimens were carried out by Rocklab Laboratory to determine the BFA of "artificial" discontinuities within each domain. BFA tests are tilt tests performed on saw-cut surfaces representative of a cohesionless joint (c = 0 kPa). The BFA (φb) is a quantity that is fundamental to the understanding of the shear strength of discontinuity surfaces. The BFA values were entered into the Rocscience RocData program, from which equivalent Mohr-Coulomb properties were derived using the Barton-Bandis model, for large-scale discontinuities.

16.2.4 Geotechnical Characterisation

This section presents and discusses the results of the geotechnical properties attained from core logging, analysis of data, and rock testing. The geotechnical characteristics of all material layers of significance are reported herein.

16.2.4.1 Geotechnical Domains

The geotechnical data gathered during the logging process was subdivided into the following geotechnical domains based on the degree of weathering, hardness and rock mass ratings:

- Weathered
- Transitional
- Poor quality
- Trans-fresh

The four domains were categorised based on their characteristics as follows:

- Weathered – completely to highly weathered, the RMR_{89} (Bieniawski, 1989) was generally less than 40 and logged as very weak to weak in terms of "hardness." Usually occurs towards the upper surface of the borehole.
- Transitional – moderately weathered, RMR_{89} between 40 and 60 and was on average 55 and logged as medium-strong rock. Transitional materials, as the name suggests, exhibit characteristics between weathered and fresh rock and were fair in quality.
- Poor quality – The poor-quality domain exhibited essentially the same properties as the weathered domain but occurred between the transitional and trans-fresh domains. Since "weathered" refers to rock that has decomposed due to external physical processes, this domain was referred to as "poor" since it is overlain by competent rock and therefore not subjected to external weathering factors.
- Trans-fresh – slightly weathered to unweathered, RMR_{89} between 60 and 80 with an average of 67 and logged as medium-strong to strong rock. This domain does not qualify as "completely fresh rock" as it exhibits signs of some degree of weathering, and only 7 % of the rock mass was logged as "unweathered."

A total of 62 % of the rock mass, represented by all the boreholes, was moderately weathered, followed by 23 % slightly weathered and only 7 % fresh rock.

A total of 58 % of the rock mass was classified as good quality, followed by 28 % of fair-quality rock.

16.2.4.2 Rock Mass Quality

The parameters logged and described in the previous section enabled the rock mass to be geotechnically characterised. Several classification systems are typically used for geotechnical design, including the rock quality designation (RQD), GSI, Barton's Q Rating (Q) and Bieniawski's rock mass rating (RMR_{89}). For open-pit slope designs, GSI and RMR are the most imperative parameters required for rock mass characterisation.

16.2.4.3 Rock Mass Classification

The geotechnical domains derived from the logging data have been defined in terms of their geotechnical characteristics. A statistical summary of the rock quality geotechnical parameters: RQD, joint spacing, RMR and GSI are presented in Table 16.1.

Each parameter mentioned above is accompanied by mean, minimum, maximum, standard deviation, 25th percentile, 50th percentile and 75th percentile values.

Table 16.1: Geotechnical Parameters with Statistical Summary for All Domains

Geotechnical Domain	Statistical Parameter	RQD (%)	Joint Spacing (cm)	GSI	RMR
Weathered and poor-quality rock	Mean	15.13	11.08	32.93	37.70
	Minimum	0.00	0.00	0.00	0.00
	Maximum	98.21	50.83	58.00	63.00
	Standard Deviation	18.90	8.33	9.51	10.36
	Percentile 25 %	11.39	9.68	30.03	34.53
	Percentile 50 %	18.30	9.97	30.75	35.75
	Percentile 75 %	19.35	10.95	34.64	39.64
Transitional	Mean	60.87	30.47	49.59	54.59
	Minimum	4.88	4.69	28.00	33.00
	Maximum	100.00	175.00	78.00	83.00
	Standard Deviation	29.80	23.32	9.91	9.91
	Percentile 25 %	47.18	26.81	46.52	51.52
	Percentile 50 %	59.84	30.44	50.04	55.04
	Percentile 75 %	66.56	34.96	51.25	56.25
Trans-fresh	Mean	87.35	73.27	62.92	67.92
	Minimum	4.85	5.40	30.00	35.00
	Maximum	100.00	380.00	89.00	94.00
	Standard Deviation	17.31	65.07	8.76	8.76
	Percentile 25 %	83.54	56.50	61.29	66.29
	Percentile 50 %	86.28	67.26	62.39	67.39
	Percentile 75 %	90.31	88.17	64.32	69.32

16.2.4.4 Laboratory Strength Tests

The summarised laboratory test results are presented in this section.

The following tests were undertaken on the selected samples:

- Uniaxial compressive strength with elastic moduli (UCM)
- Triaxial compressive strength (TCS)
- Indirect tensile strength (Brazilian Disc) (UTB)
- Base friction angle (BFA)

Table 16.2 shows a summary of the uniaxial compressive strength (UCS) test results, while Table 16.3 shows the triaxial compressive strength results.

Table 16.2: Summary of UCM Results of All Rock Types

Rock Type	Statistical Parameter	Density (g/cm^3)	Strength (UCS) (MPa)	Tangent Elastic Modulus at 50 % UCS (GPa)	Poisson's Ratio Tangent at 50 % UCS
Fenite	Mean	2.73	134.96	47.24	0.30
	Minimum	2.54	111.37	33.30	0.25
	Maximum	2.88	174.36	58.80	0.38
	Standard Deviation	0.15	24.76	11.22	0.05
C2-Carbonatite	Mean	2.84	135.32	63.13	0.29
	Minimum	2.78	133.68	55.10	0.28
	Maximum	2.91	137.79	67.70	0.31
	Standard Deviation	0.07	2.18	6.98	0.01
C3-Carbonatite	Mean	2.78	71.26	37.68	0.26
	Minimum	2.67	50.52	27.30	0.24
	Maximum	2.85	99.61	51.80	0.29
	Standard Deviation	0.09	22.27	10.23	0.02
Phonolite	Mean	2.97	168.74	67.47	0.29
	Minimum	2.80	121.13	58.90	0.24
	Maximum	3.22	201.14	82.40	0.34
	Standard Deviation	0.22	42.11	12.98	0.05

Table 16.3: Summary of Triaxial Compressive Strength Test Results for All Rock Types

Rock Type	Borehole ID	Sample ID	Depth from (m)	Depth to (m)	Failure Load (kN)	Confining Pressure σ_3 (MPa)	Strength σ_1 (MPa)	Comments
Fenite	PX105	PX-TCS-04	10.62	10.83	199.30	5.00	114.00	
	PX063	PX-TCS-07	79.01	79.16	161.93	10.00	91.50	Data point excluded – failed on discontinuity
	PX063	PX-TCS-08	84.19	84.34	372.82	15.00	210.03	
	PX038	PX-TCS-10	70.56	70.71	371.79	20.00	118.40	Data point excluded – failed on discontinuity
	PX055	PX-TCS-12	58.12	58.27	379.05	25.00	216.45	Data point excluded – failed on discontinuity
	PX057	PX-TCS-16	4.40	4.55	494.62	30.00	280.30	
C2-carbonatite	PX077	PX-TCS-09	87.08	87.22	384.94	5.00	222.35	
	PX055	PX-TCS-13	80.06	80.21	439.78	10.00	251.23	
	PX070	PX-TCS-22	44.32	44.47	355.01	15.00	201.61	Data point excluded – failed on discontinuity
	PX054	PX-TCS-20	143.59	143.75	544.62	20.00	312.45	
C3-carbonatite	PX058	PX-TCS-01	150.90	151.05	238.40	15.00	134.36	
	PX059	PX-TCS-02	51.16	51.33	267.64	5.00	151.35	Data point excluded – outlier
	PX059	PX-TCS-03	138.42	138.57	170.59	10.00	96.55	
	PX105	PX-TCS-05	21.52	21.68	165.74	2.00	94.40	
	PX051	PX-TCS-15	30.08	30.22	292.20	20.00	164.69	Data point excluded – failed on discontinuity
	PX054	PX-TCS-19	77.52	77.66	304.15	25.00	175.46	
	PX093	PX-TCS-21	77.10	77.26	304.32	30.00	171.81	
Phonolite	PX063	PX-TCS-06	66.56	66.71	532.69	5.00	299.97	Data point excluded – failed on discontinuity
	PX038	PX-TCS-11	101.43	101.59	620.57	10.00	198.76	
	PX055	PX-TCS-14	154.70	154.88	517.80	15.00	296.94	
	PX044	PX-TCS-17	131.37	131.52	384.59	20.00	218.68	
	PX044	PX-TCS-18	158.17	158.34	581.99	25.00	331.77	

The derivation of Hoek-Brown and Mohr-Coulomb failure parameters from the triaxial tests results are shown in Table 16.4 where:

- GSI is the geological strength index
- σ_c is the unconfined compressive strength
- ρ is material density
- mi is the material constant and mb is the reduced value of the material constant mi
- D is the disturbance factor due to blasting and stress relief
- s and a are constants for the rock mass
- c is cohesion and φ is friction angle

As samples of the weathered domain could not be selected, the lowest UCS value (71.26 MPa) was used in the estimation of its shear strength properties. The GSI of the weathered material was obtained from the logging data.

As expected, the shear strength properties of the transitional material are lower than those of the trans-fresh rock types.

Table 16.4: Shear Strength Properties of Rock Derived from TCS Test Results

Geotechnical Domain		Weathered	Transitional				Trans-Fresh			
Rock Properties	Unit	Fenite Breccia	Fenite	C2-Carbonatite Breccia	C3-Carbonatite	Phonolite	Fenite	C2-Carbonatite Breccia	C3-Carbonatite	Phonolite
GSI	N/A	33.00	50.00	50.00	50.00	50.00	63.00	63.00	63.00	63.00
σ_c	MPa	71.26	108.29	135.32	71.26	121.53	108.29	135.32	71.26	121.53
mi	N/A	14.00	15.44	14.07	7.23	22.29	15.44	14.07	7.23	22.29
D	N/A	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
mb	N/A	0.259	0.765	0.717	0.369	1.122	1.658	1.555	0.799	2.432
s	N/A	3.90E-05	5.13E-04	5.13E-04	5.13E-04	5.13E-04	4.00E-03	4.00E-03	4.00E-03	4.00E-03
a	N/A	0.518	0.506	0.506	0.506	0.506	0.502	0.502	0.502	0.502
ρ	kg/m^3	2,600.00	2,730.00	2,840.00	2,780.00	2,970.00	2,730.00	2,840.00	2,780.00	2,970.00
c	MPa	0.76	1.52	1.67	1.03	1.91	2.20	2.47	1.58	2.67
ϕ	degrees (°)	24.38	36.30	37.17	26.95	39.60	42.54	43.37	32.88	45.84

The UTB test results range from 4.9 MPa to 15.1 MPa for the individual samples. The statistical parameters are presented in Table 16.5, which indicates an average tensile strength of 10.4 MPa for fenite, 9.5 MPa for C2-carbonatite, 7.7 MPa for C3-carbonatite, and 11.5 MPa for phonolite.

Table 16.5: Statistical Summary of UTB Test Results

Rock Type	Statistical Parameter	UTB (MPa)
Fenite	Mean	10.4
	Minimum	7.0
	Maximum	14.1
	Standard Deviation	3.6
C2-Carbonatite Breccia	Mean	9.5
	Minimum	8.0
	Maximum	10.5
	Standard Deviation	1.3
C3-Carbonatite	Mean	7.7
	Minimum	6.4
	Maximum	9.1
	Standard Deviation	1.3
Phonolite	Mean	11.5
	Minimum	4.9
	Maximum	15.1
	Standard Deviation	5.7

BFAs range from 33° to 41° and are presented in Table 16.6. The BFAs were used to derive the discontinuity shear strength for the transitional and trans-fresh rock.

Table 16.6: Statistical Summary of BFA Test Results

Rock Type	Statistical Parameter	BFA (°)
Fenite	Mean	35.67
	Minimum	33.00
	Maximum	37.00
	Standard Deviation	2.31
C2-Carbonatite	Mean	34.50
	Minimum	34.00
	Maximum	35.00
	Standard Deviation	0.71
C3-Carbonatite	Mean	36.00
	Minimum	33.00
	Maximum	39.00
	Standard Deviation	4.24
Phonolite	Mean	39.00
	Minimum	37.00
	Maximum	41.00
	Standard Deviation	2.83

The Barton-Bandis criteria in the RocData program were used to determine the discontinuity shear strength parameters for transitional and trans-fresh rocks by entering the BFA (ϕb), joint roughness coefficient (JRC0), joint compressive strength (JCS0), and actual joint length (L0). Since there are significant scale effects that control joint behaviour, the JRC0 and JCS0 parameters were converted from laboratory-scale to in-situ scale (JRCn and JCSn) within RocData. The residual friction angle (ϕr) is derived from ϕb.

The derived discontinuity shear strength properties, cohesion (c) and joint friction angle (ϕj), are presented in Table 16.7.

Table 16.7: Discontinuity Shear Strength Parameters

Geotechnical Domain		Transitional				Trans-Fresh			
Rock Properties	Unit	Fenite	C2-Carbonatite	C3-Carbonatite	Phonolite	Fenite	C2-Carbonatite	C3-Carbonatite	Phonolite
ϕ_b	degrees (°)	33.00	34.00	33.00	37.00	36.00	35.00	36.00	39.00
ϕ_r	degrees (°)	23.00	24.00	23.00	27.00	26.00	25.00	26.00	29.00
JRCn		3	3	3	3	3	3	3	3
JCSn	MPa	46.91	56.29	21.27	51.01	56.85	56.99	30.01	71.06
ρ	kg/m^3	2,730	2,840	2,780	2,970	2,730	2,840	2,780	2,970
c	MPa	0.076	0.081	0.076	0.093	0.083	0.084	0.083	0.100
ϕ_j	degrees (°)	25.08	26.25	24.03	29.01	28.28	27.25	27.42	31.41

16.2.4.5 Discontinuity Orientation

The Rocscience Dips program was used to analyse the discontinuity data obtained from the boreholes. In order to determine the most appropriate method to group the discontinuity orientations, the following plots were analysed:

- Discontinuities per borehole
- Discontinuities per rock type
- Discontinuities per defined sector across the pit (A, B and C) according to elevation (see Figure 16.2)
- All the discontinuities combined

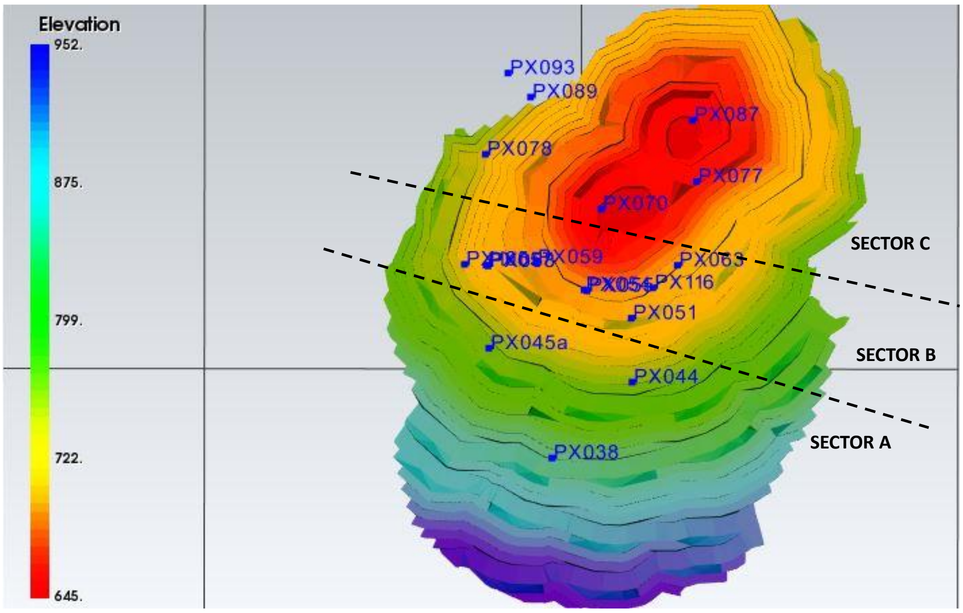


Figure 16.2: Sectors Defined According to Elevation for Discontinuity Orientation Analysis

Examination of the dips plots revealed that the trends in dominant discontinuity sets were similar irrespective of the grouping method. It was therefore concluded that a combination of all data (all boreholes and rock types) will be most representative of the rock mass for kinematic analysis. The number of data entries totalled 1,582 for the 18 boreholes. As depicted in Figure 16.3, the discontinuity data appeared to be scattered, but this may be attributed to the geological nature of the rock mass. Four joint sets were identified in the rock mass. The dips contour plot for the combined data set is shown in Figure 16.4.

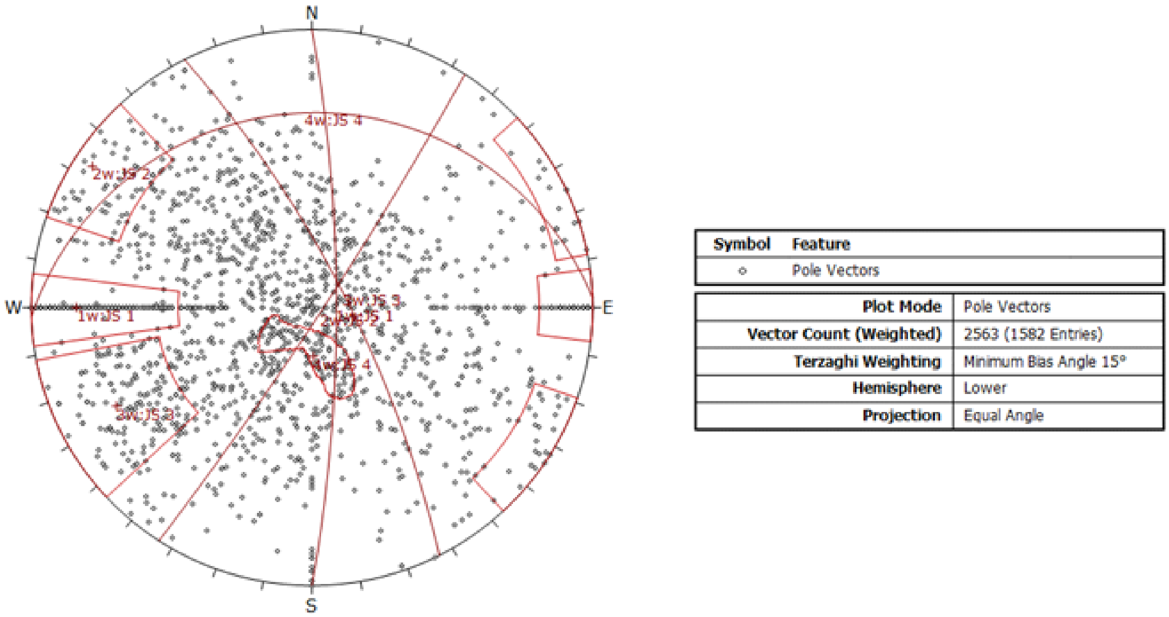


Figure 16.3: Dips Scatter Plot Showing Large Spread in Data

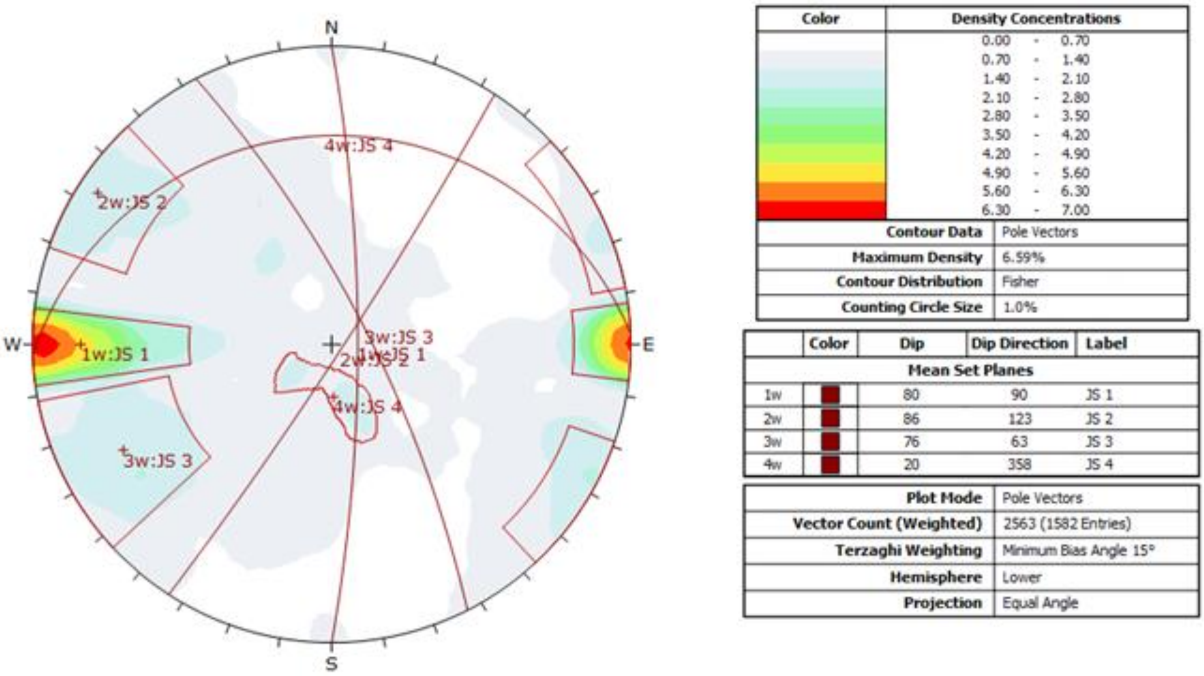


Figure 16.4: Dips Contour Plot Showing Dominant Joint Sets

The orientations of the dominant joint sets are summarised in Table 16.8.

Table 16.8: Summary of Discontinuity Sets for Songwe Hill

Set No.	Dip Angle (°)	Dip Direction (°)
JS1	80	090
JS2	86	123
JS3	76	063
JS4	20	358

16.2.5 Slope Engineering

The slope design reported herein provides recommendations for the vertical bench separation (bench or batter height), bench width or berm, bench face (or batter) angle, inter-ramp angle, and overall slope angle, for different design sectors of the open pits. The bench configuration is defined by a catch bench (or berm) width, vertical bench separation (or bench height), and bench face angle (or batter angle). The bench face angle is controlled by the material strength, the orientation of the discontinuities in relation to the face azimuth, and/or blasting and excavation practices. Production bench height is usually determined by grade control requirements and/or by equipment (production and making safe) capabilities. Multi-bench slope designs stack several production benches between catch benches so that the vertical catch bench separation is a multiple (usually two, three, or four) of the production bench height.

The inter-ramp angle (IRA) or stack angle is formed by a series of uninterrupted benches and corresponds to the inclination from the horizontal of a line joining the toes or crests of the benches.

The overall slope angle (OSA) is formed by a series of inter-ramp slopes separated by haul roads and corresponds to the angle formed by the line joining the toe of the lowest bench with the slope crest. The incorporation of ramps onto a wall will result in a slope that has a shallower overall slope angle than the inter-ramp angle.

Figure 16.5 depicts the typical slope configurations of an open-pit mine.

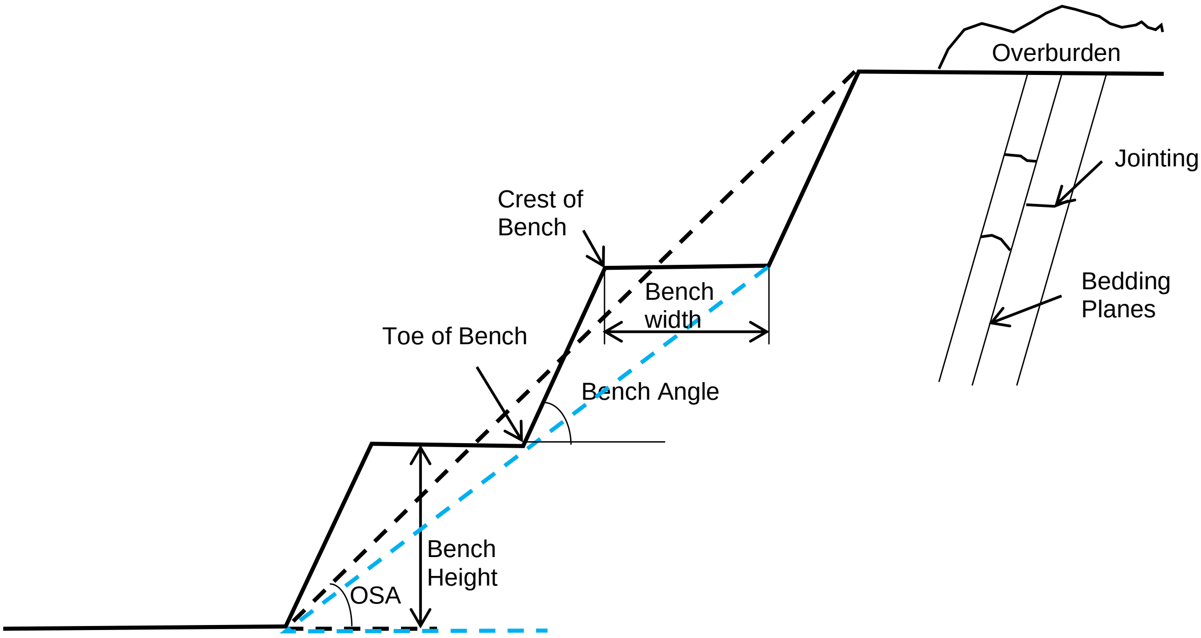


Figure 16.5: Typical Open-Pit Slope Terminology

For the limit equilibrium analysis of the weathered material, a threshold factor of safety (FOS) of 1.3 (Read & Stacey, 2008) was used to determine stable bench face angles (see Table 16.9).

Table 16.9: FOS = 1.3 Adopted for Songwe Hill Open-Pit Benches

Consequences of Failure	Examples	Minimum FOS
Not serious	No person entry	1.2
	Individual benches, small temporary slopes not adjacent to haul roads	1.3
Moderately serious	Any slope of a permanent or semi-permanent nature	1.6
Very serious	Medium-sized and high slopes carrying major haulage roads or underlying permanent mine installations	2.0

For the kinematic analysis of the transitional and trans-fresh rock and the limit equilibrium analysis of the overall slopes, pit design sectors were derived based on highwall orientation (dip direction) and on the thicknesses of the domains within each sector. Figure 16.6 illustrates the various design sectors of the fresh rock in the pit.

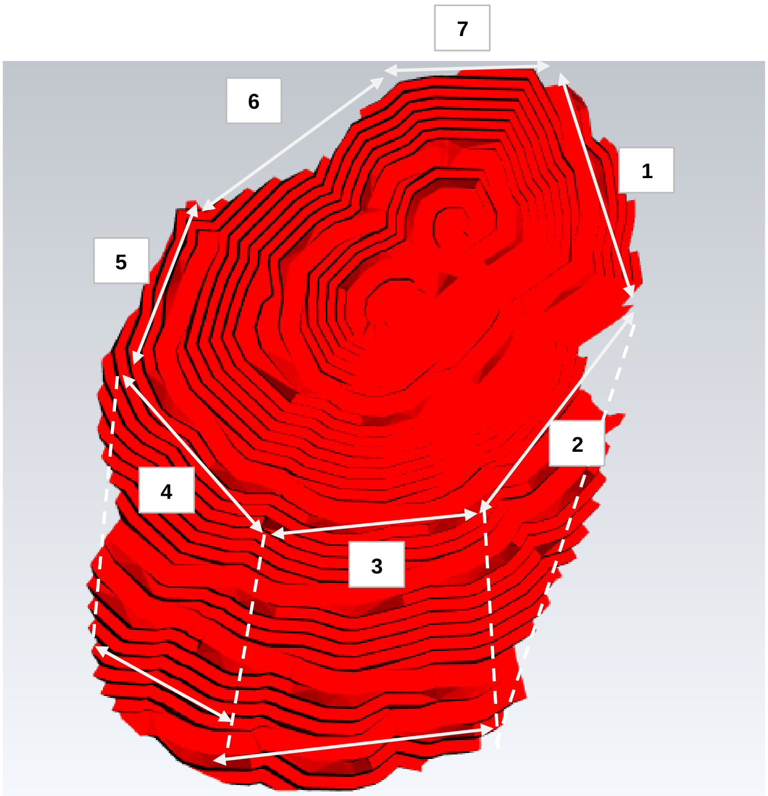


Figure 16.6: Pit Shell Layout Showing Design Sectors of Fresh Material

16.2.5.1 Slope Design Methodology

16.2.5.1.1 Limit Equilibrium Analysis

The Rocscience Slide program was used to derive the stable bench face angles for the weathered and poor-quality domains. Slide provides FOS and probability of failure (POF) as a measure of stability (or instability) and uses Mohr-Coulomb or Hoek-Brown as input parameters. For the probabilistic analysis, random variables with their statistical parameters were specified.

For Songwe Hill, the weathered material extends up to 15 m in thickness while the poor-quality material extends up to 30 m in thickness. The bench heights for weathered and poor-quality domains were fixed at 10 m. The BFA was varied from 90° to 70°. The models were simulated using completely saturated conditions.

Rock samples could not be tested for the weathered and poor-quality domains due to difficulty in obtaining intact samples. The shear strength properties (cohesion and friction angle) were therefore derived using the lowest UCS value from the rock test results and the GSI for the weathered domain from the logging data. A cohesion and friction angle of 760 kPa and 24.38°, respectively, were assigned to the weathered and poor-quality domains.

The input properties for the transitional and trans-fresh domains incorporated into the Slide models were derived from the analysis of laboratory test results presented in Table 16.4.

16.2.5.1.2 Kinematic and Deterministic Analysis

As previously stated, the Songwe Hill rock mass is dominated by transitional and trans-fresh domains. This suggests that pit slope stability will be controlled by the orientation of discontinuities rather than intact material strength. Three basic failure mechanisms are studied for rock slopes: plane failure, wedge failure, and toppling failure. As previously stated, the dominant mode of failure was wedge failure.

Kinematic analysis is the analysis of the relevant discontinuity data using stereographic projections. Rocscience Dips was used to assess the stability conditions of the transitional and trans-fresh domains at Songwe Hill to determine stable bench face angles. Major joint sets for the rock mass were identified using the relevant structural data as presented in the earlier sections.

The stability of the rock mass for each design sector was analysed using the dip direction of each sector's highwall.

The stability of the fresh material was initially analysed using Rocscience Dips and thereafter where wedge failure was likely to occur, the domains were further analysed using Rocscience SWedge, which is a deterministic analysis program. SWedge was chosen for the analysis based on the program's ability to provide FOS and POF as a measure of stability (or instability) for potential failures; Dips does not provide FOS but rather provides the percentage of poles plotting within the failure zone.

16.2.5.1.3 Seismic Coefficient

In addition to the input properties discussed above, a seismic coefficient was included in the limit equilibrium (Slide) and deterministic (SWedge) analyses. Seismic coefficients are dimensionless coefficients which represent the PGA as a fraction of the acceleration due to gravity, or $k_s = a_c/g$. Typical values are in the range of 0.1 to 0.3 (Rocscience Slide, 2017). PGA values of up to 1.3 m/s^2 can be expected for Malawi (Chapola, 2001), which equate to a k_s of 0.13.

16.2.5.2 Slope Engineering Results

This section presents the bench heights, bench face angles, bench widths, and overall slope angles derived from the slope engineering procedures as discussed in previous sections.

16.2.5.2.1 Bench Height

Mining equipment used to drill and blast the rock determines the bench height. Currently, most large mining operations adopt 10 m to 15 m bench heights. For the Songwe Hill open pit, a maximum of 10 m bench heights were adopted based on the PFS mine design criteria.

16.2.5.2.2 Bench Face Angles

Based on the SWedge analysis results, a bench face angle of 70° is suggested for both transitional and trans-fresh domains.

Since it is deemed impractical and uneconomical to completely eliminate all failures, it is suggested that operational protocols be implemented to monitor the behaviour of the rock mass in relation to the potential failures.

16.2.5.2.3 Bench Widths

The bench widths for all domains were determined empirically by using the following formula:

$$\boldsymbol{Bench\ Width} = \sqrt[3]{(\boldsymbol{FailureVolume} \times \boldsymbol{Bulking\ Factor})}$$

Equation 1
(Holley et al., 2006)

The slice weights of potential failure were derived from Rocscience SWedge and Slide, which were used to calculate the failure volume (see Equation 2).

$$\boldsymbol{Failure\ volume} = \boldsymbol{Mass}\ \div \boldsymbol{Density}$$

Equation 2

For the individual transitional and trans-fresh benches (spill benches), failure volumes were extracted from SWedge. For weathered spill benches and geotechnical berms (catch benches) between stacks, the failure volumes were derived from Slide.

For the weathered and poor-quality domains, 5 m spill bench and 10 m geotechnical bench widths (catch bench) are suggested. Spill benches are implemented after every single bench, while geotechnical benches are wider and are implemented after every stack. For the transitional domain, spill bench widths range from 5 m to 9 m with geotechnical bench widths ranging from 10 m to 12.5 m. For the trans-fresh domain, spill bench widths of 5 m to 8.5 m are suggested, with geotechnical bench widths of 9 m to 15 m, depending on the stack heights.

16.2.5.3 Overall Slope Angles

Overall slope angles range from 39° to 47°. The mean FOS obtained for the overall slope stability of the final wall designs ranged between 2.05 and 4.09, which were above the threshold criteria of 1.5 as stipulated.

16.2.5.4 Slope Configurations

The final slope configurations for the seven design sectors within the pit are summarised in Table 16.10. The slope diagrams for each design sector are depicted in Figure 16.7 to Figure 16.12.

Table 16.10: Summary of Slope Configurations

Design Sector	Stack No.	Geotechnical Domain	No. of Benches	Bench Face Angle (°)	Max. Bench Height (m)	Min. Bench Width (m)	Geotechnical Bench Width (m)	Stack Angle (°)	Overall Slope Angle (°)
1	1	Weathered, Trans-Fresh	5	70	10	5	12	49	47
	2	Transitional	4			5	12.5	49	
	3	Transitional	3			5	Pit floor	49	
2	1	Weathered	2	70	10	5	10	49	44
	2	Trans-Fresh	3			5.5	9	48	

Design Sector	Stack No.	Geotechnical Domain	No. of Benches	Bench Face Angle (°)	Max. Bench Height (m)	Min. Bench Width (m)	Geotechnical Bench Width (m)	Stack Angle (°)	Overall Slope Angle (°)
	3	Trans-Fresh	4			5.5	12	48	
	4	Transitional	3			6	10	46	
	5	Transitional	5			6	Pit floor	44	
	1	Weathered	2			5	10	49	
	2	Transitional	4			8	12.5	41	
	3	Trans-Fresh	4			7.5	12	42	
	4	Transitional	4			8	12	37	
3 and 4	5	Poor Quality	3	70	10	5	10	49	40
	6	Trans-Fresh	4			7.5	12	42	
	7	Trans-Fresh	3			7.5	9	42	
	8	Transitional	4			8	12.5	41	
	9	Transitional	3			8	Pit floor	41	
5	1	Weathered, Trans-Fresh	6	70	10	5	15	45	42
	2	Transitional	4			7	12.5	43	
	3	Transitional	4			7	Pit floor	43	
6	1	Weathered, Trans-Fresh	6	70	10	5	15	45	43
	2	Transitional	4			6	12.5	46	
	3	Transitional	3			6	Pit floor	46	
7	1	Weathered, Trans-Fresh	5	70	10	8.5	12	39	39
	2	Transitional	6			9	Pit floor	36	

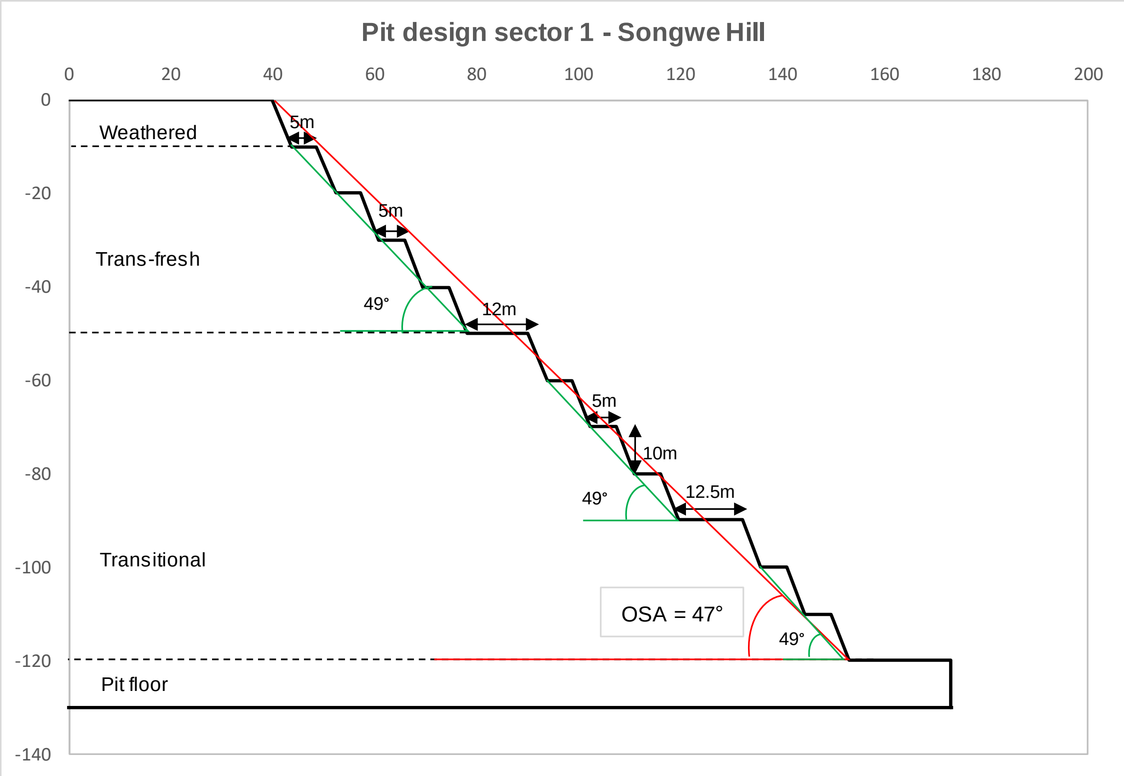


Figure 16.7: Diagram Showing Slope Geometry for Sector 1

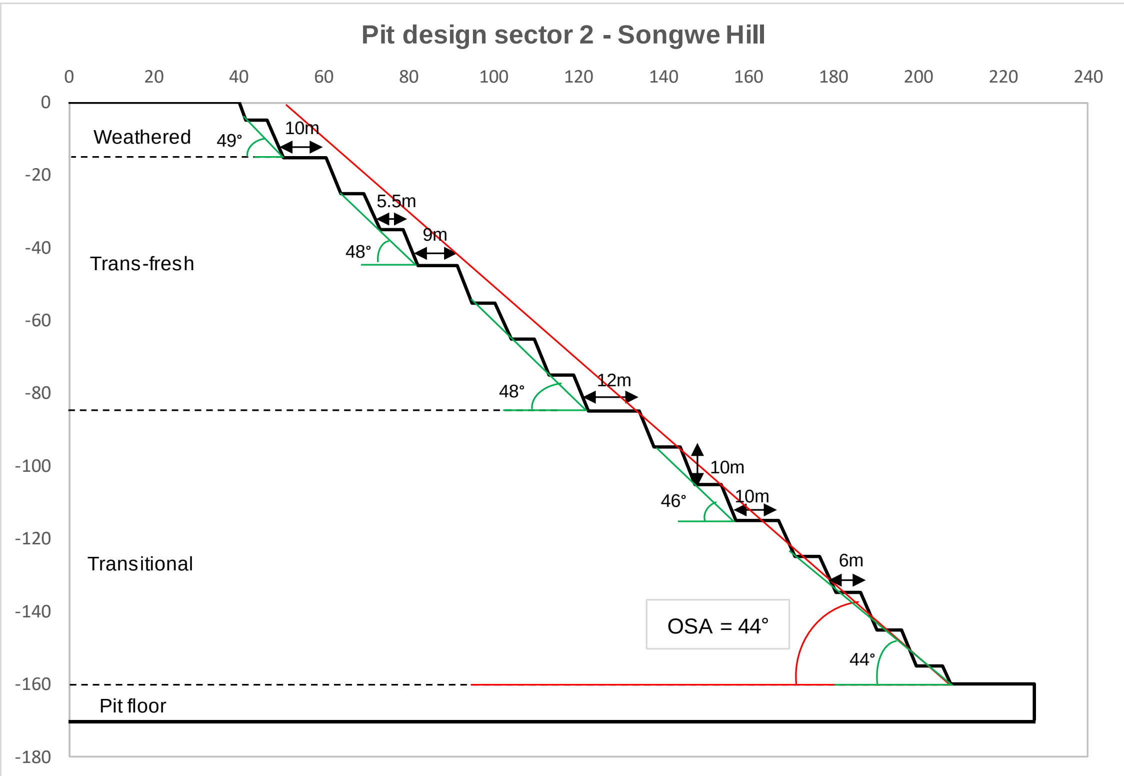


Figure 16.8: Diagram Showing Slope Geometry for Sector 2

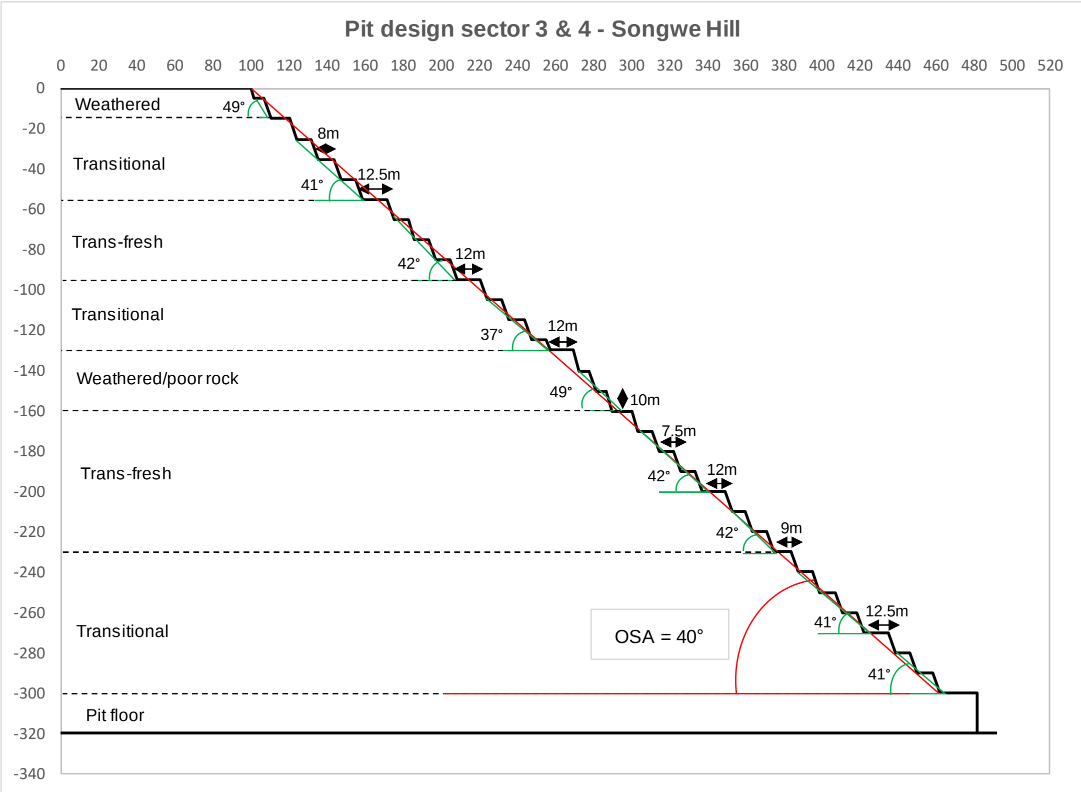


Figure 16.9: Diagram Showing Slope Geometry for Sectors 3 and 4

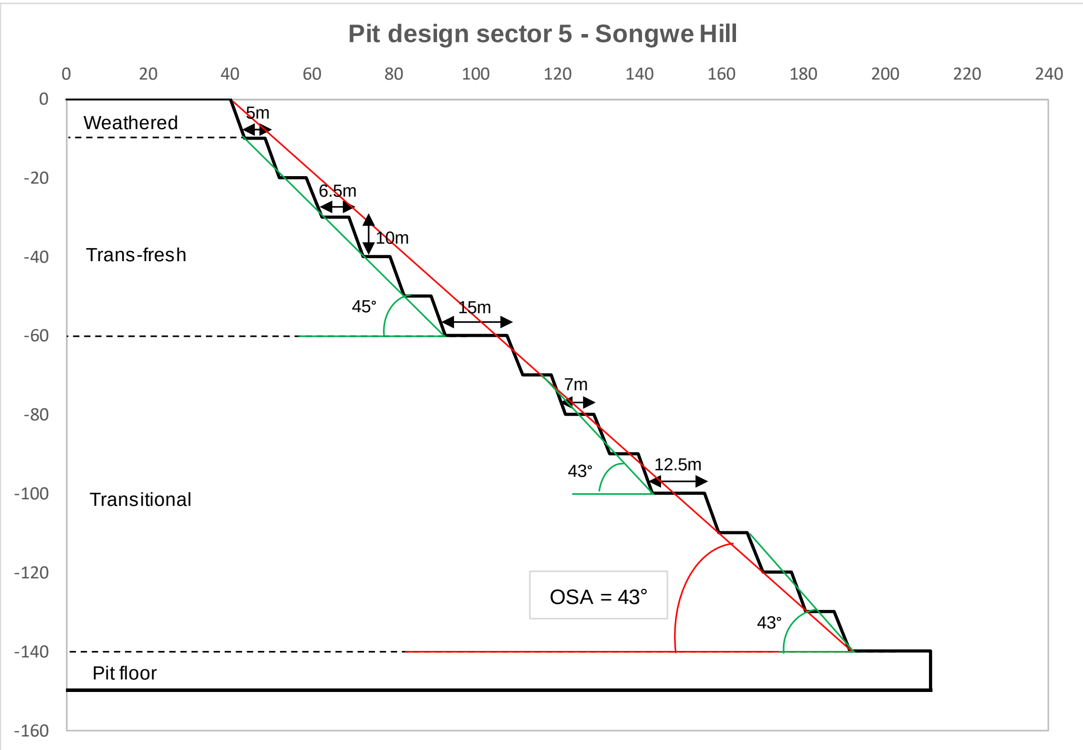


Figure 16.10: Diagram Showing Slope Geometry for Sector 5

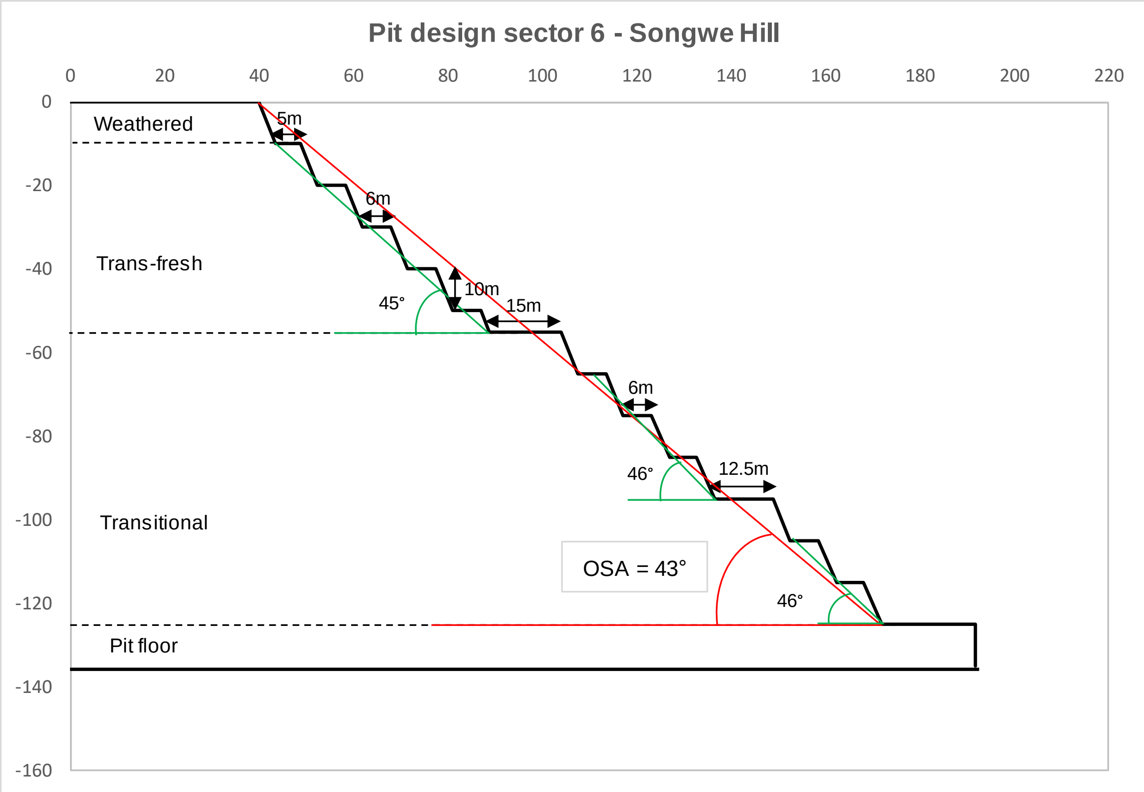


Figure 16.11: Diagram Showing Slope Geometry for Sector 6

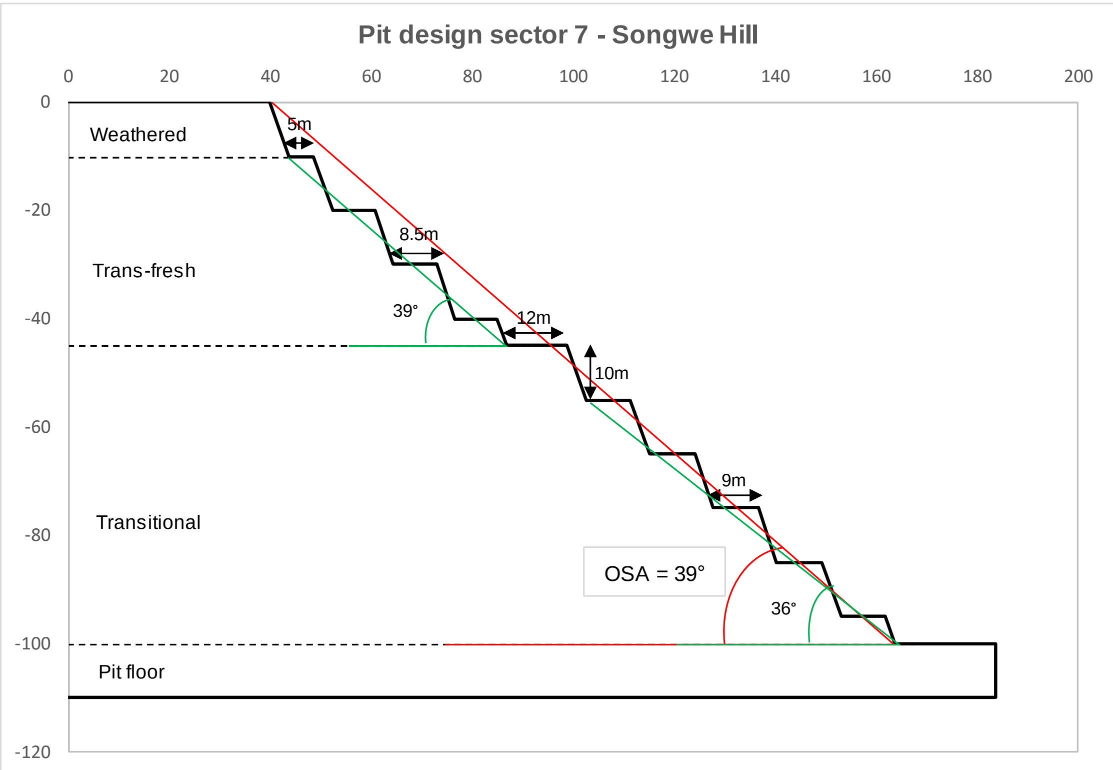


Figure 16.12: Diagram Showing Slope Geometry for Sector 7

16.3 MINE OPERATION

The mining operation at Songwe Hill will be outsourced to a contract mining company. Ore and waste will be drilled and blasted, then excavated using a hydraulic shovel and loaded onto dump trucks for hauling out of the pit to the ROM stockpile or waste dumps.

Waste will be transported to the waste dump sites, which are either the tailings storage facility (TSF) or the designated waste dump. The waste rock will be used for the construction of the outer wall of the tailings dam. During early mining and site construction, a limited amount of waste will be used as construction material and fill.

Ore will be transported to the ROM pad adjacent to the processing plant in preparation for feeding to the plant, or to the medium-grade stockpile area adjacent to the pit. Ore will be placed in specific low- and high-grade stockpile areas on the ROM pad. The ore will be fed into the primary crusher using a front-end loader (FEL). Blending of the ore and feeding of the crusher will be the responsibility of the plant operations personnel.

Waste and ore will be transported from the pit to the waste dump, ROM pad or stockpile by dump trucks of 40 t capacity. Loading and hauling of waste will be a two-shift-per-day operation while mining of ore will be carried out during the day shift only, to allow for effective grade control to be maintained.

A number of contractors have been approached and have submitted proposals to Mkango for the operation of the open-pit mining based on these shift cycles and working arrangements.

16.3.1 Drill and Blast

It is expected that all ore and waste will require drilling and blasting. The geological logs, as well as observations on site, show very little weathered overburden which will not require blasting.

Blast designs were completed for both ore and waste assuming the rock characteristics described in Section 16.2. The Kuz-Ram equation was used to estimate the powder factor required to achieve a specific particle size distribution of the blasted muck pile. The input parameters used in the estimate for waste and ore are as follows:

- UCS – 135 MPa
- Poisson's ratio – 0.3

The blast design for ore targeted 50 % passing 270 mm and 100 % passing 1.0 m. For waste blasting, the target is 100 % passing 1.5 m.

This resulted in the blast designs given in Table 16.11.

Table 16.11: Drill and Blast Design

Item	Value	
	Waste	Ore
Bench height (m)	10	10
Hole diameter (mm)	152	127
Subdrill (m)	1.5	1.5

Item	Value	
	Waste	Ore
Hole depth (m)	11.5	11.5
Powder factor (kg/m^3)	0.5	0.7
Bulk explosive SG (t/m^3)	1.05	1.05
Charge length (m)	9.22	9.60
Charge per hole (kg)	176	128
Metres cubed broken per hole (m^3)	351	182
SG (in situ) (t/m^3)	2.73	2.90
Tonnes blasted per hole (t)	959	528
Area per hole (m^2)	35.1	18.2
Spacing to burden ratio	1.2	1.2
Burden (m)	5.4	3.9
Spacing (m)	6.5	4.7
Broken tonnes per metre drilled (t/m drilled)	83	46

The drill rig specified by the Mining Contractor is a Sandvik Pantera 1500. This rig is capable of drilling both 152 mm and 127 mm diameter holes.

The design powder factor is 0.5 t/m^3 and 0.7 t/m^3 for wase and ore, respectively.

Bulk emulsion explosives and the associated initiation systems will be provided by a service provider in Malawi. The product will be imported from Zambia where a number of explosives suppliers have manufacturing facilities and distribution hubs.

16.3.2 Load and Haul

The mining will be done by contractors using 90 t excavators loading into 40 t articulated dump trucks. The specifications of a Caterpillar 740B ADT were used to determine the truck fleet size in a hauling route simulation model.

The material will be loaded and hauled via the required routes to either the plant, waste dump or stockpiles, to determine the cycle times and number of trucks required for the operation.

Material from the pit will be hauled to one of five destinations. Waste will either be hauled to the wall of the tailings storage facility or to the designated waste dump. During periods of tailings facility wall construction, waste will be dumped on the tailings storage facility wall. All other waste will be placed on the designated waste dump.

Type 2 material will be hauled to the Type 2 material stockpile, situated on the north side of the waste dump.

In the first five years of mining, low-grade ore (less than 1.2 % TREO) will be placed on the medium-grade stockpile to the northeast of the pit. During this period, high-grade ore (greater than 1.2 % TREO) will be hauled directly to the ROM pad at the plant site.

From Year 6 onwards, the split of medium-grade ore sent directly to the plant or to the stockpile will be controlled by the grade control department to maintain a steady feed grade to the plant. High-grade ore will continue to be hauled directly to the plant from the pit.

In the final years of the LOO, from Year 15 onwards, open-pit mining is completed, and the only hauling that takes place is to move the medium-grade ore from the stockpile area to the plant.

Figure 16.13 shows the haul routes from the pit to the various material destinations.

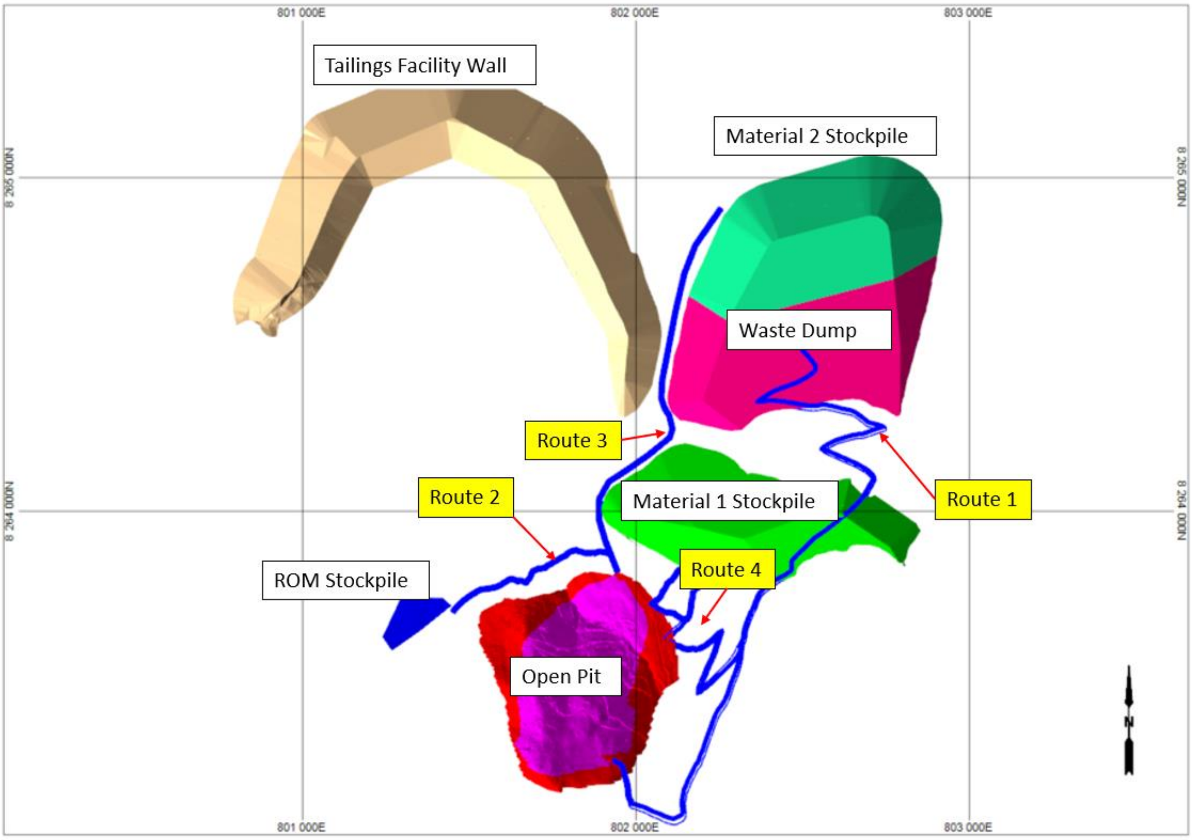


Figure 16.13: Haul Routes and Material Destinations

A haul route simulation was carried out using Deswik.LHS®. This allowed the average haul distances and haul route gradients to be calculated by period throughout the LOO.

16.3.3 Technical Services

Mining technical services on the mine will consist of the following functions:

- Geology and grade control
- Survey
- Mine planning

16.3.3.1 Grade Control

The geology department will provide a grade control service to the mining production teams.

Grade control drilling will be performed to provide sampling information, which will be used for the demarcation of the waste and ore boundaries and for evaluation of the ore blocks.

An allowance has been made in the operating cost model for the drilling of approximately 2,400 m per month of grade control holes. This will suffice for a spacing of 10 m × 10 m, with holes drilled to a depth of 30 m to cover three benches.

Prior to the mining of each flitch, the ore/waste boundary will be clearly marked by the geology department. Grade controllers will be on site at the point of loading at all times during the loading of ore.

On-site exploration and resource definition will also be undertaken by the site geological team.

A fully equipped assay laboratory will be established and operated on site. The laboratory will handle all regular plant and mining grade and quality control assay samples. The assay laboratory will be located in the vicinity of the plant and will be operated by an independent laboratory company. By far the largest number of samples that will be treated by the laboratory will be for plant control; however, the laboratory will handle all mining grade control samples as well.

16.3.3.2 Survey

The survey department will conduct routine surveys of the open pits, waste dumps, stockpiles and tailings storage facilities to comply with legal requirements and to ensure that adequate control over the operations is maintained. The mine surveyor will also conduct check surveys to confirm the quantities invoiced by the Mining Contractor.

16.3.3.3 Mine Planning

The mine planning function will ensure the optimal extraction of the orebody by providing planning assistance and guidance to the mining production teams. Short- and medium-term plans will be drawn up, evaluated, and implemented to ensure that the strategic plan of the mine is adhered to. The technical services function will monitor the mining of the ore and waste volumes, mined actuals versus planned, and reconcile the metal produced against the metal called for from the geological models to ensure that the grade control and grade estimation are continually improved.

16.4 IN-PIT SERVICES

16.4.1 Dewatering

The primary sources of water into the open-pit mine will be precipitation and groundwater.

16.4.1.1 Precipitation

Due to the topography of the open pit located on the side of Songwe Hill, precipitation water reporting into the mine will primary be from direct rainfall. Storm water diversion berms may be required on the eastern boundary to divert runoff water and prevent it from entering the pit.

Figure 16.14 to Figure 16.16 show the pit catchment areas in Years 2, 8, and 13, respectively. The runoff direction is indicated by the black arrows.

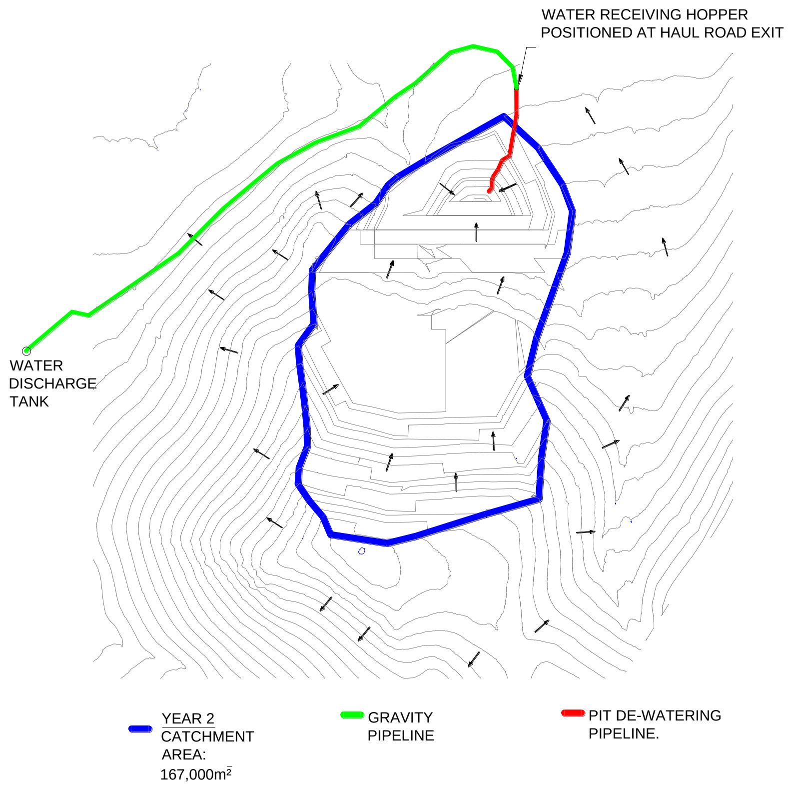


Figure 16.14: Pit Outline at Year 2

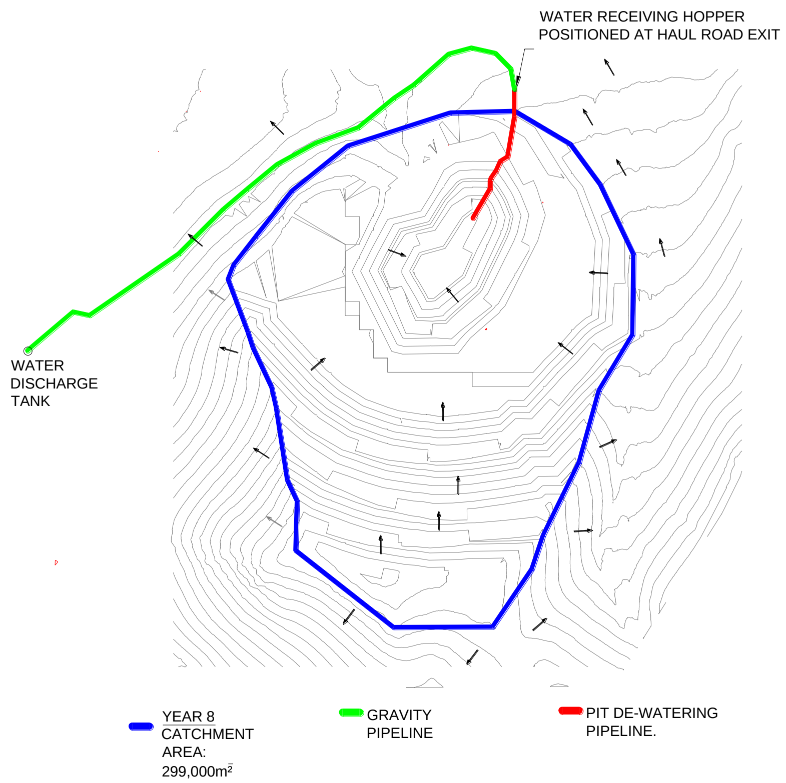


Figure 16.15: Pit Outline at Year 8

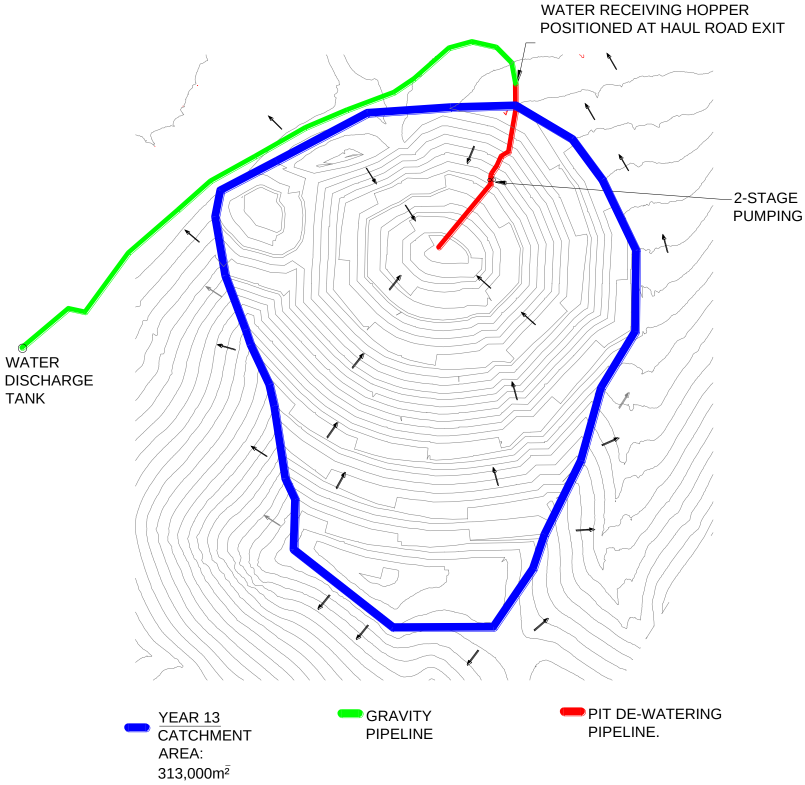


Figure 16.16: Pit Outline at Year 13

The pit catchment area increases up to approximately Year 8, whereafter the catchment area does not increase significantly, i.e. the volume of water reporting to the pit from precipitation remains consistent after Year 8.

After Year 8, the depth of the pit increases and will require an additional pumping stage to overcome the rise in the static head.

The average monthly rainfall was used to determine the volume of water that will report into the open pit over time and used to size the dewatering system.

It is impractical to attempt to match the inflow from a large storm event with the pumping system. As such, the mining sequence should ensure that a sufficiently sized sump is available at the lowest section of the pit to cater for summer storms. Water accumulating in the sump will be dewatered over a period of a few days as required by the plant operations.

Should an adequately sized sump not be available, machines and equipment in the mine pit must be moved to higher ground before or during a storm event. Procedures for this should be described in a code of practice developed by the mine.

16.4.1.2 Groundwater

The following extracts from the *Digby Wells 2021* are instructive:

- Pit dewatering will be minimal and may only be needed for the later years of mining, when mining of the pit nears the deepest part; this is not expected to have a significant impact on third-party groundwater supplies.
- The calculated range of potential pit inflows and years in which this may occur are not detailed enough for a DFS design of the pit sump pump requirements. If this design is required, a DFS-level groundwater study should be carried out to narrow the range of pit inflows.
- Groundwater in-pit inflows will likely vary between ~20 m^3/d and ~500 m^3/d for the last years of mining.

The dewatering design considered the most conservative estimate of 500 m^3/d at Year 13 and assumed 50 % of the maximum flow at Year 8.

16.4.1.3 Total Water Inflow

The average monthly volume of water into the mining pit from precipitation and groundwater for Year 2 and Year 13 is graphically shown in Figure 16.17 with the orange and blue lines, respectively.

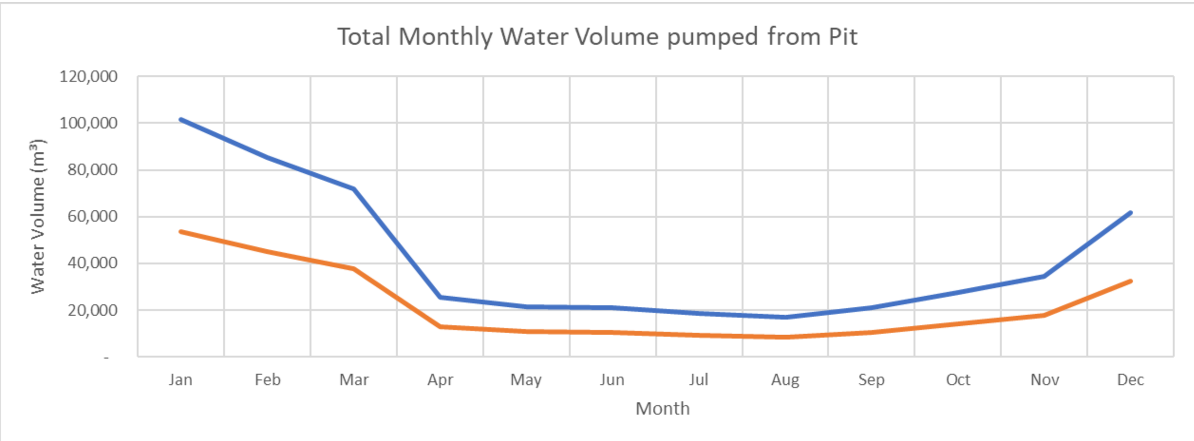


Figure 16.17: Monthly Water Inflow

16.4.1.4 Dewatering Configuration

Figure 16.18 shows the proposed dewatering configuration from initial mining to approximately Year 8.

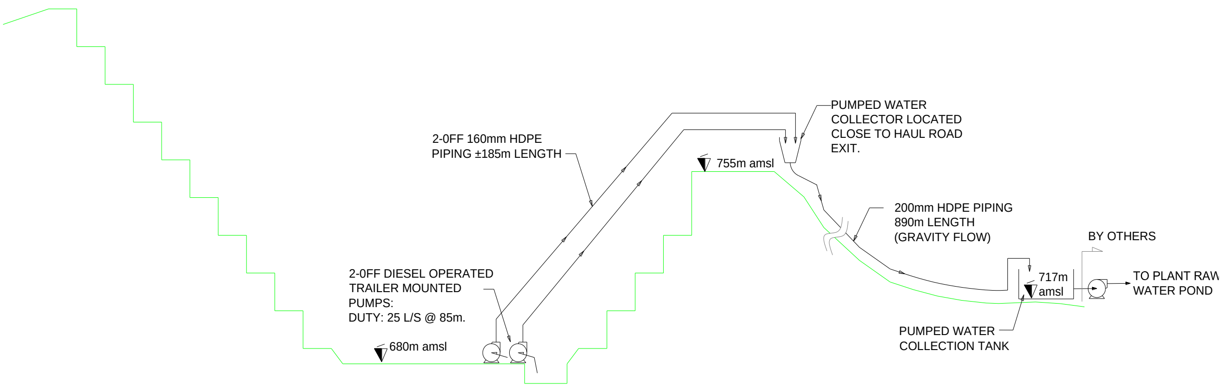


Figure 16.18: Flow Diagram up to Year 8

An additional pumping stage will be introduced when the pit is mined 75 m deeper than the truck haul road entrance. Figure 16.19 shows the proposed dewatering configuration from approximately Year 8 for the LOO.

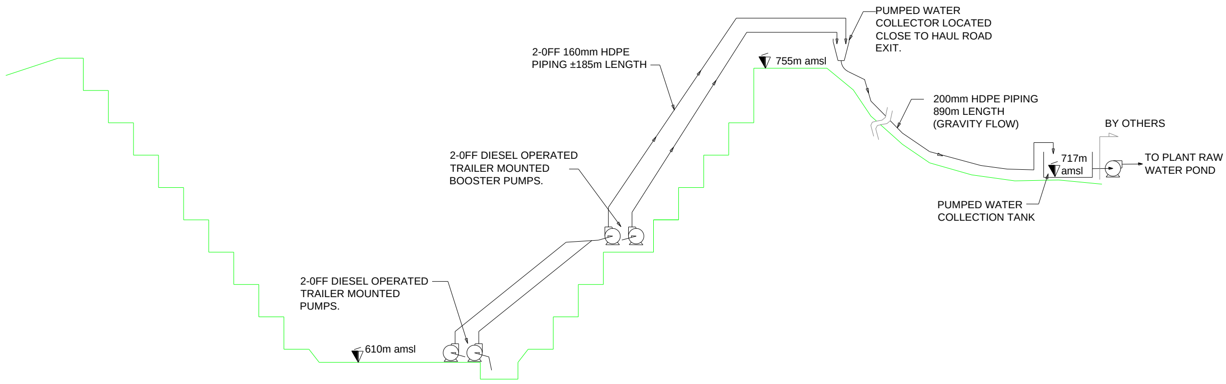


Figure 16.19: Flow Diagram from Year 8

Diesel-driven pumps were proposed for the project as diesel will be transported into the pit for refuelling the drills and the excavators and will negate the need for expensive power cables from surface operations to the pumps. In addition, electrical cables in the pit are at risk of blast damage.

Two operational pump sets, each with a pumping capacity of 25 L/s, will be provided. During the dry season, one pump will operate between 3 h/d and 10 h/d. During the peak rainy season, two pump sets will operate up to 20 h/d.

A pump water receiving hopper will be installed near the pit entrance next to the truck haul road. This receiving hopper will receive water from the operating pumps in the pit and channel the water under gravity into a dewatering pipeline to a tank located at the primary crusher. The plant operations will pump the water from this tank at the primary crusher to the plant raw water dam. This configuration was proposed to use the electrical power located at the primary crusher, avoiding routing electrical power to the pit rim.

16.4.2 Lighting

Lighting for night-shift operations will be by diesel-generated mobile units. The units will be supplied, operated, and maintained by the Mining Contractor.

16.5 WASTE DUMP AND STOCKPILES

16.5.1 Introduction

The mining of the REE resource at Songwe Hill will produce various grades of ore and waste rock.

Selected material types will be disposed of for permanent storage, whilst other types of mined material, namely ore (of different grades), will only require temporary storage to allow for future blending and processing.

The mined materials (excluding high-grade ore) that require storage include the following:

- Waste rock
- Medium-grade ore
- Type 2 material

The high-grade ore will be mined and transported directly from the pit to the ROM pad and blending area.

16.5.2 Design Criteria

Table 16.12 provides a summary of the design criteria for the selected mined materials storage facilities.

Table 16.12: Waste Rock and Ore Storage Facility Design Criteria

Design Criteria	Value	Unit	Source
Total waste rock tonnes	27	Mt	Bara
Waste rock bulk density	1.74	t/m^3	Bara
Total waste rock volume (LCM)	15.69	Mm^3	Bara
Volume of waste rock required for the TSF	5.50	Mm^3	Epoch Resources
Waste rock storage requirement	10.19	Mt	Calculation
Total medium-grade ore tonnes	6.60	Mt	Bara
Medium-grade ore bulk density	1.74	t/m^3	Bara
Medium-grade ore storage requirement	3.79	Mm^3	Calculation
Total Type 2 material tonnes	12.60	Mt	Bara
Type 2 material bulk density	1.76	t/m^3	Bara
Type 2 material storage requirement	7.16	Mm^3	Calculation

16.5.3 Site Selection

The selection of suitable sites for the storage of the various mined materials was guided by the following criteria:

- Avoid, as far as practical, all residential and environmentally sensitive or “no-go” areas.

- Minimise impact on groundwater and surface water resources.
- Avoid, where possible, all areas with cultural heritage significance, e.g. graveyards.
- Limit haul distances from the pit to the various material stockpiles.
- Accommodate the require volume of material.
- Effectively manage drainage and surface water.
- Ensure stable land forms during operation and post closure.
- Avoid close proximity to the Mozambican border located to the east of the mining area.

The general Songwe Hill project area is constrained with regard to available surface area. Following the positioning of the key major infrastructure areas, i.e. the processing plant and TSF, the remaining available area was assessed for the positioning of the ROM ore stockpile, waste rock dump, and Type 2 material stockpile. The general areas identified for the facilities are located northeast of the pit.

Following numerous volumetric modelling iterations, the medium-grade ore, waste rock and Type 2 material facilities were sized and positioned as described below.

16.5.3.1 Medium-Grade Ore Stockpile

The medium-grade ore stockpile is positioned against a hill, directly adjacent to the pit and close to the ROM pad. This is a stand-alone facility with its own water management measures.

16.5.3.2 Waste Rock Dump and Type 2 Material Stockpile

The area to the east of the TSF and northeast of the pit was identified as the preferred location for the waste rock dump and Type 2 material stockpile. The northern extent of the facility is bordered by the Phindani Cemetery. The Nazazi Cemetery is currently located within the proposed footprint for the waste rock dump and Type 2 material stockpile. Through a consultation process between Mkango, the ESHIA consultants and the community, it has been agreed to move the cemetery to an alternative location. In order to accommodate the waste rock and Type 2 material on the available footprint, the material will be co-disposed on the same facility. The waste rock will be disposed of on the southern portion of the facility, with the Type 2 material on the northern portion. The Type 2 material will be placed up against the waste rock, and the interface marked and surveyed.

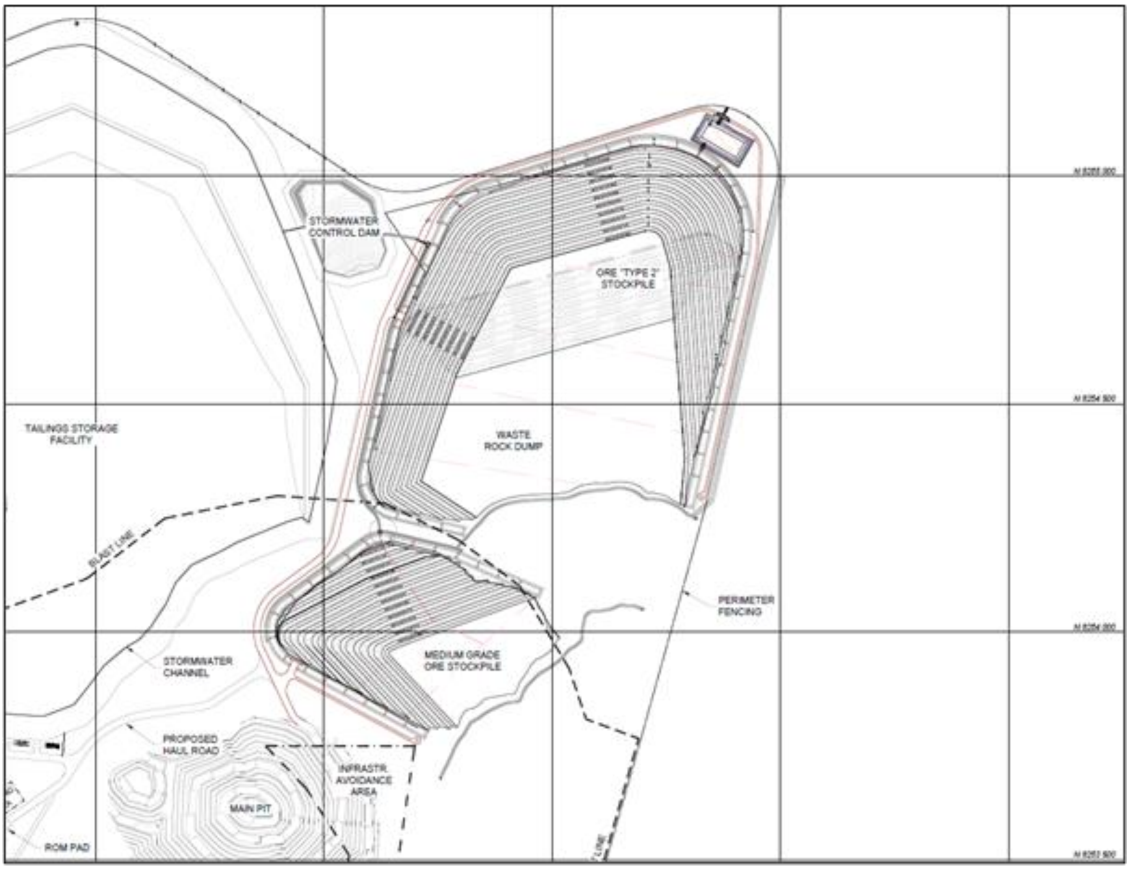


Figure 16.20: Positions of Mined Material Storage Facilities

16.5.4 Geotechnical Investigation

A geotechnical investigation has been undertaken by Zutari to evaluate the geotechnical conditions and provide recommendations for the development of the medium-grade ore stockpile, waste rock dump, and Type 2 material stockpile. The fieldwork was undertaken by Geoconsult and included the excavation of test pits and profiling of the near-surface soil horizons. Samples were collected for laboratory testing to determine the mechanical properties of the materials. Zutari then produced an interpretative report from the data collected during the fieldwork phase and laboratory testing.

The typical ground profiles associated with the material stockpiles and waste dump are described as follows:

- **Medium-Grade Ore Stockpile**
  The soil profile is associated with the hill slopes and is characterised by coarse materials and boulder beds. The material comprises gravels, cobbles, and boulders in a clayey-silty sandy matrix. The overall consistency is dense.

- **Waste Rock Dump and Type 2 Material Stockpile**
  The ground profile over this area varies as the footprint covers varied topography. The profile is comprised of gravels, cobbles, and boulders in a clayey-silty sandy matrix against the hill side. The lower-lying area is underlain by deep sandy silty clays with

some gravels, cobbles and boulders and extends to a depth of 5 m. A portion of the footprint at the base of the hill has a typical profile comprising a firm sandy silty clay horizon, underlain by dense ferricrete and gravels in a silty sandy matrix, with cobbles and boulders in places. Below this depth, firm to stiff sandy silty clays, with pockets of ferricrete and gravels, are present.

No groundwater was encountered in any of the test pits.

The near-surface materials classify as clayey sands with gravels and clayey gravels, with clay contents ranging from 5 % to 19 %, and are of medium plasticity.

The mechanical laboratory testing results indicate maximum dry densities ranging between 1,805 kg/m^3 and 1,960 kg/m^3, with optimum moisture contents ranging between 8.8 % and 11.7 % for the gravelly soils. The finer, sandy silty materials have maximum dry densities ranging between 1,908 kg/m^3 and 1,990 kg/m^3 at optimum moisture contents of between 7.5 % and 12.3 %.

The permeability of the gravelly materials is expected to be medium to low with the finer material expected to have low to very low permeability.

The mechanical behaviour is described in terms of its COLTO (Committee of Land Transport Officials) classification, which ranges from a G7 to G9, all natural gravelly and sandy soils. The gravelly soils (G7) are considered suitable for use as a selected material in pavement layer works and engineered fills. The finer materials (G9) are not suitable for construction of engineered fills.

The suggested ground model for the medium-grade ore stockpile, waste rock dump, and Type 2 material stockpile areas was presented by Zutari in terms of mechanical properties.

16.5.5 Waste Rock Geochemical Characterisation

The anticipated waste rock from the Songwe Hill REE Project is comprised of fenite, fenite breccia and phonolite, with minor proportions of overburden, syenite and oxidised material. The waste rock has been shown, from the laboratory testing conducted, to be non-acid generating, owing to the abundance of neutralising carbonate minerals and lack of sulphidic minerals.

Geochemical characterisation of the Type 2 material has shown that it is non-acid generating due to its low sulphur content (0.01 %) and high acid neutralisation capacity (380 kg $CaCO_3$/t) (see Digby Wells report: Songwe SP0803 Type 2 material ABA and Sulphur specification).

16.5.6 Slope Stability and Seepage Analyses

The stability of the medium-grade ore stockpile, waste rock dump, and Type 2 material stockpile will be assessed in the detailed design phase when the in-situ shear strength and permeability parameters will be determined.

16.5.7 Design

16.5.7.1 Operational Plan

16.5.7.1.1 Low-Grade Ore Stockpile

The low-grade ore will be trucked from the pit to the low-grade ore stockpile located adjacent to the pit for temporary storage. During the operational period, the medium-grade ore will periodically be reclaimed from the stockpile and trucked to the ROM pad and blending area.

16.5.7.1.2 Waste Rock Dump and Type 2 Material Stockpile

The waste rock will be trucked from the pit to the waste rock dump, which has been allocated the southern portion of the waste rock dump and Type 2 material stockpile. The waste rock will initially be deposited at the northern extent of its footprint and progress in a southern direction up against the hill. The waste rock is not expected to be moved in future, and the waste rock dump is considered to be final in its proposed position.

The Type 2 material will be deposited on the northern portion of the waste rock dump and Type 2 material stockpile. The material will initially be deposited at the northern extent of its allocated footprint and develop in a southern direction. The Type 2 material will ultimately be deposited up against the waste rock dump.

The waste rock and Type 2 material storage configuration is such that the Type 2 material can be reclaimed in the future for processing, should it be deemed feasible at the time. The remainder of the facility (i.e. the waste rock dump) can be rehabilitated in situ and against the hill as a single landform. Should the Type 2 material not be processed, then the facility in its entirety can be rehabilitated as a single landform.

In order to distinguish between the two materials when removing the Type 2 material, the interface will need to be surveyed. The alternative is to install a physical barrier such as a thin layer of material that is different in terms of physical or visual properties, i.e. different in colour, different in grading. A geosynthetic material, e.g. geotextile can also be used.

16.5.7.2 Layout and Geometry

16.5.7.2.1 ROM Stockpile

The medium-grade stockpile will cover a total footprint of 16 ha against the steep hillside adjacent to the pit. The facility will have a maximum capacity of 4.05 Mm^3, which translates into a tonnage of 7.05 Mt. The peak volumetric capacity requirement is 3.79 Mm^3. The material will be deposited in 7.5 m lifts, with 7.5 m wide benches and intermediate slide slopes of 1V:1.5H. The maximum downstream height is 95 m. The intention is to place the medium-grade material on the ROM stockpile for temporary storage before removal for further blending at the ROM pad with high-grade material. The final capacity of the medium-grade ore stockpile is therefore variable over time.

16.5.7.2.2 Waste Rock Dump and Type 2 Material Stockpile

The combined waste rock dump and Type 2 material stockpile will be developed similarly to the medium-grade ore stockpile, with 7.5 m lifts, 7.5 m wide benches and intermediate slide slopes of 1V:1.5H. The waste rock dump will cover a footprint (natural ground) of approximately 36 ha, with a final downstream height of 64 m. The Type 2 material stockpile will cover a natural ground footprint of approximately 14.7 ha, with a final downstream height of 75 m. The storage capacities of the waste rock dump and the Type 2 material stockpile are summarised below:

- Waste rock dump: 10.26 Mm^3/17.85 Mt
- Type 2 material stockpile: 7.45 Mm^3/13.1 Mt

16.5.7.3 Preparatory Works

16.5.7.3.1 Basal Layer

Following the removal of the vegetation and the topsoil layer over the footprints of the facilities, the basal layer will be prepared by scarification of the top 200 mm (where possible) and recompaction to a 93 % MOD AASHTO density. The geotechnical investigation will confirm the near-surface profile and the physical properties of the soils to be recompacted.

16.5.7.3.2 Containment

Each of the facilities will include a toe embankment wall behind which the material will be deposited. The waste rock dump toe wall will also indicate the division between the waste rock dump and the Type 2 material stockpile at ground level. The toe wall will be constructed from selected fill material to a height of 1.5 m, with side slopes of 1V:1.5H and with a crest width of 2 m.

16.5.7.4 Underdrainage System

An underdrainage system is proposed for each of the facilities to reduce seepage to the groundwater and to maximise the collection of water from the facilities for reuse in the process water circuit.

The underdrainage system will comprise the following aspects:

- Slotted uPVC Class SN4 pipes will be positioned across the basins of each of the facilities to collect seepage through the material and surface runoff during the early stages.
- The slotted pipes will be covered with a 250 mm layer of selected crushed waste rock, overlain by an additional layer of protective waste rock. The placed layers of rock will function as a coarse filter and protect the pipeline against initial traffic from haul trucks depositing the material.
- The slotted pipes will transition to a solid pipe section to convey collected seepage and runoff to the perimeter solution trench.

16.5.7.5 Surface Water Management

It will be required to maximise the collection of any rainfall runoff from dirty water areas for use in the process water circuit. The majority of the make-up water is sourced from a well field; therefore, additional water harvested from the runoff is advantageous.

Runoff from the ROM ore stockpile, waste rock dump and Type 2 material stockpile will be collected in perimeter catchment paddocks. The paddocks are 10 m wide and 50 m long, with the catchment paddock walls and division walls constructed from selected material to 1.5 m and 1 m, respectively. Each paddock will include a paddock drain comprising a 300 ND reinforced concrete spigot and socket that will drain the collected runoff and direct rainfall either into the perimeter solution trench or into the next paddock downstream. Areas with a very steep gradient will have paddocks drain into the next paddock instead of directly into the solution trench, which is positioned on the perimeter of the ROM ore stockpile, waste rock dump and Type 2 material stockpile. The trench is lined with 150 mm thick grouted stone pitching, has a depth of 1 m, side slopes of 1V:1.5, and a basin width of 1 m. The purpose of the solution trench is to collect all the water from the medium-grade ore stockpile, waste rock dump and Type 2 material stockpile (drainage and runoff) and convey it to the appropriate containment facility (e.g. return water dam and waste rock dump and Type 2 material stockpile storm water control dam (SWCD)).

16.5.7.5.1 ROM Stockpile Surface Water Management

Runoff collected from the catchment paddocks and drainage collected from the underdrainage system will be conveyed in the perimeter solution trench to a stilling basin located at the northern corner of the facility. The stilling basin is comprised of a reinforced concrete box with plan dimensions of 6 m by 6 m, and a total depth of 2 m. The stilling basin will collect sediment over time and will require periodic emptying and then cleaning. From the stilling basin, all the water collected from the ROM stockpile will flow in a northern direction via another solution trench, which becomes the solution trench for the waste rock dump and Type 2 material stockpile along its western perimeter.

16.5.7.5.2 Waste Rock Dump and Type 2 Material Stockpile Surface Water Management

The western perimeter solution trench receives runoff from the western perimeter catchment paddocks of the waste rock dump and the drainage from the waste rock dump and Type 2 material stockpile underdrainage system, apart from the northernmost drainage line. This solution trench terminates in a stilling basin (Stilling Basin 2) located east of the return water dam. The stilling basin is comprised of a reinforced concrete box with plan dimensions of 6 m by 10 m, and a total depth of 2 m. From the stilling basin, collected runoff and drainage from the ROM stockpile and a portion of the waste rock dump and Type 2 material stockpile are conveyed to the return water dam via a culvert and a solution trench.

The eastern and northern perimeter solution trenches of the waste rock dump and Type 2 material stockpile collect runoff from the eastern and northern catchment paddocks and the northern underdrainage line, and terminate in Stilling Basin 1, situated on the north-eastern perimeter. Similar to the ROM stockpile stilling basin, Stilling Basin 2 is comprised of a reinforced concrete box with plan dimensions of 6 m by 6 m, and a total depth of 2 m. From the silt trap, collected water flows into the waste rock dump and Type 2 material stockpile SWCD. Water collected in the SWCD is intended for reuse in the process water circuit.

The waste rock dump SWCD has the following design parameters:

- Capacity: 8,000 m^3
- Freeboard: 0.8 m
- Internal side slopes: 1V:3H
- Maximum depth: 3.3 m

The barrier system of the facility will include the following components:

- Primary liner comprising a 1.5 mm HDPE geomembrane
- Layer of low-permeability in-situ compacted material, assumed to be clayey sand
- Underdrainage and monitoring system comprising perforated drainage pipe, encased in 19 mm stone
- Drainage manhole, to which the underdrainage and monitoring system report

In the event of excess water being collected in the SWCD, the water will be discharged via a concrete-lined emergency spillway into the downstream receiving environment. The spillway will lead to a drift crossing and then into an energy dissipation structure (rough stone pitching with rock protrusions) to disperse the water before it discharges into the downstream environment.

16.5.7.6 Storm Water Management

The waste rock dump, Type 2 material stockpile and ROM stockpile are all positioned on the side of a hill and also at the downstream end of a large natural catchment area to the south of the facilities. It is required to divert any clean water away from the facilities and return it to the natural environment downstream of the facilities. Best practice regarding storm water management requires the separation of clean and dirty water systems. Storm water management measures are required to accommodate a precipitation event with a selected return period and magnitude. The design storm event selected for the storm water management measures is the 1:50-year 24 h storm event (Digby Wells, 2021). The magnitude of the storm has been determined as 148 mm (Digby Wells, 2021).

In order to divert clean storm water runoff from the upstream catchment, a series of storm water diversion berms and channels are positioned upstream of the waste rock dump, Type 2 material stockpile and ROM stockpile. The general direction of the diversion is to the northeast, with the ultimate position of clean storm water discharge at the north-eastern corner of the waste rock dump and Type 2 material stockpile.

Each diversion measure will comprise a channel lined with light, naturally established vegetation such as short grass, with a constructed berm on the downstream side of the channel. The channels are 1 m deep with 1V:1.5 side slopes and basin widths ranging from 1 m to 3 m. Each of the channel sections will terminate in an energy dissipator comprised of rough stone pitching to reduce the velocity of the diverted storm water and mitigate soil erosion.

The channels and berms will require seasonal maintenance to ensure that the channels are kept free of large debris or excessive silt build-up which could influence the hydraulic function and capacity of the channels. Erosion gulleys may also have to be repaired following rainfall and erosion events.

There are a few locations where culvert structures are required to allow for the conveyance of surface water runoff from the facilities and diverted storm water from natural upstream catchments.

16.5.8 Rehabilitation and Closure

The ROM stockpile will be an active facility throughout the operational period as material is placed and removed over time. Rehabilitation activities will include the removal of concrete and uPVC pipes and stone pitching etc. The remaining material will be graded over the site and mixed with topsoil to encourage the growth of vegetation at closure.

The economic feasibility of the removal and processing of Type 2 material will be determined at a later stage. Regardless of which material is left on the waste rock dump and Type 2 material stockpile, the following rehabilitation activities are envisaged:

- Push the intermediate slope angles of the benches down to 1V:2.5H.
- Blend topsoil with the waste rock on the surface of the final landform.
- Establish vegetation by hydroseeding.
- Reshape the crest to promote runoff.
- Remove any concrete and stone pitching, HDPE geomembrane and drainage materials, and mechanical and electrical equipment if applicable.
- Where possible, grade and blend the remainder of the disturbed surface areas with topsoil to encourage the growth of vegetation.

16.6 MINE SCHEDULING

16.6.1 Schedule Parameters

ROM feed to the crusher was planned at a rate of 1,000,000 t/a. To keep the stripping ratios as low as possible, the high-grade pit was mined first, as the first phase of mining. This pit targets material with a TREO_PCT above 1.5 % or as close as possible for a period of five years. Material below the Phase 1 cut-off grade of 1.2 % will be stockpiled on a medium-grade stockpile close to the pit exit to the east on the Type 1 ore stockpile.

16.6.2 Production Requirements

The production rates for the mining schedule build up to 800,000 t per month for the first 12 months to access sufficient high-grade material to meet the plant feed requirements. The following five years are mined at a nominal 500,000 t per month, after which the required mining rate is 300,000 t per month. The stockpiled material will be processed for a further five to six years.

The loading rates have been determined as 6,000 t/d and 10,000 t/d per team. Three teams will be required for the first year with two teams doing 10,000 t/d and one team doing 6,000 t/d. One team can be removed after the first year, and then the smaller of the remaining two teams can be removed after Year 6 of production. A total of 18,25 Mt of ROM ore is mined at an overall average TREO_PCT grade of 1.16 %. The processing inventory is given in Table 16.13.

Table 16.13: Processing Tonnage and Grade

Processing	Unit	6 Years	Total
Total Throughput	t	5,187,400	18,147,781
Total TREO ROM Grade	% TREO	1.50	1.16
Total TREO Recovered Grade	% TREO	0.53	0.41
High Grade – Tonnage	t	5,005,600	8,092,786
High Grade – TREO Content	t	7,654,506	12,245,942
High Grade – TREO ROM Grade	% TREO	1.53	1.51
High Grade – TREO Recovered Grade	% TREO	0.54	0.54
Medium Grade – Tonnage	t	181,800	10,054,995
Medium Grade – TREO Content	t	146,557	8,852,439
Medium Grade – TREO ROM Grade	% TREO	0.81	0.88
Medium Grade – TREO Recovered Grade	% TREO	0.29	0.31

Figure 16.21 and Figure 16.22 show a graph of the production from the open pit by material type by year and by month, respectively.

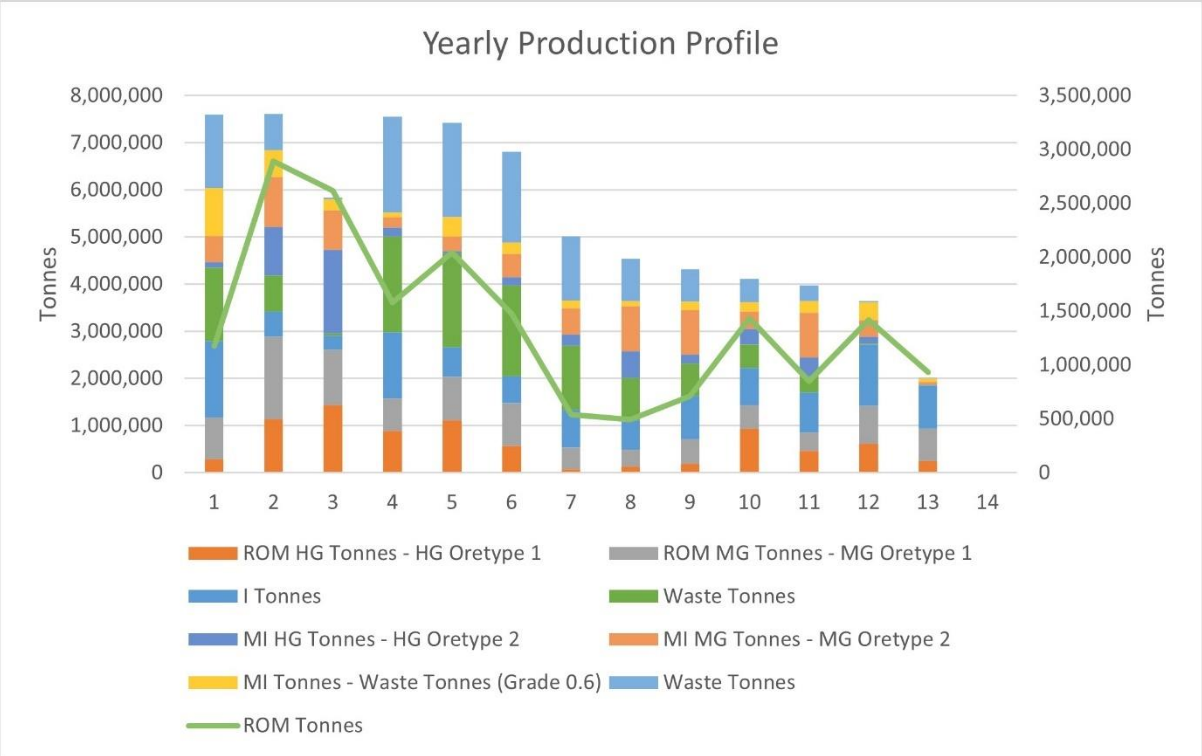


Figure 16.21: Yearly Production Profile

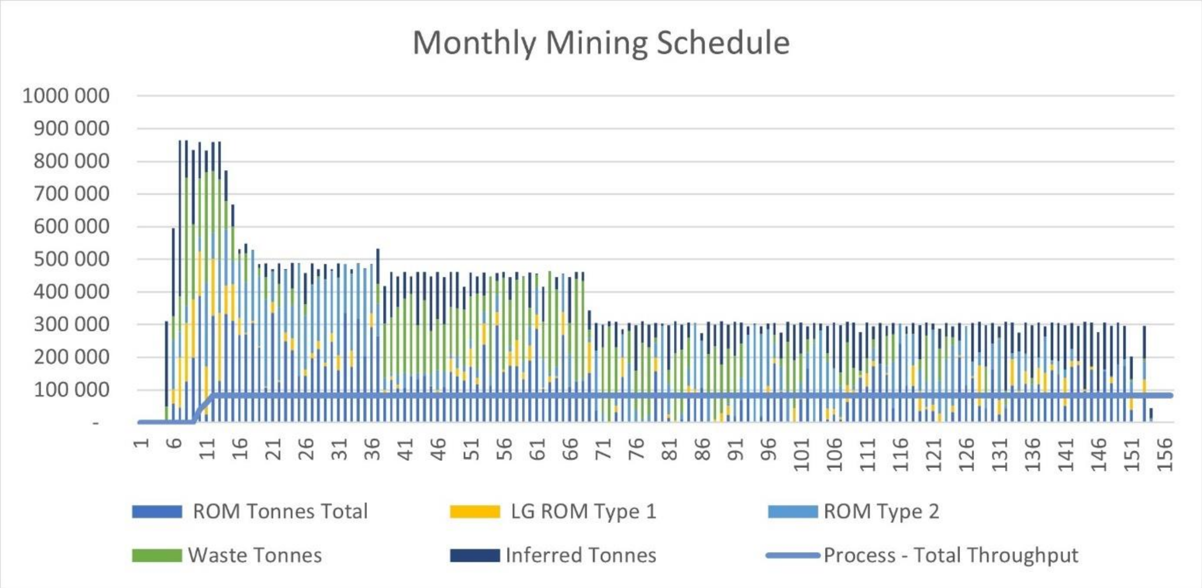


Figure 16.22: Monthly Mining Production Profile

Figure 16.23 shows the processing schedule by month. The processing schedule extends beyond the mining schedule as the medium-grade ore produced during the first five years of mining is processed after mining from the pit is ceased.

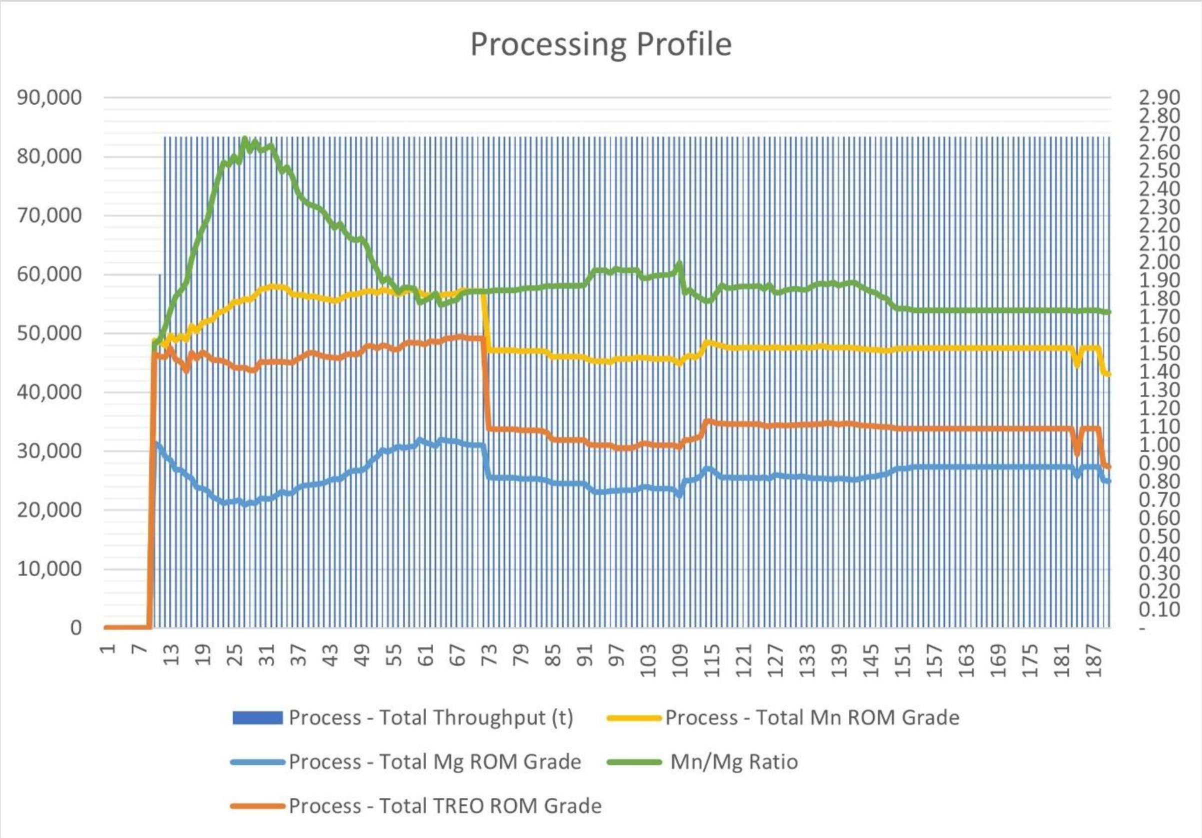


Figure 16.23: Processing Monthly Profile

16.6.3 Mining Sequence

The sequence of mining is to access the high-grade pit in the first five years to achieve the plant feed of 1.5 % TREO_PCT. The processing schedule for the first six years of operation is shown in Figure 16.24.

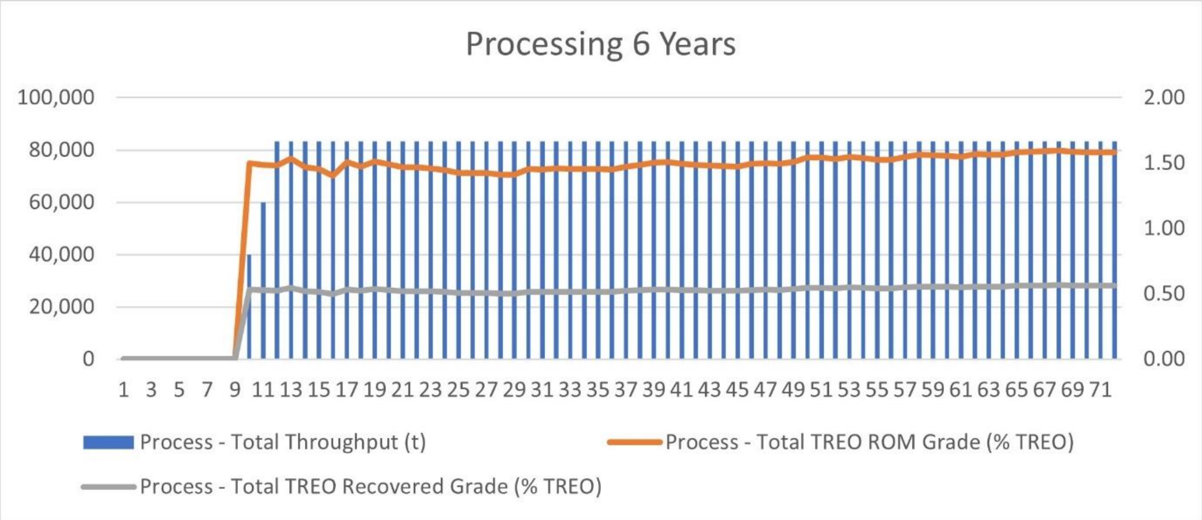


Figure 16.24: Initial Six Years' Processing Monthly Profile

The mining of the hillside and final pushback commences in Year 4 of operation. The strip ratio will increase for the next few years to get to the Type 1 ore in the final pushback.

The total mining inventory from the open pit is given in Table 16.14.

Table 16.14: Mining Inventory from Pit

Description	Value
ROM Tonnes Type 1 Ore (high grade and medium grade)	18,147,781
Waste Tonnes	12,119,018
Tonnes Type 1 Ore (below cut-off grade)	3,909,565
Tonnes Type 2 Material	12,267,019
Inferred Tonnes	11,258,330
Total Waste Tonnes	40,553,931
Strip Ratio	2.23

The overall strip ratio of the mine is 2.23 (waste tonne:ore tonne).

Figure 16.25 to Figure 16.33 show the development of the pits over time. The high-grade Phase 1 pit is shown in purple and the final pit in red.

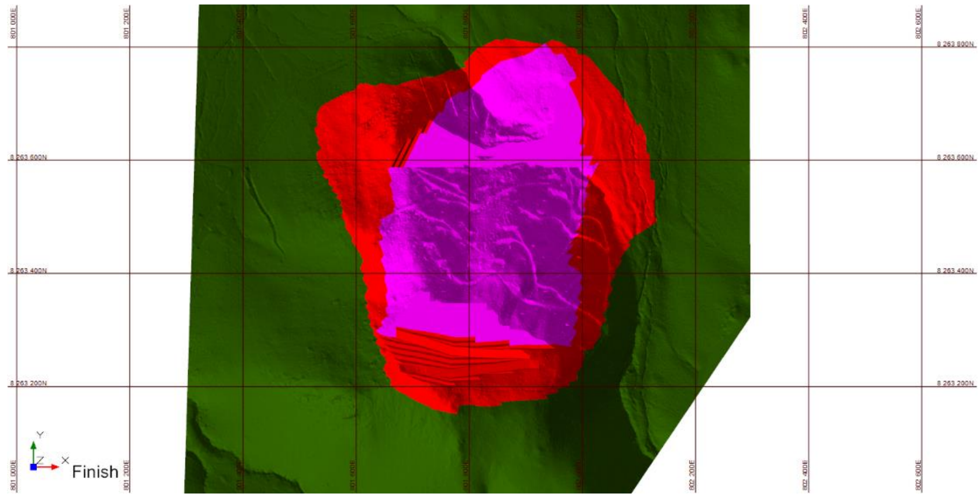


Figure 16.25: Year 1

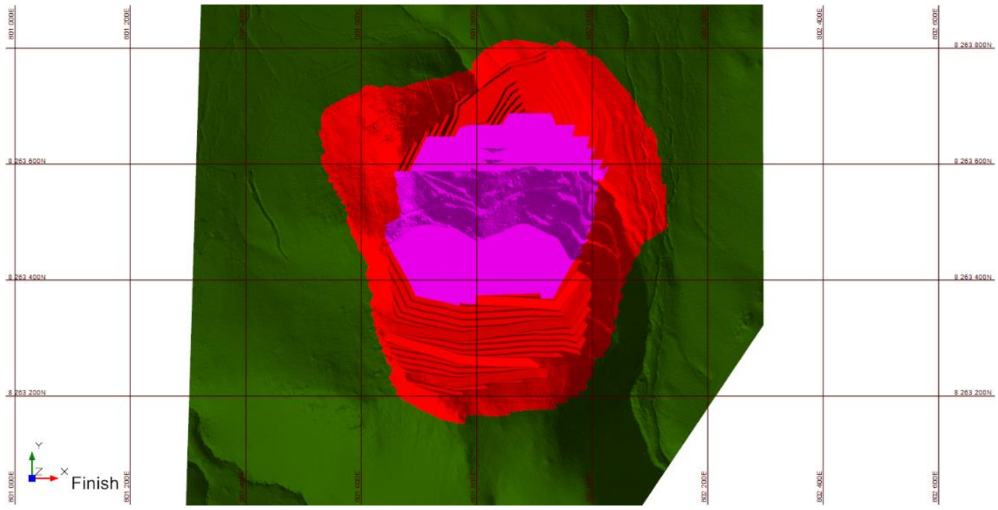


Figure 16.26: Year 2

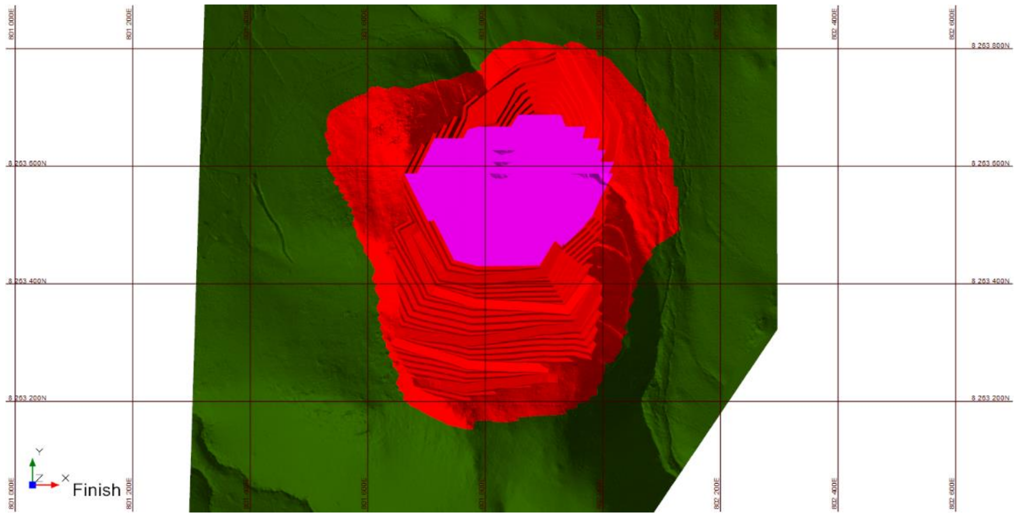


Figure 16.27: Year 3

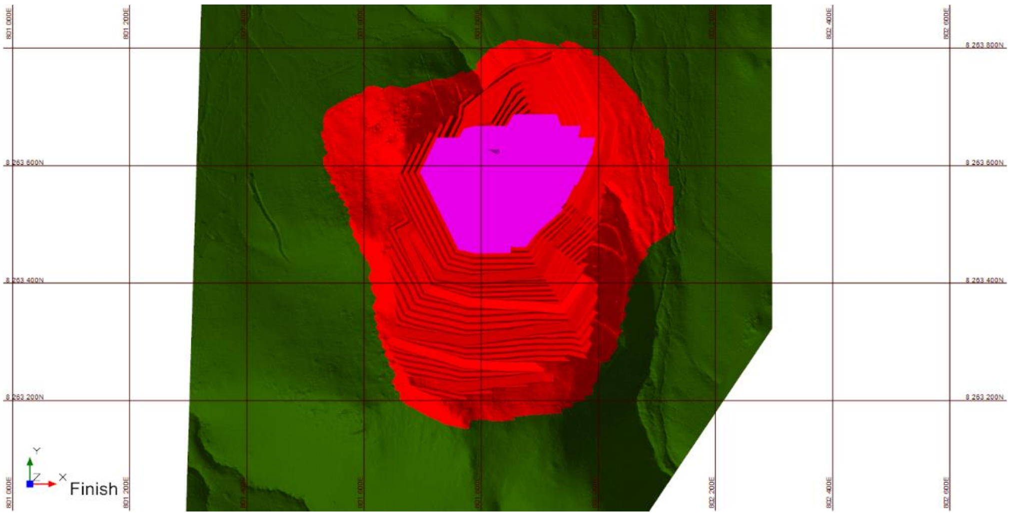


Figure 16.28: Year 4

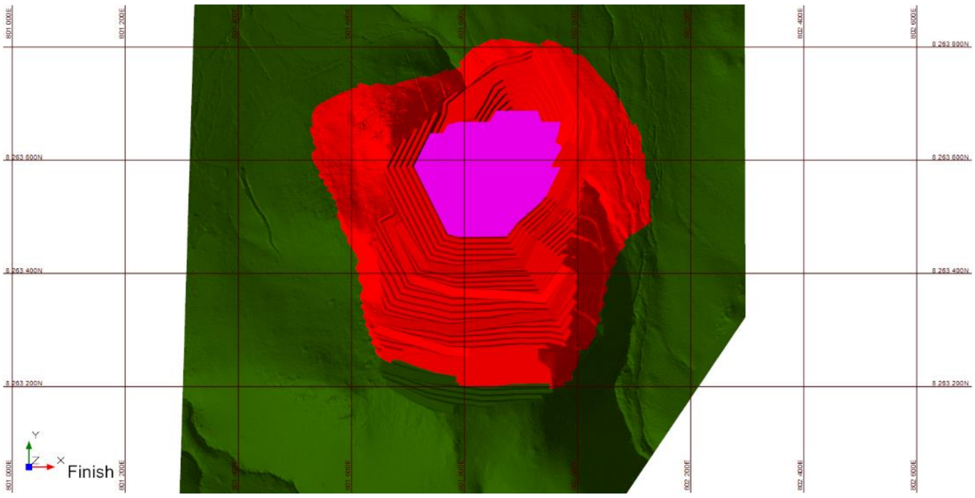


Figure 16.29: Year 5

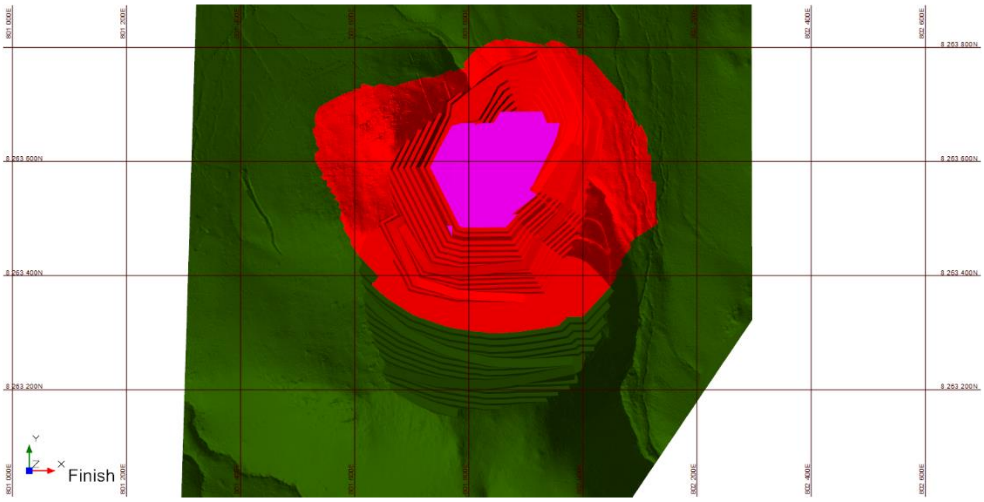


Figure 16.30: Year 6

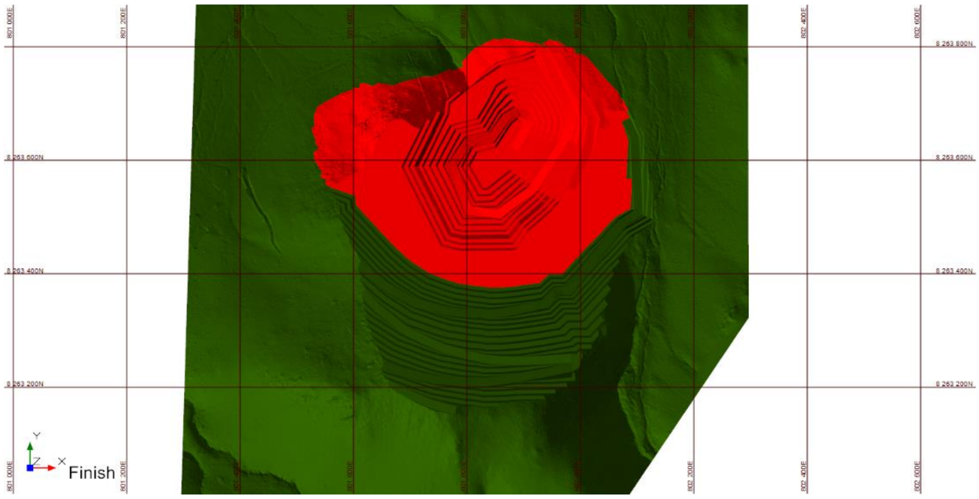


Figure 16.31: Year 8

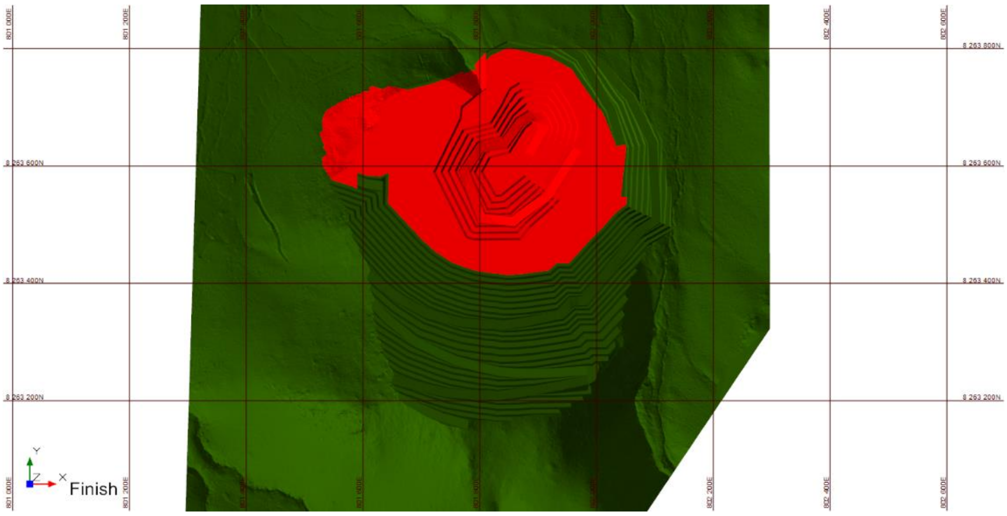


Figure 16.32: Year 10

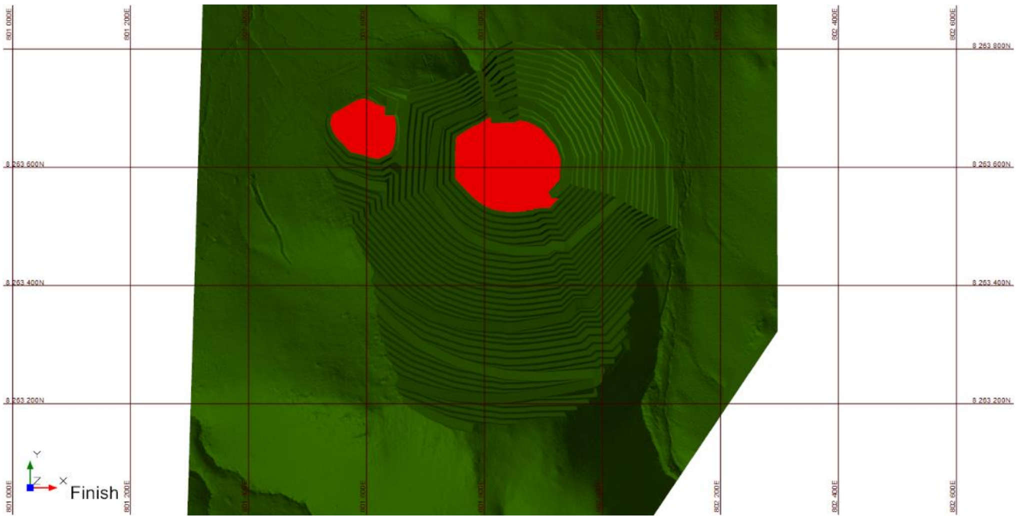


Figure 16.33: Year 13

16.7 MINING EQUIPMENT

A list of the required mining equipment has been provided by the Mining Contractor and was estimated based on the production rate required to supply the processing plant with the correct quantities of ore.

Productivity calculations were performed by Bara to check the fleet specified by the contractor. The productivity calculations are based on the following assumptions:

- Operating days per year – 356 (9 lost days)
- Operating shifts per day – 2 × 11 h shifts
- Hours operated per shift – 8 h (includes allowance for shift change, availability (80 %) and utilisation (80 %) of equipment)

The requirement for secondary equipment was also specified by the contractor.

Table 16.15 shows the mining fleet requirement as specified by the contractor as well as the Bara estimate for the primary equipment requirement.

Table 16.15: Mining Fleet Requirement

Unit Type	Typical Model	Contractor Estimate	Bara Estimate
Primary Mining Fleet			
Excavator	Volvo EC950 Excavator	3	3
Haul Truck	Volvo A40G Articulated Dump Truck (ADT)	14	12
Drill (Explosives)	Pantera 1500	2	2
Drill (Grade Control)	–	1	1
Secondary Vehicles			
Dozer	Caterpillar D8R	3	
Grader	Caterpillar 140H	2	
Compactor	Caterpillar CS533E Compactor	1	
Front-End Loader	Caterpillar 966H Wheel Loader	2	
Diesel Lights	–	8	
Tractor loader backhoe (TLB)	Caterpillar 428	1	
Diesel-Driven Dewatering Pumps	Xylem diesel-driven pump	3	
Light Vehicles	Toyota Land Cruiser	8	
Water Truck	Caterpillar 745C	2	
Diesel Bowser	Bell B18	1	
Bus	Toyota Troop Carrier	2	
Service Truck (Breakdown)	–	1	
Crane Truck	–	1	
Diesel Generator	–	2	

Total	57	

16.8 MANPOWER

In order to estimate the manpower requirement for the operation of the Songwe Hill Project, data was sourced from a number of sources. Many of the operations, including mining operations, will be undertaken by contractors. As part of this report, contractors were approached to provide proposals for the mining operation. The manpower plans submitted by these contractors have been used in determining the overall site manpower plan.

Employees sourced from areas remote to the mine will be housed in a camp on site, locally hired employees will continue to reside in the local communities. It is envisaged that all people at Paterson Band B and below will be sourced from the local villages and will not be housed on site. These employees will receive two meals per day on site, prepared by the camp operator.

All other employees, Paterson Band C and above, both contractor and mine employees, will be housed in the camp on site, which is to be operated by the mine owner. Accommodation costs will be charged back to the contractor at US$15 per person per day. Meals provided to personnel who are not residents in the camp will be charged at US$3.00 per meal.

The complement of people required by the mine owner to manage and operate the mine has been estimated. Labour costs have been applied to this complement to estimate the manpower portion of the owner's cost.

The labour schedule has been built up in monthly periods from the ramp-up period to full production.

Table 16.16 shows a summary of the manpower requirement at steady-state operation. Table 16.17 shows a summary of manpower by employer (mine owner or contractor).

Table 16.16: Summary of Manpower Plan

Description	Number of Shifts	Complement per Shift	Total Complement	Mine/Contractor
Contract Manager	1	1	1	Mine
Technical Manager	1	1	1	Mine
Production Manager	1	1	1	Contractor
Training Manager	1	0	0	Contractor
Pit Superintendent	1	1	1	Contractor
Pit Controller	2	2	4	Contractor
Safety Health and Environment (SHE) Controller	2	1	2	Contractor
SHE Manager	1	1	1	Contractor
Trainer	1	1	1	Contractor
Surveyor	1	1	1	Contractor
Surveyor Assistant	1	2	2	Contractor
Surveyor	1	1	1	Mine
Surveyor Assistant	1	1	1	Mine

Description	Number of Shifts	Complement per Shift	Total Complement	Mine/Contractor
Senior Geologist	1	1	1	Mine
Geologist	1	2	2	Mine
Geological/Grade Control Technicians	2	2	4	Mine
Geotechnical Engineer	1	1	1	Mine
Geotechnicians	1	2	2	Mine
Buying Clerk	1	4	4	Contractor
Logistics Controller	1	1	1	Contractor
Mine Planner	1	2	2	Mine
Human Resources (HR) Administrator	1	1	1	Contractor
Store Clerk	1	4	4	Contractor
HR Clerk	1	1	1	Contractor
Data Capturing Clerk	1	1	1	Contractor
Administration Clerk (SHE)	1	1	1	Contractor
Drilling Foreman	1	1	1	Contractor
Drill Rig Operator	1	6	6	Contractor
Assistant Drill Rig Operator	1	6	6	Contractor
Load and Haul Foreman	2	1	2	Contractor
Earth-Moving Plant Foreman	1	0	0	Contractor
Dump Truck Operator	2	14	28	Contractor
Excavator Operator (Excavator and Shovel)	2	3	6	Contractor
Dozer Operator	1	1	1	Contractor
Loader Operator	1	1	1	Contractor
Diesel Bowser Operator	1	1	1	Contractor
Grader Operator	1	1	1	Contractor
Water Bowser Operator	1	1	1	Contractor
Wheel Dozer Operator	1	1	1	Contractor
FEL Operator	1	1	1	Contractor
Dewatering Pump Operator	2	1	2	Contractor
People Bussing Operator	2	4	8	Contractor
Tyre Handler Operator	1	1	1	Contractor
Service Truck (Breakdown) Operator	1	1	1	Contractor
Roller Operator	1	1	1	Contractor
Multi-Skilled Operator	2	4	8	Contractor
Workshop Foreman	1	1	1	Contractor
Auto Electrician	1	1	1	Contractor
Boilermaker	1	2	2	Contractor
Diesel Mechanic	2	1	2	Contractor
Earth-Moving Mechanic (Breakdown)	2	2	4	Contractor
Maintenance Planner	1	1	1	Contractor
Apprentice	1	2	2	Contractor
General Worker (Cleaner, Water Pump Attendant, Surveyor)	1	6	6	Contractor
General Worker	1	5	5	Mine
Explosives Team	1	4	4	Contractor

Description	Number of Shifts	Complement per Shift	Total Complement	Mine/Contractor
OEM Specialist	1	2	2	Contractor
IT Support	1	1	1	Contractor
Total		**115**	**150**	

Table 16.17: Summary of Manpower by Employer

Employer	Complement
Mine	**21**
Skilled (Paterson Band C and above)	15
Semiskilled (Paterson Band A and B)	6
Contractor	**129**
Skilled (Paterson Band C and above)	48
Semiskilled (Paterson Band A and B)	81
Total	**150**

The owner's team will be responsible for the management of the Mining Contractor and for the provision and maintenance of the surface infrastructure required to support the mining and plant operator contractors.

Of the 150 people comprising the total manpower mining complement, 15 are expected to be expatriates, 63 will be skilled workers (Paterson Band C and higher), and 87 will be semi-skilled workers.

The manpower cost of the owner's team has been calculated by applying a cost-to-company rate, estimated by Bara, to the complement. The cost of manpower employed by the Mining Contractor is included in the contract rates, as discussed in Section 21.

17 RECOVERY METHODS

17.1 OVERVIEW

The process design is based on a comprehensive test work programme, which is discussed in more detail in Section 13. Mkango is targeting a high-grade rare earth enriched, mixed rare earth carbonate product that is cerium depleted. The key design parameters for the processing plant are summarised in Table 17.1. The more detailed process design is described in the sections below.

Table 17.1: Key Design Parameters

Parameter	Unit	Value
ROM Feed Rate	t/a	1,000,000
ROM Head Grade	% w/w TREO	1.5
Operating Hours	h/a	8,760
Crushing Plant Availability	%	65
Flotation Feed Particle Size	µm, P_{80}	16.7
Flotation and Hydrometallurgical Plant Availability	%	92
Flotation Plant Feed Rate (Design)	t/h	138
Concentrate Mass Pull	%	7.4
Concentrate TREO Recovery	%	74.1
Concentrate TREO Grade	% w/w TREO	15
Hydrometallurgical Plant Feed Rate (design)	t/h	10.8
Rare Earth Carbonate Produced	t/a dry solids	10,826
Contained TREO in Product	t/a	5,954

The concentrator plant flowsheet consists of the comminution and flotation circuits. Figure 17.1 shows the high-level flowsheet of the concentrator plant.

The hydrometallurgical plant flowsheet consists of several unit operations aimed at extracting, purifying and recovering rare earth elements. Figure 17.2 shows the high-level flowsheet of the hydrometallurgical plant.

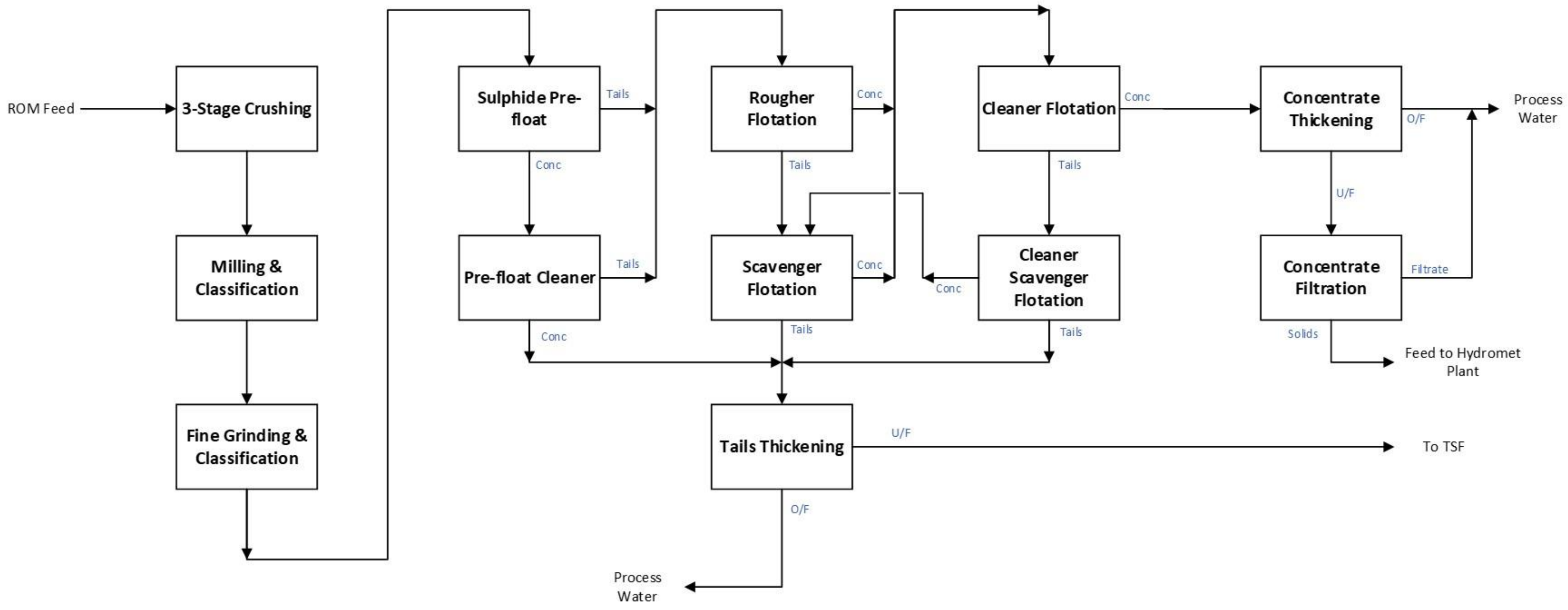


Figure 17.1: Concentrator Plant Flowsheet

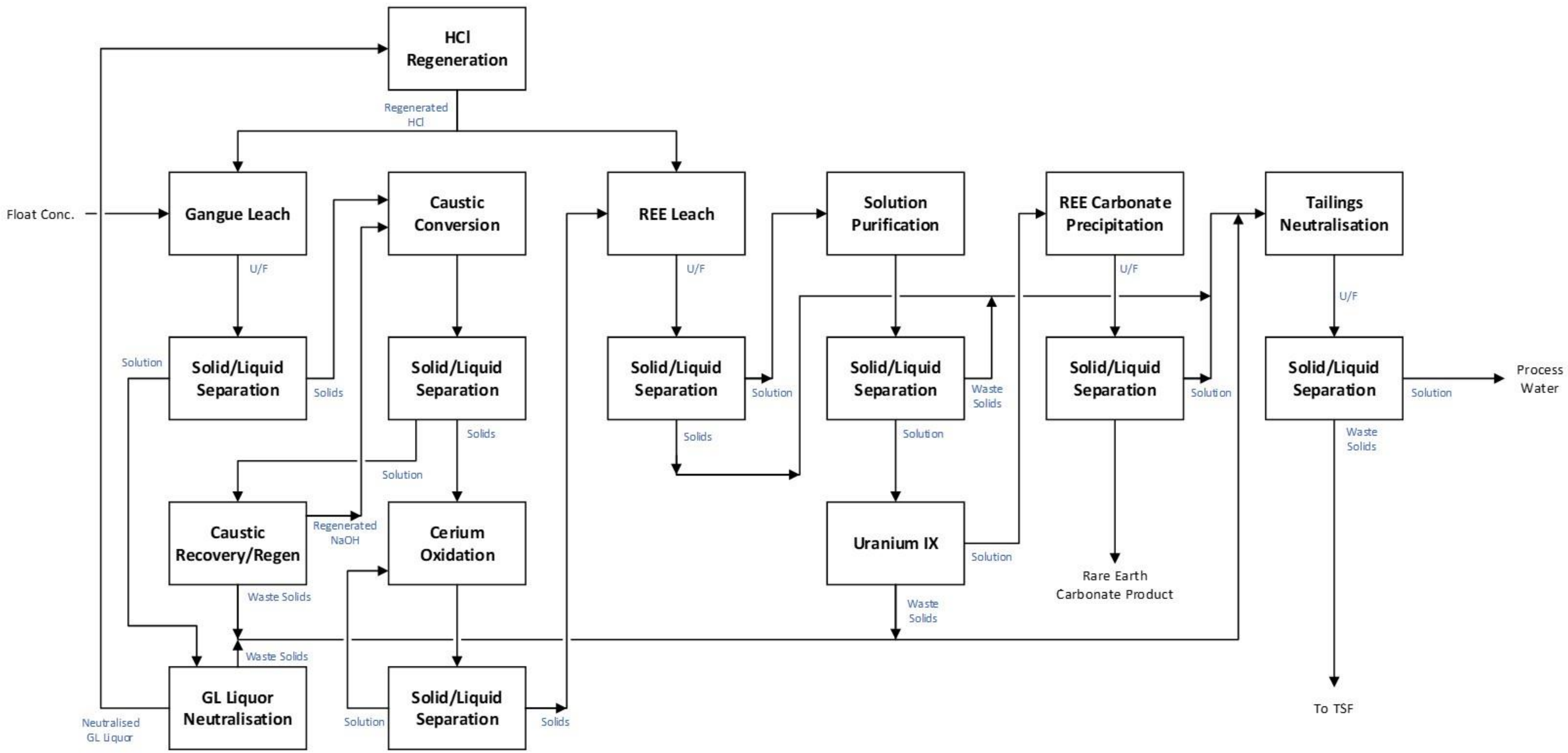


Figure 17.2: Hydrometallurgical Plant Flowsheet

17.2 PROCESS DESCRIPTION

17.2.1 Introduction

Songwe Hill is a rare earth elements deposit in the south-eastern region of Malawi. It comprises mostly carbonaceous gangue minerals and rare earths associated with oxides. Minor amounts of sulphide minerals are also present. The purpose of the concentrator plant or “front end” is to produce a rare earth oxide concentrate, which is to be treated in a subsequent hydrometallurgical plant.

Flotation of oxide minerals is typically more difficult to achieve than flotation of sulphide minerals, and a defining characteristic of this project has been to develop a flotation circuit and reagent suite that effectively float the rare earth oxides from the other oxidic gangue. The key in achieving flotation recovery lies in the combination of fine grinding, high-intensity conditioning, elevated temperature, and the correct reagent suite and dosages.

A PFS was completed for Songwe Hill by SNC-Lavalin in 2014, after which SENET was commissioned to proceed with several scoping studies to define the scope of the subsequent DFS and develop the NI 43-101 Technical Report. Continuous flotation test work drove the development of the process design, and the current flotation circuit has been proven to produce good recoveries and concentrate grades.

The crushing circuit consists of a primary jaw crusher and secondary and tertiary cone crushers. Primary and secondary screens are used to optimise the size of the crushers. The crushed product is milled in a ball mill in a closed circuit with a primary cyclone cluster. The cyclone overflow is ground in stirred media mills and classified before being pumped to the flotation circuit.

The flotation circuit starts with sulphide pre-float rougher and cleaner cells to remove sulphide minerals ahead of the main rare earth oxide flotation. Pre-float tails are conditioned and fed into rare earth oxide roughers and scavengers. The rougher and scavenger concentrate is treated in cleaner cells, and the cleaner concentrate ultimately reports to the concentrate thickener. The thickener underflow is filtered and sent to the hydrometallurgical plant for further processing. The cleaner tails are treated in cleaner scavenger cells, and the concentrate is recycled to the rougher scavenger feed. The rougher, scavenger and cleaner scavenger tails report to the tailings thickener and are pumped to a TSF.

The hydrometallurgical plant receives the flotation concentrate from the flotation plant and treats it with an up-front gangue leach to dissolve the acid-consuming gangue minerals with dilute acid. Gangue leach liquor is purified to precipitate impurities, filtered, and dosed with calcium chloride and sulphuric acid to regenerate hydrochloric acid and produce solid gypsum for possible sale.

Gangue leach residue is contacted with concentrated NaOH solution at a high temperature in order to convert insoluble rare earth minerals into soluble rare earth hydroxides in the caustic conversion. The caustic conversion residue proceeds to cerium oxidation, where the slurry is sparged with air to oxidise cerium and render it insoluble in the subsequent rare earth leach. The caustic conversion solution is evaporated to reconcentrate it and then undergoes a causticisation process to regenerate sodium hydroxide for reuse in the process.

Cerium oxidation residue is thickened and filtered before being fed into a more severe rare earth leach with hydrochloric acid. The leach residue is thickened and filtered before being repulped in the hydrometallurgical tails neutralisation area, and then combined with flotation and other hydrometallurgical tails streams to be sent to the TSF. Rare earth leach liquor is purified of heavy metals and radionuclides before being precipitated as a mixed rare earth carbonate product.

17.2.2 Crushing

ROM ore is delivered to the plant by haul trucks that tip the ore directly into the ROM bin. Material is withdrawn via an apron feeder and vibrating grizzly arrangement to feed the primary jaw crusher. A rock breaker is installed in the ROM bin area to break any oversize material that could become stuck in the primary crusher. The primary crusher product is discharged onto the primary crusher product conveyor. An overhead magnet installed on the conveyor removes any tramp steel. A belt weightometer installed on the primary crushing product conveyor controls the circuit feed tonnage by varying the speed of the ROM bin reclaim apron feeder.

The primary crusher product is conveyed to the secondary screen, which removes the target size material from the feed to the secondary cone crusher. The screen oversize is fed to the secondary crusher via a bin and pan feeder arrangement. The screen undersize joins the secondary crusher product and tertiary crusher product and is conveyed to the tertiary screen.

The tertiary screen oversize is fed into the tertiary cone crusher via a bin and pan feeder, and the tertiary screen undersize is conveyed to the ball mill feed bin. The tertiary crusher product is combined with the secondary screen undersize and secondary crusher product and conveyed to the tertiary screen to be classified once more in a recirculating loop.

The ball mill feed bin provides a process de-coupling between crushing and milling, and it also provides an 8 h surge capacity to allow for the lower availability in the crusher circuit. The mill feed bin overflows onto an emergency stockpile; the mill feed bin overflow can then be reclaimed with front-end loaders (FELs) and returned to the mill feed conveyor. The mill feed bin discharges onto the mill feed conveyor via a belt feeder.

A weightometer installed on the ball mill feed conveyor is used to control the mill circuit feed by varying the speed of the mill feed bin discharge belt feeder. The mill feed conveyor weightometer is used for metallurgical accounting purposes.

Conveyor skirting and dust enclosures, together with dust extraction systems, are included in the design as a means of containing the dust produced by the crushing circuit.

17.2.3 Ball Milling

The milling circuit comprises a ball mill operating in a closed circuit with a classification cyclone. Fresh feed to the ball milling circuit consists of crushed ore that is milled down prior to further grinding in the fine grinding circuit. Process water is fed at a ratio of the mill feed tonnage required to obtain the target in-mill solids density and is also added at a controlled rate to the mill discharge sump to achieve the set cyclone feed solids density.

Milled slurry overflows from the mill through the trommel screen to remove scats, and into the mill discharge sump. Scats are collected in a bunker and removed periodically using an FEL.

Mill discharge slurry is pumped to a cluster of hydrocyclones for classification. The cyclone overflow gravitates to the fine grinding circuit for further processing while the cyclone underflow gravitates back to the ball mill feed chute.

Steel grinding media are added into the mill feed chute by means of a magnet, hoist and kibble system. The media level in the mill is determined by measuring the mill power draw, and fresh media is added when the power draw decreases below a set limit.

Spillage in the area is contained by a concrete bunded area with a sloped floor to direct spillage to the mill feed side spillage sump, equipped with a vertical spindle pump to return the spillage to the mill discharge sump.

17.2.4 Fine Grinding

The product from the ball mill circuit gravitates to the regrind mill feed sump for ultra-fine grinding, which comprises several regrind mills operating in a closed circuit with a classification cyclone. The regrind mills use ceramic grinding media and stirrers to further decrease the size of the flotation feed slurry.

The cyclone underflow flows to a splitter box to feed four regrind mills operating in parallel, with one additional mill on standby. The product from the regrind mills reports back to the circuit feed sump to be classified once more in a recirculating loop.

The cyclone overflow gravitates to the flotation feed sampler, which comprises a two-in-one sampling system. The cyclone overflow material is passed through a trash screen, which separates out undesirable material, such as wood chips, to a skip. The screened underflow material gravitates to the pre-float rougher surge tank for further processing.

17.2.5 Flotation

The cyclone overflow from the fine grinding circuit reports to the flotation circuit of the concentrator.

The flotation circuit consists of rougher and cleaner sulphide pre-flotation, total rare earth oxide (TREO) rougher flotation, TREO scavenger flotation, TREO cleaner flotation, and TREO cleaner scavenger flotation. All cells are tank cells with forced-draft air systems.

Automatic head sampling consists of a feed box, launder, and a two-in-one sampling system (primary cross-cut sampler and vezin sampler) and provides flotation feed samples at regular intervals for metallurgical accounting purposes.

An on-line stream analyser is provided on the key feed, concentrate and tailings streams for process control purposes.

17.2.5.1 Pre-Flotation Rougher Flotation

The cyclone overflow material from the fine grinding cyclone cluster reports to the pre-float surge tank, where it is diluted with process water to the desired solids density for froth flotation. The diluted slurry is pumped, at a controlled rate and density, from the surge tank to an overflow conditioning tank, where collector and frother reagents are added. The reagents are dosed at the dosage rates required for optimal flotation performance. The conditioned slurry overflows by gravity to the first of four cells in series in the flotation bank. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells gravitates into the pre-float rougher flotation concentrate sump, from where it is pumped to pre-float cleaner flotation. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to improve flow.

Tailings gravitate to the pre-float rougher flotation tailings tank, from where they are pumped to the TREO rougher flotation.

Pressure pipe samplers are installed on the pre-float rougher flotation feed and tailings pump discharge lines, providing sample material to the automatic on-line stream analyser for plant control. Recirculating streams from the on-line stream analyser are directed back to the pre-float rougher flotation and rougher flotation feed surge tanks.

Spillage in the pre-float rougher flotation bunded area reports to the pre-float rougher flotation surge tank.

17.2.5.2 Pre-Flotation Cleaner Flotation

The pre-flotation cleaner flotation circuit is fed directly with pumped pre-float rougher concentrate material. This section comprises two cells in series. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells gravitates into the pre-float cleaner concentrate sump, from where it is pumped to scavenger flotation. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to prevent/minimise gangue material recovery or entrainment to the concentrate.

Tailings gravitate to the pre-float cleaner tailings tank, from where they are pumped to the TREO rougher flotation.

Pressure pipe samplers are installed on the pre-float cleaner concentrate and tailings discharge lines, providing sample material to the automatic on-line stream analyser for plant control. Concentrate and tailings return material from the on-line stream analyser are directed back to the scavenger flotation and rougher flotation feed surge tanks, respectively.

Spillage in the pre-float cleaner flotation bunded area reports to the first cell in the circuit.

17.2.5.3 TREO Rougher Flotation

The TREO rougher flotation circuit receives tailings material from the pre-float rougher and cleaner circuits via the rougher flotation surge tank. Steam is sparged into the surge tank to heat the slurry to the target temperature for downstream processing. The slurry is pumped, at a controlled rate and density, from the surge tank to a series of three overflow conditioning tanks, where further steam is sparged along with M4P, M7, caustic soda, collector, and frother. The reagents are dosed at the rates required for optimal flotation performance. The conditioned slurry overflows by gravity to the first of four cells in series in the flotation bank.

The flotation feed pumps from the surge tank control the level in the conditioning tanks and the feed rate to the flotation cells. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells gravitates into the TREO rougher concentrate sump, from where it is pumped to cleaner flotation. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to improve flow.

Tailings gravitate to the TREO rougher tailings tank, from where they are pumped to the scavenger flotation circuit, with the option of being bypassed to tailings thickening.

Pressure pipe samplers are installed on the rougher flotation concentrate and tailings discharge lines, providing sample material to the automatic on-line stream analyser for plant control. Concentrate and tailings return material from the on-line stream analyser are directed back to the cleaner and scavenger feed surge tanks, respectively.

Spillage in the rougher flotation bunded area reports to the rougher flotation surge tank.

17.2.5.4 TREO Scavenger Flotation

The TREO scavenger flotation circuit receives TREO rougher tailings and cleaner scavenger concentrate via the scavenger flotation surge tank. Steam is sparged into the surge tank to heat the slurry to the target temperature for downstream processing. The slurry is pumped, at a controlled rate and density, from the surge tank to a series of two overflow conditioning tanks ahead of flotation, where further steam is sparged along with M7, collector, and frother. The reagents are dosed at the dosage rates required for optimal flotation performance. The conditioned slurry overflows by gravity to the first of two cells in series in the flotation bank.

The flotation feed pumps from the surge tank control the level in the conditioning tanks and the feed rate to the flotation cells. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells gravitates into the scavenger concentrate sump, from where it is pumped to cleaner flotation, with the option of being bypassed to concentrate thickening. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to improve flow.

Tailings gravitate to the scavenger tailings tank, from where they are combined with cleaner scavenger tailings and pre-float cleaner concentrate and pumped to the tailings thickening circuit.

Pressure pipe samplers are installed on the scavenger flotation concentrate and the combined tailings discharge lines, providing sample material to the automatic on-line stream analyser for plant control. Rejects material from the on-line stream analyser is directed back to the scavenger feed surge tank.

Spillage in the scavenger flotation bunded area reports to the scavenger flotation surge tank.

17.2.5.5 TREO Cleaner Flotation

The TREO cleaner flotation cells receive as feed the concentrate streams from the rougher flotation and scavenger flotation circuits via the cleaner flotation surge tank. Steam is sparged into the surge tank to heat the slurry to the target temperature for downstream processing. The slurry is pumped, at a controlled rate and density, from the surge tank to a series of two overflow conditioning tanks ahead of flotation, where additional steam is sparged along with collector and frother reagents. The reagents are dosed at the dosage rates required for optimal flotation performance. The conditioned slurry overflows by gravity to the first of four cells in series in the flotation bank.

The flotation feed pumps from the surge tank control the level in the conditioning tanks and the feed rate to the flotation cells. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells gravitates into the cleaner flotation concentrate sump, from where it is pumped to concentrate thickening. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to prevent/minimise gangue material recovery or entrainment to the concentrate.

Tailings gravitate to the cleaner flotation tailings tank, from where they are pumped to the cleaner scavenger flotation circuit, with the option of being bypassed to the cleaner scavenger circuit.

Pressure pipe samplers are installed on the cleaner flotation concentrate and tailings discharge lines, providing sample material to the automatic on-line stream analyser for plant control. Concentrate and tailings rejects material from the on-line stream analyser is directed back to the cleaner feed surge tank and scavenger feed surge tank, respectively.

Spillage in the cleaner flotation bunded area reports to the cleaner flotation surge tank when required.

17.2.5.6 TREO Cleaner Scavenger Flotation

The cleaner flotation tailings material is pumped to the cleaner scavenger flotation surge tank ahead of the cleaner scavenger flotation. Steam is sparged into the surge tank to heat the slurry to the target temperature for downstream processing, and collector reagent is dosed at the required dosage rate. The conditioned slurry overflows by gravity to the first of three cells in series in the flotation bank.

The flotation feed pumps from the surge tank control the level in the conditioning tanks and the feed rate to the flotation cells. Blower air is provided via the low-pressure air reticulation system.

The concentrate from the cells collects in overflow boxes and flows gravimetrically to the cleaner scavenger flotation concentrate sump to be pumped to the feed surge tank on the scavenger flotation circuit. Spray water is provided at the concentrate launder of each cell to assist with washing down the froth and to prevent/minimise gangue material recovery or entrainment to the concentrate.

Tailings from the cleaner scavenger circuit collect in the cleaner scavenger flotation tailings sump, from where they are pumped to the scavenger flotation tailings tank along with pre-flotation concentrate to feed the tailings thickener.

A pressure pipe sampler is installed on the discharge line from the cleaner scavenger flotation tailings pumps. The sample reports to the automatic on-line stream analyser for plant control. Rejects from the on-line stream analyser are directed to the scavenger flotation area surge tank.

Spillage in the cleaner scavenger flotation bunded area is pumped via a spillage pump to the cleaner scavenger flotation surge tank when required.

17.2.6 Concentrate Thickening

The cleaner flotation concentrate slurry is pumped to the concentrate thickener for dewatering ahead of filtration. Scavenger flotation concentrate may also be bypassed intermittently to the concentrate thickener when required.

The concentrate slurry to the thickener is mixed with diluted flocculant in the feed well of the thickener to aid settling. The thickener underflow is pumped to the concentrate filter feed tank.

Clear thickener overflow water gravitates to the concentrate thickener overflow tank, from where it is pumped to the process water pond via the heat exchanger

The thickener feed passes through an automatic sampling system consisting of a stilling box, launder, and primary cross-cut and secondary vezin samplers. The final flotation tailings metallurgical accounting sample is taken at regular intervals at this point. Rejects from the secondary sampler, with by-passed sampler feed, are directed back to the concentrate thickener feed tank.

Spillage in the concentrate thickening area is contained in a bunded area and pumped back to the thickener using the spillage pump.

17.2.7 Concentrate Filtration

The concentrate thickener underflow material is pumped to the agitated filter feed tank for surge storage capacity ahead of the filters. The two duty concentrate filters are operated in a parallel, staggered cycling arrangement to match downstream processing in the hydrometallurgical plant.

The thickened concentrate material is further dewatered by a pressing action between the cloth surfaces of the filter press and forms the filter cake. After a completed filter cycle, the concentrate filter cake is discharged onto the concentrate filter transfer and discharge conveyors, which offload the filter cake either to the emergency stockpile during process upset conditions or to the conveyor feeding the hydrometallurgical plant for repulping and further downstream processing.

The cloth wash water tank pumps raw water to the filters for cloth cleaning.

The filtrate gravitates to the filtrate tank and is pumped back to the concentrate thickening tank.

A weightometer is fitted onto the filter discharge conveyors for metal accounting of the final concentrate from the plant.

17.2.8 Tailings Thickening

The tailings thickener receives feed slurry from the combined flotation tailings sump in the scavenger flotation circuit for dewatering ahead of disposal in the TSF. Rougher tailings may also be bypassed intermittently to the tailings thickener when required.

The tailings slurry to the thickener is mixed with diluted flocculant in the feed well of the thickener to aid settling. The thickener underflow material is pumped to the agitated final tailings tank, from where it is pumped to the TSF. A dedicated system consisting of a tank and pumps for supplying high-pressure gland seal water for the tailings disposal pumps is provided.

Clear thickener overflow water gravitates to the tailings thickener overflow tank, from where it is pumped to the process water pond via the heat exchanger

The thickener feed passes through an automatic sampling system consisting of a stilling box, launder, and primary cross-cut and secondary vezin samplers. The final flotation tailings metallurgical accounting samples are taken at regular intervals at this point. Rejects from the secondary sampler, with bypassed sampler feed, are directed back to the tailings thickener feed tank.

Spillage in the tailings thickening area is contained in a bunded area and pumped back to the thickener using the spillage pump.

17.2.9 Tailings Storage and Return Water

Thickened tailings from the tailings thickener underflow are pumped to the TSF, along with the hydrometallurgical plant final tailings. Water from the settled tailings is siphoned off and pumped via return water pumps to the TSF return water pond.

The return water pumps pump water from the TSF return water pond to the process water pond for use in the plant process water circuit.

17.2.10 Reagents

Various reagents are used in the flotation circuits to achieve a concentrate grade that is as rich in the value-bearing minerals as possible. The following reagents are added at selected points within the flotation circuit:

- pH modifier: Modifier 2
- Flocculant: Magnafloc 351 or equivalent
- Modifiers: Modifier M7 and Modifier M4P
- Frother: F1P
- Collectors: C15P and PAX

Each reagent area is equipped with an eye-wash station and a safety shower. Hoists are provided to lift reagent bags/drums.

17.2.10.1 Sodium Hydroxide

Sodium hydroxide (caustic) is delivered to site in bulk bags, lifted using a hoist, broken via a bulk bag breaker, fed into the caustic make-up tank, and mixed mechanically via the caustic make-up agitator with the required amount of raw water to attain a target concentration of 5 % w/w. Once the solution is made up, it is pumped via transfer pumps to the concentrator sodium hydroxide dosing tank or the hydrometallurgical sodium hydroxide dosing tank.

The flotation circuit requires cleaner sodium hydroxide than the hydrometallurgical circuit, which is why the concentrator sodium hydroxide dosing tank does not receive regenerated sodium hydroxide from the evaporator and sodium hydroxide regeneration circuit. Positive displacement pumps dose sodium hydroxide to the rougher flotation area, and the sodium hydroxide flow rate is controlled by pH measurement, which adjusts the positive displacement pump speed.

Regenerated sodium hydroxide is pumped into the hydrometallurgical plant sodium hydroxide dosing tank and topped up with freshly made-up sodium hydroxide to account for sodium hydroxide consumption, losses and bleed streams in the process.

Spillage in the caustic area is contained in a bunded area and directed to the floor sump, which is equipped with a spillage pump that pumps the spillage into the tailings thickener feed tank.

17.2.10.2 Flocculant

The flocculant make-up plant feeds dilute flocculant solution to the concentrate thickener and the tailings thickener.

The flocculant bags are lifted and emptied into the flocculant feed hopper. The flocculant in the flocculant feed hopper is withdrawn using a screw feeder. The flocculant powder is then transferred to a liquid jet eductor driven by high-pressure raw water. The screw feeder is programmed to operate on a timer, set to deliver the required amount of dry flocculant to prepare a batch of the desired concentration.

After the flocculant powder is wetted in the liquid jet eductor, it is discharged into the mixing tank. The concentrated flocculant solution is mixed at the target concentration of 0.25 % w/v using a low-shear agitator and then pumped to the flocculant dosing tank. Flocculant dosing is controlled by varying the speed of the flocculant dosing pumps prior to in-line dilution to the target concentration of 0.025 % w/v with recirculating thickener overflow in the respective areas.

Spillage in the flocculant make-up area is contained in a bunded area, which is equipped with a spillage pump that pumps the spillage into the tailings thickener feed tank.

17.2.10.3 Flotation Modifiers

17.2.10.3.1 Modifier M7

M7 is delivered to site in liquid form via bulk tankers and stored in on-site storage tanks. Concentrated M7 is transferred from the storage tank to the make-up/mixing tank, where it is combined with the required amount of raw water to attain the target concentration of 4 % v/v required in the flotation process. From the make-up tank, the diluted M7 solution is pumped via transfer pumps to the dosing tank. Dedicated dosing pumps deliver the diluted M7 solution at the required dosage rates from the dosing tank to the relevant dosing points within the flotation circuit.

Spillage in the M7 make-up area is contained in a bunded area and directed to the floor sump, which is equipped with a spillage pump that pumps the spillage into the tailings thickener feed tank.

17.2.10.3.2 Modifier M4P

M4P is delivered to site in powder form in bulk bags, lifted using a hoist, broken via a bulk bag breaker, fed into and mixed mechanically via an agitator in the make-up tank with the required amount of raw water to attain a target concentration of 1 % w/w. Once the solution is made up, the M4P is pumped via transfer pumps to the dosing tank. Dedicated dosing pumps deliver diluted M4P solution at the required dosage rates from the dosing tank to the relevant dosing points within the flotation circuit.

Spillage in the M4P make-up area is contained in a bunded area and directed to the floor sump, which is equipped with a spillage pump that pumps the spillage into the tailings thickener feed tank.

17.2.10.4 Frother

Frother is used in the flotation process to produce the froth or foam to which the valuable minerals attach (in and on the surface of a froth layer) for recovery.

Frother solution is delivered in an IBC. A drum pump is used to pump neat frother into the dilution tank, where it is combined with the required amount of raw water to attain a target concentration of 2 % w/w solution prior to transfer to the dosing tank. Dedicated dosing pumps deliver diluted frother at the required dosage rates from the dosing tank to the relevant dosing points within the flotation circuit.

Spillage in the frother make-up area is contained in a bunded area and directed to the floor sump, which is equipped with a spillage pump that pumps the spillage into the tailings thickener feed tank.

17.2.10.5 Collectors

A collector attaches to the mineral surface and produces a hydrophobic surface to improve recovery in the flotation process.

17.2.10.5.1 C15P

The collector bags are delivered to the make-up area and lifted onto the top of the make-up tank using the reagent area hoist. The operator lifts the bags onto the bag breaker, which discharges the collector powder into the make-up tank, which is half-filled with raw water. Once the required number of bags has been added to the make-up tank, the tank is topped up with the required amount of raw water to attain a target concentration of 5 % w/w.

After the collector powder is dissolved completely during the make-up process, the solution is pumped to the collector dosing tank using a transfer pump. Dedicated dosing pumps deliver diluted collector solution at the required dosage rates from the dosing tank to the relevant dosing points within the flotation circuit.

17.2.10.5.2 PAX

The PAX bags are delivered to the make-up area and lifted onto the top of the make-up tank using the reagent area hoist. The operator lifts the bags onto the bag breaker, which discharges the PAX powder into the make-up tank, which is half-filled with raw water. Once the required number of bags has been added to the make-up tank, the tank is topped up with the required amount of raw water to attain a target concentration of 0.5 % w/w.

After the PAX powder is dissolved completely during the make-up process, the solution is pumped to the PAX dosing tank using a transfer pump. Dedicated dosing pumps deliver diluted PAX solution at the required dosage rates from the dosing tank to the relevant dosing points within the flotation circuit.

17.2.11 Grinding Media

Grinding media storage bunkers are constructed in the milling area to hold the ball mill and regrind mill grinding media.

17.2.11.1 Ball Mill

The ball loading system for the ball mill consists of a ball loading hopper (fed by an FEL) with a transfer chute and ball loading kibble. The overhead travelling hoist is used to lift the kibble and feed the steel balls to the ball feeding hopper located at the mill feed chute. The ball addition rate is based on the mill power draw. A detailed, standard operating procedure for this method will be developed in later project stages.

17.2.11.2 Regrind Mill

The ball loading method used for the regrind mill consists of an overhead travelling hoist, which is used to lift the ceramic media bulk bags and feed the media into the media feeding hopper located at the mill feed chute, inside the vendor package. A detailed, standard operating procedure for this method will be developed in later project stages and provided by the mill supplier.

17.2.12 Air Services

The plant air high-pressure compressors supply the plant air required for the concentrate filter press receiver and the instrument air receiver, in a single duty/standby arrangement. Air from the compressors to the filter press is filtered through a pair of air filters before it is stored in the filter air receiver.

Instrument air is passed through a pair of air filters and the instrument air dryer. Dried instrument air is filtered again through a pair of air filters before it is stored in the instrument air receiver. The instrument air is distributed from the receiver to all the air-operated instruments throughout the plant.

A common air services plant supplies the concentrator and hydrometallurgical plants with air services.

The low-pressure compressors (one duty and one standby) supply the low-pressure air required for the flotation circuit in a flotation air ring main.

17.2.13 Water Services

17.2.13.1 Process Water Distribution

The sources of process water are the concentrate thickener overflow, tailings thickener overflow, the raw water top-up, and TSF return water. Process water is used in milling and the flotation circuits for dilution, launder spray water, flushing, hosing, and screen washing applications.

Process water from the flotation concentrate thickener and flotation tails thickener is still at the flotation temperature – approximately 50 °C. This thickener overflow is not sent to the TSF because of the contained heat that will be lost. Instead, it is stored in a separate pond with an interchange heat exchanger to salvage heat from the incoming solution and transfer it to the process water stream being pumped to the milling and flotation circuit.

The following solution streams are sent to the TSF:

- Moisture with the flotation tails slurry
- Moisture with the hydrometallurgical plant waste residue filter cakes
- Barren solution from rare earth carbonate precipitation (containing chlorides and ammonium)

The TSF is lined and sized to accommodate the impurities present in the above-mentioned moisture streams based on the geochemical characterisation performed by SGS.

The TSF return stream to the process water pond has the ability to be wholly or partially fed through a reverse osmosis (RO) plant, which will prevent the build-up of deleterious elements in recirculating water streams from the plant. Impurities that build up in the process water stream with repeated circulation in the flotation circuit will also be removed in the process water reverse osmosis plant, as will any impurities present in the borehole water entering the system as top-up to accommodate moisture losses in the processing plant. Brine from the RO plant is pumped to the TSF, where it is diluted with other waste liquor streams, of which a certain percentage remains on the TSF as it fills up. A combined TSF water stream is then returned to the plant to be partially or wholly purified, depending on the water quality. During the next phase of study, the brine handling will be further refined and optimised along with the potential recovery of ammonium and chloride discussed below.

The SENET mass balance has included hydrological studies from the environmental and tailings consultants to determine the level to which elements such as chlorine and ammonium will build up in the TSF return water stream.

During the next phase of study, options will be evaluated to further reduce the recirculating chloride and ammonium quantities, with the possibility of regenerating reagents for reuse in the plant or for sale to external customers.

17.2.13.2 Raw Water Distribution

Raw water is drawn from a wellfield of boreholes and, once abstracted, is stored in a borehole receiving tank, from which it is pumped to the raw water pond. Raw water is also used for potable water top-up, fire water top-up, primary crushing (dust suppression), and process water top-up.

Water is pumped from the raw water pond, via the concentrator raw water pumps, to the vendor filter package. Filtered water from the filtration plant is stored in a gland water tank to supply gland service water to the concentrator plant and the hydrometallurgical plant. Filtered water is also pumped to the concentrator raw water tank, which supplies water to the reagents, steam and concentrate filtration circuits.

17.2.13.3 Potable Water Distribution

Raw water is supplied to the potable water treatment plant and treated for potable water distribution. Potable water is stored in the potable water storage tank and delivered to the potable water hydrospheres. The hydrospheres are used to maintain the required pressure in the potable water distribution and safety shower headers. Potable water is used for the safety showers of the concentrator plant and the hydrometallurgical plant. A potable water line is also installed to supply water by gravity to the surrounding infrastructure (site camp, administration buildings and mining services).

17.2.13.4 Fire Water Distribution

Fire water is drawn from the raw water pond. The raw water pond has pump suction locations at different levels along the pond wall – the top-level suctions feeding the raw water pumps supplying raw water to the rest of the plant, and the lower-level suctions providing water for fire suppression. This is done to ensure that there is always sufficient fire water capacity and that the required fire water capacity is not used by another part of the plant. An electric pump serves as the primary fire water pump, with a diesel-driven pump as a standby pump to supply water to the fire water system in the event of a power outage. A jockey pump maintains the fire water system pressure for the concentrator plant and the hydrometallurgical plant.

17.2.13.5 Steam Plant

The steam plant consists of vendor-supplied electrical boilers (configured in a duty/standby arrangement), operating in a closed circuit with the hydrometallurgical plant condensate return. Filtered raw water is converted to steam in electrical boilers. Steam is required for direct injection via spargers at surge tanks and conditioner tanks in the flotation circuit, to maintain the targeted slurry temperature. Steam is also used in the hydrometallurgical plant for the caustic conversion, gangue leach and caustic evaporation processes.

17.2.14 Gangue Leach

The flotation concentrate is conveyed into an open-top, agitated repulp tank that is dosed with regenerated hydrochloric acid and dilution water to achieve the correct pre-leach slurry solids concentration.

The repulped gangue leach slurry is pumped into the first of four closed-top, agitated leach tanks, where gangue minerals are selectively dissolved into solution. Each leaching tank overflows into the next, and the circuit has the flexibility to remove any one tank from duty without interrupting the process. Acidic fumes from the reaction between carbonaceous gangue and hydrochloric acid are ducted away to a scrubber.

The incoming hydrochloric acid solution passes through a gangue leach heat exchanger to be heated up with hot water before entering the repulp and leaching tanks. The hot water used to heat up the hydrochloric acid is also circulated through coils in the first two leaching tanks in order to maintain the temperature of the gangue leach at 80 °C. Hydrochloric acid solution is added to the tanks in order to maintain the acidity of the leach at a pH of 4.

The leached slurry is pumped from either Tank 4 or Tank 3 (if Tank 4 is offline) into the feed tank of the gangue leach thickener. The high-rate gangue leach thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated gangue leach filter feed tank. The thickener overflow is collected in an overflow tank, and from there it is pumped to gangue leach liquor purification tanks.

The filter feed slurry is pumped with high-pressure pumps into the gangue leach filter. The filter is a horizontal recessed chamber filter. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The gangue leach filter discharge conveyor discharges the filter cake into the caustic conversion repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the gangue leach thickener.

17.2.15 Caustic Conversion

The gangue leach residue filter cake is conveyed into an open-top, agitated repulp tank that is dosed with regenerated sodium hydroxide and dilution water to achieve the correct solids density before caustic conversion.

The repulped caustic conversion slurry is pumped into the first of four closed-top, agitated conversion tanks, where rare earth minerals that are refractory to hydrochloric acid leach are converted into more soluble rare earth hydroxides. Each tank overflows into the next, and the circuit has the flexibility to remove any one tank from duty without interrupting the process. Fumes from the hot caustic solution are ducted away into a scrubber.

The temperature in the caustic conversion process is measured and maintained at between 90 °C and 100 °C via the sparging of low-pressure saturated steam into the first and second caustic conversion tanks.

The converted slurry is pumped from either Tank 4 or Tank 3 (if Tank 4 is offline) into the feed tank of the caustic conversion thickener. The high-rate caustic conversion thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated gangue leach filter feed tank. The thickener overflow is collected in an overflow tank, and from there it is pumped to the caustic evaporation feed tank.

The filter feed slurry is pumped with high-pressure pumps into the gangue leach filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The gangue leach filter discharge conveyor discharges the filter cake into the cerium oxidation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the caustic conversion thickener.

17.2.16 Cerium Oxidation

The caustic conversion residue filter cake is conveyed into an open-top, agitated repulp tank that is fed with cerium oxidation thickener overflow solution to achieve the correct solids density before cerium oxidation.

The repulped cerium oxidation slurry is pumped into the first of four closed-top, agitated tanks, where cerium is oxidised with air in order to render it insoluble during the rare earth leach. The process temperature is not controlled. Air flow is controlled at a volumetric set point that is determined by test work and verified during commissioning to achieve an optimal oxidation of cerium. Air is supplied by a duty-standby arrangement of air blowers with control instrumentation, and air is sparged into all four cerium oxidation tanks. Each tank overflows into the next, and the circuit has the flexibility to remove any one tank from duty without interrupting the process.

The discharge slurry is pumped from either Tank 4 or Tank 3 (if Tank 4 is offline) into the feed tank of the cerium oxidation thickener. The high-rate cerium oxidation thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated cerium oxidation filter feed tank. The thickener overflow is collected in an overflow tank, and from there it is pumped to the cerium oxidation repulp tank.

The filter feed slurry is pumped with high-pressure pumps into the cerium oxidation filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The cerium oxidation filter discharge conveyor discharges the filter cake into the rare earth leach repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the cerium oxidation thickener.

17.2.17 Rare Earth Leach

The converted and oxidised filter cake is conveyed into an open-top, agitated repulp tank that is dosed with regenerated hydrochloric acid and dilution water to achieve the correct pre-leach slurry density.

The repulped leach slurry is pumped into the first of four open-top, agitated leach tanks, where the rare earth minerals are dissolved. Each leaching tank overflows into the next, and the circuit has the flexibility to remove any one tank from duty without interrupting the process.

The incoming hydrochloric acid solution is not heated, and the reaction takes place at ambient temperatures and pressure. The pH is controlled at a set point of 2 by the addition of hydrochloric acid solution into either of the first two leaching tanks.

The leached slurry is pumped from either Tank 4 or Tank 3 (if Tank 4 is offline) into the feed tank of the rare earth leach thickener. The high-rate gangue leach thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated rare earth leach filter feed tank. The thickener overflow is collected in an overflow tank, and from there it is pumped to the PLS purification tanks.

The filter feed slurry is pumped with high-pressure pumps into the rare earth leach filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The rare earth leach filter discharge conveyor discharges the filter cake into the hydrometallurgical tails neutralisation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the rare earth leach thickener. The filter press package contains all auxiliary equipment such as a cloth wash water tank and pumps, and manifold flush.

17.2.18 PLS Purification

The PLS from the rare earth leach thickener contains significant amounts of zinc and other base metals, but also minor amounts of radium, so it is necessary to purify it.

The PLS solution is pumped into the first of six agitated, open-top purification tanks that overflow from the first into the next.

Sodium hydroxide is dosed into either or both of the first two purification tanks to control the pH at approximately 5. Sodium sulphide is added to the first two tanks to precipitate zinc and other base metals as sulphides, which become insoluble at a pH of approximately 5. Sodium sulphide is controlled by the volumetric flow of the feed solution and the concentration of the base metals as indicated by test work.

Barium chloride and calcium sulphate are dosed into Tank 3 and/or Tank 4 to facilitate the precipitation of radium sulphate. Dosing is controlled by the volumetric flow and the concentration of radium in the feed solution, determined by test work.

Tanks 5 and 6 serve to provide residence time and sufficient reaction kinetics for the respective reactions to reach equilibrium. The discharge from Tank 6 or Tank 5 (if Tank 6 is offline) is pumped into the feed tank of the PLS purification thickener. The high-rate PLS purification thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated PLS purification filter feed tank. A recycle stream is taken from the thickener underflow pumps and returned to the first or second tank to serve as a reseed for crystal growth in the tanks. The thickener overflow is collected in an overflow tank, and from there it is pumped to the uranium ion exchange feed tank.

A bleed stream from the PLS purification thickener overflow is taken and mixed with flocculant before being reintroduced to the thickener feed in order to improve the settling rate of the solids.

The filter feed slurry is pumped with high-pressure pumps into the PLS purification filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The PLS purification filter discharge conveyor discharges the filter cake into the hydrometallurgical tails neutralisation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the PLS purification thickener.

17.2.19 Uranium Ion Exchange

The purified PLS contains trace amounts of uranium that may precipitate with any rare earths.

The uranium ion-exchange plant consists of a feed tank that receives PLS from PLS purification. Three fixed-bed ion-exchange columns operate in a lead-lag-guard configuration, in which fresh PLS is pumped through the adsorption columns countercurrently to the flow of resin. The respective roles of the columns are alternated in cycles to load and elute the resin.

The loaded resin is washed and stripped with hydrochloric acid in an elution cycle that prepares the resin for use in the adsorption cycle once more. The resin inventory is measured and topped up with new resin as required.

The PLS stripped of uranium is pumped to the rare earth precipitation area. Waste eluate is neutralised, during which uranium is precipitated as a solid which is disposed of along with the rest of the tails.

17.2.20 Rare Earth Precipitation

The PLS from the uranium ion exchange plant is received into the first or second of four open-top, agitated precipitation tanks in series. The tanks overflow from one to the other, and valving arrangements allow for any one tank to be taken offline without interrupting the process.

The ammonium bicarbonate solution is dosed into Precipitation Tank 1 and/or Precipitation Tank 2, and the volumetric flow of the ammonium bicarbonate solution is controlled to maintain the pH of the precipitation process at 6 to 6.5.

The discharge slurry from Tank 4 or Tank 3 (if Tank 4 is offline) is pumped into the feed tank of the rare earth precipitation thickener. The high-rate rare earth precipitation thickener sufficiently increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated rare earth precipitation filter feed tank. A recycle stream is taken from the thickener underflow pumps and returned to the first or second tank to serve as a reseed for crystal growth in the tanks. The recycle stream density is measured and controlled according to the solids flow back to the precipitation tanks. The thickener overflow is collected in an overflow tank, and from there it is pumped to the hydrometallurgical tails neutralisation tank.

The filter feed slurry is pumped with high-pressure pumps into the rare earth precipitation filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The rare earth precipitation filter discharge conveyor discharges the filter cake onto a product stockpile, from where it is loaded with an FEL into a drumming plant for product packaging. The filtrate is collected in a sloped-bottom tank and pumped back to the rare earth precipitation thickener.

17.2.21 Hydrometallurgical Tails Neutralisation

The combined hydrometallurgical plant tailings streams are the following:

- Rare earth leach residue
- Causticisation residue
- PLS purification residue
- Gangue leach liquor neutralisation residue

The combined hydrometallurgical tailings, along with spillage from several areas, are either pumped or conveyed into the open-top, agitated hydrometallurgical tailings neutralisation repulp tank along with raw water to achieve the correct slurry solids density.

The repulped tailings slurry is pumped to the first of three open-top, agitated tanks in series for neutralisation. The tanks overflow from one into the next, and valving arrangements allow for any one tank to be taken offline without interrupting the process.

The hydrated lime slurry is dosed into the first and/or second tank, and the volumetric flow of the lime is controlled to maintain the pH of the neutralisation tanks at approximately 10.

The discharge slurry from Tank 3 or Tank 2 (if Tank 3 is offline) is pumped into the feed tank of the hydrometallurgical tails neutralisation thickener. The high-rate hydrometallurgical tails neutralisation thickener increases the slurry density prior to tails discharge. The thickener underflow is pumped to the flotation tails thickener underflow tank, from where it is pumped to the TSF with the flotation tails.

17.2.22 Gangue Leach Liquor Purification

The gangue leach liquor contains significant amounts of detrimental elements that interfere with reactions and build up in the system due to the recycle of regenerated hydrochloric acid. Before the gangue leach liquor can be fed into the hydrochloric acid regeneration process, it must first be purified of certain metal species in solution such as iron and aluminium.

The gangue leach thickener overflow is pumped into the first of three open-top, agitated purification tanks that overflow from one to the next.

The hydrated lime slurry is pumped into Tank 1 and/or Tank 2, and the volumetric flow of the lime slurry is controlled to maintain the pH at approximately 10 to facilitate the precipitation of impurity base metals as insoluble base metal hydroxides.

The discharge slurry from Tank 3 or Tank 2 (if Tank 3 is offline) is pumped into the feed tank of the gangue leach liquor neutralisation thickener. The high-rate gangue leach liquor neutralisation thickener increases the slurry density prior to filtration. The thickener underflow is pumped to the agitated gangue leach liquor neutralisation filter feed tank. A recycle stream is taken from the thickener underflow pumps and returned to the first or second tank to serve as a reseed for crystal growth in the tanks. The recycle stream density is measured and controlled according to the solids flow back to the precipitation tanks. The thickener overflow is collected in an overflow tank, and from there it is pumped to the hydrochloric acid regeneration tanks.

The filter feed slurry is pumped with high-pressure pumps into the gangue leach liquor neutralisation filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The gangue leach liquor neutralisation filter discharge conveyor discharges the filter cake into the hydrometallurgical tails neutralisation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the gangue leach liquor neutralisation thickener.

17.2.23 Hydrochloric Acid Regeneration

The purified gangue leach liquor contains significant amounts of calcium and chloride, which are utilised to regenerate the hydrochloric acid for use in the gangue leach and rare earth leach processes.

The purified gangue leach liquor is pumped into the first of four open-top, agitated overflow tanks in series. The valving arrangements allow for any one tank to be taken offline at any time without interrupting the process.

The calcium chloride solution and concentrated sulphuric acid are pumped into Tank 1 and/or Tank 2 to react with each other and the residual calcium chloride in solution to form gypsum and hydrochloric acid according to the following formula:

$$CaCl_{2(aq)} + H_2SO_{4(l)} \rightarrow CaSO_{4(s)} + 2HCl_{(aq)}$$

The reaction is mildly exothermic, and the temperature is controlled at approximately 50 °C with the use of cooling water circulating through coils in the tanks.

The discharge slurry from the last tank is pumped into the agitated hydrochloric acid regeneration filter feed tank.

The filter feed slurry is pumped with high-pressure pumps into the hydrochloric acid regeneration filter. The filter is a pressure belt filter that operates continuously and discharges waste solids onto a hydrochloric acid regeneration filter discharge conveyor. The filter cake is continuously washed by circulating a predetermined amount of raw water through the bed of solids. The hydrochloric acid regeneration neutralisation filter discharge conveyor discharges the filter cake onto a stockpile, from where it is collected with an FEL and loaded into a bagging plant. The filtrate is collected in a sloped-bottom tank and pumped to the hydrochloric acid regeneration dosing tank, from where it is pumped to the gangue leach and rare earth leach processes.

The generated gypsum is used in the PLS purification process as a source of sulphate, and the remainder is sold for use in local cement manufacture.

17.2.24 Sodium Hydroxide Evaporation

The caustic conversion thickener overflow contains the unreacted sodium hydroxide, as well as some impurity elements mobilised during the caustic conversion. The caustic conversion overflow is pumped into a multiple-effect evaporator plant that uses low-pressure steam to evaporate moisture from the overflow stream and increase the concentration of sodium hydroxide in solution.

The evaporator package consists of various vessels operating under vacuum and heated with recycled steam, which incrementally heats up the process stream vessel by vessel and also incrementally evaporates the moisture. Heat exchangers ensure the efficient recycle of heat, and a mechanical vapour recompression system facilitates the efficient use and recycle of steam.

The discharge solution is concentrated in sodium hydroxide at an elevated temperature (> 90°C). The discharge solution is pumped into a closed-top, agitated cool down tank that cools down the solution by circulating cooling water through coils in the tank. A decrease in temperature drives the precipitation of impurity sodium salts, such as sodium carbonate and sodium fluoride, transforming the solution into a slurry.

The discharge slurry is pumped into an agitated evaporator discharge filter feed tank. The filter feed slurry is pumped with high-pressure pumps into the evaporation discharge filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The evaporation discharge conveyor discharges the filter cake into the causticisation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped to the regenerated sodium hydroxide storage tank.

17.2.25 Causticisation

The sodium salts precipitated during caustic evaporation are repulped in an open-top, agitated repulp tank. Raw water is added to the tank to ensure the correct solids density in the repulped slurry.

The repulped slurry is pumped from the repulp tank into the first or second of four open-top, agitated overflow tanks in series. Lime is added to the first and/or second tank, and the volumetric flow of the lime slurry is controlled by the stoichiometric requirements of calcium for the amount of sodium salts being fed to the process. Test work will indicate the composition of the sodium salts and determine the dosing of calcium hydroxide set point.

The precipitated sodium salts dissolve in raw water under ambient conditions and neutral pH, and calcium hydroxide reacts with the dissolved species to regenerate the sodium hydroxide and insoluble calcium salts in the following ionic exchange reactions:

$$Ca(OH)_{2(aq)} + 2NaF_{(s)} \rightarrow 2NaOH_{(aq)} + CaF_{2(s)}$$

$$Ca(OH)_{2(aq)} + Na_2CO_{3(s)} \rightarrow 2NaOH_{(aq)} + CaCO_{3(s)}$$

The discharge slurry is pumped from the last tank to the causticisation filter feed tank. The filter feed slurry is pumped with high-pressure pumps into the causticisation filter. The filter is a horizontal recessed chamber filter press. The filter cake is washed by circulating a predetermined amount of raw water through the bed of solids. The causticisation filter discharge conveyor discharges the filter cake into the hydrometallurgical tails neutralisation repulp tank. The filtrate is collected in a sloped-bottom tank and pumped back to the feed of the caustic evaporator since dilution and washing have again diluted the sodium hydroxide in solution.

17.2.26 Off-Gas Scrubbing

Acidic and alkaline fumes from the gangue leach and caustic conversion processes are ducted from the top of the tank to the off-gas scrubber.

The polluted off-gas is extracted with a fan from all the gangue leach and caustic conversion tanks and is circulated from the bottom of a packed bed column to the top. The packed bed is filled with media to obstruct the flow of air and to ensure good contact with the down-flowing liquor. The polluted off-gas and alkaline scrub solution flow countercurrently to each other in the packed bed column so that the solution can make contact with the off-gas and adsorb acidic and environmentally unfriendly species.

Sodium hydroxide slurry is pumped from the sodium hydroxide make-up area to the sodium hydroxide feed tank inside the vendor package. The sodium hydroxide slurry is added to the recirculating scrub solution, determined by the pH of the scrub solution. As the recirculating volume of the scrub solution decreases in pH, it is periodically bled from the system and pumped to hydrometallurgical tails neutralisation tanks. Fresh sodium hydroxide and water are added to maintain an inventory of recirculating scrub solution.

The scrubber off-gas is released into the atmosphere via an off-gas stack.

17.2.27 Lime

Hydrated lime ($Ca(OH)_2$) solid powder is delivered to site in bulk bags and lifted by a hoist onto a bag breaker installed on top of the lime make-up tank. Lime is delivered in the hydrated form and therefore no slaker is required.

Hydrated lime powder is mixed with water in the correct ratio to achieve a 20 % w/w slurry in an open-top, agitated tank.

The made-up slurry is pumped into a dosing tank that operates on level control, and from there the slurry is pumped to the process areas.

17.2.28 Purification Reagents 1 – Sodium Sulphide

Sodium sulphide is delivered to site in bulk bags and hoisted onto a bag breaker installed on an open-top, agitated make-up tank. Sodium sulphide powder is added to the make-up tank in the correct ratio with raw water to produce a 20 % w/w solution.

The made-up solution is pumped to a dosing tank, which operates on level control, and then pumped to the PLS purification circuit.

17.2.29 Purification Reagents 2 – Barium Chloride and Calcium Sulphate

17.2.29.1 Barium Chloride

Barium chloride is delivered to site in bulk bags and hoisted onto a bag breaker installed on an open-top, agitated make-up tank. Barium chloride powder is added to the make-up tank in the correct ratio with raw water to produce a 20 % w/w solution.

The made-up solution is pumped to a dosing tank, which operates on level control, and then pumped to the PLS purification circuit.

17.2.29.2 Calcium Sulphate

Calcium sulphate is produced in the hydrochloric acid regeneration area. The majority of the gypsum is sold to cement manufacturers in the region, but a small portion is reused in the process.

Calcium sulphate bags are transported from the gypsum bagging plant and hoisted onto a bag breaker installed on an open-top, agitated make-up tank. Calcium sulphate powder is added to the make-up tank in the correct ratio with raw water to produce a 20 % w/w solution.

The made-up solution is pumped to a dosing tank, which operates on level control, and then pumped to the PLS purification circuit.

17.2.30 Ammonium Bicarbonate

Ammonium bicarbonate is delivered to site in bulk bags and hoisted onto a bag breaker installed on an open-top, agitated make-up tank. Ammonium bicarbonate powder is added to the make-up tank in the correct ratio with raw water to produce a 20 % w/w solution.

The made-up solution is pumped to a dosing tank, which operates on level control, and then pumped to the PLS purification circuit.

17.2.31 Calcium Chloride

Calcium chloride is delivered to site in bulk bags and hoisted onto a bag breaker installed on an open-top, agitated make-up tank. Calcium chloride powder is added to the make-up tank in the correct ratio with raw water to produce a 20 % w/w solution.

The made-up solution is pumped to a dosing tank, which operates on level control, and pumped to the PLS purification circuit.

17.2.32 Steam

Filtered raw water is pumped into the electrical steam boiler plant. A raw water supply tank provides raw water inventory for the electrical steam boilers to produce low-pressure (7 bar(g)) steam for the purpose of process heating. The generated steam is directed to process areas that require heating.

A hot water tank is filled with filtered raw water and supplies a hot water ring main to the gangue leach tanks. The temperature is controlled by modulating the flow of steam into spargers located in the hot water tank. Hot water is circulated with pumps, and the ring main returns cooled-down water to the hot water tank to be heated once more.

17.2.33 Air Services

A duty/standby arrangement of air compressors supplies the compressed air to a header that

Before the compressed air is directed to the air receivers in the concentrator and hydrometallurgical plants, the air is

- Filtered for use as plant air
- Filtered, dried, and filtered again for use as instrument air

17.2.34 Process Water

The TSF return water is pumped into the process water pond, which provides storage and surge capacity for use in the concentrator and hydrometallurgical plants.

The flotation concentrate thickener overflow and flotation tails thickener overflow are pumped into a process water heat exchanger to transfer the heat from the flotation thickener overflow at approximately 50 °C to the process water leaving the process water pond.

The process water pond discharge pumps pump the process water through the process water heat exchanger to be heated before being directed to the plant areas for use – primarily the milling and flotation sections.

17.2.35 Raw Water Distribution

Several boreholes in the area of Songwe Hill will be sunk, and borehole pumps will be installed to supply the plant and site with raw water.

The borehole pumps supply raw water to a local surge tank, from where the raw water is pumped with centrifugal pumps to a raw water storage pond that is located on site.

Raw water is pumped from the pond to top up the process water and to supply reagent make-up and fire water systems, etc.

Raw water is also pumped to a raw water filtration plant to remove solids and provide filtered raw water for use in the gland water reticulation system. The filtered raw water is received from the raw water filtration plant and stored in a filtered raw water storage tank, from where it is supplied to pump gland seals.

17.2.36 Potable Water

Raw water is pumped from the raw water storage pond to a reverse osmosis water processing plant. The reverse osmosis plant removes impurities from the raw water and renders it clean enough for use as potable water for consumption and in the plant safety shower system.

Potable water is stored in a potable water storage tank and pumped to site offices, accommodation, and safety shower systems. Hydrospheres on the supply lines of the safety shower systems provide pressure in case of pump failure or power outage.

18 PROJECT INFRASTRUCTURE

18.1 PROJECT ON-SITE INFRASTRUCTURE – PROCESS PLANT

The Songwe Hill Project is a greenfield project, and as such minimal infrastructure has been established on the project site. The on-site infrastructure required will be related to the processing plant and the supporting facilities as follows:

- Earthworks
- Civil works
- Plant buildings
- Process plant site drainage
- Sewage disposal
- Security
- Water supply
- Power supply
- Process plant diesel backup generators
- Communications

The main plant areas are shown in the plant layout in Figure 18.1.

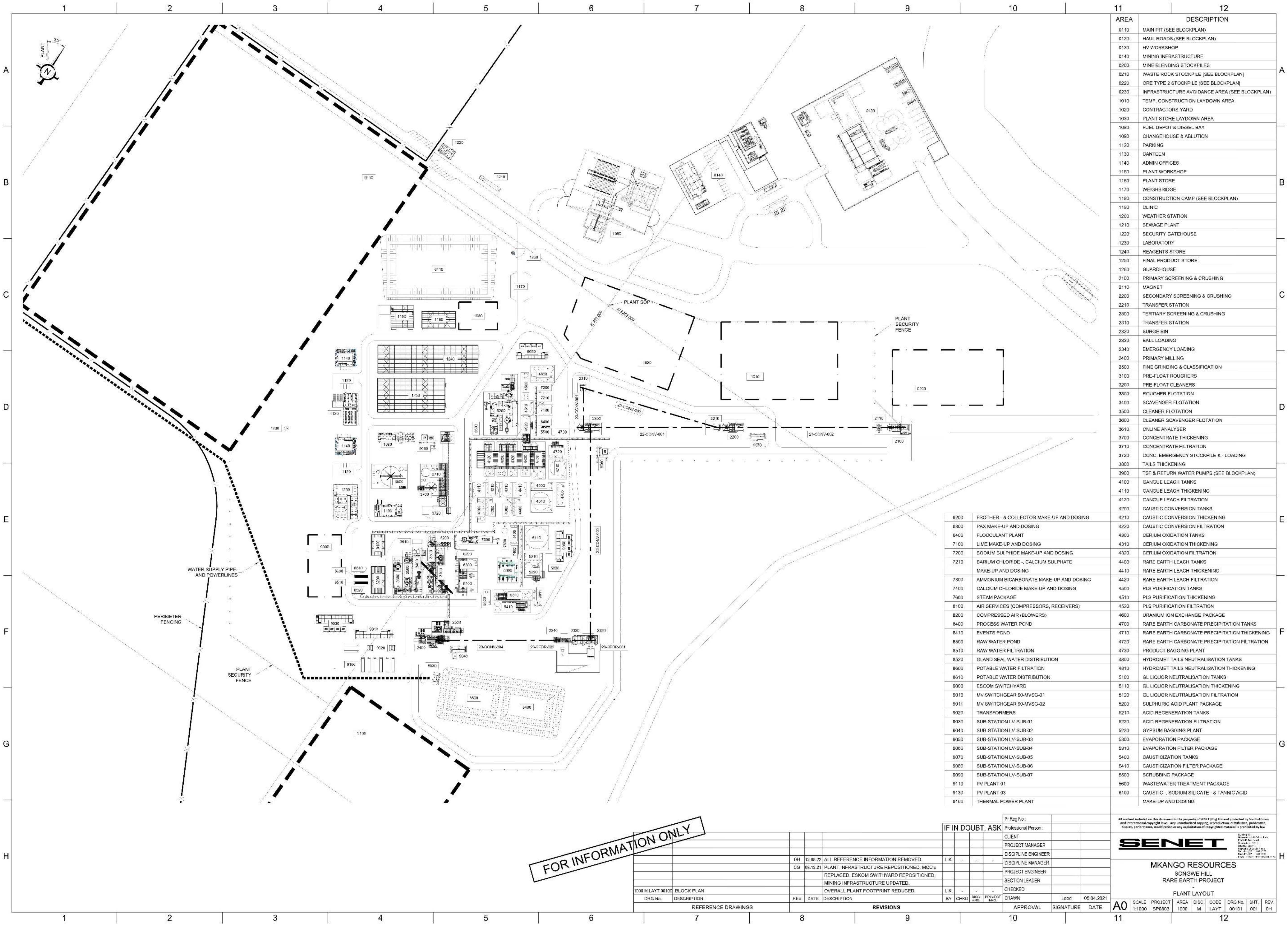


Figure 18.1: Plant Layout

18.1.1 Earthworks

18.1.1.1 General Earthworks

Earthworks allowances were made for terracing, roads and storm water infrastructure on the processing plant, photovoltaic (PV) plants, construction camp and fuel depot. No allowances were made for any mining-related infrastructure.

The average slope of the natural ground over the processing plant area is 1:15, which makes this an unusually steep site for the construction of a processing plant. To best utilise the slope and minimise the earthworks, the plant was divided into terraces with earth berm drops on smaller level differences and strategically positioned concrete retaining walls where steeper drops were required.

The terrace levels were influenced by several factors including process flows, equipment locations and tie-in levels. As a result, the plant terracing is complex in construction and post-construction operation and will require further consideration and refinement in the detailed design phase.

It should be noted that the proposed concrete retaining walls between terraces would require a good coordination between the Earthworks and Civil Works Contractors and would also require them to work simultaneously in specific areas. This could have a potential impact on the construction schedule.

The following initial design assumptions were made while the geotechnical investigation was still ongoing:

- A 2 m deep soil improvement was assumed below all the earthworks platforms.
- All the required fill material was assumed to be available within a 2 km radius from either necessary excavations or designated borrow pits.
- It was further assumed that 20 % intermediate and 15 % hard rock excavations would be required, and an allowance was made accordingly.
- Provision was made to grade the PV plants to a maximum gradient of 14 % to allow for the axial movement of the panels.
- The process water pond and events pond were considered to have double HDPE liner systems while the raw water pond was considered to have a single HDPE liner system. All the relevant geotextiles and installation of the systems were included.
- The ROM wall was included as a mechanically stabilised earth wall with a gabion face. It was assumed that the gabion rock for that wall face would be locally available, either from site or from commercial sources.

Once the geotechnical report was complete, a review of the report recommendations supported most of the initial design assumptions calculations. A short discussion of the major design assumptions is given below:

- The soil improvements recommended in the geotechnical report range in depth from 1 m to 2.2 m; therefore, the initial average of 2 m is satisfactory.
- The report did not include an investigation for potential borrow pits in the area, and this might pose a risk to the assumption that G5 and G6 materials, to be used as fill

material, will be available in a 2 km radius, either from necessary excavations or borrow pits.
- With the many boulders encountered on site, the respective 20 % and 15 % allowances made for intermediate and hard rock are deemed satisfactory.
- The availability of suitable gabion rock material on site, however, is unknown.

Further geotechnical investigations and an update of the geotechnical report is planned before the detailed design phase commences to address the areas in the geotechnical report that were not conclusive. All the design assumptions will be reviewed and updated where necessary after the updated report has been reviewed.

18.1.1.2 Processing Plant Access and Formalised Roads

The existing road (T415 – currently being upgraded to the west of the proposed process plant will be diverted to the east and west to grant access to the processing plant and PV Plant 4, respectively. The preliminary design for these roads assumed these to be 8 m wide gravel roads with 500 mm of compacted road layers and a gravel wearing course of 300 mm.

Selected fill gravel roads were also considered on PV Plants 1 and 4 where formal access to infrastructure needed to be allowed for. The preliminary design for these roads assumed these to be 5 m wide gravel roads with 500 mm of compacted road layers and a gravel wearing course of 300 mm.

18.1.1.3 Internal Roads

The internal roads on the plant are divided into three categories for the Songwe Hill project:

- **Access ramps** between platforms, which will be constructed by compacting suitable material in layers to a specified density, levels and requirements to be stipulated in the detailed design. A gravel wearing course will be constructed on these access ramps as per the detailed design. The access ramps will provide a throughway between the platforms on different levels and ensure that access to all critical areas is possible for stipulated vehicles.
- **In-plant roads,** which will allow access to the infrastructure on the relevant platforms. These will be constructed as part of the platform earthworks, and their location will be demarcated.
- **Perimeter roads** on the PV plants along the security fence. These roads will be considered informal roads stripped of vegetation and topsoil.

18.1.2 Civil Works

The following design assumptions were made in quantifying the civil works for this project:

- All the structural concrete was assumed to be 30 MPa.
- Raft foundations were assumed for areas sensitive to differential settlement and any area requiring acid protection.
- Surface beds and bases were assumed for lower-load and less-sensitive areas.
- Bunded area volumes were assumed to allow for the containment of 110 % of the volume of the largest vessel in the bund.

- Ring beams for all tanks were assumed at a minimum height of between 600 mm and 750 mm, depending on the tank size or the required height with regard to the process.
- The foundations for the solar panel structures on PV Plants 1 and 3 were assumed to be pre-drilled for steel profiles and backfilled with concrete.
- The foundations for the solar panel structures on PV Plant 4 were assumed to be directly rammed steel profiles.

Civil works allowances were made for all the structures on the plant including the construction camp, sewage treatment plant, electrical infrastructure, Escom switchyard, prefabricated buildings, pre-engineered structural steel buildings, and solar panel foundations. No mining-related infrastructure was considered.

The particular areas that were identified as requiring acid protection were considered according to the specific chemical and mechanical abrasiveness. Particular acid protection systems were considered for the respective areas based on the area properties.

Although the current design assumptions are not expected to change significantly in the detailed design phase, all the design assumptions will nevertheless be reviewed and updated, where necessary, after the conclusive geotechnical report has been reviewed.

18.1.3 Plant Buildings

The plant buildings will consist of the following:

- Gatehouse
- Change house and laundry
- Clinic
- Canteen
- Plant control rooms (two)
- Office buildings (two)
- Metallurgical laboratory
- Plant workshop
- Plant main store
- Reagents store
- Final product store
- Air services building
- Blower air building

18.1.4 Process Plant Site Drainage

18.1.4.1 Storm Water and Drainage

Storm water diversion berms will be constructed to separate clean and dirty storm water. All dirty/contaminated storm water will be collected and contained within the storage facilities on site while the clean water will be routed to run off into the natural watercourse.

The berms will be constructed using the material from the bulk excavations when the bulk earthworks are carried out.

Concrete-lined storm water channels and grid inlets will be constructed throughout the plant area to ensure that any storm or dirty water runoff that is not contained in the bunded areas is diverted to discharge into the event pond located north of the plant store.

18.1.4.2 Erosion Protection

Provision has been made for all sloped earth embankments to be protected from erosion by installing an earth stabilising system to reinforce the embankments, mitigating possible erosion damage whilst promoting and enabling vegetation growth.

18.1.5 Sewage Disposal

A 45 m^3/h containerised sewage treatment plant will be provided north of the main plant terrace for the treatment and disposal of the sewage generated by the process plant as well as the mining operations.

The technology selected is compact, simple and robust, and is based on a standard activated sludge system, where the biochemical oxygen demand is broken down using air and bacteria that grow in this medium. This system provides optimised nitrification and an effluent quality to a standard that complies with the requirements of the Department of Water Affairs and Forestry for the release of treated effluent back into the environment, in accordance with the General Limit Values in terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998).

18.1.6 Security

The perimeter of the site will be fully enclosed by a low-security fence to keep out animals and unauthorised people. The process plant, construction camp, fuel farm, backup fuel and electrical ring main unit will be enclosed by a medium-security fence. The PV plants, explosives magazine and electrical transformer are considered higher risk areas and provision has therefore been made for these areas to be enclosed with a high-security fence. An additional allowance was made for low-security stock fencing around the raw and process water ponds, event pond, and return water pond.

Access to the plant site will be restricted to one access point at the main gate, which will be equipped with a gatehouse that is manned 24 h/d. Other emergency and maintenance access gates will be provided but will be kept locked at all times.

Booms to control vehicle access will be provided at the entry gate to the process plant and at the entrance to the waste facility perimeter road leading to the mine access area.

Furthermore, the plant will be fitted with CCTV cameras installed at strategic locations. The cameras will be integrated with the plant’s overall network, and dial-up into these cameras via the Internet will be enabled. Views from the cameras will be fed to the central security control room situated in the gatehouse to a central security control room situated in the security office.

18.1.7 Water Supply

To ensure an uninterrupted supply of water to the plant, water will be supplied via on-site raw water and process water ponds.

These ponds will be fed from two sources:

- Boreholes located to the west of the plant. This borehole water will be filtered through a sand filter to remove most of the suspended solids and be collected in a supply tank. From this tank, the water will be pumped to the raw water pond (RWP), from where it will be processed through a reverse osmosis plant for potable water supply to the plant infrastructure.
- The TSF water return system (50 m^3/h design flow rate)

The interaction of the various flows for the process plant and TSF is described in detail in Section 18.4, which was the basis for the water balance. This water balance was used as the basis for sizing the water storage dam. Water stored in the RWP will be pumped to the process plant for make-up operations.

The pit dewatering requirements to cater for the ground and rainwater ingress have been met by diesel-powered water pumps located in the pit. This water is then pumped to a high point next to the pit into a collection tank. The water is then gravity fed to another collection tank located at the primary crusher, from where it will be pumped to the RWP.

A floating barge system will be installed at the TSF to house the two return pumps, which pump the process water to the RWP. Pumps at the RWP pump the return water to the process water pond located in the plant.

18.1.7.1 Potable Water Distribution

Raw water will be supplied from the raw water pond to the potable water storage tank situated in close proximity to the pond. Potable water will be supplied to all the areas inside the plant via piping running above ground in the plant area. Potable water will be supplied directly to safety showers, ablution areas, and the change house.

The potable water plant will be a containerised unit capable of producing 15 m^3/h of potable water. The water will be chemically oxidised, and the pH will be adjusted. Then the water will flow through an arsenic removal filter and an activated carbon filter.

18.1.7.2 Fire Water Distribution

There will be an electric and a diesel-powered fire water pumping system. The electric-powered pump will be used in the event of a fire, and the diesel pump will be a backup in case the MCCs are on fire. A jockey pump will be provided to maintain the pressure in the fire water header during normal plant runs. An alarm will be sounded at the plant site for low system pressure.

The fire water system will consist of a fire water loop and hydrant system at the plant site, ancillary buildings, and at the process plant. Hose cabinets will be placed at the fire hydrant locations, and the system will be supplemented with portable fire extinguishers placed within the process plant facilities. The administration building, change house, and canteen will have hose reels and portable fire extinguishers.

A complete self-contained fire alarm system will be installed in all the buildings in order to comply with the local codes and insurance underwriter's regulations for fire protection.

18.1.8 Power Supply

After considering the results established in the technical and commercial evaluation, Mkango plans to have electricity supplied by an independent power producer (IPP) to reduce the initial upfront capital.

Three options were evaluated based on reliability, utilisation, and redundancy in order to achieve the best cost of energy:

- Thermal power generation
- Hybrid system with thermal and solar PV power generation
- Hybrid system with thermal, solar PV and energy storage system power generation

The operating cost of thermal power plants is significantly high due to their fuel consumption, and consequently the cost of energy is high since it is related to the fuel cost. Commercial solar PV power has been proven to provide lower cost energy for longer life cycle projects. A hybrid system uses PV power generation to reduce the loading of the thermal generators, which results in a considerable saving on fuel consumption and lowers the environmental impact of the emissions produced by the plant. However, the PV penetration is limited due to the minimum loading requirement for the generators, as well as the operating reserve required for the PV generation capacity, which ensures network stability in the event of a sudden change in PV generation capacity or load requirements. The option that was found to achieve the best cost of energy was the hybrid system in combination with a suitably sized battery energy storage system to provide operating reserves and to enable the thermal plant to run at its best efficiency point to allow for higher solar PV penetration and lower fuel consumption.

This option is designed to deliver the lowest cost of energy and reliable electricity, but it also includes a strong renewable energy component that will significantly reduce the carbon footprint of the mine.

18.1.8.1 Power Demand

An outline of the electrical power demand is shown in Table 18.1, based on the mechanical equipment list and plant infrastructure.

Table 18.1: Electrical Power Demand

Project Load	Continuous Power Demand (kW)	Maximum Start-Up Demand (kW)
Process Plant	20,201	–
Off-Site Infrastructure	1,447	–
Camps	418	–
Ball Mill	3,004 (3,400[a])	4,640
Total	**25,071**	
[a] Rated		

The maximum steady-state continuous power demand is estimated at 25,071 kW, with the ball mill being the only load of critical relevance to the maximum start-up energy demand. The ball mill drive will be driven by a squirrel cage motor, and the start-up current will be limited with a VSD. It is anticipated that the VSD will reduce the starting power demand of the ball mill to a maximum of 1.0 to 1.30 times the rated capacity of the motor.

The start-up sequence of the ball mill will last for approximately 60 s to 180 s, and it will increase the plant's maximum power demand to 26,487 kW. The power system should be suitably designed to deliver the required power for the start-up duration without interruptions to the other loads and will limit the voltage regulation to within 10 % of the rated system voltage.

18.1.8.1.1 Power Plant

The Songwe Hill Project will have access to the Malawian national grid and solar PV as a secondary source. The grid will be predominantly in use during night-time and in the event that the condition for solar PV is unfavourable. Furthermore, if the grid is not available, there are provisions for six 1.6 MW backup generators (five running and one on standby) to supply only the essential load during this scenario.

The use of solar PV has been proven to offer lower operating costs for projects by reducing the power purchased from the grid. Furthermore, the renewable energy component significantly reduces the carbon footprint of the mine.

18.1.8.1.2 Thermal Generation

The backup thermal diesel generators are configured to operate in a prime operating mode. The total number of allocated backup generators is six to allow for an n+1 redundancy.

The diesel generator parameters are provided in Table 18.2.

Table 18.2: Diesel Generator Sets

Item	Description
Prime Rated Power	2,000 kVA/1,600 kWe at 0.8 pf
Total Generation Capacity	8.0 MW/10 MVA at 0.8 pf, Prime
Rated Voltage	11 kV
Fuel Consumption, 100 % Load	0.248 L/kWh
Fuel Consumption, 75 % Load	0.251 L/kWh

18.1.8.1.3 Solar PV Plant

The PV plant shall only use Tier 1 manufacturers for key components such as inverters, transformers, PV modules and metering equipment.

The PV modules shall use mono PERC (passivated emitter and rear cell) crystalline bi-facial technology supplied by Tier 1 manufacturers with a 30-year linear degradation guarantee. The modules shall comply with IEC 61215 and IEC 61730. The parameters of the PV plant are shown in Table 18.3.

Table 18.3: Solar PV Plant

Item	Description
AC Power Rating	24.386 MW
DC Power Rating	31.58 MWp
Production, Year 1 – P50 (probability percentage)	67 661 MWh/a
Specific Production	2 142.53 kWh/kWp/a
Guaranteed Degradation	< 2 % for Year 1, 0.45 % from Years 2 to 30
PV Module Size	540 Wp
Number of PV Modules	58,493

The grid-tied PV system is aimed at both reducing the cost of energy and the impact on the environment, while also increasing the reliability of the power system. This enables Mkango to meet their sustainable development goals.

This efficient solution will enable a significant reduction in emissions (see Table 18.4) when compared to a conventional grid solution.

Table 18.4: Reduction in Emissions

Emissions	Grid Only (t/a)	Grid and PV (t/a)	% Saving Compared to Grid Only[a]
Carbon Dioxide	53,411	34,932	35
Carbon Monoxide	5.06	3.39	33
Unburned Hydrocarbons	0.41	0.27	34
Particulate Matter	0.78	0.52	33
Sulphur Dioxides	4.83	3.23	33
Nitrogen Oxides	19.30	12.93	33

[a] A reduction in emissions includes indirect emissions from the lower grid energy consumption as well as reduced fuel consumption from backup diesel generators, currently estimated to generate 2,995 MWh for the grid-only option vs 1,953 MWh for the grid-with-PV option due to an allowance of 416 h of grid outages per year. This would decrease the diesel purchase from 735,501 L/a to 493,501 L/a, which is a 33 % saving.

The following assumptions have been made:

- The grid will have one outage a week for 8 h.
- The essential load will be capped at a constant 7.2 MW, 90 % of the generator capacity.
- Infrastructure equipment will have a 0.65 diversity factor.
- The grid will be available three months before the concentrator is commissioned.

18.1.8.2 Electrical On-Site Infrastructure

The electrical on- and off-site infrastructure caters for the following infrastructure:

- On-site:
  - Plant Stores
  - Change House and Ablutions
  - Canteen
  - Administration Offices
  - Plant Workshop

  - Clinic
  - Sewage Plant
  - Security Gatehouse
  - Reagents Store
  - Final Product Store
  - Metallurgical Laboratory

- Off-Site:

  - Heavy Vehicle Workshop
  - Mining Infrastructure
  - Fuel Depot and Diesel Bay
  - Camp

Power reticulation will be done at the following voltages:

- Medium voltage: 11,000 V
- Low voltage: 400/230 V
- Control voltage: 110 V AC

18.1.8.3 Transformers

Distribution transformers will be manufactured in accordance with IEC 60076 and other relevant international standards, and will be as follows:

- Outdoor oil immersed type
- Insulation medium air ONAN (oil natural air natural)
- Three-phase
- Copper windings
- Vector Group Dyn 11
- Offload tap changer ± 2 × 2.5 %

18.1.8.4 Low-Voltage Distribution

The maximum transformer rating for low-voltage supplies will be 2,500 kVA. Each transformer will feed a 400 V MCC that supplies power to a dedicated section of the plant. Feeds to the MCCs will be single feeds only.

The MCCs will feed the lighting distribution boards that will supply lighting and small power distribution (normal) at 400 V/230 V (single-phase or three-phase).

18.1.8.5 Motor Control Centres

Five containerised MCCs have been allocated for the process plant. The MCCs will be of the compartmentalised, non-withdrawable type with moulded case circuit breakers, magnetic contactors and earth bus, and they shall comply with IEC 61439-2.

18.1.8.6 Electrical Motor Control Stations

The electric motors are as per the requirements on the equipment list. Motors shall be of Efficiency Class IE3 (premium efficiency) in accordance with IEC 60034-30-1.

The control of these motors can be summarised as follows:

- Start-Stop/Emergency-Stop push-button stations will be located at each motor.
- Stations located in wet process areas or outdoors will be of watertight construction.

18.1.8.7 Earthing and Lightning Protection

Provision has been made for earthing of all electrical equipment and buildings where applicable.

The earthing philosophy for the supply of plant equipment shall be the TN-S earthing system, where one of the points in the generator or transformer is connected to earth, usually the star point in a three-phase system. The enclosure of the electrical device is connected to earth via this earth connection at the transformer.

Provision has been made for earth resistivity testing prior to the installation. Earth mats shall be installed at all medium-voltage substations, ring main units, and transformers.

High mast lighting shall form part of the plant's lightning protection system by serving as lightning surge arrestors.

18.1.8.8 Electrical Cables

The following shall apply to electrical cables:

- All cables specified shall comply with the relevant part of SANS 1507.
- All outdoor cables shall either be buried in the ground or placed on cable racking.
- Cables shall cross underneath roads in dedicated sleeve polyvinyl chloride pipes.
- Grouped cables shall be de-rated in accordance with SANS 10142-1 for 600 V/1,000 V cables.

18.1.8.9 Cable Racking

Cable racking shall be used where cables are running on structures or indoors, or where cable support is required.

18.1.8.10 Lighting

Provision has been made for light-emitting diode (LED) lighting, which will be structure-mounted to ensure safe working conditions. Lighting will also be installed to ensure that visual security monitoring can be conducted at all times in and around the process plant and associated infrastructure to maintain a safe work environment. The final design and layout will be confirmed during the implementation phase.

18.1.8.11 Fire Detection System

Provision has been made for fire detection systems for all medium-voltage switches, MCCs, servers and control rooms. These rooms will also be equipped with handheld firefighting equipment. The fire detection systems will be integrated with the plant's central control system to alert the plant operators of any fire incidents.

18.1.9 Process Plant Diesel backup generators

The diesel backup generators for the plant will consist of six 1.6 MW diesel-powered generators. These units have been sized to allow adequate power to the process and hydrometallurgical plant to ensure that the process will not be interrupted during a power outage. The supply calculations were done only to keep the agitators running to avoid settlement in the process tanks.

The diesel will be transported from the supply facility operated by the Fuel Supply Contractor by means of a diesel bowser to the two storage tanks. The self-bunded storage tanks can store 20 m^3 diesel each.

18.1.10 Communications (IT Network)

The communications system (IT network) for the plant will be specified by Mkango. A provision for this system has been made under the Owner's pre-production cost.

An Airtel communication tower was installed in 2021, west of the plant area on a hill very close to the proposed process plant location. This tower has been used with good results thus far.

18.2 PROJECT ON-SITE INFRASTRUCTURE – MINING

Figure 18.2 is a sketch of the proposed mining infrastructure area.

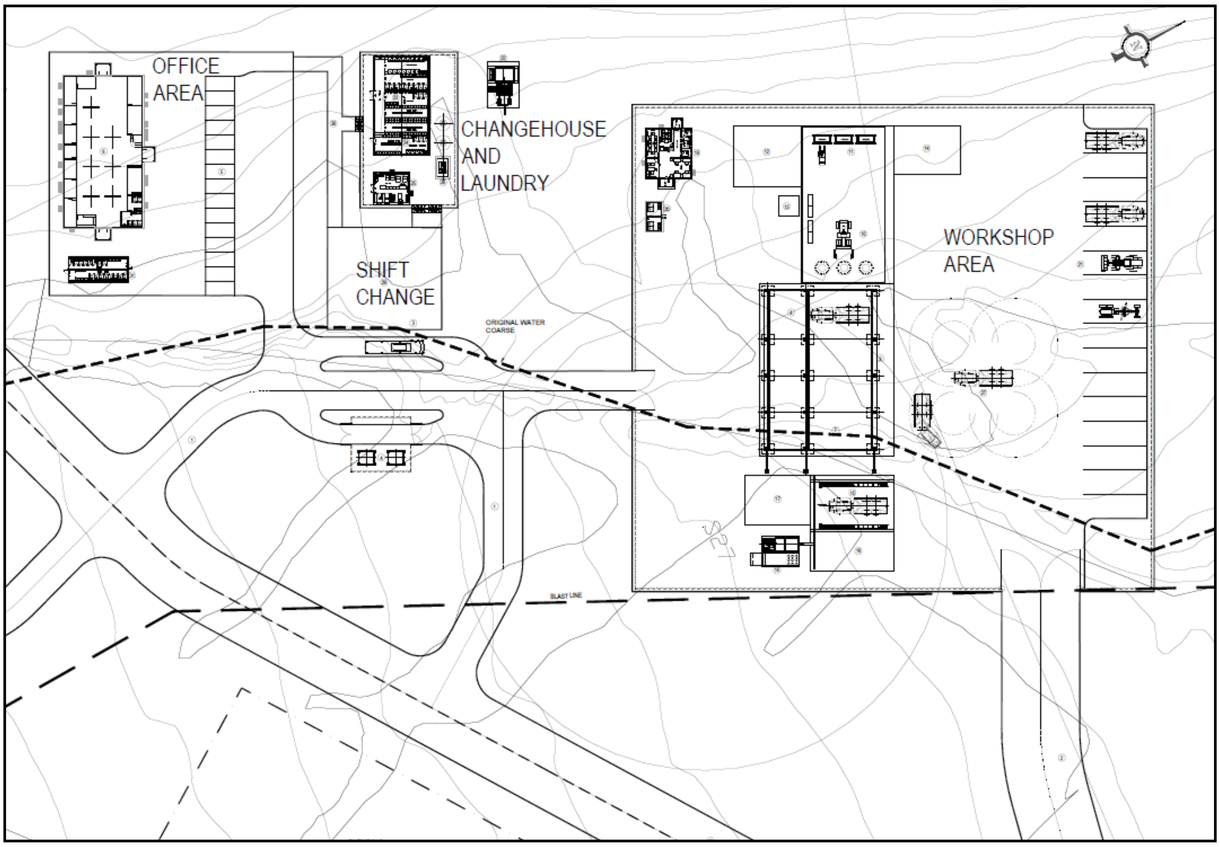


Figure 18.2: Mining Infrastructure Site Layout

The natural terrain at the Songwe Hill project area is sloped and will require earthworks to create terraces for the infrastructure. The terraced areas were divided into logical areas to reduce the volume of the earthworks. The terraced areas provided include an area for the offices, with parking, change house and laundry area, shift change and workshop areas. The mining infrastructure is located outside of the 500 m blast radius.

18.2.1 Mining Staff Complement

The mining manpower plan is presented in Section 16.8. The total mining complement is 150 people, made up of 129 contractor employees and 21 mine employees. The infrastructure described below is designed to accommodate the staff complement.

18.2.2 Offices for Management and Operations

The proposed terraced layout for the mining operations is divided into three areas, with the following dimensions for the terraces:

1. General offices: 50 m × 30 m
2. Change house: 30 m × 20 m
3. Workshop offices: 20 m × 15 m

The sections below describe the provisions made for the buildings and facilities in each of the three areas.

18.2.2.1 General Offices

The general offices are intended to accommodate up to 30 people.

18.2.2.2 Change House Area

The change house area will accommodate up to 110 people over two shifts. The peak number of users will be 74 people in one shift. The ratio of change house male to female users was assumed to be 80:20.

A laundry was provided separately from the change house.

18.2.2.3 Workshop Offices

The workshop offices are intended to accommodate up to five people and are equipped Mine Workshop and Vehicle Servicing

Due to its remote location, servicing of the mining equipment will take place at the mine. Table 16.15 shows the mining fleet that is required for the mining operations and that was used to determine the workshop requirements.

The primary workshop primarily services the haul trucks. The drill rigs and excavators are usually serviced in the mining pit but may be transported to the primary workshop for major repairs.

18.2.3 Diesel Storage

Diesel will be provided from a central fuel farm supplied and operated by others. The Mining Contractor will collect the fuel from the fuel farm by either refuelling at the central station or distributing it to the in-pit users with a fuel bowser.

18.2.4 Explosives Magazine Storage

The Mining Contractor is responsible for the supply and storage of the explosives and blasting accessories required for the liberation of ore. The Mining Contractor is also responsible for providing their own level, prepared platform, complete with storm water management and drainage, in a suitable location on which to build their explosives magazine storage facility.

The Mining Contractor shall ensure that the facility is properly secured and that it complies with the requirements of the Malawian standard for the construction of explosives storage.

18.2.5 Potable Water

Potable water will be supplied to the mining office infrastructure from the plant operations from the bulk water supply system and reticulated to the individual buildings from a tank and pressure boost station.

18.2.6 Other Supporting Infrastructure

Provision was made for the following:

- Emulsion receiving, storage and distribution area.
- A shift change area for people to wait for the buses transporting people to the pit.
- Explosives magazine and detonator store. The bunkers are located 500 m away from the main infrastructure.

18.2.7 Waste Water

Waste water from the individual buildings will be reticulated to a lift station. The lift station will pump the waste water to a central sewage treatment and disposal plant operated by others.

18.2.8 Power Supply and Reticulation

Power supply to the mining infrastructure area will be provided from the plant by others. Power will be reticulated to the infrastructure buildings from a local mini-substation unit.

The mining infrastructure equipment installed load is 233 kW and consists of the loads detailed in Table 18.5.

Table 18.5: Installed Loads for Mining Infrastructure

Description	Number of Motors/Loads	Rated Power per Motor/Load (kW)	Total Installed Motors/Loads (kW)
Laundry	1	–	46.0
Change house (male and female)	1	–	26.9
Offices (620 m²)	1	10	10.0

Description	Number of Motors/Loads	Rated Power per Motor/Load (kW)	Total Installed Motors/Loads (kW)
Emulsion storage	1	2	2.0
Sewage pumping	1	15	15.0
Explosives destruction	1	2	2.0
Workshop	1	-	112.1
Area lighting	8	9.6	19.2
Total			**233**

18.2.9 Storm Water Management

Storm water runoff from the mining infrastructure area reports to a new drainage system that diverts the water to the TSF storm water dam. The new drainage system will be developed as part of the TSF infrastructure development by others.

Any storm water collected as dirty water at the workshop areas will report to the workshop's silt and oil trap area. From here, the water will be treated with a biological process and then stored for reuse.

18.2.10 Haul Roads

The Songwe Hill mining area will include a network of major haul roads linking the following primary areas:

- Open pit
- ROM pad and blending area
- Medium-grade ore stockpile
- Waste rock dump
- Type 2 material stockpile
- Mining infrastructure area

Minor haul roads will be positioned on the perimeter of the ore stockpile and waste rock dump for the purpose to provide access.

18.2.10.1 Haul Road Design Criteria

The haul roads are required to facilitate bi-directional travel for the major routes and single directional travel for the minor access routes. Table 18.6 provides a summary of the haul road geometry and layer works.

Table 18.6: Haul Road Design Criteria

Description	Item	Source
Vehicle type	40 t ADT (e.g. Caterpillar 740B)	Bara
Vehicle width	3,801 mm	CAT
Vehicle operating weight (max.)	74,363 kg	CAT
Vehicle axle weight (max.)	25,638 kg	CAT

Description	Item	Source
Single carriageway width factor	2	Prime Resources
Single carriageway width (min.)	7.6 m	Prime Resources
Dual carriageway width factor	3.5	Prime Resources
Dual carriageway width (min.)	13.3 m	Prime Resources
Cross-slope gradient	2 %	Prime Resources
Road gradient (max.)	10 %	Prime Resources
Drainage	Side drainage channel	Prime Resources

18.2.10.2 Haul Road Geometry

The dual- and single-carriageway haul road widths have been selected as 13.5 m and 8 m, respectively. The crossfall on the surface of the haul roads is 2 %. The total length of the haul roads is approximately 4 km. The topography of the mining area is very steep, specifically the areas along the hills surrounding the pit, which require a maximum road gradient of 10 %.

The crossfall on the road surface allows for surface runoff to flow into a drainage channel positioned alongside the haul road. The drainage channel will comprise a trapezoidal profile, with a depth of 0.5 m, a base width of 0.5 m, and side slopes of 1V:1.5H. Light vegetation such as short grass should be allowed to establish in the channel to avoid erosion within the channel. The channels should be maintained and kept free of large debris or excessive silt build-up which could influence the hydraulic function and capacity of the channels. Runoff collected in the channel will be diverted into the surrounding environment with mitre drains. The spacing will range from 50 m to 200 m, with spacing decreasing with increases in the road gradient.

18.2.10.3 Haul Road Layer Works

A series of dynamic cone penetration (DCP) tests were undertaken along the centreline of the proposed haul road route to determine the in-situ material resistance to penetration.

The DCP results, most of which indicated values of between approximately 5 mm and 10 mm per blow, are indicative of dense to very dense soils. Loose and soft soils were also encountered in places.

The DCP results were converted to California Bearing Ratio (CBR) values, and the haul road layer works were designed as per the CBR cover curve method (Thompson, et al., 2018), assuming a fully laden total truck mass of approximately 74 t and a maximum wheel-to-ground pressure of 352 kPa. An in-situ CBR value of 6 % was selected as the basis of design. The layer works materials specification was adopted from the South African recommended standards for road construction materials (Committee of State Road Authorities, 1985).

Table 18.7 summarises the proposed haul road layer works specifications. The compaction specifications are stated as relative compaction density, in a percentage of MOD AASHTO density at optimum moisture content.

Table 18.7: Haul Road Layer Works

Layer	Thickness (mm)	Minimum CBR (%)	Material Type	Relative Compaction (%)
Wearing course	200	80	G4 (natural gravel)	98
Base	200	45	G5 (natural gravel)	95
Sub-base	300	25	G6 (natural gravel)	93
Subgrade (in situ)	200	6	G7 (natural gravel)	90

18.3 PROJECT OFF-SITE INFRASTRUCTURE

18.3.1 Site Location and Accessibility

Songwe Hill is located approximately 110 km (2 h) northeast of Blantyre, which also has the closest airport to the project. The project is west of the Mozambiquan border, south of Lake Chilwa (see Figure 18.3).

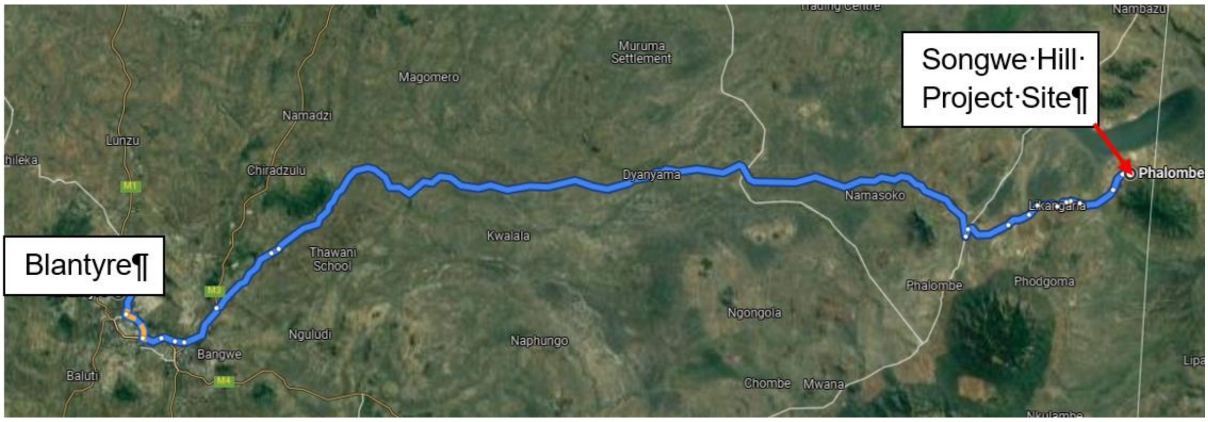


Figure 18.3: Main Access to the Project Site

Access to the project site from Blantyre is north via the S146, branching off east on the S145 to the town of Siana. From Siana, the S147 north is taken for approximately 600 m before the split east at the village of Migowi onto the T415. From Migowi, the T415 is followed northeast, through the town of Likangaria, for approximately 10 km until it reaches the project site. From this point, a new access road will be constructed heading east into the proposed processing plant area.

Sections of the S145 between Blantyre and Siana are currently being upgraded to a Class 1 bitumen road, which will improve access conditions up to this point.

Further to this, upgrades to the T415, from Migowi past the Songwe Hill site, are also currently under way by the government. Although this road section will not be surfaced, it is being formalised, which will improve access conditions to the project site.

As part of the project, a diversion of the T415 will be constructed to the north of the project site in order to route around the proposed project infrastructure.

18.3.2 Camp and Catering Facilities

18.3.2.1 Existing Camp

Mkango has currently established certain administrative and support infrastructure off site in the form of an exploration camp, complete with sample storage buildings and accommodation for exploration and security staff. The camp has its own kitchen and ablution facilities. This tented accommodation will be utilised during the early works phase of the project until the new accommodation facility has been erected.

18.3.2.2 New Accommodation Facility

The new accommodation facility will be adequate to house a total of 320 people. It will be divided into tented accommodation and flat pack accommodation. The tented accommodation will be used for the 150 general labourers required during the construction phase. This tented accommodation will be temporary and can be removed once the construction phase of the project has been completed.

The flat pack accommodation will consist of a flat pack containerised unit for managers and plant equipment vendors during the construction phase. There will be 20 single accommodation units with en suite ablutions and 75 double accommodation units with en suite ablutions, for a total of 170 people. After construction, these units will remain and be utilised for the permanent accommodation of non-local personnel and visitors.

The accommodation facilities will be equipped with a complete kitchen, laundry and two dining areas for the 320 occupants. A containerised sewerage and water treatment (reverse osmosis) plant will form part of this stand-alone facility, with two 400 kVA diesel generators for the power supply to the accommodations until the final electrical infrastructure is in place and installed from the process plant.

Raw water will be fed from the borehole complex to the west, and the water will be treated through the reverse osmosis plant to ensure the quality for potable use.

The total accommodation comprises the following:

- Single and double quarters (sized for 170 people sharing)
- Tented accommodation (sized for 150 people sharing)
- Dining hall and kitchen (sized for 320 people)
- Potable water storage and septic tank arrangements
- Services reticulation
- Fencing and gate for security control
- Two 400 kVA diesel generators, complete with reticulation building units
- Earthworks for terraces and civil works for building hard stands

18.3.2.3 Catering Facilities

All catering and housekeeping services will be managed by the catering and camp management services team. This includes food and consumables management, room cleaning, personnel laundry services, and pesticide spraying.

In addition to catering for the staff at the camps, food will also be prepared for lunch time meals at the process plant. The process plant has its own kitchen and dining room.

Appointing a housekeeping and catering services contractor can be considered as an alternative.

18.3.3 Medical Facilities

All medical services will be managed by the clinic in the process plant.

18.3.4 PV Power Plants

The PV plants are located in three different areas. PV Plants 1 and 3 are situated within the fenced process plant area while PV Plant 4 is located further northwest and will be fenced off separately for security and access control.

18.3.5 Diesel Fuel Storage

The diesel for the mining fleet and the process plant will be supplied and operated by a fuel supplier.

The storage of the diesel will be at the mining fleet dispensing station, located west of the mining infrastructure buildings, where allowance has been made for 10 d storage of diesel for mining, plant and emergency power generation.

18.3.6 Communication

An integrated information system will be provided by Mkango, including the latest operating systems enabling effective telephonic and digital communications.

18.3.7 Water Supply System

A continuous supply of potable water will be provided to a connection point at the accommodation area. This is the same water supply that feeds the process plant and will be fed from the borehole complex on the western side of the plant.

The accommodation area will be equipped with a stand-alone water system including a reverse osmosis plant to ensure potable water quality.

18.3.8 Sewage Disposal

The accommodation area has its own stand-alone sewage water treatment facility to cater for the full complement of the accommodation facility.

18.4 TAILINGS STORAGE FACILITY

18.4.1 Introduction

In 2020, Mkango commissioned a DFS of the Songwe Hill Rare Earth Element Project (Songwe Hill), under the study lead of SENET. Epoch Resources (Pty) Ltd (Epoch) was in turn appointed by SENET to undertake the DFS design of the tailings storage facility (TSF) associated with Songwe Hill.

The battery limits for the DFS design of the TSF are as follows:

- The downstream infrastructure around the TSF, within the access road and catchment paddocks where the access road is absent, comprising the tailings dam (TD) and storm water control dam (SWCD)
- Downstream of the point where the slurry delivery pipeline crosses the toe line of the TD embankment wall
- The top surface of the decant/excess water pond on the TD/SWCD (i.e. excluding the decant turret)

18.4.2 Design Criteria and Project Information

18.4.2.1 TSF Design Parameters

The key TSF design parameters are summarised in Table 18.8 with references to the source of the information where applicable.

Table 18.8: Key TSF Design Parameters

Item	Design Criteria	Value	Source
1	Tailings Material	Rare earth elements	Project specific
2	Typical Tailings Deposition Rate	1 Mt/a	Mkango
3	LOO Storage	20 years	Mkango
4	Total Tonnage	20 Mt	Mkango
5	Tailings Specific Gravity	2.8	Laboratory test work from Western Geotechnical and Laboratory Services (WGLS)
6	Tailings Particle Size Distribution (PSD)	94 % passing 75 µm sieve	WGLS
7	Slurry Percentage Solids by Mass	50 % solids by mass	SENET
8	Slurry Density	1.47 t/m^3	Epoch, calculated from percentage solids and SG
9	Tailings Settled Void Ratio	1	Estimated from laboratory test results
10	Placed Dry Density	1.4 t/m^3	Estimated from laboratory test results
11	Freeboard	1 m above the Inflow Design Flood	Epoch, calculated based on Canadian Dam Association (CDA) wave run-up guidelines
12	Geochemical Characteristics of Tailings	TBC	Geochemistry test work currently under way

Item	Design Criteria	Value	Source
13	TSF Lining System	TSF will be lined with 2 mm HDPE	Project decision based on generally accepted practice
14	Depositional Methodology	Spigot/open-ended discharge	Epoch
15	Type of Facility	Full containment	Epoch
16	Return Water Management Strategy	Return water sump and SWCD	Epoch
17	Storm Water Management Strategy	Storm water diverted around TD into SWCD	Epoch
18	TSF Decant System	Turret system	Epoch
19	Maximum Height of TSF	42 m	Epoch
20	Survey Information	Minimum contour interval of 1 m and an accuracy of 0.1 m	SENET, based on received PhotoSat survey
21	Mean Annual Rainfall (MAR)	334 mm	Digby Wells
22	Mean Annual Evaporation (MAE)	1,047 mm	Digby Wells
23	Maximum Credible Earthquake (MCE)	1:10,000 recurrence interval for Extreme Consequence facilities	As per Global Industry Standard on Tailings Management (GISTM)
24	Peak Ground Acceleration (PGA) for MCE	0.239 g	As per seismic hazard assessment
25	Environmental Design Flood	1:200 7 d storm event: 267 mm	Epoch
26	Inflow Design Flood	Probable maximum precipitation (PMP): 1,082 mm	Based on CDA guidelines for freeboard design

18.4.2.2 Design Legislation/Codes/Guidelines

As Malawi does not have any existing TSF design legislation, codes, or guidelines, the design process is based on the Global Industry Standard on Tailings Management (GISTM) (2020). The following additional guidelines were used:

- For freeboard and storm diversion design recommendations:
  - CDA, Dam Safety Guidelines (2013)
  - CDA, Application of Dam Safety Guidelines to Mining Dams (2019)
- For positioning of the test pits and boreholes for the geotechnical site investigation:
  - South African Institution of Civil Engineering (SAICE) – *Geotechnical Division, Site Investigation Code of Practice* (2010).

18.4.3 Characterisation of the Tailings

The plant comprises the following two sections:

- Concentrator plant: comprising size reduction, froth flotation, flotation tails thickening, and concentrate thickening and filtration.
- Hydrometallurgical plant: comprising a series of leaching, conversion, and purification stages

The following tailings streams from these two sections are delivered to the TSF:

- A flotation tailings slurry of approximately 50 % w/w solids to liquid ratio. The solution will contain residual flotation reagents such as collectors, depressants, and pH modifiers. These solids will also include a small quantity of sulphide pre-float concentrate, combined with the flotation tails samples.
- A combined hydrometallurgical solid residue and tailings stream as a composite of several other smaller streams from the hydrometallurgical plant, including the following:
  - Rare earth leach residue, the largest single solids waste stream from the hydrometallurgical plant (2.11 t/h dry). The solids will be filtered before being repulped in the neutralisation area, and they will contain ore minerals that have not leached in the two leaching or caustic conversion stages.
  - Gangue leach purification residue, comprising impurity precipitates such as salts of aluminium, iron and manganese. The residue is approximately 0.6 t/h on a dry basis and is filtered.
  - Causticisation residue, precipitated as impurities from a solution of redissolved sodium salts that are crystallised during evaporation. The solids comprise mainly calcium carbonate and calcium fluoride, estimated at 1.18 t/h of dry solids.
  - PLS purification residue, produced at 0.018 t/h, including polished salts of iron, aluminium, phosphorus, and an estimated 1.47 kg/h of thorium.
- A barren solution stream from the rare earth carbonate precipitation with ammonium bicarbonate which forms part of the tailings slurry mixture and is not conveyed to the TSF as a separate stream. This solution is high in primarily chloride and ammonium. SENET and ANSTO have proposed treatment options to recover chloride and/or ammonium from this liquor; these will be evaluated at a later stage.

The tailings streams are summarised in Table 18.9.

Table 18.9: Tailings Streams

TSF Feed Stream	Unit	Flow
Flotation Tails Solids (50 % of slurry mixture)	t/h	114.2
Flotation Tails Liquid (50 % of slurry mixture)	m^3/h	93.4
Rare Earth Leach Residue	t/h	2.11
Gangue Leach Purification Residue	t/h	0.6
Causticisation Residue	t/h	1.17
PLS Purification Residue	t/h	0.018
Barren Solution	m^3/h	32.45

18.4.3.1 Geotechnical Characterisation of the Tailings

The physical and geotechnical characterisation of the tailings has been based on the following:

- Indicator tests to determine the PSD
- Triaxial tests to determine shear strength parameters
- Permeability tests

- Consolidation tests
- Drained and undrained settlement tests

The tailings sample on which the tests were conducted comprises the components listed in Table 18.10.

Table 18.10: Tailings Sample Components

Sample Component	Percentage by Mass (%)
Gangue Leach Neutralisation Precipitate	0.3
Causticisation Residue	1.1
Rare Earth Leach Residue	2.7
Flotation Tailings	95.8

The results of the testing show that

- The PSD curve for the tailings sample, shown in Figure 18.4, indicates a fine material, with 94 % of the material passing the 0.075 mm sieve.
- Table 18.11 summarises the parameters adopted for the tailings and the study. In the slope stability analyses, the slip circle remains within the confines of the waste rock embankment wall; therefore, the strength parameters of the tailings do not affect the results.

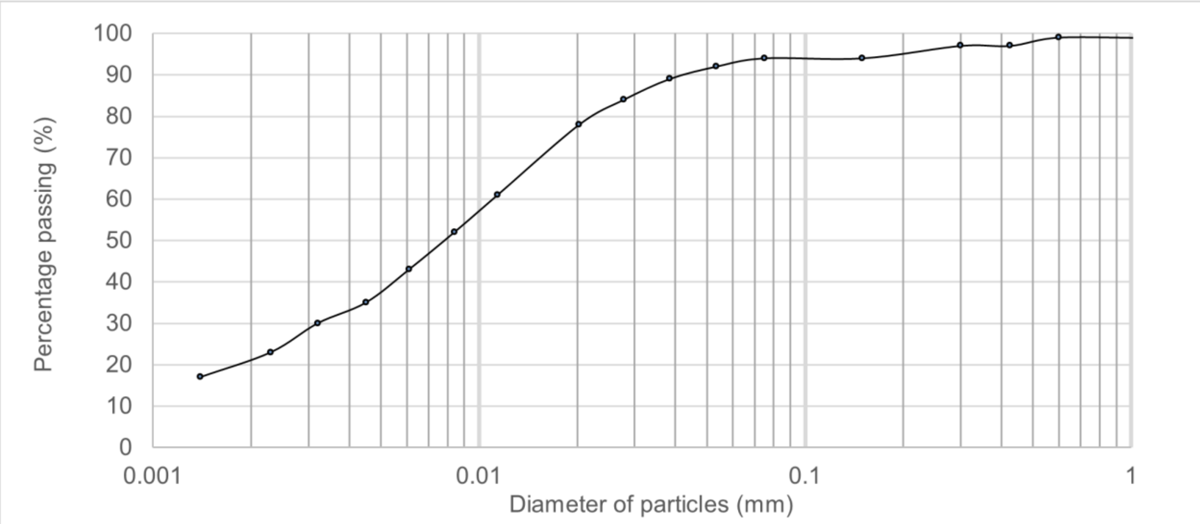


Figure 18.4: PSD for Rare Earth Tailings

Table 18.11: Material Parameters Adopted for the TSF Slope Stability Analyses

Material Description	Unit Weight (kN/m^3)	Effective Friction Angle, φ' (degrees)	Effective Cohesion, c' (kPa)	Hydraulic Conductivity (m/s)
Rare Earth Tailings	13	32	0	4×10^{-7}

18.4.3.2 Radioactive Characterisation of the Tailings

Due to the presence of naturally occurring radionuclides in the rare earth deposit, Digby Wells commissioned AquiSim Consulting (Pty) Ltd (AquiSim) as Radiation Protection Specialist to conduct the Radiological Public Safety Assessment (RPSA) to assess the potential radiological impact on members of the public from the Songwe Hill Project.

The findings of the assessment are summarised below:

- The contribution of radon, thoron and dust inhalation as well as animal and crop ingestion are all below the total effective dose (less than 20 % of the dose limit of 1,000 μSv.year^{-1} for public exposure) at selected receptor locations. As a result, no additional management or mitigation measures are required from a regulatory compliance perspective.
- A simplified one-dimensional numerical groundwater model was used to assess the radiological consequences of leaching of radionuclides from the TSF, using a compartmental modelling approach to represent the migration and fate of contaminants in the environment. As a compliance point, a borehole 500 m away from the TSF was selected, assuming members of the public consume the contaminated groundwater daily. The findings of the assessment are summarised below.
- Groundwater modelling was undertaken as part of the radiation study and determined that potential doses through the groundwater pathway reach peak concentrations after 20,000 years and the peak dose would be below 20 μSv.year^{-1}. This is significantly less than the public dose limit of 1,000 μSv.year^{-1}.

18.4.3.3 Geochemical Characterisation of the Tailings

SGS Perth Environmental Laboratory was appointed by Digby Wells to conduct the geochemical analysis on the tailings and barren liquor stored in the TSF. One barren liquid and six tailings composite samples were analysed with the following composition:

- Gangue Leach Neutralisation Precipitate
- Causticisation Residue
- Rare Earth Leach Residue
- Combined Hydrometallurgical Purification Residue
- Combined Front- and Back-End Hydrometallurgical Tailings
- Flotation Tailings

The analytical suite included the following:

- Mineralogical analysis – X-ray diffraction (XRD) analysis to determine the mineral constituents of the samples
- Total metal analysis – X-ray fluorescence (XRF) and acid digestion (aqua regia) followed by semi-quantitative 29 elements inductively coupled plasma (ICP) scan
- Synthetic precipitation leaching procedure (SPLP) and deionised water leaching test at 1:4 solid to liquid ratio
- Acid-base accounting (ABA) tests including sulphur speciation (total sulphur, sulphate sulphur and sulphide sulphur)

- Non-acid generating (NAG) test, where an oxidising agent (hydrogen peroxide) is used to assess whether a sample can neutralise the potential acidity on complete oxidation of sulphides

The results of the analyses are as follows:

- The reactive minerals in the tailings were acid neutralising minerals, namely carbonates (1.5 % to 57 %), aluminosilicates (1.3 % to 17 %) and goethite (3.7 % to 4.1 %), contributing to the overall neutralisation potential (NP) of the tailings.
- The tailings streams were acidic to alkaline (pH 4.4 to 13) in the short term. The acidic tailings streams were rare earth leach residue (pH 4.4) and combined hydrometallurgical purification residue (pH 4.9).
- Consistent with the mineralogy results, total sulphur in the tailings ranged from 0.14 % to 1.2 %. The sulphur occurred predominantly as sulphate (0.14 % to 1.0 %). Sulphide sulphur ranged from 0 to 0.2 %.
- The NAG pH ranged from pH 4.3 to 13. All the tailings streams will be non-acid forming (NAF) in the long term except the rare earth leach residue and combined hydrometallurgical purification residue, which were inconclusive and classified as Uncertain.
- The leachate from the tailings streams were highly alkaline (pH 9.1 to 13) except for rare earth leach residue (pH 4.3) and combined hydrometallurgical purification residue (pH 4.7). The leachates are saline (total dissolved solids (TDS), 3,045 mg/L to 22,516 mg/L) except rare earth leach residue (TDS, 838 mg/L) and flotation tails (TDS, 230 mg/L). The potential parameters of concern in the tailings' leachates were identified as alkalinity, arsenic (As), calcium (Ca), chloride (Cl), chromium (Cr), fluoride (F), sodium (Na), TDS, and zinc (Zn).

18.4.4 Geochemical Characterisation of the Waste Rock Material

Bara Consulting (Pty) Ltd was appointed to identify potential pollutants associated with the waste rock material and to assess the metal-leaching and acid-generating potential of these materials. The TSF will be constructed from the waste rock made available from mining operations; therefore, the test work is relevant to the TSF design.

The anticipated waste rock from the Songwe Hill REE Project is comprised of fenite, fenite breccia and phonolite, with minor proportions of overburden, syenite and oxidised material. The waste rock is predicted to be non-acid generating, owing to the abundance of neutralising carbonate minerals and lack of sulphidic minerals. Five composite waste rock samples were selected to represent the dominant lithologies anticipated in the waste rock dump. The geochemical analyses of the waste rock composite samples include the following:

- Aqua-regia digestion and analyses by inductively coupled plasma mass spectrometry (ICP-MS) and optical (atomic) emission spectrometry (ICP-OES) to determine the total elemental composition
- Synthetic precipitation leaching procedure at a 1:20 solid to liquid ratio and water leaching at a 1:4 ratio to determine the readily soluble and mobile fractions of the material
- Qualitative X-ray diffraction (XRD) analysis to determine the mineralogy

The following may be concluded based on the test work conducted:

- The composite samples have insufficient sulphide present (below the limit of 0.3 %) to sustain long-term acid generation if oxidised.
- The leach test results have shown that the pH of the leachate exceeds the IFC standard (maximum pH of 9) for discharge; however, the pH was within the Malawi Bureau of Standards drinking water quality requirement (maximum pH of 9.5). The runoff from the waste rock dump is therefore anticipated to be alkaline with minor enrichment of contaminants of concern and REEs.
- The waste rock is enriched in barium (Ba), cadmium (Cd), manganese (Mn), molybdenum (Mo), lead (Pb), selenium (Se), strontium (Sr), thorium (Th), Zn and REEs. The mobility of these elements in the leaching experiments, except for some of the REEs, was found to be below the IFC guidelines and therefore poses a low risk of pollutant release in the short term. The non-acid generating pH was pH 9.3, indicating that the waste rock will be non-acid forming in the long term.

Although the anticipated runoff from the waste rock is not considered to be of a high risk due to its lack of acidity and low concentrations of regulated contaminants, there is potential for the waste rock to release an elevated alkaline discharge (high pH) with minor concentrations of REEs which could pose a risk to freshwater resources. It is recommended that protection of groundwater resources should be prioritised due to their extensive use in the region. Therefore, an engineered basal liner of compacted in-situ soil or similar is recommended to restrict ingress of potentially contaminated runoff to groundwater.

18.4.5 Site Selection

A site selection study was conducted for the initial required storage capacity of 30 Mt, and the self-raising TSF considered in previous assessments prior to the DFS was replaced with a more robust, full-containment facility after taking the publication of GISTM in 2020 into account in the design, and also taking cognisance of the seismic nature of the area. The following criteria were considered in the TSF footprint optimisation process within the previously selected TSF configuration for the revised design criteria:

- Available space for the plant
- Available space for the waste rock dump and ore stockpile
- Proximity to the graveyard boundaries
- Proximity to the school, road and villages to the north
- Potential for expansion should the LOO be extended or the tailings production rate be increased
- A high-level capital cost of the major earthworks and HDPE lining for each site option

Four potential sites were identified. The four TSF footprint options were assessed for cost optimisation, as well as the potential to avoid any of the major graveyards, the road, school and villages to the north. Each site option is positioned directly upstream of the surrounding villages that will not be relocated and Mpoto Lagoon and is classified as an Extreme Consequence dam (further explained in Section 18.4.7.1).

Table 18.12 summarises the trade-off between the four options based on the criteria listed above. Fatal flaws are highlighted in red, and undesirable flaws are highlighted in orange.

Table 18.12: Site Selection Aspects

Item Description	Option 1	Option 2	Option 3	Option 4
Space for the plant	Yes South of TSF	Yes Southwest of TSF	Yes South of TSF	No
Space for the waste rock dump and ore stockpile	Yes East of TSF	Potentially West of TSF	Yes East of TSF	No
Proximity to the 100 m graveyard boundaries	Requires relocation of Maoni graveyard	Requires relocation of most graveyards	Requires relocation of Maoni graveyards	No relocation of graveyards required
Proximity to the school, road and villages to the north	Requires relocation of village around the road on the west	Requires relocation of village around the road on the east	Requires relocation of some villages	Requires relocation of some villages
Potential for expansion should the LOO be extended or the tailings production rate be increased	Yes	Yes	Yes	No (no space for plant)
High-level capital cost (US$ million)	85	88	100	90
Fatal flaws are highlighted in red, and undesirable flaws are highlighted in orange.				

Option 1 has been selected as the final site on which the DFS design will be conducted, for a design storage capacity of 20 Mt of dry tailings, with the potential to expand to 30 Mt in the future, because of the following:

- It was the most economical site based on the high-level capital cost estimate, and one of the lower risk sites.
- It can be expanded for the 30 Mt scenario should the LOO increase.
- There is sufficient space available for the construction of a SWCD system downstream of the TD, a plant to the south, and waste rock and ore stockpiles to the east.
- It lies downstream of the plant and pit; therefore, in the event of a TSF failure, it will not affect these structures.

18.4.6 Geotechnical Investigation

18.4.6.1 Geotechnical Site Investigation of the TSF Site

Geoconsult Pty Ltd, appointed by SENET, undertook a geotechnical site investigation of the preferred TSF footprint identified for the design. The locations of the test pits and boreholes were selected in accordance with the guidelines specified in the Site Investigation Code of Practice (SAICE, 2010).

The laboratory test work on the samples collected by Geoconsult was conducted by Zutari. Suitable samples for the triaxial test work were not available; therefore, a geotechnical engineer will be appointed to retrieve adequate samples from test pits on site, prior to the detailed design, to complete the test work campaign on the in-situ materials.

18.4.6.2 Laboratory Test Work

The test results for the test pit showed the soil to have a predominantly medium plasticity index (PI) range falling within the CL (inorganic clays of low to medium plasticity, silty clays) to SC (clayey sands and sand clay mixtures) Unified Soils Classification System (USCS) classification range, indicating a blend of cohesive soils with sand.

The soil parameters for the study were estimated based on recommended parameters provided by Zutari and shall be revalidated once the triaxial test results become available. The shear strength and permeability parameters of the in-situ and remoulded soils beneath the TSF embankment for preliminary design purposes are shown in Table 18.13.

Table 18.13: Recommended Design Parameters

Soil Type	Estimated Parameters					
	Effective Cohesion, c' (kPa)	Effective Friction Angle, φ' (degrees)	In-situ Permeability Coefficient (m/s)	Remoulded Permeability Coefficient (m/s)	Classification	Bulk Unit Weight (kN/m³)
Silty Clay	2	24	5.5×10^{-8}	1×10^{-9}	CL	18
Clayey Sand	0	34	3.0×10^{-6}	1×10^{-7}	SC	20

18.4.7 Tailings Storage Facility Design

The TSF comprises the following:

- A 2,000 µm HDPE-lined, full-containment valley TD constructed in four downstream lifts following the construction of the initial starter embankment
- The TD embankment constructed from waste rock material sourced from mining operations, with a 10 m wide crest comprising a 5 m layer of fine-grained material on the upstream face of the 5 m wide waste rock embankment wall
- A 2,000 µm HDPE-lined SWCD comprising a 1 m high wall, 3.5 m cut basin with a maximum storage capacity of 66,000 m^3
- Associated infrastructure, including the slurry distribution pipeline, catchment paddocks, toe drain system, underdrainage system, curtain drain system, solution collection pipeline, collection sumps and manholes, seepage cut-off trench, storm water diversion trenches, emergency spillways and leakage detection drains
- A floating turret to decant the supernatant tailings slurry water and storm water from the facility back to the plant

Figure 18.5 shows a close-up of the TSF configuration.

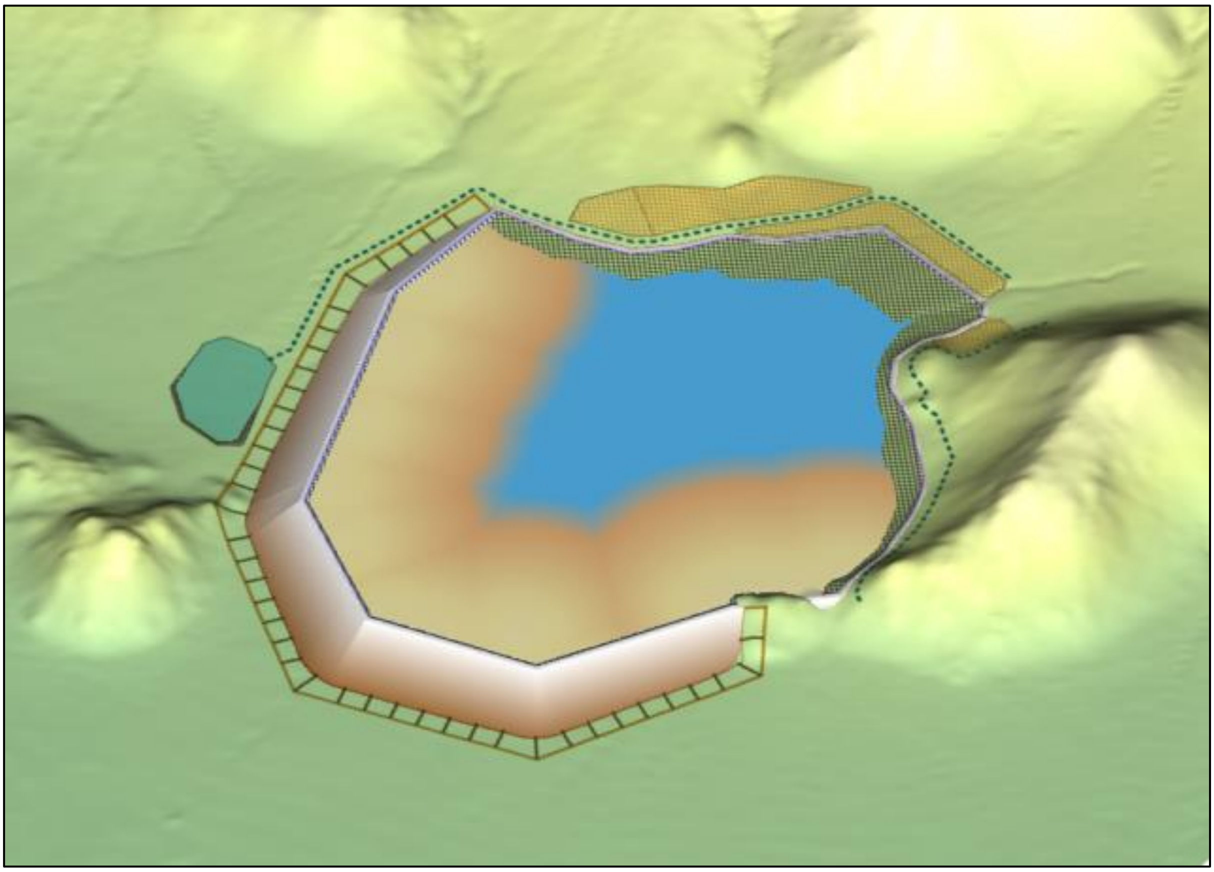


Figure 18.5: Close-Up of the TSF Site

18.4.7.1 Tailings Dam Consequence Classification

The Consequence Classification of the TSF has been carried out in accordance with the GISTM (2020) guidelines and provides the required design loading conditions to be adopted and applicable to Songwe Hill's TSF, including flood events, earthquake loading and wind events, which are applied for the design, construction, operation, and closure phases of a TSF. The Consequence Classification for Songwe Hill's TSF is Extreme, implying that the maximum prescribed loading conditions/events are to be adopted and applied for the TSF design.

The TSF is to be constructed as a valley deposit behind a compacted waste rock embankment that is unlikely to liquefy should a seismic event take place. The delineation of the breach zone of the TSF is, however, based on the premise that a failure of the embankment wall will occur, resulting in the release of water and eroded/liquefied tailings from the facility.

A preliminary assessment using simple and conservative procedures has been done to obtain a first approximation of the theoretical inundation zone and thus level of consequences. A more comprehensive dam break analysis will be completed at the detailed design stage to more accurately define the potential inundation extent of the TSF

18.4.7.2 Design Aspects of the TSF

The TSF has been designed taking cognisance of the following aspects:

- The topography, the immediate surroundings, and mine infrastructure
- A total dry tailings storage capacity of 20 Mt at a deposition rate of 1 Mt/a over the LOO of 20 years
- Phased construction of the TSF over the LOO

Table 18.14 summarises the key parameters associated with the TSF. The TSF shall be constructed in five phases over the LOO.

Table 18.14: Key Parameters Associated with the TSF

Tailings Dam Parameter	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Total footprint area of the facility within the tailings surface and pond (ha)	64	77	82	89	95
Maximum design embankment wall elevation (mamsl)	681.5	686.5	691.0	694.5	698
Maximum design embankment wall height (m)	23.5	28.5	33.0	36.5	41.0
Outer side slope of embankment wall	1V:3H				
Inner side slope of embankment wall	1V:2H				
Embankment wall crest width (m)	10				
Embankment wall material	Waste rock from mining operations (5 m) and suitable fine-grained material to upstream embankment wall face (5 m)				
Years of tailings deposition	4	4	4	4	4
Cumulative years of tailings deposition	4	8	12	16	20
Tonnes of dry tailings stored in TSF (Mt)	4	4	4	4	4
Cumulative tonnes of dry tailings stored in TSF (Mt)	4	8	12	16	20

18.4.7.2.1 Staged Capacity Curves

The stage capacity curves show the development of the TSF over time and illustrate the relationship between tailings elevation, rate of rise, storage volume, footprint area, cumulative tonnage and time.

The compacted earth embankment of the TSF is constructed in phases over its operational life, reaching a final height of 41 m above NGL, corresponding to an elevation of 698 mamsl. For each phase, tailings will be deposited behind the embankment wall until the maximum elevation is reached at the freeboard level below the crest elevation. By this time, the embankment wall of the subsequent phase will have been constructed and be ready to contain the deposited tailings. Table 18.15 summarises the tailings elevation, operational years, and dry tonnes of tailings per phase over the LOO.

Table 18.15: Staged Capacity of the TSF

Phase of Facility	Tailings Elevation (mamsl)	Cumulative Years	Cumulative Tonnage (Mt)
1	681.5	4	4
2	686.5	8	8
3	691.0	12	12
4	694.5	16	16
5	698.0	20	20

18.4.7.2.2 Preparatory Works

The preparatory works associated with the TSF are shown in the drawings and comprise the following for Phase 1 of the TSF:

- Topsoil stripping to a depth of 0.2 m within the TSF footprint, including the embankment wall footprint area and associated TSF infrastructure area.
- A shear key 4.0 m deep beneath the compacted earth embankment, using suitable fine-grained material.
- A compacted waste rock embankment with a 10 m wide crest, an outer side slope of 1V:3H, and an inner side slope of 1V:2H.
- A 5 m wide layer of suitable fine-grained material on the upstream face of the waste rock embankment wall, forming part of the total embankment wall width of 10 m.
- A compacted layer of suitable fine-grained material to a depth of 1.0 m beneath the TSF embankment wall to limit seepage through the waste rock embankment wall into the environment.
- A 1 m high bund wall with an outer side slope of 1V:3H and an inner side slope of 1V:2H along the final TSF perimeter.
- A 3 m wide elevated toe drain located on an elevated platform at 368 mamsl, along a section of the embankment corresponding to the first three months of tailings deposition elevation. During this time period, the pond is pushed away from the drain, which comprises slotted 160 nominal diameter (ND) HDPE piping, suitably graded filter sand, and intermediate and coarse graded stone, all wrapped in non-woven geofabric. The drain serves to draw down the phreatic surface within the TSF.
- A 3 m wide toe drain, constructed where the elevated toe drain is absent, comprising suitably graded filter sand, intermediate and coarse graded stone, and 160ND slotted HDPE piping, all wrapped in non-woven geofabric. This serves to draw down the phreatic surface within the TSF.
- Drains that are 3 m wide, constructed within the basin in the form of a grid, above the liner, comprising suitably graded filter sand, intermediate and coarse graded stone, and 160ND slotted HDPE piping, all wrapped in non-woven geofabric. This serves to draw down the phreatic surface within the TSF.
- A 0.75 m wide vertical curtain drain within the Phase 1 main embankment, extending from the embankment wall base to an elevation of 674 mamsl, comprising suitably graded filter sand, coarse graded stone, 160ND slotted HDPE piping, and non-woven geofabric. This serves to prevent the phreatic surface from migrating through the TSF embankment and exiting on the downstream side in the case of a liner leak.

- Pipes (160ND non-slotted HDPE) at specified intervals along the perimeter of the elevated toe drains, underdrains, and vertical curtain drains, channelling the water collected by these drains into the solution pipeline.
- A 355ND HDPE buried solution pipeline with 1 m backfill cover to channel the water from the various drain outlets to a water collection sump.
- Solution collection manholes spaced at intervals along the solution pipeline to collect seepage from the outlet pipes to be conveyed to the collection sump via the solution pipeline.
- A seepage cut-off drain located ~15 m downstream of the Phase 1 embankment downstream toe. It is 1 m wide and 2 m deep and collects sub-surface seepage water. The drain comprises coarse drainage material, 19 mm stone, two 160ND slotted HDPE pipes, all wrapped in non-woven geofabric.
- A water collection sump for the collection of water from the solution pipeline and seepage cut-off manhole, from where it is pumped back onto the TSF and ultimately to the process plant for reuse.
- Catchment paddocks that are 1.5 m high, along the perimeter of the TSF.
- A 5 m wide gravel access road to divert the existing road around the TSF.
- A 1.5 m deep, 1V:1.5H side slope and 1.0 m wide base, trapezoidal dirty storm water diversion and associated cut to fill berm, leading into the SWCD.
- A 400 OD HDPE, PE100 PN10 SDR 17 slurry distribution pipeline along the perimeter length of the TSF, with discharge outlets located at 36 m intervals.
- An emergency spillway, with 1V:2H side slopes, 8 m wide base and a 0.3 m Reno mattress, to prevent overtopping of the TSF embankment wall in the unlikely event that the pond size increases, resulting in emergency decanting from the TSF.
- A 3.5 m deep SWCD basin and 1.5 m high compacted embankment wall with a 10 m wide crest.
- Leakage detection drains beneath the SWCD liner, comprising suitably graded filter sand, intermediate and coarse graded stone, and 160ND slotted HDPE piping, all wrapped in non-woven geofabric.
- A water collection manhole for the collection of leakage water beneath the liner.

The preparatory works associated with Phases 2, 3, 4 and 5 of the TSF predominantly comprise the following:

- The downstream lifting of the compacted earth embankment wall with suitable open-pit overburden material and fine-grained material on the upstream face.
- The augmentation or extension of the associated infrastructure where warranted, e.g. toe drains, solution trench, paddocks, and spillway.

18.4.7.2.3 Tailings Dam Depositional and Operational Methodology

The proposed depositional methodology for the TSF is by spigot/open-ended discharge behind a fully contained valley-type dam concept. This requires that each phase of the TSF embankment be built to its required height prior to commencing with that phase's associated deposition. During the initial commissioning stage of the project, it is crucial that the tailings not be deposited directly onto the various toe drains as this would lead to erosion and possible blinding of the toe drain system. Tailings should be deposited into the basin of the TSF by means of an open-ended deposition technique whereby flexible hosing, positioned at 36 m interval off-takes, is utilised. Prior to the tailings reaching the various toe drains, coarse tailings should be used to cover and further protect the drains. Open-ended deposition shall continue above the covered toe drains to the final elevation of each phase.

Surface water accumulating onto the TSF emanates from the following sources:

- Supernatant slurry water on the TSF
- Storm water runoff from the surface of the TSF

Supernatant water and storm water collected on the TSF shall be decanted by a floating turret arrangement and pumped back to the plant for reuse as process water. As the pond migrates up the valley, so too does the floating turret. Given that turret systems make use of electricity to pump slurry water back to the plant, it is often good practice to have standby pumps or a diesel generator to adequately cope with rapid ingress during an emergency. Furthermore, it is important that careful consideration be given to the anchorage of the floating turret. The operational target limit for the pond volume is approximately 5 d of slurry water or a sufficient pond depth (0.4 m deep) to enable operating and management of the turret.

The development of the TSF and anticipated movement of the TSF pond over the LOO is shown in Figure 18.6 and Figure 18.7. The pond extent is a function of the required depth for the operation of the turret, the volume of water required by the plant and a safe distance from the embankment wall. From a safety standpoint, the ideal pond extent to be maintained throughout the LOO has been depicted as 0.4 m deep, as shown in the figures below.

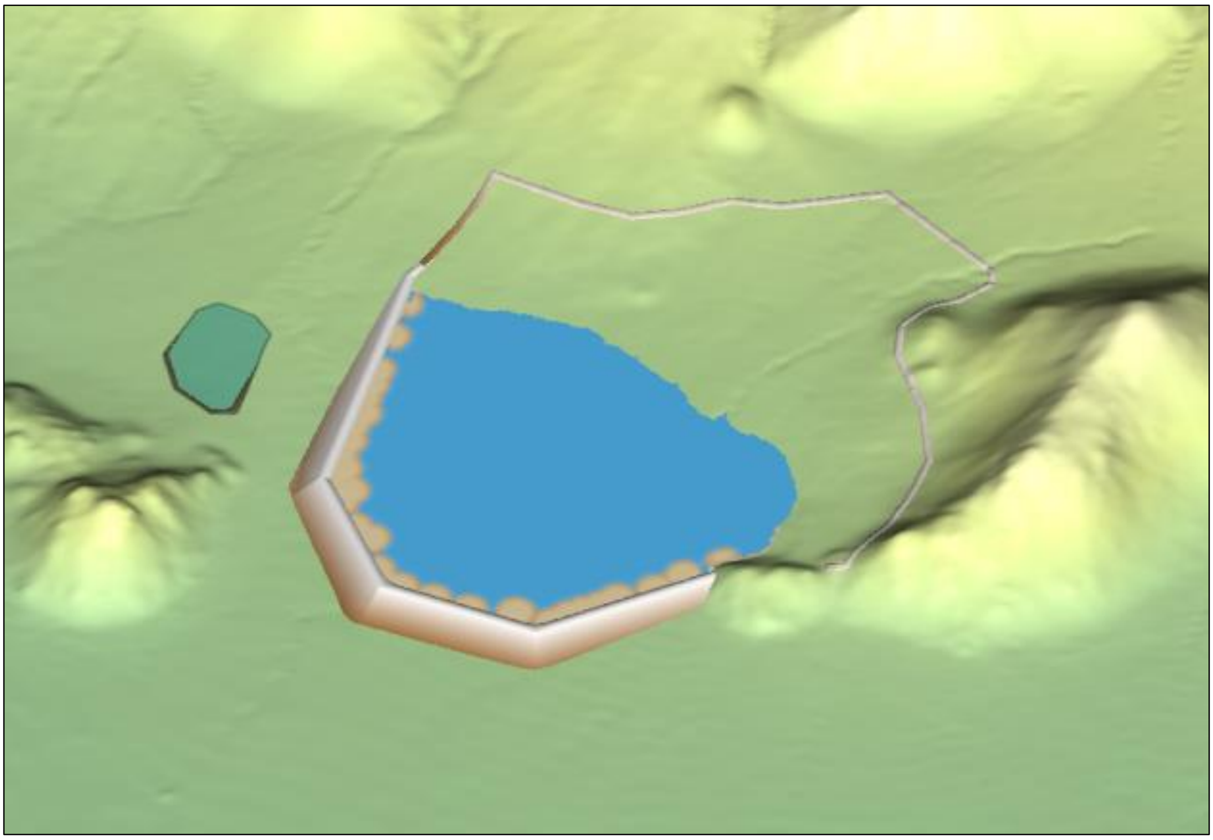


Figure 18.6: TSF Development at Phase 1 in Year 4 of the LOO

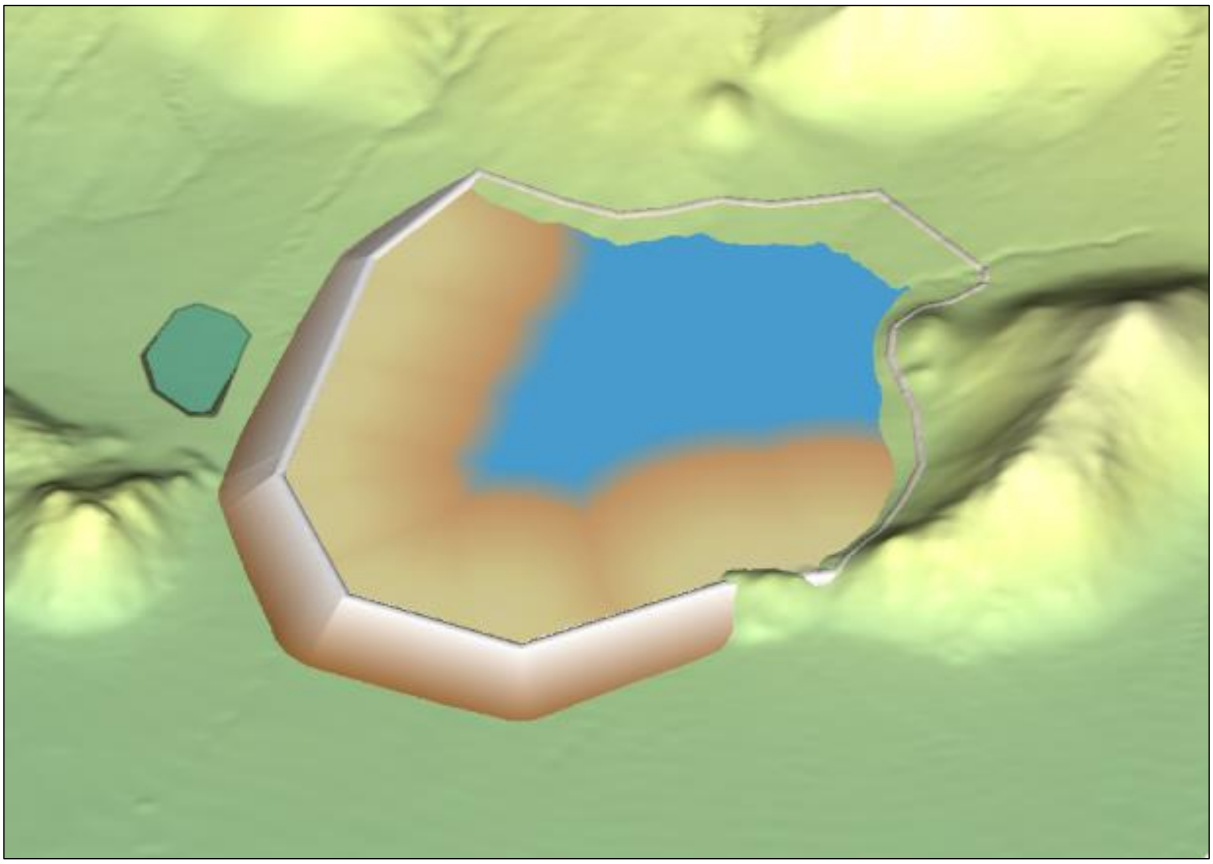


Figure 18.7: TSF Development at Phase 5 in Year 20 of the LOO

The purpose of the SWCD is to

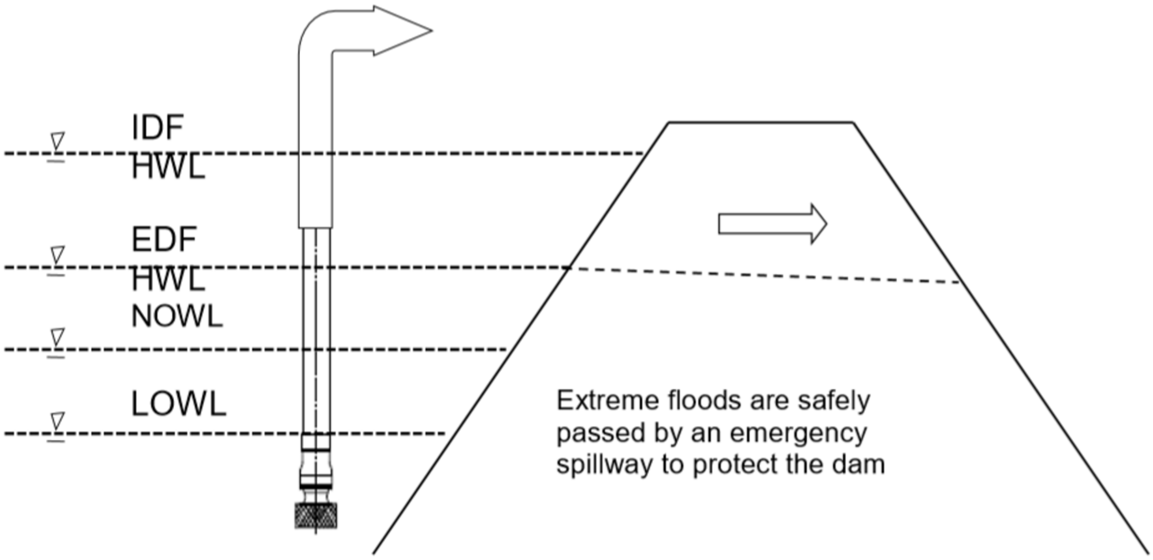
- Collect dirty storm water runoff from the mining areas.
- Contain the pond water pumped from the TSF at closure prior to the installation of the beach cover (At closure, the installation of a dry cover over the tailings beach would first require the removal of the remaining TSF water in the basin).
- Receive the seepage water from the drainage system on the floor of the TSF basin to desaturate the tailings prior to and during the installation of the beach cover.
- Receive the seepage water from the drainage system throughout operations for seepage monitoring purposes.

Seepage water from the various drains shall be collected in a solution pipeline leading into a collection sump, from where it shall be pumped back onto the TSF. Seepage from the southern half of the underdrainage network will lead into the SWCD. Mkango requested that the SWCD be positioned away from the north of the TSF to avoid the settlements downstream as far as possible, and it was therefore positioned to the east. SENET has requested that the runoff from the mining areas be diverted into the SWCD to prevent dirty water from flowing into the environment downstream towards the settlements. The SWCD has been designed to store the water from the 1 in 100-year, 7 d storm event, collected by the storm diversion trench along the southern perimeter of the TSF, from the upstream catchment where the plant is positioned. This is 40,000 m^3 of water that may be stored in the SWCD. SENET has also requested that the calculated runoff from the waste rock dump be diverted to the SWCD and has provided the design flow of 26,000 m^3. The SWCD is therefore designed to store the required capacity of 66,000 m^3. In the case of water shortages, all the water available in the SWCD will be pumped to the TD, to be returned to the plant. Dirty water will not be discharged into the environment.

An emergency spillway has also been allowed for in each phase in the unlikely event that the pond size increases, resulting in emergency decanting off the TSF. Strict management and control of the location and size of the pond that develops over time and the freeboard during the later stages of the TSF development should, however, negate the occurrence of such an event.

18.4.7.2.4 TSF Pond Water Management Philosophy

Figure 18.8, extracted from the CDA guidelines, shows a section through a typical TSF, indicating the defined levels of water stored and conveyed, with an emergency spillway for passage of the IDF.



HWL: High water level
LOWL: Low operating water level
NOWL: Normal operating water level

Figure 18.8: Typical Appurtenances Required for EDF Storage and IDF Conveyance

Storage capacity of the EDF is required above the normal operating water level (NOWL) during the period when the EDF is retained. The TSF has been sized to store the EDF of the 1 in 200-years, 7 d storm event of 267 mm.

According to the CDA guidelines, the IDF is “the most severe inflow flood for which a dam and its associated facilities are designed.”

Table 18.16 presents the criteria for IDF target levels in the GISTM guidelines. These are considered applicable for the construction, operation, and transition phases. The IDF for the Extreme consequence class dam is the Probable Maximum Flood (PMF), 24 h PMP of 1,082 mm provided by Digby Wells (2021).

Table 18.16: GISTM Flood Design Criteria

Consequence Class	Operations and Closure (Active Care) Return Intervals
Low	1/200
Significant	1/1,000
High	1/2,475
Very High	1/5,000
Extreme	1/10,000 or PMF

The emergency spillway allows safe passage of the IDF from the TSF pond to draw down the TSF to at least the EDF level following the storm event. Management of the TSF pond to maintain levels between the low operating water level (LOWL) and the NOWL is required in cases where the TSF can be subject to seasonal and environmental constraints that result in the retention of water in the TSF.

The LOWL and NOWL were estimated to be a 0.4 m deep pond sufficient for turret operation and the seasonal rainfall of the three wettest months.

18.4.8 Slope Stability Analyses

Slope stability analyses were carried out on a variety of possible operational and upset conditions.

The tailings strength parameters were derived from laboratory test work results conducted by WGLS. The critical slip circles occur within the confines of the main embankment, thus negating the influence of the tailings geotechnical parameters and the phreatic surface within them.

The mine site is situated within the East African Rift, which has historically experienced earthquakes with a moment magnitude of up to 7.3, causing heavy damage to infrastructure. A deterministic and probabilistic seismic assessment was therefore conducted by Prof. Kijko of Natural Hazard Assessment Consultancy CC. The MCE was selected as the 1/10,000 return period, as per the GISTM recommendation for Extreme Consequence facilities. The PGA, defined as the maximum horizontal ground acceleration that occurred during an earthquake, is 0.239 g ± 0.101 g for the MCE, which will be used for the TSF slope stability modelling. A ground motion having the potential to cause significant risk to a structure's architectural or structural components is a PGA of > 0.05 g. Based on the available information, the Deterministic Seismic Hazard Assessment (DSHA), the Probabilistic Seismic Hazard Assessment (PSHA), and the classification procedure by Shedlock et al. (2000), the mine site's seismic hazard is rated as “Moderate”.

The outcomes from the slope stability analyses are summarised as follows:

- The critical slip circles occur within the confines of the main embankment, thus negating the influence of the tailings geotechnical parameters and the phreatic surface within them.
- The FOS, reliability index and probability of failure of the TSF for the various scenarios considered meet the minimum prescribed values.

18.5 LOGISTICS

Mkango nominated C. Steinweg Bridge (Pty) Ltd as the freighter forwarder to conduct the route survey due to their proven track record and experience in Africa. Furthermore, C. Steinweg Bridge has been recommended to be the freighter forwarder during the execution of the project.

Africa Route Clearance Consultants (Pty) Ltd (ARC) was commissioned by C. Steinweg Bridge to carry out a logistics study to identify the limitations on a transportation route for various loads (including abnormal loads with a laden height of up to 6.40 m).

The packing list suggests that the components would be transported either from premises in Johannesburg (Vereeniging was used as a typical point of origin) or from the ports of Durban and Richards Bay in South Africa to the Mkango Mine near Songwe Hill in Malawi.

The Logistics Study Report addresses the following:

- Identifies the most suitable route(s)
- Identifies the clearance limits on the routes based on the largest vehicle combination abnormalities as follows:
  - Length 7.20 m
  - Width 6.16 m
  - Height 5.30 m
  - Laden Height (using an 800 mm high lowbed) 6.10 m
  - Laden Height (using a 1,200 mm high multi-axle) 6.40 m
  - Weight/Mass 35 t
- Makes recommendations based on the consultants' previous experience from similar projects

In general terms abnormal loads are classified as such when they exceed the following dimensions:

- Maximum normal vehicle length of 22.0 m
- Maximum normal vehicle width of 2.60 m
- Maximum normal vehicle height of 4.30 m
- Maximum normal vehicle weight of 56.0 t

Vehicle combinations within the above specifications have no problem travelling on any road infrastructure throughout all of the countries on the route.

Limitations that are insurmountable determine the "window"/"geometric envelope" for any specific route or can "fatally flaw" the use of a specific route.

Typically, insurmountable limitations comprise the following:

- Overhead bridge structures (These cannot be modified.)
- Overhead Eskom (South African electricity public utility) transmission power lines (Some of these cannot be de-energised or lifted.)
- Weak bridge structures that cannot be "propped"/bypassed

For this report, height clearance (which must apply to the laden height of the vehicle combination) was the focus although width at 6.16 m was also considered.

NOTE: Cargo dimensions + the height of the trailer + any spreader beams/sleepers/rockers/ other supports to secure the cargo make up the laden height.

Typically, trailer-bed heights range from 800 mm to 1,200 mm above road level. Therefore, a route with a maximum height clearance of 6.40 m will accommodate payload dimension heights of only 5.20 m to 5.50 m, depending on the trailer combination used.

Logistics and transport studies were conducted to

- Define the possible access routes to site.
- Identify port facilities and capabilities at the point of discharge.
- Determine the most efficient routing and method of transport to site.
- Determine road/bridge upgrade requirements to ensure the safe delivery of all shipments.
- Determine the total logistics budget to complete the movement to site of all project cargo.
- Determine customs and excise requirements in Malawi and their effect on the project programme/budget.

18.5.1 Routing

Four routing options were considered for containers, abnormal and break bulk:

- Port of Durban (South Africa) to Blantyre (Malawi) by road freight
- Port of Richards Bay (South Africa) to Blantyre (Malawi) by road freight
- Port of Beira (Mozambique) to Blantyre (Malawi) by road freight
- Port of Nacala (Mozambique) to Blantyre (Malawi) by road freight

For airfreight, the routing option was from Johannesburg O.R. Tambo Airport (South Africa) to Blantyre Airport (Malawian) via commercial airlines.

ARC embarked on a route study of the most probable route, **which was identified as travelling through South Africa, Zimbabwe, Mozambique (northern section crossing from Zimbabwe to Malawi – see Figure 18.9) and into Malawi to the final destination, the Mkango Mine near Songwe Hill.**

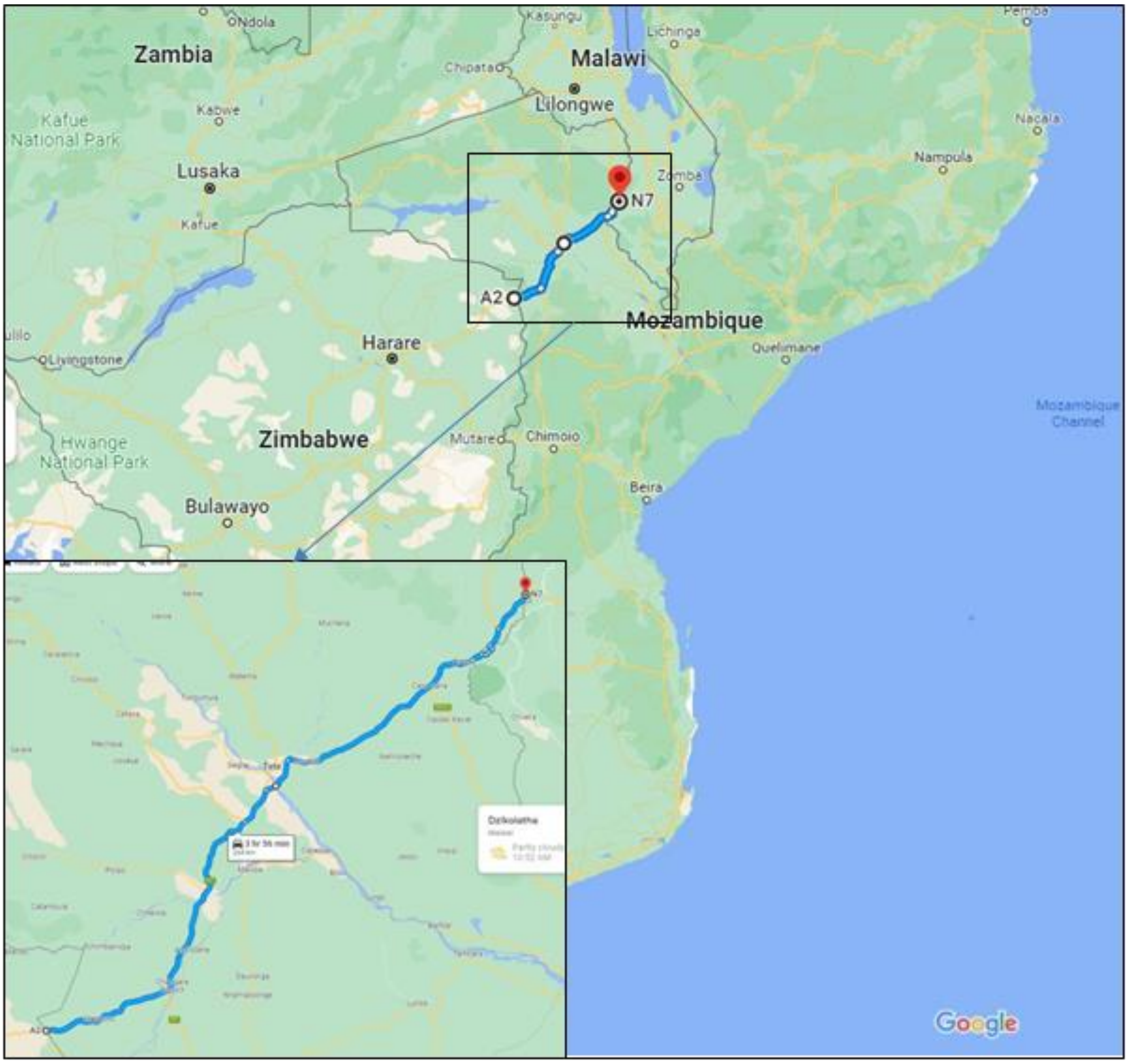


Figure 18.9: Route through Mozambique

Travelling from either of the two ports in Mozambique, through Mozambique inland to the Malawi border is not the preferred option based on the following:

- Mozambique, as an abnormal load route, has the most limitations of any country in the SADC (Southern African Development Community) region.
- While Mozambique may provide the shortest route to Malawi, this route is limited to normal heavy goods vehicles (HGVs). Using this route to accommodate abnormal load transportation – specifically abnormalities such as a laden height of 6.40 m – is not possible.

Accordingly, and in association with their colleagues ESA Lda in Mozambique and David Consulting Engineers in Malawi, ARC embarked on route inspections of the most probable route for sections that have not recently been inspected or had unknowns as to limitations.

The focus was on abnormal load routes as these routes have a larger “window”/“geometric envelope” than normal HGV routes, noting the laden height of the proposed combination, which is significant at 6.40 m.

The bulk of abnormal load transportation in South Africa emanates from the Port of Durban, with larger abnormal loads (super loads particularly with height restrictions) utilising the Port of Richards Bay.

18.5.2 Port Facilities

Based on ARC's experience in clearing routes from each of the above-mentioned ports over the past 35 years, this section describes the suitability of each port based on ease of operation from each port.

Based on the route and climate conditions, as well as the size of cargo to be transported, any of the four routes can be used for the project.

18.5.2.1 Port of Durban, South Africa

The Port of Durban is Africa's biggest container port in terms of capacity. Located on some of the world's busiest shipping routes, it is South Africa's main port for general cargo and containers. It handles an average of 83,000 containers each month at the Port of Durban Container Terminal.

Points to be noted:

- All routes exiting Durban Harbour (three in total) involve severe traffic congestion.
- The two routes exiting Durban Harbour from "C Shed and D Shed", the most commonly used exit gates, require travel out of Durban via the city centre.
- Contraflow travel is required for a section of the route through the Durban CBD as well as exiting the greater Durban area for all loads exceeding 5.5 m to avoid overhead portal signs and bridges.
- Loads departing Durban Harbour from Pier 1 (Bay Head Road) will experience severe HGV congestion.
- All loads with a laden height of more than 6.00 m will need to utilise an abnormal loads bypass through private property to avoid overhead bridge structures.
- All loads with a laden height of more than 5.66 m will need to utilise a small abnormal loads bypass to avoid an overhead pedestrian bridge.
- Exiting the greater Durban area requires travel on a single-lane road through the congested and densely populated suburbs of Isipingo/Umlazi/Umbumbulu.
- Pedestrians/livestock and/or very poor driving conditions are prevalent throughout these suburbs until departing the greater Durban area after Umbumbulu.
- As of 12 April 2022, the greater Durban area has been affected by flooding from torrential rains which has affected numerous areas, including and specifically the abnormal load route out of Durban.
- The Durban to Johannesburg (and beyond) route for normal HGV cargo is the most highly trafficked route in Southern Africa and perfectly suited for the purpose.
- As an abnormal load route for loads of the proposed dimensions, significant co-ordination and clearances from provincial and municipal authorities, as well as Eskom and Telkom (South African wireline and wireless telecommunications provider), will be required to accommodate the proposed laden height of the abnormal load combinations.

In light of the above, the abnormal loads route out of Durban is not recommended as the preferred route to use for high abnormal load transportation.

18.5.2.2 Port of Richards Bay, South Africa

The Port of Richards Bay is located approximately 160 km northeast of Durban and 465 km south of Maputo on the eastern seaboard of South Africa. The port has excellent road connections to the north and south, as well as to inland regions in the west.

The Port of Richards Bay is South Africa's leading port in terms of cargo volumes handled. It is also the biggest port in size, covering an area of approximately 3,773 ha, a large portion of which is still available for further expansion.

Points to be noted:

- The Port of Richards Bay is considerably less congested than the Port of Durban and has more abnormal load facilities.
- Highlights of the Port of Richards Bay and route are as follows:
  - Lack of congestion inside the port
  - Abnormal load staging/parking area inside the port
  - Abnormal load weighbridge inside the port
  - Abnormal load permit printing facility at the abnormal load weighbridge inside the port
  - Wide and uncongested route exiting the port and travelling through Richards Bay suburbs and CBD to the N2 (national route)
  - N2 can accommodate the use of off-ramps and on-ramps at numerous intersections if required to avoid overhead bridge structures
  - N2 can accommodate the use of contraflow travel as well as interchange on-ramps/off-ramps if required to avoid overhead bridge structure limitations

18.5.2.3 Port of Beira, Mozambique

The Port of Beira, located strategically in the centre of the country, links directly, by road or by rail, the main markets of the Southern African hinterland (Zimbabwe, Botswana, Malawi, Zambia and the Democratic Republic of the Congo) to the marketing and routes of international trade.

The facilities include a 645 m long quay with a depth of 12 m. The terminal has four container gantry cranes, two of which have the capacity to carry 65 t.

The terminal can store more than 10,000 TEUs (twenty-foot equivalent units) and has 148 electricity connection points for refrigerated containers. Currently, the terminal can handle 300,000 TEUs a year.

18.5.2.4 Port of Nacala, Mozambique

The Port of Nacala, also called the Nacala Port Complex, is a Mozambican port located in the cities of Nacala and Nacala-a-Velha. It is the deepest port in Southern Africa. The natural deep harbour serves northern areas of Mozambique, as well as the landlocked Malawi with a

931 km (578 mi) railway. A railway extension also serves parts of Zambia, in particular the inland Port of Chipata.

The infrastructure belongs to the Mozambican government, which is responsible for its administration through the public-private joint venture company "Integrated Northern Logistical Corridor Society" (CLIN). CLIN was created to administer licences for cargo terminals in addition to passenger terminals.

There are four general cargo berths and one container berth.

18.5.3 Summary of Findings

There are no insurmountable height restrictions on the proposed routes that would preclude the use of the proposed routes for abnormal load travel for the proposed combinations.

In all the countries, electricity and telecommunications clearances will need to be obtained as there are numerous overhead electrical and telephone cables along the route (predominantly in Zimbabwe/Mozambique and Malawi) that will need to be raised to accommodate the passage of the loads. This is likely to require that the electricity and telecommunications authorities in all the countries arrange for personnel to travel ahead of the loads to physically lift the overhead lines.

The proposed lengths/widths/weights of the abnormal load combinations do not present any problems or limitations on any of the proposed routes.

18.5.4 Consultants' Recommendations

The most probable route was identified as travelling through South Africa, Zimbabwe, Mozambique and into Malawi to the final destination of the Mkango Mine near Songwe Hill.

At the route clearance stage (one month prior to the physical travel of the loads), the Abnormal Vehicle Permits will have to be obtained.

The co-ordination of overhead line lifting capabilities for electricity and telephone cables will need to be arranged in each country.

It may be possible (by prior arrangement with the authorities in each country) for the abnormal load transporter to carry out the lifting of these overhead lines themselves. To do so, the abnormal load escort vehicle will need to travel ahead of the combinations with a 6.40 m height pole mounted to the vehicle and equipped with 6.50 m to 7.00 m insulated lifting poles to raise lines where required.

It is emphasised that permission to perform the latter must be sought from the authorities in each country who are the custodians of the infrastructure and who, in many cases, insist on carrying out such activities themselves to ensure that no damage is done.

The removal/replacement of overhead portal signs will also be arranged (usually by the Route Clearance Consultant providing the route to be travelled) at the route clearance stage prior to the physical travel of the abnormal load combination(s).

Listing the constraints of each of the routes may have been a somewhat superfluous exercise at this juncture. However, this logistics study has been produced to identify whether or not there are any insurmountable obstructions that would hinder the passage of the proposed abnormal loads, and there are not.

Certainly, when carrying out an updated inspection of the route prior to the passage of the loads (route clearance stage), any limitations that may have arisen since the production of this report will be identified and listed as part of the Route Clearance Report.

18.5.5 Charter Aircraft and Airfreight

In the event that the project programme requires chartering an aircraft to swiftly transport goods into the country, the aircraft can be deployed into Chileka International Airport in Blantyre. These costs would have to be negotiated at the time of shipment.

The landing runway at Chileka International Airport has the following specifications:

- Runway: 7,628 ft (2,325 m)
- Elevation: 2,555 ft (778 m)
- Surface: Asphalt

The landing runway, therefore, meets the landing runway distances required for the types of airplanes and specified payloads stated in Table 18.17.

Table 18.17: Typical Planes and Payloads

Aircraft	Maximum Payload	Runway Requirement	Main Hold Size	Main Door Size	Volume
	kg	m	cm (l × w ×h)	cm (w × h)	m³
Ilyushin IL-76 TF	60,000	1,800	3,114 × 345 × 325	345 × 325	400
Ilyushin IL-62	40,000	3,150	2,798 × 317 × 212	345 × 200	230

Cargo can also be airfreighted to Blantyre on scheduled daily flights, provided that the cargo weighs less than 3 t and its dimensions are less than 3.0 m (length), 2.0 m (width) and 1.50 m (height).

18.5.6 Project Cargo

Table 18.18 provides a summary of the project cargo, outlining the number of trucks estimated to be required to transport the cargo to site.

Table 18.18: Number of Trucks

Description	Number of Trucks
Structural Steelwork	90
Plate Work (Chutes etc.)	26
Plate Work (Tanks)	41
Mechanical	94
Piping and Valves	73
Electrical	42
C&I	7

Description	Number of Trucks
Civil and Earthworks	40
Water and Sewage Treatment Plants	12
Infrastructure	28
Spares	11
Contingency	46
Abnormal Loads – Ball Mill and Other Break Bulk Items	18
TOTAL	**528**

19 MARKET STUDIES AND CONTRACTS

The information in this section has been compiled by Adamas Intelligence, an independent research and advisory firm contracted by Mkango to forecast long-term supply, demand and prices for REEs as well as emerging trends in the market.

19.1 RARE EARTH MARKET

19.1.1 Introduction to the Rare Earth Elements

Compared to similarly abundant elements in nature, such as copper, lead, and tin, global annual production of REEs is notably low.

Nevertheless, REEs have become critical enablers of technologies at the heart of clean energy initiatives worldwide, as well as ubiquitous gadgetry and electronics that have pervaded modern society.

REEs are used in small, but often necessary, amounts in hundreds of different technologies, materials, and chemicals worldwide for commercial, industrial, social, medical, and environmental applications.

In just a period of decades, REEs have seeped deeply into the fabric of modern technology and industry and have proven exceptionally challenging to duplicate or replace.

19.1.2 Classification and Terminology

On the Periodic Table of Elements, REEs include the lanthanide series, plus yttrium and scandium (see Figure 19.1).

Yttrium is classified as a rare earth element because of its similar ionic radius to the lanthanides, as well as its similar chemical properties, whereas scandium is classified as a rare earth element because of its tendency to concentrate into many of the same minerals.

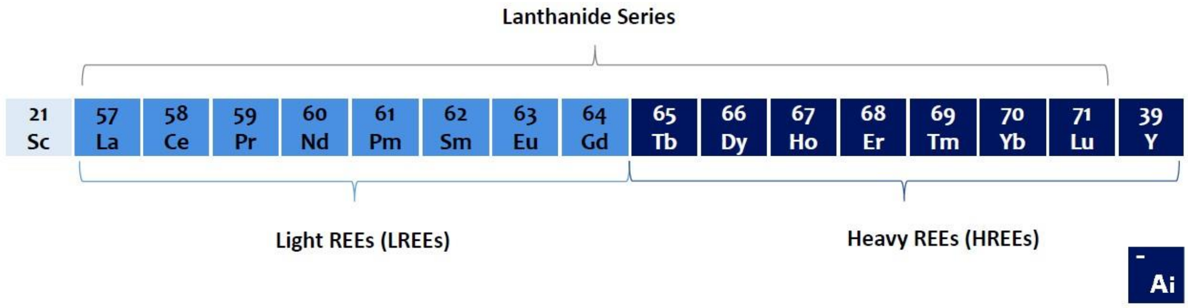


Figure 19.1: REEs include the Lanthanide Series plus Scandium and Yttrium

REEs are arbitrarily classified as light rare earth elements or oxides ("LREEs" or "LREOs") or heavy rare earth elements or oxides ("HREEs" or "HREOs") based on their electron configurations.

By virtue of having a higher crustal abundance, LREOs collectively make up over 90 % of the total rare earth oxide ("TREO") content of a typical rare earth deposit and thereby also make up the vast majority of the world's TREO output each year. Heavy rare earth oxides, on the other hand, are present in the Earth's crust in substantially lower concentrations than LREOs and as such make up a relatively small portion of the world's TREO output each year.

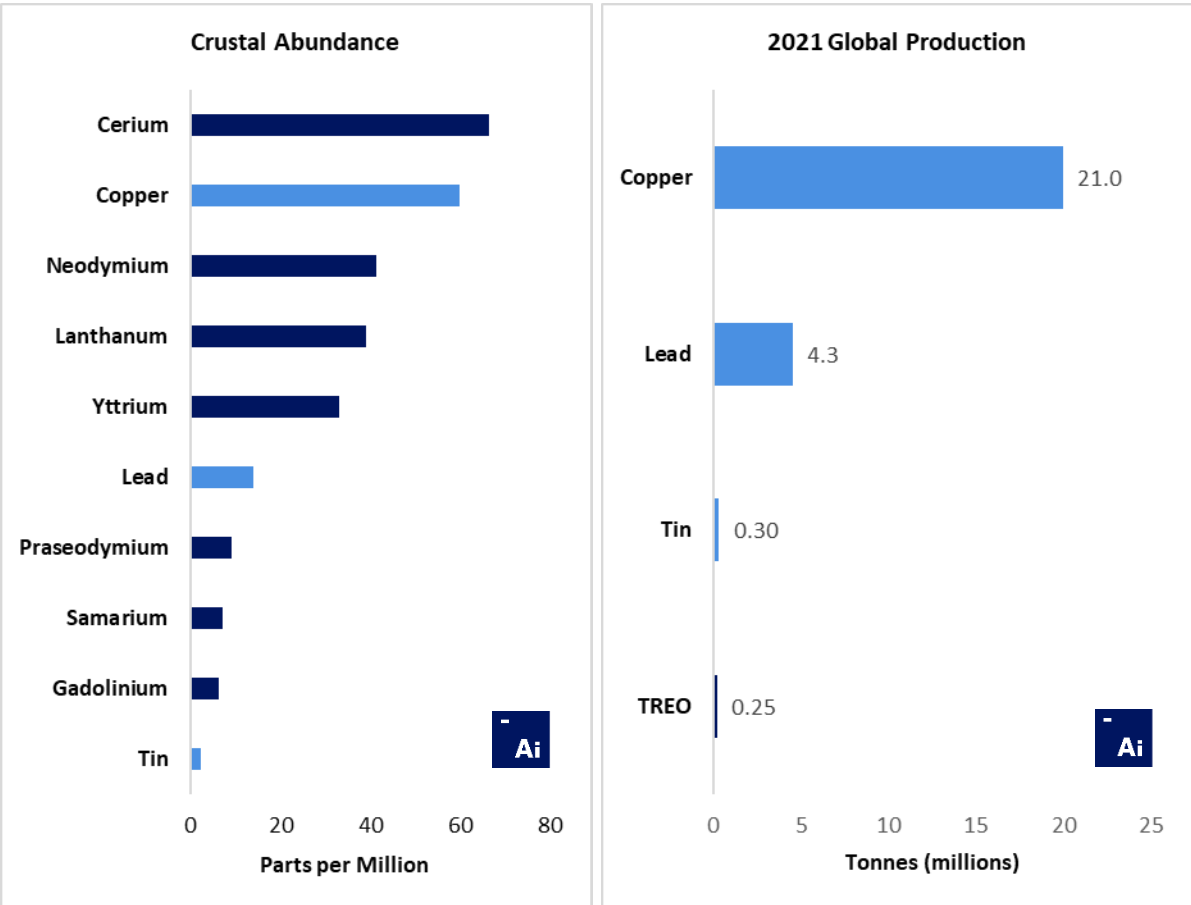
19.1.3 Rarely Enriched in Nature

REEs are not remarkably rare in nature, but rather are rarely concentrated into economically significant amounts for extraction and processing owing to certain physical and chemical characteristics that promote their broad dissipation in most rock types.

In fact, cerium is more abundant in the Earth's crust than copper; neodymium, lanthanum and yttrium are more abundant than lead; and praseodymium, samarium and gadolinium are more abundant than tin (see Figure 19.2, on the left).

Despite this fact, only 254,000 t of all 17 REOs combined (TREOs) were produced globally in 2021 versus 21.0 Mt of copper, 4.3 Mt of lead, and 300,000 t of tin in the same year (see Figure 19.2, on the right).

Global production of REEs is remarkably low compared to similarly abundant elements.



Source: Adamas Intelligence research, USGS, Jefferson Lab

Figure 19.2: Global Production of REEs

19.1.4 Eight End-Use Categories

REEs are used in hundreds of unique end uses and applications that collectively fall into one of eight end-use categories: 1) battery alloys, 2) catalysts, 3) ceramics, pigments and glazes, 4) glass polishing powders and additives, 5) metallurgy and alloys, 6) permanent magnets, 7) phosphors, and 8) other end uses and applications (see Table 19.1).

Table 19.1: Rare Earth Applications and End Uses

End-Use Category	Description
Battery Alloys (La, Ce, Pr, Nd)	REEs are used to produce anode materials for nickel-metal hydride (NiMH) batteries. NiMH batteries are used in hybrid electric vehicles, consumer electronics, cordless shavers, cordless power tools, baby monitors, and other applications of rechargeable batteries.
Catalysts (La, Ce)	REEs such as cerium and lanthanum are used in catalytic converters of gasoline- and diesel-powered vehicles, as well as fuel cracking catalysts and additives used by oil refiners to break down crude oil into lighter distillates, such as gasoline, diesel, kerosene and more.
Ceramics, Pigments and Glazes (La, Ce, Pr, Nd, Y)	REEs are used to produce decorative ceramics, functional ceramics, structural ceramics, bio ceramics, and many other types of ceramics used in everything from jet engine coatings to ceramic cutting tools, dental crowns, ceramic capacitors, ceramic tiles, and more.
Glass Polishing Powders and Additives (Ce, La, Er, Gd, Y)	REEs such as cerium are used to polish optical glass, hard disk drive platters, liquid crystal display (LCD) screens and gemstones, among a long list of applications. Cerium is also used as an additive in ultraviolet-filtering glass and container glass, whereas lanthanum, yttrium and gadolinium are used to produce high-quality optical glass used in camera lenses, microscopes and telescopes.
Metallurgy and Alloys (La, Ce, Ho, Gd, Y)	Rare earth mischmetal (a mixture of light REE metals) is used during production of some types of steel, as well as ductile iron making. REEs are also used to produce a variety of different alloys, such as ferro-cerium, ferro-holmium, ferro-gadolinium and a growing list of others.
Permanent Magnets (Nd, Pr, Dy, Tb, Sm)	REEs are used to produce high-strength permanent magnets that have enabled the production of ubiquitous gadgets and electronics, such as mobile phones and laptops, as well as power-dense energy-efficient electric motors and generators used in electric vehicles, wind turbines, energy-efficient appliances and hundreds of other applications.
Phosphors (Ce, La, Y, Tb, Eu)	REEs are used in phosphors for energy-efficient lamps, display screens and avionics, and are added to fiat currency in some nations as an anti-counterfeit measure.
Other (La, Ce, Nd, Dy, Tb, Gd, Lu, Tm)	Aside from the end uses and categories described above, REEs are used in a long list of other end uses and applications, including many in the defence, medicine, health, wellness, aerospace, agriculture, high-tech and chemical industries.

19.1.5 Global Rare Earth Consumption in 2021

By volume, permanent magnets and catalysts were collectively responsible for over 65 % of the global TREO consumption in 2021 (see Figure 19.3). However, by value, permanent magnets alone were responsible for 95 % of the total value of the global TREO consumption in 2021 (see Figure 19.3), and this share is poised to expand further as the demand for (and prices of) neodymium, praseodymium, dysprosium and terbium continues to rise strongly in the years ahead.

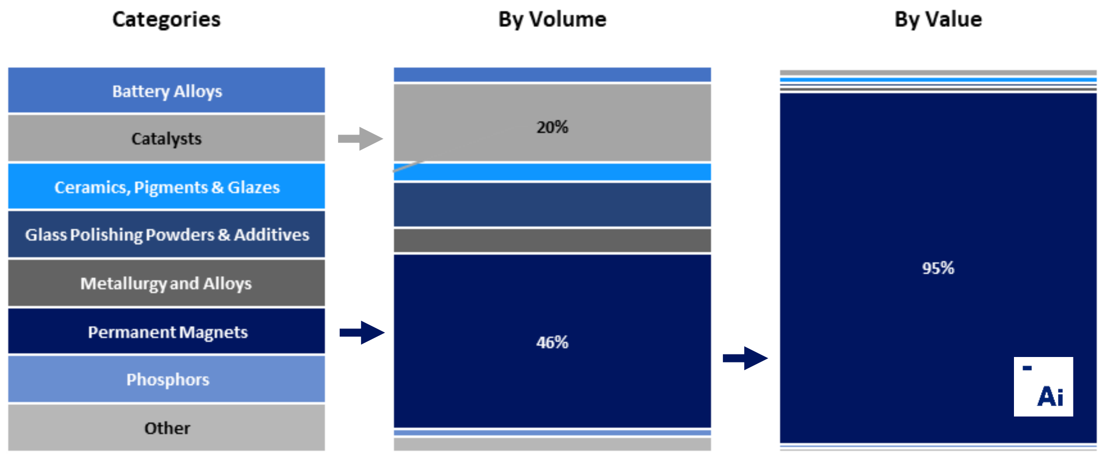


Figure 19.3: Permanent Magnets and Catalysts – Largest Demand Drivers of REEs

Not only does the demand for neodymium, praseodymium, dysprosium and terbium collectively make up the majority of global value today, but in the years ahead demand for these four REEs is expected to grow faster than the demand for all the other REEs, challenging the ability of the supply side to keep up.

Adamas Intelligence forecasts that global annual demand for didymium oxide and dysprosium oxide (or oxide equivalents) will substantially exceed global annual production by 2025, leading to the depletion of historically accumulated inventories and, ultimately, shortages of these critical magnet materials if substantial additional sources of supply are not developed (see Figure 19.4).

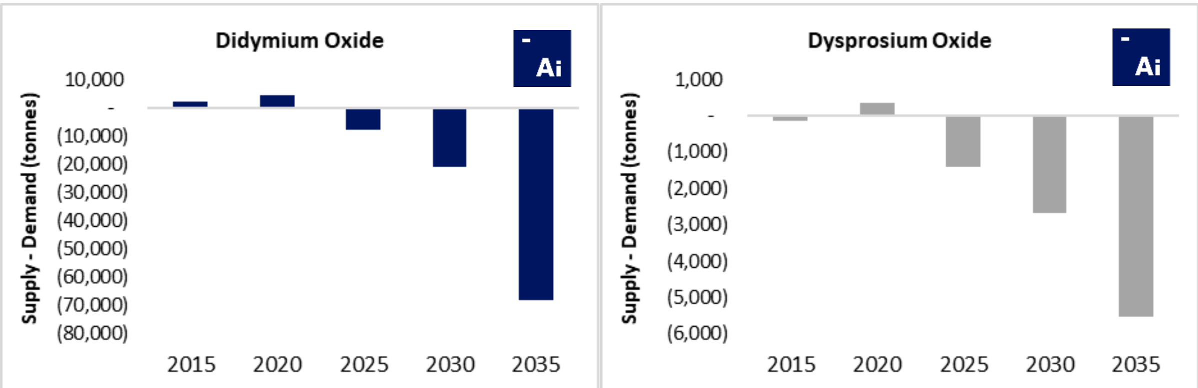


Figure 19.4: Supply Side vs Rising Demand for Didymium and Dysprosium

19.1.6 Rare Earth Balance Problem

Over the past decade, rare earth producers globally have sacrificially overproduced certain low-value REEs, such as cerium oxide (see Figure 19.5, on the left), in order to keep up with the rapidly growing demand for other high-value REEs and compounds, such as didymium oxide (see Figure 19.5, on the right).

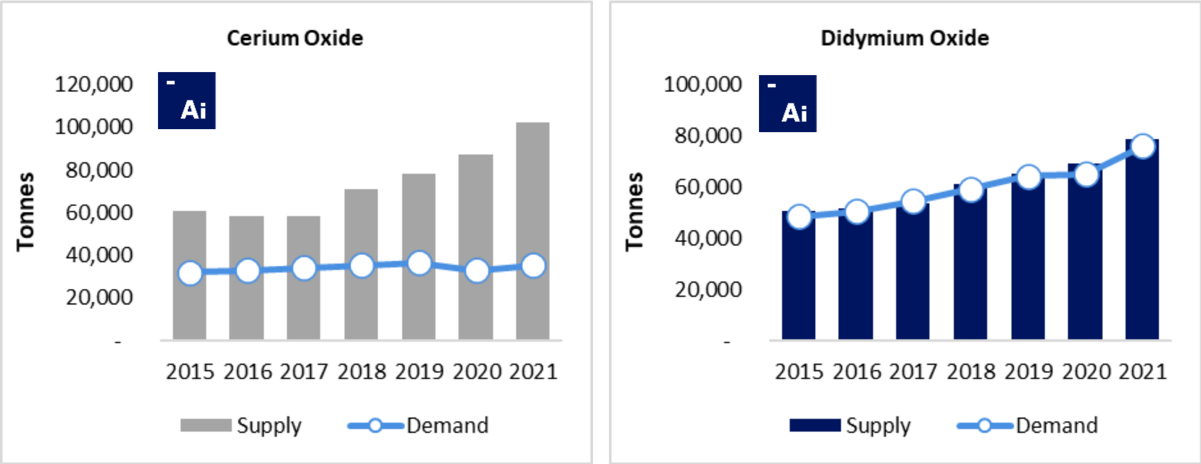


Figure 19.5: Sacrificial Overproduction of Cerium to Satisfy Rapidly Growing Demand for Didymium

Adamas Intelligence forecasts that the ever-increasing demand for rare earth permanent magnets will drive the global demand for didymium oxide (or oxide equivalent) to towering new heights (see Figure 19.6, on the right), exacerbating the imbalance between the production of and the demand for other REEs, such as cerium oxide (Figure 19.6, on the left), if the industry continues on a path of business as usual.

As a result, emerging rare earth producers like Mkango should focus primarily on opportunities related to the magnet rare earths (i.e. neodymium, praseodymium, dysprosium and terbium) as market conditions for most of the other REEs are expected to remain less favourable in the foreseeable future.

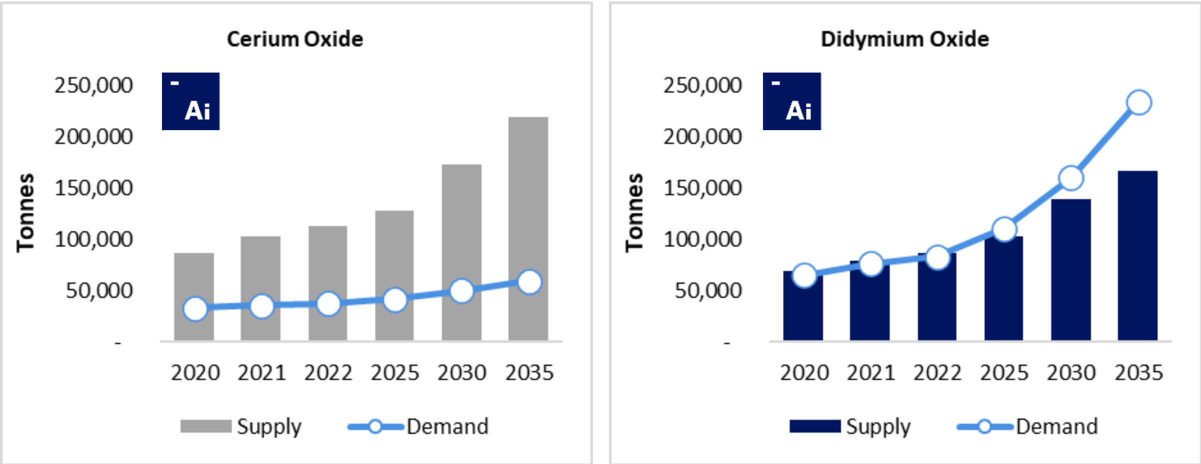


Figure 19.6: Strong Future Demand Growth for Permanent Magnets will Exacerbate the Balance Problem

19.1.7 Implications of the Balance Problem

Unless new end uses and applications are developed for cerium, lanthanum, and other sacrificially overproduced REEs in the near term (see Figure 19.7 – light grey arrows), Adamas Intelligence expects that prices of high-demand elements, like neodymium, praseodymium, dysprosium and terbium, will stay strong and/or rise accordingly (see Figure 19.7 – dark blue arrows) to compensate for losses that producers are chronically incurring by necessarily overproducing the other unsaleable, surplus rare earths.

The industries that will feel these price increases the most in the coming years are those reliant on the use of high-strength NdFeB permanent magnets, such as the automotive industry, the wind power sector, the consumer electronics industry, the defence industry, and many others.

Ultimately, price increases of magnet input materials may upend the economics of using rare earths in some of the aforementioned sectors – pushing some manufacturers to adopt alternatives to rare earth permanent magnets where possible.

However, for the most promising of end-use sectors – such as electric vehicles, wind power, general automotive, industrial applications, and others – the economics of using REEs are robust, and these segments will continue to fuel strong demand growth into the foreseeable future.

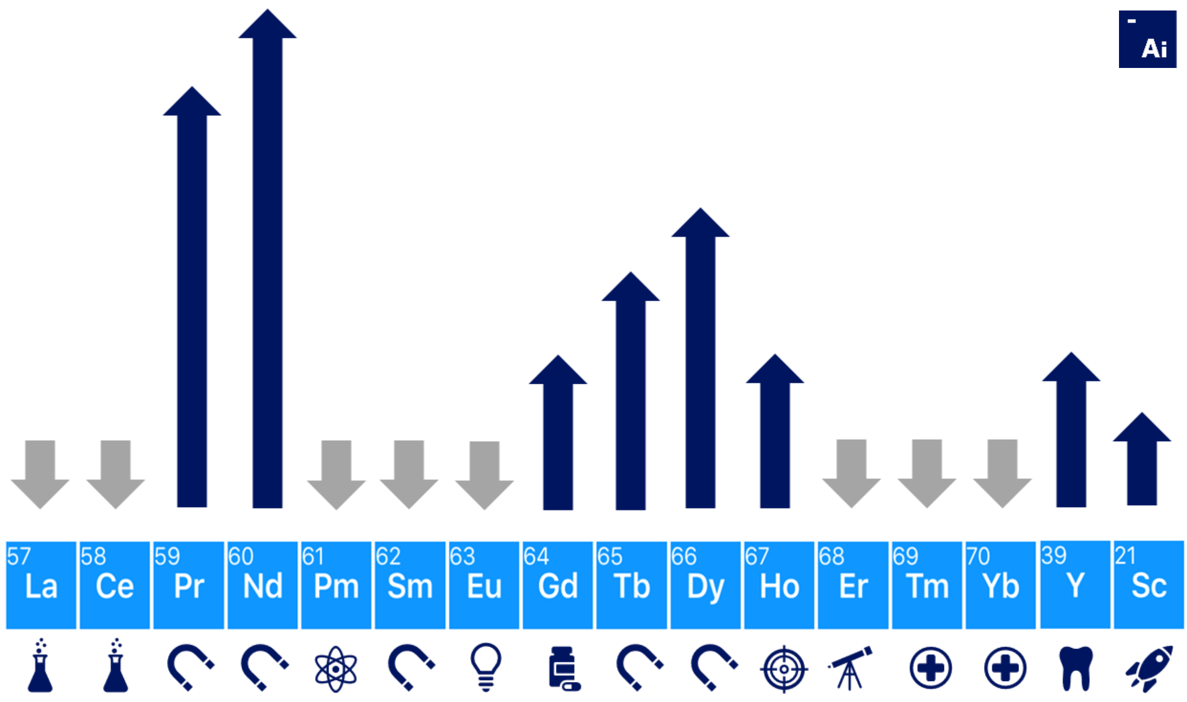


Figure 19.7: Prices of Magnet Rare Earths rising to Compensate for Losses incurred on other Rare Earths

19.1.8 Forecasted TREO Demand by End-Use Category

Following a 7.1 % pandemic-induced drop in global TREO consumption in 2020, Adamas Intelligence data indicates that global consumption jumped 13.2 % higher in 2021, bolstered by the materialisation of pent-up consumer and industrial demand from 2020 (see Figure 19.8).

From 2022 through 2035, Adamas Intelligence forecasts that the global TREO demand will rise at a compound annual growth rate (CAGR) of 6.0 %, from 190,500 t to 407,500 t, driven primarily by the permanent magnet sector (see Figure 19.8).

In the years ahead, the global TREO demand for permanent magnets and “other” end uses and applications is projected to rise at market leading CAGRs of 8.3 % and 7.0 %, respectively (see Figure 19.8).

Conversely, over the forecast period, the global TREO demand for all the other end-use categories, except for phosphors, is projected to grow at market lagging CAGRs of 2.1 % to 4.8 %, while the TREO demand for phosphors is projected to fall at a CAGR of −5.5 % (see Figure 19.8).

In the years ahead, the rapid TREO demand growth expected for permanent magnets will lead the end-use category to continuously absorb market share from incumbent categories.

By 2030, Adamas Intelligence projects that permanent magnets will drive 55 % of the global TREO demand by volume and over 95 % of the market’s value each year.

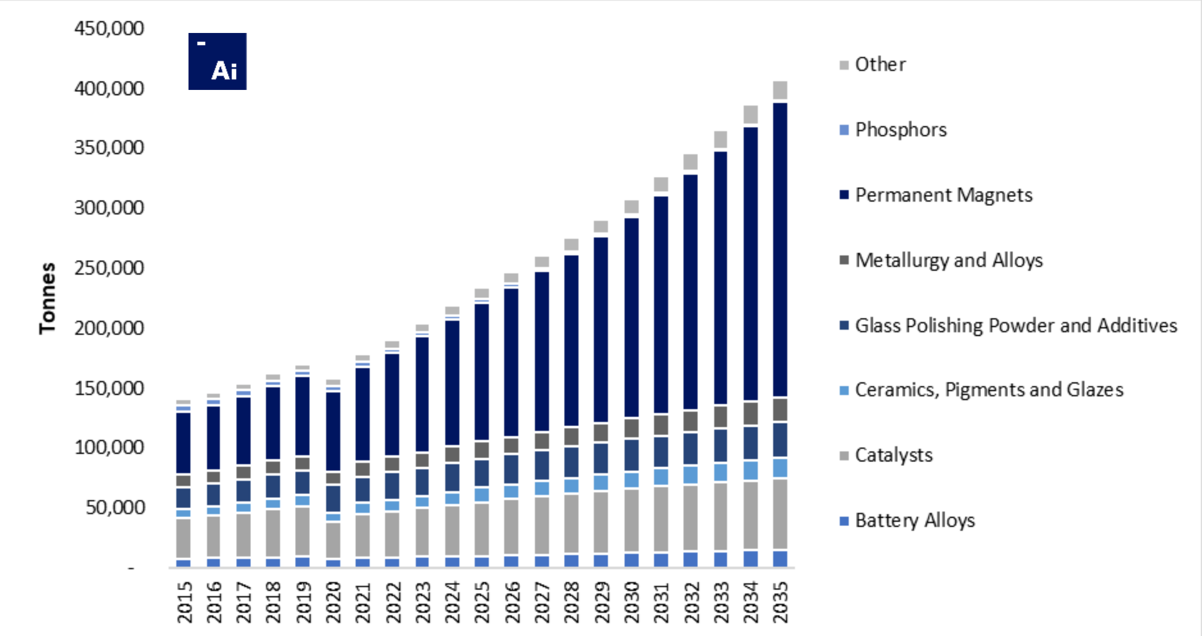


Figure 19.8: Forecasted Global TREO Demand by End-Use Category from 2022 through 2035

19.1.9 NdFeB Permanent Magnets: Enablers of Modern Technology

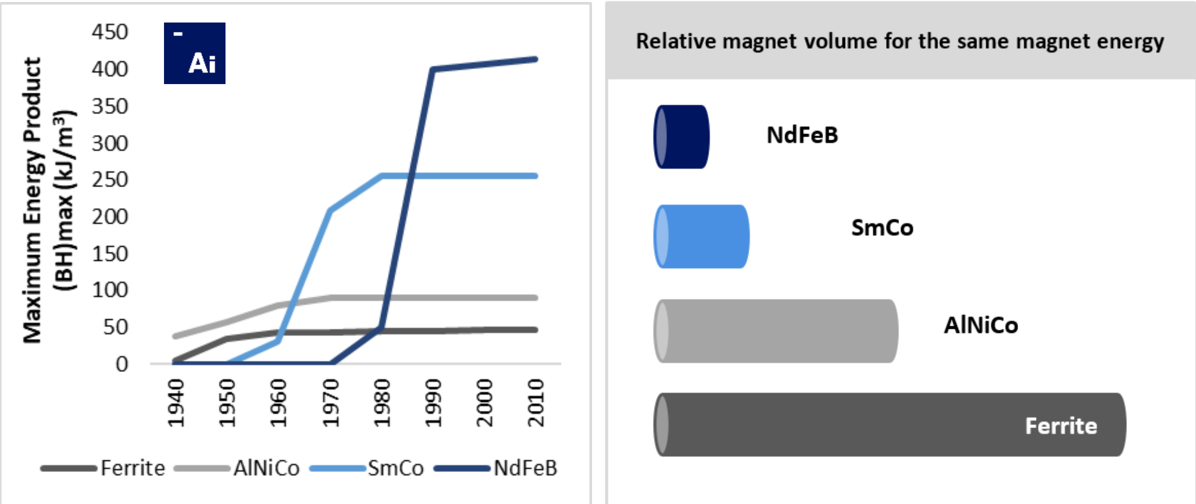
Neodymium-iron-boron (NdFeB) is a permanent magnet alloy that was developed and commercialised in the 1980s as an alternative to costly samarium-cobalt (SmCo) alloy that was developed and commercialised three decades earlier.

As the name suggests, NdFeB alloy is comprised primarily of neodymium, iron, and boron in a $Nd_2Fe_{14}B$ tetragonal crystalline structure, and often contains minor concentrations of praseodymium, dysprosium, terbium, copper, cobalt, niobium, and other metals to optimise the alloy's properties for certain applications.

NdFeB permanent magnet alloy is the strongest type of permanent magnet material commercially available today in terms of maximum energy product (i.e., magnetic flux output per unit volume, measured in megagauss-oersteds (MGOe) or Joules per cubic meter (J/m^3)) (see Figure 19.9).

As such, NdFeB magnets have largely supplanted SmCo, AlNiCo, and ferrite magnets in many size- and weight-sensitive applications since the 1980s, and simultaneously have enabled the conception and miniaturisation of a wide array of ubiquitous gadgets and electronics that have pervaded modern society.

NdFeB permanent magnets are used in hundreds of different end uses and applications – many of which we interact with daily, whether we realise it or not. From mobile phone loudspeakers and vibration motors to hard disk drives, optical disc drives, electric vehicle traction motors, wind power generators, and beyond – NdFeB permanent magnets are literally all around us.



Source: After Kallaste et al. (2012), Adamas Intelligence research

Figure 19.9: NdFeB – the Strongest Permanent Magnet Material Commercially Available Today

19.1.10 Forecasted TREO Demand for Permanent Magnets by End-Use Category

From 2022 through 2035, Adamas Intelligence forecasts that the global TREO demand for

- Permanent magnets will increase at a CAGR of 8.3 %, from 87,000 t to 246,000 t, boosted by strong demand growth from electric vehicle (EV), wind power, general automotive and other applications of NdFeB magnets (see Figure 19.10).

- Passenger EV traction motors, commercial EV traction motors and “other e-mobility” applications will collectively increase at a CAGR of 14.0 %, together representing the single largest demand driver by 2035 (see Figure 19.10).
- Automotive micromotors, sensors and speakers will collectively increase at a CAGR of 4.9 %, growing faster than the underlying vehicle market as automakers increasingly employ NdFeB-powered motors, sensors and speakers in new models to reduce vehicle weight and thereby improve fuel efficiency, reduce emissions and/or maximise electric driving range (see Figure 19.10).
- Direct drive and hybrid direct drive wind power generators for onshore and offshore applications will increase at a CAGR of 13.0 % as the increasingly competitive economics of wind power generation (and low maintenance of direct drive generators) continue to spur rising adoption (see Figure 19.10).
- All other end uses and applications of NdFeB permanent magnets will increase at CAGRs of 3.4 % to 5.4 %, forgoing the market share to EVs, wind power generators, and other high-growth applications (see Figure 19.10).

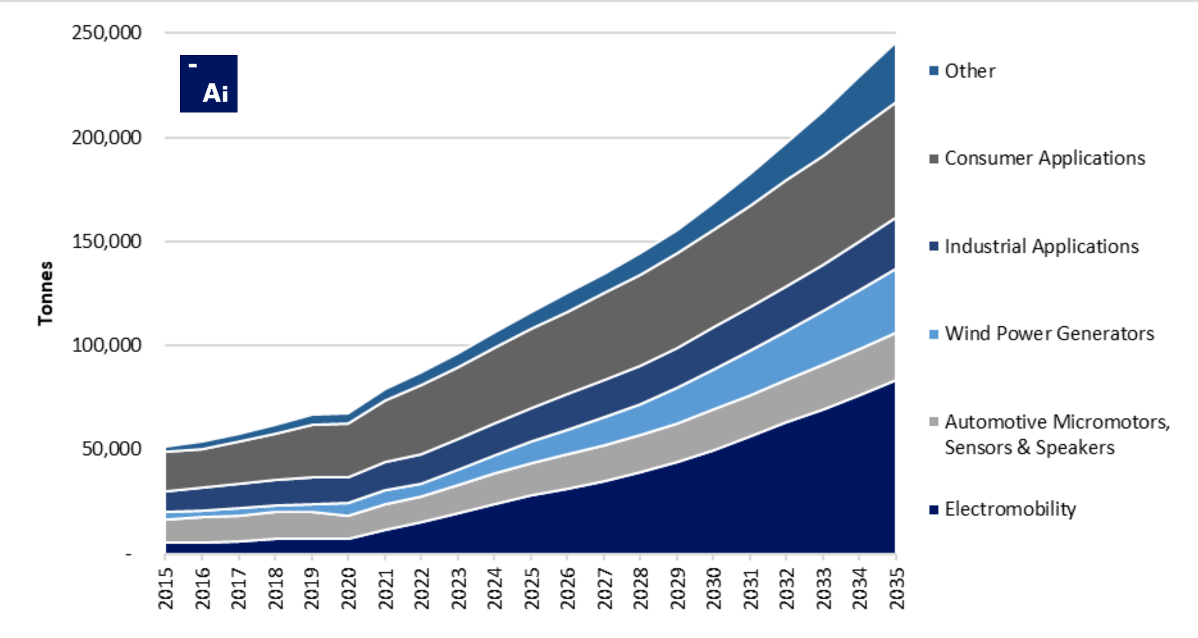


Figure 19.10: Historical Global Consumption and Forecasted Demand for Magnet Rare Earth Oxides by End-Use Category

19.1.11 EVs to Drive over 40 % of Global Magnet Earth Oxide Demand by 2035

By 2035, Adamas Intelligence forecasts that the passenger EV traction motors, commercial EV traction motors and other e-mobility types, such as electric bicycles, motorcycles, and scooters, will collectively be responsible for 36 % of the total global NdFeB magnet demand. Considering the additional uses of NdFeB magnets in EVs, including micromotors, sensors and speakers, Adamas Intelligence conservatively projects that EVs will be responsible for 42 % of the total global NdFeB magnet demand by 2035, but an even higher share of the total global consumption (see Figure 19.11 – dark blue bars).

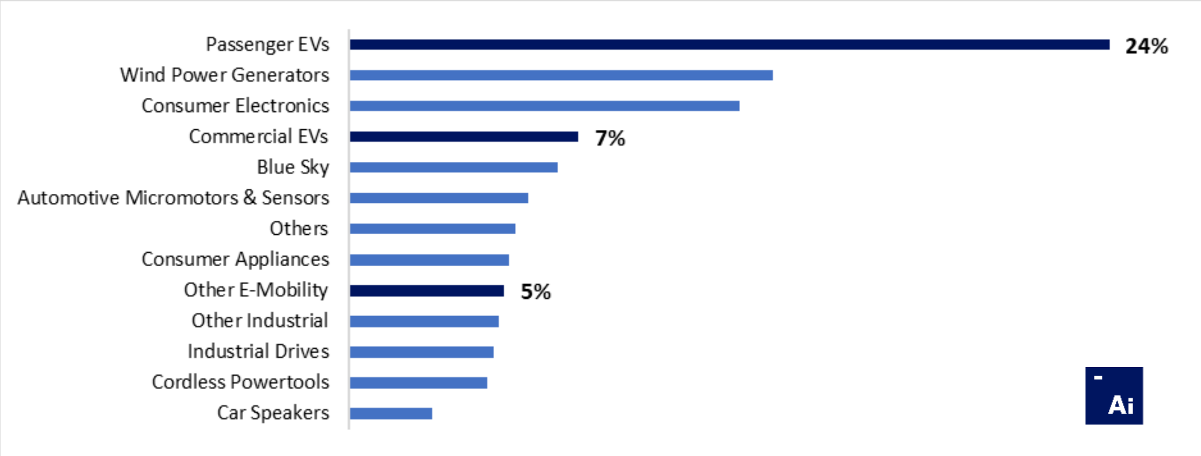


Figure 19.11: Forecasted Breakdown of Global TREO Demand for Permanent Magnets by End-Use Category in 2035

Moreover, given that EV traction motors and generators tend to use high-temperature-performance grades of NdFeB magnets that contain elevated concentrations of the heavy REEs dysprosium and terbium, Adamas Intelligence forecasts that passenger EV traction motors, commercial EV traction motors, and other e-mobility types will collectively drive more than 50 % of the total global dysprosium and terbium oxide demand annually by 2035 (see Figure 19.12 – dark blue bars).

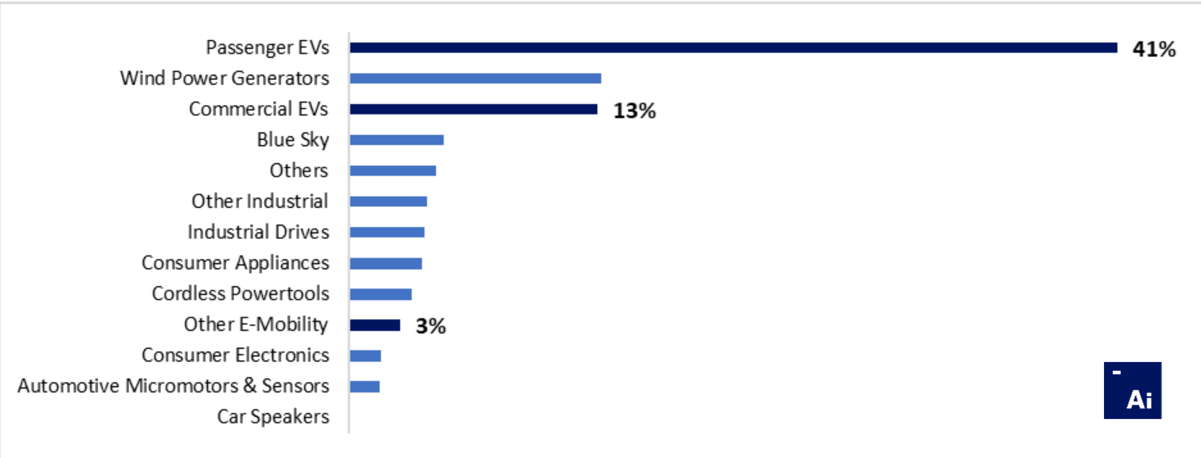


Figure 19.12: Forecasted Breakdown of Dysprosium and Terbium Oxide Demand for Permanent Magnets by End-Use Category in 2035

19.1.12 Forecasted Production-Demand Balance for Didymium, Dysprosium and Terbium to 2035

Adamas Intelligence projects that global production in 2022 of neodymium oxide and praseodymium oxide (or oxide equivalents), combined, will exceed global demand by a mere 3,000 t; however, from 2023 onward, this trend is expected to reverse as demand growth increasingly exceeds supply growth (see Figure 19.13, on the left).

By 2025, Adamas Intelligence forecasts that the global market's underproduction will rise to nearly 8,000 t annually, resulting in the depletion of historically accumulated inventories and persistent shortages from 2026 onward (see Figure 19.13, on the left).

Conversely, Adamas Intelligence forecasts that global consumption in 2022 of dysprosium oxide (or oxide equivalent) will exceed global production by 200 t, rising to over 500 t in 2023, resulting in the depletion of historically accumulated inventories and dysprosium oxide shortages from 2024 onward (see Figure 19.13, on the right).

Similarly, Adamas Intelligence forecasts that global consumption in 2022 of terbium oxide (or oxide equivalent) will exceed global production by nearly 300 t, resulting in the drawdown of historically accumulated inventories and terbium oxide shortages from 2022 onward (see Figure 19.13, on the right).

By 2035, Adamas Intelligence projects the global rare earth market will be short more than one times China's NdPr oxide supply and over five times China's Dy and Tb oxide supply annually (referring to China's 2022 production levels) should supply not increase substantially more than what is currently anticipated.

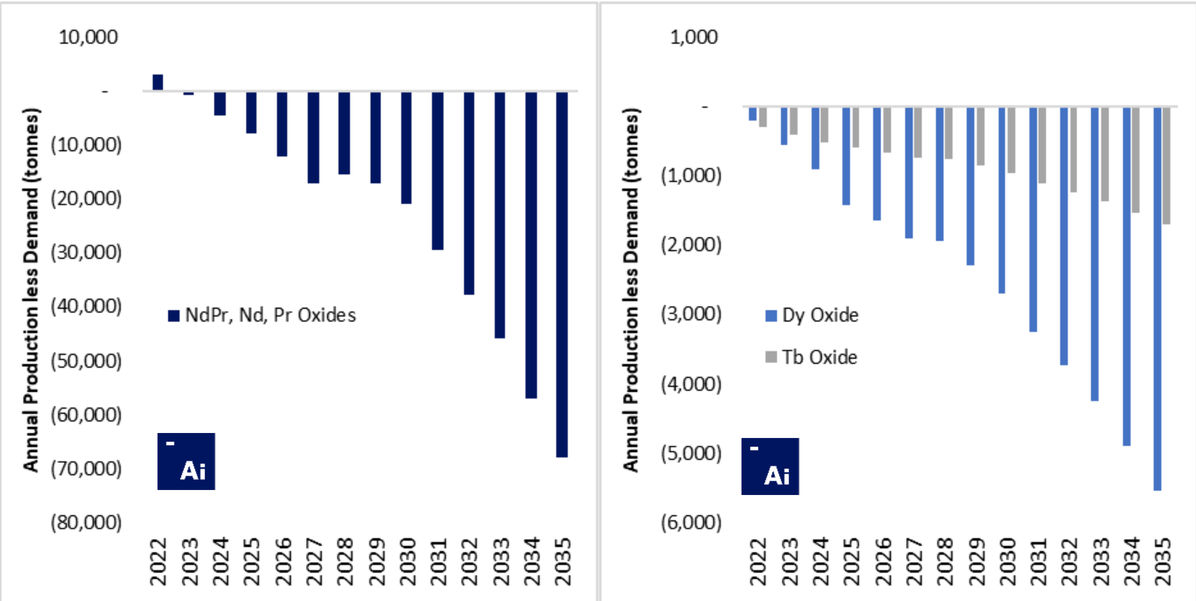


Figure 19.13: Forecasted Global Production-Demand Balance for Rare Earth Oxides used in Permanent Magnets

19.2 FORECASTED REO PRICES TO 2035

As per its latest "Rare Earth Magnet Market Outlook to 2035" report (Q2 2022), Adamas Intelligence forecasted annual average prices for each rare earth oxide to 2035 under three scenarios (see Figure 19.14).

19.2.1 Base Case

In the base case scenario, Adamas Intelligence forecasts that magnet rare earth prices will trend steadily higher from 2022 through 2025 on the back of increasingly tight supplies and rapidly growing demand for EV traction motors, wind power generators, and other applications of NdFeB magnets.

From 2025 through 2029, however, Adamas Intelligence expects that battery materials and/or other component shortages will slow the EV market's growth by 15 % to 30 %, leading magnet rare earth prices to more or less plateau over the four-year period.

Thereafter, from 2029 through 2035, Adamas Intelligence projects that the EV market will return to unhindered growth, exacerbating the imbalance between global supply and demand while sending magnet rare earth prices steadily higher through the end of the forecast period.

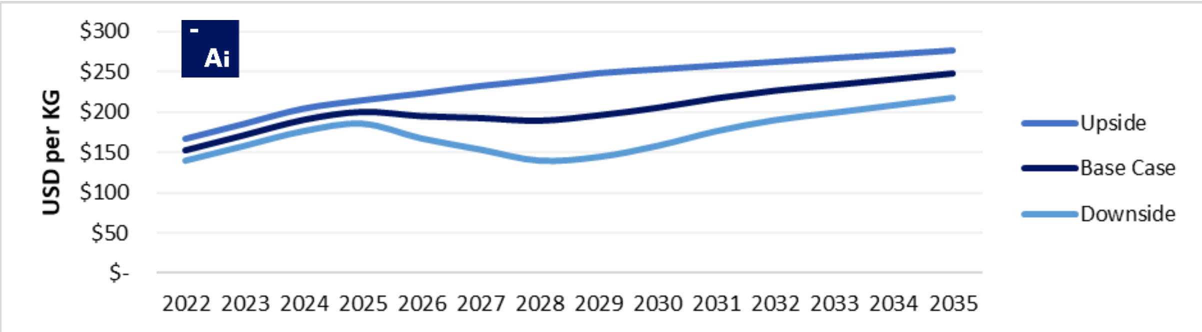
19.2.2 Upside

In the upside scenario, Adamas Intelligence forecasts the outlook for magnet rare earth prices in a future with unconstrained EV production and sales growth from 2022 through 2035.

In this scenario, magnet rare earth prices are expected to rise steadily throughout the forecast period as demand progressively outpaces supply, and EVs, wind power and other less-price-sensitive applications increasingly make up a larger and larger share of the overall NdFeB demand.

19.2.3 Downside

In the downside scenario, Adamas Intelligence considers a future in which battery materials and/or component shortages temporarily slow global EV production from 2022 through 2029 by an additional 20 % to 30 % (versus what is expected in its base case scenario) before returning to unhindered growth in 2029, translating into a more volatile outlook for magnet rare earth prices.



NOTE: Forecasted prices are in real 2022 US dollars and include 13 % VAT. If selling into China, VAT should be deducted. If selling ex-China, the prices above should be taken at face value.

Figure 19.14: Forecasted Contribution per REO to Songwe Hill Basket Value in 2035

Figure 19.15 shows the relative distribution of rare earth oxides in the mixed rare earth carbonate concentrate from Songwe Hill. By volume, the four critical magnet rare earth oxides (neodymium, praseodymium, dysprosium and terbium) make up 33.7 % of the TREO contained in the concentrate.

Oxide	Relative %
La	39.1 %
Ce	18.4 %
Pr	**7.7 %**
Nd	**25.1 %**
Sm	3.3 %
Eu	0.9 %
Gd	1.9 %
Tb	**0.2 %**
Dy	**0.7 %**
Ho	0.1 %
Er	0.2 %
Tm	0.0 %
Yb	0.1 %
Lu	0.0 %
Y	2.4 %
TREO	**100.0 %**

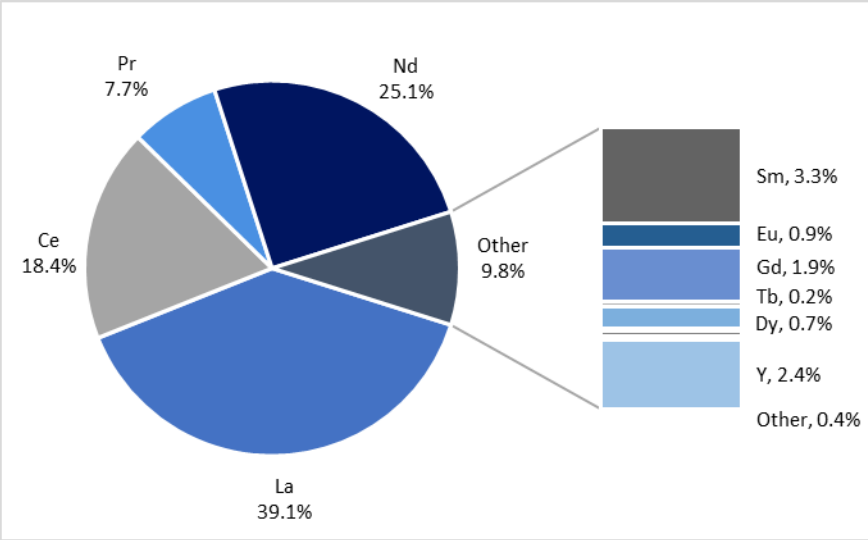


Figure 19.15: Relative Distribution of Rare Earth Oxides in Mixed Rare Earth Carbonate from Songwe Hill

Figure 19.16 shows the forecasted contribution per REO to the Songwe Hill TREO basket value in 2035. By value, the four critical magnet rare earth oxides (neodymium, praseodymium, dysprosium and terbium) are projected to drive 95.1 % of the Songwe Hill basket value in 2035, up from 94.9 % in 2025 and 94.1 % this year.

Oxide	Relative %
La	0.5 %
Ce	0.2 %
Pr	**19.0 %**
Nd	**65.1 %**
Sm	0.2 %
Eu	0.3 %
Gd	2.5 %
Tb	**5.9 %**
Dy	**5.2 %**
Ho	0.3 %
Er	0.1 %
Tm	0.0 %
Yb	0.0 %
Lu	0.1 %
Y	0.6 %
TREO	**100.0 %**

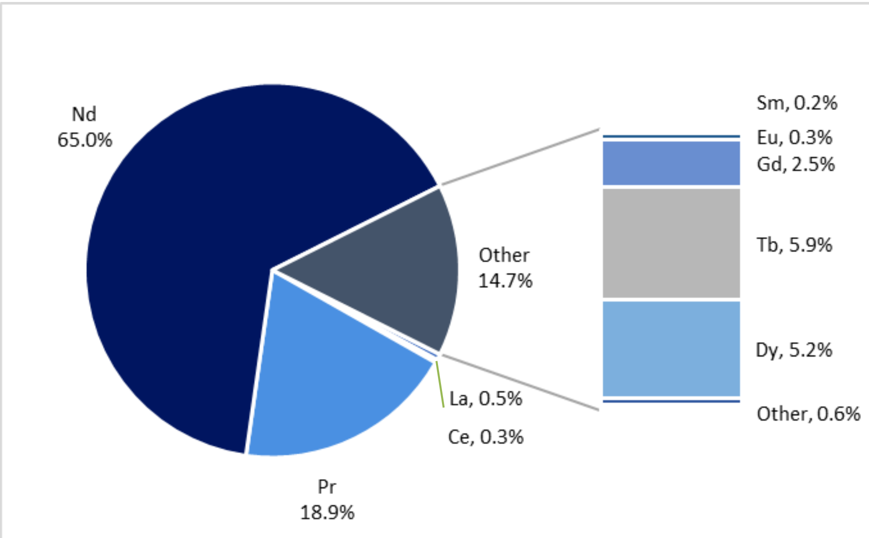
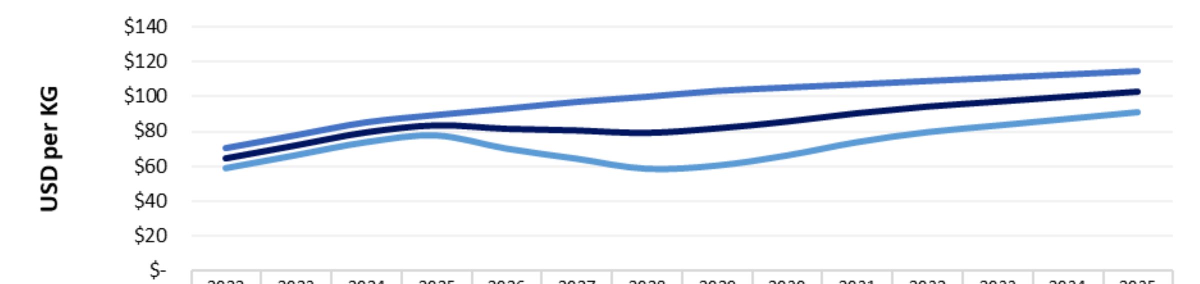


Figure 19.16: Contribution per REO to Songwe Hill Basket Value in 2035

19.2.4 Forecasted Basket Value and Implications for Project

Taking Adamas Intelligence's latest price forecasts into account, along with the relative distribution of rare earth oxides in the mixed rare earth carbonate concentrate from Songwe Hill (see Figure 19.14), the Songwe Hill basket value (i.e. value of rare earth oxides contained in 1 kg of separated TREO produced from the project) was projected for each year from 2022 through 2035, as shown in Figure 19.17.

In Adamas Intelligence's base case, upside and downside price forecast scenarios, the Songwe Hill Project basket value will increase from 2022 through 2035 at a CAGR of 3.6 %, 3.8 % or 3.4 %, respectively.



	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Upside	$70.59	$77.98	$85.33	$89.54	$93.16	$96.99	$99.99	$103.28	$105.24	$107.11	$108.98	$110.85	$112.72	$114.59
Base Case	$64.81	$72.22	$79.60	$83.62	$81.67	$80.72	$79.33	$81.89	$85.75	$90.50	$94.28	$97.11	$99.94	$102.76
Downside	$59.03	$66.47	$73.86	$77.70	$70.18	$64.45	$58.67	$60.50	$66.26	$73.88	$79.58	$83.37	$87.16	$90.94

NOTES:
1 Basket values include 13 % VAT; forecasted prices are in real 2022 dollars.
2 If selling into China VAT, should be deducted. If selling ex-China, the above prices should be taken at face value.

Figure 19.17: Forecasted Songwe Hill Basket Value from 2022 through 2035

In all the scenarios examined, Adamas Intelligence projects that the magnet rare earth oxides (i.e. neodymium, praseodymium, dysprosium and terbium) will collectively make up 95 % of the Songwe Hill basket value in 2035, up from 94 % in 2022 (see Figure 19.18).

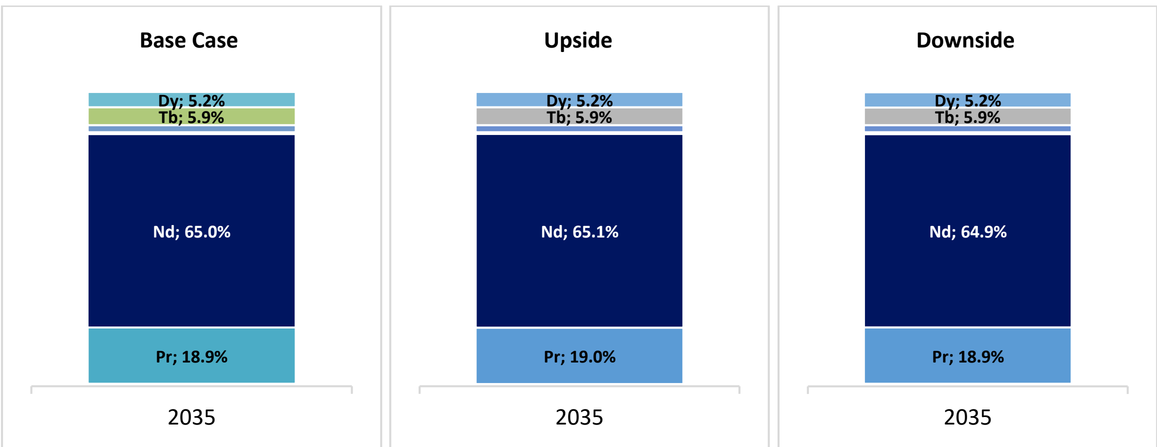


Figure 19.18: Contribution of Magnet Rare Earth Oxides to the Songwe Hill Basket Value in each Scenario

19.2.5 Forecasted Value of Mixed Rare Earth Carbonate Concentrate from Songwe Hill

Over the past 16 months, comparable mixed rare earth chemical concentrates sold in China, the world's largest rare earth market, were priced at a level equal to 61 % to 82 % of the value of rare earth oxides contained in the concentrates, averaging 73 % throughout the observation period (see Figure 19.19).

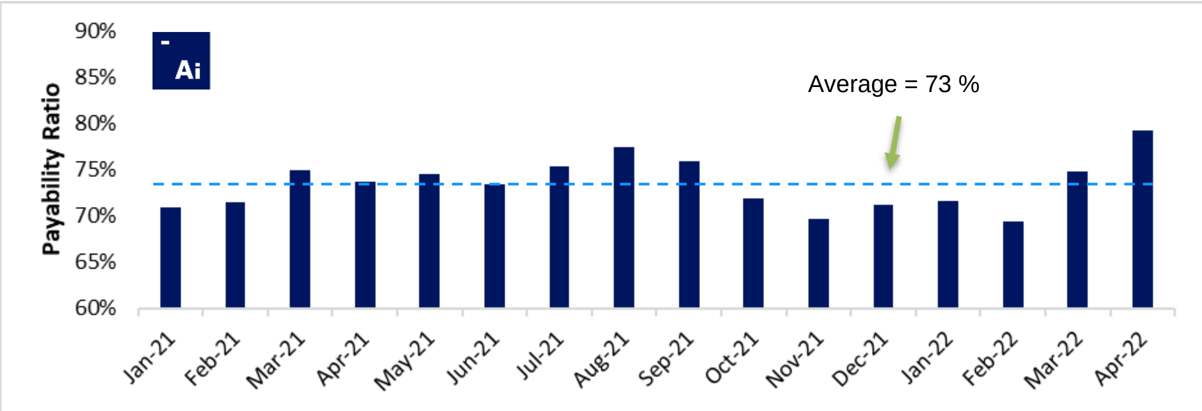
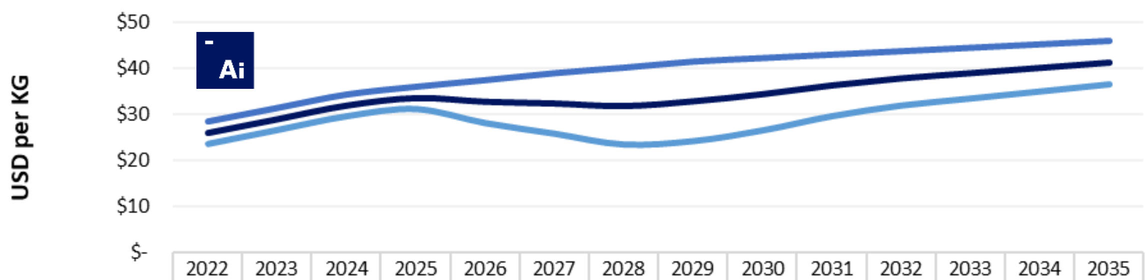


Figure 19.19: China Mixed Rare Earth Chemical Concentrate Price as a Percentage of Contained Rare Earth Oxide Value

Taking the above into account, along with the forecasted TREO basket prices forecasted in Section 19.2.4, Adamas Intelligence forecasts that the mixed rare earth carbonate concentrate from Songwe Hill (55 wt% TREO) will have a value of US$23.70/kg to US$28.34/kg of concentrate in 2022 and will increase overall to US$36.51/kg to US$46.01/kg in 2035 (see Figure 19.20).



	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Upside	$28.34	$31.31	$34.26	$35.95	$37.40	$38.94	$40.15	$41.47	$42.25	$43.01	$43.76	$44.51	$45.26	$46.01
Base Case	$26.02	$29.00	$31.96	$33.57	$32.79	$32.41	$31.85	$32.88	$34.43	$36.33	$37.85	$38.99	$40.12	$41.26
Downside	$23.70	$26.69	$29.66	$31.19	$28.18	$25.88	$23.56	$24.29	$26.60	$29.66	$31.95	$33.47	$34.99	$36.51

NOTES:
1. Prices are in US dollars per kilogram of concentrate; concentrate contains 55 wt% TREO.
2. China's REO and concentrate prices were used as the basis for the forecasts, along with assays provided by Adamas Intelligence.
3. All prices include 13 % VAT; forecasted prices are in real 2022 dollars.
4. If selling into China, 13 % VAT should be deducted from the above. If selling ex-China, the prices above should be taken at face value.

Figure 19.20: Forecasted Value of Mixed Rare Earth Carbonate Concentrate from Songwe Hill

19.2.6 Competitive Landscape

Outside of China, there are 42 advanced rare earth exploration projects globally that are aiming to reach production within the next decade, although the vast majority, in Adamas Intelligence's opinion, will not be successful for one reason or another.

Twenty of the 42 (48 %) advanced rare earth projects have completed a preliminary economic assessment (PEA) – an early-stage assessment of the economic potential of developing a mine from their deposit (see Figure 19.21).

Eight of the 42 (19 %) projects have advanced further and completed PFS, which is a more detailed study to evaluate the financial case for developing a mine (see Figure 19.21).

Twelve of the 42 (29 %) projects, including Mkango' Songwe Hill Project, are even more advanced and have completed a DFS, which is the final detailed study that a project owner completes before raising development capital to start building a new mine.

Lastly, only three of the 42 (7 %) advanced rare earth projects have started mine development as of Q2 2022 (see Figure 19.21).

Figure 19.21: Pre-Production Development Stages of 42 Advanced Rare Earth Exploration Projects Globally

Thirteen of the 42 (31 %) advanced rare earth projects outside of China are located in North America, ten projects (24 %) are located in Australia, eight projects (19 %) are located in Africa, seven (17 %) in Europe, and four (10 %) in South America (see Figure 19.22).

The Songwe Hill Project is one of three active projects in Africa at the DFS level and one of two projects in Africa to complete a DFS within the past five years.

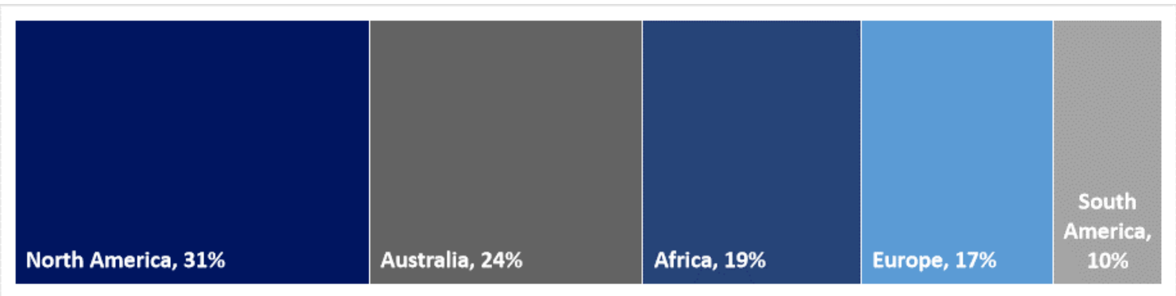


Figure 19.22: Global Distribution of the 42 Advanced Rare Earth Projects outside of China

19.2.7 International Supply Chain Development

Outside of China and Japan, there is currently a lack of capacity to convert rare earth oxides into the metals, alloys and magnets used globally in EV traction motors, wind power generators, energy-efficient consumer appliances, and more.

These supply chain gaps present major risks for automakers, wind power generator manufacturers, and other end users in Europe and North America, spurring public and private sectors into action over the past twelve months.

19.2.7.1 Company Announcements

In late 2021, MP Materials and Vacuumschmelze announced plans to build NdFeB magnet-making plants in the United States, from which they will supply General Motors and presumably others.

Similarly, in late 2021, Neo Performance Materials and the Estonian government jointly announced their intent to develop NdFeB production capacity in the nation, where the former currently produces rare earth oxides.

Moreover, in mid-2021, Mkango and Grupa Azoty announced plans to develop a rare earth oxide separation plant in Poland that would feed critical rare earth materials into the European magnet, motor and generator supply chains.

19.2.7.2 Government Announcements

In early 2022, United States President Biden invoked the Defense Production Act to give the government enhanced powers and funding to expedite development of critical minerals supply chains needed for advanced technologies, such as electric vehicles, while reducing long-term dependence on China.

Similarly, in early 2022, Canada announced a critical minerals strategy that includes US$3 billion in support of critical minerals project infrastructure investments and tax credits aimed at expediting project development.

Moreover, in early 2022, Canada and the European Commission issued a joint statement highlighting their mutual commitment to ensuring security of critical minerals and metals supply chains to reduce dependence on Russian minerals while facilitating the shift to a climate-neutral economy.

19.2.7.3 Alternative Supply Chains

These recent announcements, and others to come, reflect a growing concern in North America and Europe about supply chain sustainability and signal the coalescing of new alternative international mine-to-magnet supply chains connecting North America, Europe and Africa.

19.2.8 Market Risks

19.2.8.1 Supply Side

For the supply side of the global rare earths market to satisfy, let alone exceed, magnet rare earth oxide demand in the years ahead, the market will need to develop an additional

84,000 t/a to 140,000 t/a of LREE-rich TREO production capacity by 2030 and a further 270,000 t/a to 450,000 t/a by 2035 – over and above the major increases Adamas Intelligence already anticipates – which is highly unlikely to happen in Adamas Intelligence's view.

As such, Adamas Intelligence considers the risk of long-term oversupply to be low.

19.2.8.2 Demand Side

Should battery materials or other component shortages significantly bottleneck global electric production in the years ahead, it could consequentially slow NdFeB magnet demand growth.

Adamas Intelligence's demand and price forecasts have already built in the expectation of moderate electric vehicle production bottlenecks through the end of the decade, along with upside and downside price forecast scenarios for more or less extreme outcomes.

Ultimately, because electric vehicles are just one of many different end uses and applications of NdFeB magnets, the potential downside impact of electric vehicle production constraints on rare earth prices would be modest in Adamas Intelligence's view.

19.2.8.3 Prices

Looking forward, Adamas Intelligence believes that the current strong pricing environment for rare earth materials is here to stay, notwithstanding the market's usual ebbs and flows on the back of seasonality and other transient factors.

19.2.9 Current State of the Market

Following an REO price upward trend in late 2021 into 2022, prices of rare earths (along with a wide array of other metals) trended lower in March and April due to seasonality, ongoing automotive industry bottlenecks, and strict pandemic lockdowns in China – the world's engine for raw materials demand.

As of June 2022, magnet rare earth prices were trending steadily higher again and China's pandemic lockdowns were ending. Going forward, Adamas Intelligence expects that these transitory conditions will ease through the second half of the year, fuelling a latent demand pop and continued near-term strength for prices and demand growth.

Moreover, as noted previously, in the medium to long term, Adamas Intelligence believes that the strong rare earth pricing environment observed in 2021 and 2022 to date is here to stay, notwithstanding the market's usual ebbs and flows on the back of seasonality and other transient factors.

Adamas Intelligence believes that a return to lower magnet rare earth price levels going forward would be unsustainable as it would stimulate those cost-sensitive, yet nimble, end users walking away from the rare earth market today (e.g. Amazon) to return en masse, pushing demand up to levels even more out of reach for the supply side, which, because of long lead times and high incentive prices needed to develop new production, cannot respond sufficiently at those lower price levels.

As such, just as "high prices provide the cure for high prices" in more agile commodity markets like oil and gas, Adamas Intelligence contends that "low prices will provide the cure for low prices" in the lumbering rare earth space, adding ongoing support for the current strong pricing environment.

Figure 19.23 shows recent fluctuations in the Nd oxide prices compared with the Adamas Intelligence base case price for 2022, demonstrating their relatively close alignment.

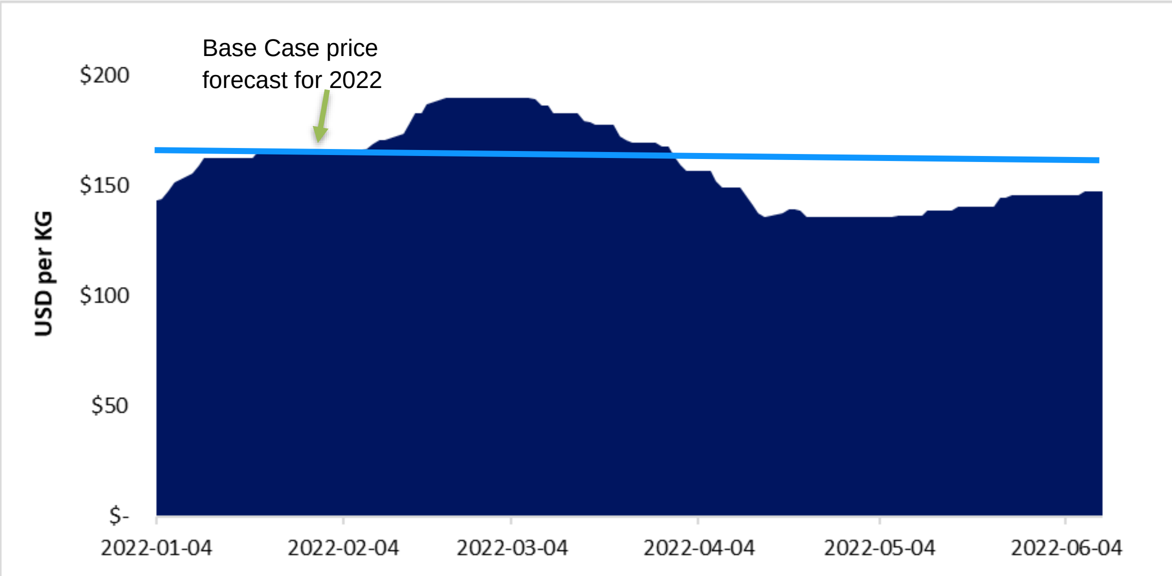


Figure 19.23: Year-to-Date Average Nd Oxide Price Closely Tracking Adamas Intelligence's Base Case Scenario

19.2.10 Conclusions

Adamas Intelligence has drawn the following conclusions:

- From 2022 through 2035, Adamas Intelligence forecasts that global demand for NdFeB magnets will increase at a CAGR of 8.6 %, bolstered by double-digit growth from electric vehicle and wind power sectors, translating into comparable demand growth for the rare earth elements (i.e. neodymium, praseodymium, dysprosium and terbium) that these magnets contain.
- Over the same period, Adamas Intelligence forecasts that global production of neodymium, praseodymium, dysprosium and terbium will collectively increase at a slower CAGR of just 5.4 % as the supply side of the market increasingly struggles to keep up with rapidly growing demand.
- From 2023 through 2035, Adamas Intelligence forecasts that the global rare earth industry will consistently underproduce neodymium, praseodymium, dysprosium and terbium oxides (or oxide equivalents), resulting in the depletion of historically accumulated inventories and, ultimately, shortages of these critical magnet materials if supply is not increased beyond levels currently anticipated.
- The Songwe Hill Project offers strong economic exposure to the rare earth permanent magnet sector, which is the fastest-growing end-use category and most in need of additional rare earth supplies.

- From a marketing, logistics and economic standpoint, the high proportion of valuable magnet-related REEs in the Songwe Hill Project's prospective TREO production means that a future mine (with separation) could generate approximately 95 % of its rare earth revenues from just 34 % of its production volume.
- Looking forward, Adamas Intelligence believes that the current strong pricing environment for rare earth materials is here to stay, notwithstanding the market's usual ebbs and flows on the back of seasonality and other transient factors.
- In its **Base Case** scenario, Adamas Intelligence forecasts that the **basket value** of the Songwe Hill TREO production will total US$64.81/kg in 2022 and will increase to US$102.76/kg in 2035. In its upside scenario, Adamas Intelligence forecasts the basket value will total US$70.59/kg in 2022 and will increase to US$114.59/kg in 2035. In its downside scenario, Adamas Intelligence forecasts the basket value will total US$59.03/kg in 2022 and will increase to US$90.94/kg in 2035.
- In its **Base Case** scenario, Adamas Intelligence forecasts that the **value of mixed rare earth carbonate** produced by the Songwe Hill Project will amount to US$26.02/kg of concentrate in 2022 and will increase to US$41.26/kg of concentrate in 2035. In its upside scenario, Adamas Intelligence forecasts that the value of mixed rare earth carbonate produced by the Songwe Hill Project will amount to US$28.34/kg of concentrate in 2022 and will increase to US$46.01/kg of concentrate in 2035. In its downside scenario, Adamas Intelligence forecasts that the value of mixed rare earth carbonate produced by the Songwe Hill Project will amount to US$23.70/kg of concentrate in 2022 and will increase to US$36.51/kg of concentrate in 2035.

20 ENVIRONMENTAL STUDIES, PERMITTING AND SOCIAL OR COMMUNITY IMPACT

Mkango appointed Digby Wells Environmental (Digby Wells) to undertake the Environmental, Social and Health Impact Assessment (ESHIA) process. The ESHIA process was undertaken with in-country partners ENVIROCONSULT. Digby Wells compiled the ESHIA for the project as stipulated in Section 31 of the Environment Management Act, 2017 (Act No. 19 of 2017) (the EMA Act), as well as in accordance with the International Finance Corporation (IFC) Performance Standards (PSs) and Good International Industry Practice (GIIP). The ESHIA was submitted to the Malawi Environment Protection Authority (MEPA) in July 2022 for their review and comment prior to finalisation and submission for permitting. The ESHIA identified all the expected environmental and social impacts associated with the project, including the prevention of pollution, treatment of waste, the safeguarding of natural resources, progressive reclamation and rehabilitation, and the minimising of the effects of mining activities.

Environmental and social baseline studies have been conducted by Digby Wells in collaboration with a team of Malawian specialists associated with ENVIROCONSULT. These studies are aligned with the requirements of the Equator Principles, the IFC Performance Standards as well as specific requirements and interpretations of Malawian Legislation. Baseline conditions for various biophysical and social environmental aspects were determined, considering seasonal variation and input from various stakeholders. The sections below provide a summary of the biophysical and socio-economic baseline of the project area.

20.1 LEGAL FRAMEWORK

The legal framework applicable to the Songwe Hill Project is set out in the sections below.

20.1.1 Malawian Legislation

20.1.1.1 The Constitution of the Republic of Malawi

Chapter 3 of the Constitution of the Republic of Malawi (1994)[1] sets out fundamental principles under Section 13 and addresses to promote the welfare and development of the Malawian people by progressively adopting and implementing policies and legislations.

Under the goal of Environment, the Constitution states that the environment must be managed responsibly to achieve the following:

(i) Prevention of degradation of the environment
(ii) Provision of a healthy living and working environment for the people of Malawi
(iii) Accordance of full recognition to the rights of future generations by means of environmental protection and the sustainable development of natural resources
(iv) Conservation and enhancement of the biological diversity of Malawi

The Private Sector Agreement document states that a Development Agreement must be compiled for the project. Mkango seeks to enter into a Development Agreement with the Government of Malawi. A Development Agreement is a concession agreement which governs

[1] The Constitution of Malawi of 1994 with amendments through 2017.

the relationship between the Government and a licence holder for the exploration of a certain area of land for minerals or for the mining of minerals in a certain area in exchange for royalties, taxes and other obligations.[2]

20.1.1.2 Environmental Legislation

20.1.1.2.1 National Environmental Action Plan and Policy

The National Environmental Policy (NEP) (1996), revised in 2004, is an overarching framework instrument that calls for the strengthening of institutional mechanisms, and the review and formulation of environmental legislation. The goal of this policy is to promote sustainable development through an efficient and sound management of the environment and natural resources.

The National Environmental Action Plan (NEAP) was prepared in 1994 in response to Agenda 21 that required signatories to the 1992 Rio Declaration on Environment and Development to prepare an action plan for integrating environmental issues into socio-economic development programmes. The NEAP was subsequently updated in 2004. The main objectives include the following:

- Document and analyse all major environmental issues and measures to alleviate them.
- Promote sustainable use of natural resources in Malawi.
- Develop an Environmental Protection and Management Plan.

20.1.1.2.2 Environment Management Act and ESHIA

The EMA Act, 2017 makes provision for the protection and management of the environment. Part VI of the Act addresses Environmental Management and ESHIAs.

Part VII of the Act sets out the environmental standards:

- Air quality standards (Section 36)
- Water quality standards (Section 37)
- Standards for discharge of effluent into water (Section 38)
- Standards for control of obnoxious smells (Section 39)
- Standards for control of noise and vibrations (Section 40)
- Soil quality standards (Section 41)
- Standards for minimisation of impact of ionising and other radiation (Section 42)
- Other environmental quality standards (Section 43)
- Standards under other written law (Section 44)

Other sections include the following:

- Provisions for environmental monitoring, where the developer must compile an Environmental Management Plan, which will be used by the developer to manage the project (Section 33)

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[2] https://negotiationsupport.org/glossary/mining-development-agreement (Accessed 24 May 2021).

- Provisions for the management, transportation, treatment and recycling, reduction, and the safe disposal of waste, and the prohibition of littering in public places (Section 56 (1))
- Prohibition of persons from handling, storing, transporting, classifying, or destroying waste without the proper licence (Section 57 (1))
- Provision for the exportation of hazardous waste under a permit (Section 58 (1))
- Provision of guidelines for the management of toxic and hazardous substances (Section 59 (1))
- Prohibition of the release of effluent into the environment without a licence (Section 61)
- Prohibition of the emission of gaseous substances or other pollutants that can cause air pollution (Section 62)
- Prohibition of noise emissions exceeding the established standards (Section 63)

The Guidelines for ESHIAs as prescribed in the EMA Act, 2017, outline the basis for the ESHIA process in Malawi and provide a mechanism for integrating environmental and social development concerns. Through this process, sustainable development and improved living standards for Malawians can be achieved, and ecosystems as well as social and cultural values can be preserved.

20.1.1.2.3 Atomic Energy Act

The Atomic Energy Act, 2011 (Act No. 16 of 2011), supported by the Atomic Energy Regulations (2012), specifies the requirements for the protection of people against exposure to ionising radiation, the safety of radiation sources, waste management, and for the protection of the environment. The Act aims to prevent unlicensed access or damage to, and loss, theft or unlicensed transfer of, radioactive sources so as to reduce the likelihood of accidental harmful exposure to such sources. The Act requires the development, implementation and documentation of a radiation safety programme commensurate with the nature and extent of the risks associated with a project.

20.1.1.3 Mining Legislation

The Mines and Minerals Act, 2019 (Act No. 8 of 2019) repealed the Mines and Minerals Act, 1981 (Act No. 1 of 1981) and makes provision for the search for and mining of minerals. It also sets out the rules of engagement for players in the mining sector.

Retention Licence RTL 0001/21 (the “Licence Area”) covers an area of 25 km^2 and is one of a contiguous block of 11 RTLs with a total area of 250 km^2. The block falls within the former EPL 0284/10 that had an area of 849.1 km^2 and was originally granted to Lancaster Exploration Ltd (Lancaster), a 100 % subsidiary company of Mkango, on 21 January 2010 with a three-year term. It was renewed successively for two-year periods until 20 January 2015, 19 January 2017, 21 January 2019, and 21 January 2021 by the Minister of Natural Resources, Mines and Energy under the Act. The EPL was then converted to an EL on 19 January 2021 to comply with the Act. Most recently, a block of 11 RTLs was applied for and granted on 1 June 2021, and the Songwe Hill REE Project falls within one of these licences, RTL 0001/21.

Mkango is in receipt of a legal opinion from Blantyre law firm Gustave and Company that its 100 % owned subsidiary, Lancaster, is the legal holder of 100 % interest in RTL 0001/21, which is valid and existing as of the date of this opinion, 19 May 2022. The opinion further states that the RTL is unencumbered and in good standing.

The RTL allows Mkango to explore for all 17 rare earths elements including yttrium, strontium, niobium, iron ore, manganese, gold, silver, copper, bauxite, fluorite, phosphate, uranium, thorium, monazite nepheline, syenite, zircon, tantalum, clay, kaolinite and associated minerals (the "Mineral Rights"). The RTL remains in good standing, in full force, and has not been revoked.

Mkango aims to convert the Retention Licences into a mining licence application once the feasibility studies are completed. The licences give Mkango the *exclusive priority right to apply for a mining licence* if the feasibility and bankability studies are successful.

20.1.1.4 Applicable Malawian Legislation

Other applicable national legislation for the project includes the following:

- Plant Protection Act (1969)
- Forestry Act (1997)
- Mines and Minerals Policy (2019)
- Water Resources Act (2013)
- Land Act (2016)
- Customary Land Act (2016)
- Lands Acquisition Act (1970)
- National Sanitation Policy (2006) and Public Health Act (1984)
- Occupational Safety, Health and Welfare Act (1997)

20.1.2 Licences Required for the Project

The licences and/or permits identified in Table 20.1 must be applied for and granted to enable Mkango to undertake the project.

Table 20.1: Licences Required for the Project

Authorisation	Enabling Legislation	Description	Competent Authority
Large-Scale Mining Licence	Mines and Minerals Act, 2019	For mineral extraction.	Ministry of Mines
Water Use Licence	Water Resources Act, 2013	Permit is required to use and/or abstract water, build dams (TSF, RWD and SWCD), and for the discharge of effluent.	Water Resources Board: Water Abstraction Control Sub-committee
Effluent Discharge Consent	Water Resources (Water Pollution Control) Regulations	To control water pollution. Effluent must conform to standards set by the Malawi Bureau of Standards.	Pollution Control Sub-committee
Air Pollution Licence	Environment Management Act, 2017	Licence is required to emit any gas or other pollutants into the atmosphere.	Department of Environmental Affairs
Waste Licence	Environment Management Act, 2017	A licence is required to handle, store, transport, classify or destroy waste other than domestic waste, or operate a waste disposal site.	Department of Environmental Affairs

Authorisation	Enabling Legislation	Description	Competent Authority
Hazardous Waste Licence	Environment Management Act, 2017 Occupational Safety, Health and Welfare Act, 1997	A permit is required to import or export and transport any hazardous waste in Malawi.	Department of Environmental Affairs
Storage of Explosives Licence	Explosives Act, 1968	Authorises the holder to store explosives on the premises described in the licence.	Chief Inspector of Explosives
Dealer's Licence	Explosives Act, 1968	Authorises the holder to purchase, sell and deal in explosives.	Chief Inspector of Explosives
Permit to Possess Explosives	Explosives Act, 1968	Authorises the holder to purchase and possess explosives.	Chief Inspector of Explosives
Blasting Licence	Explosives Act, 1968	Authorises the holder to use explosives for the purpose of blasting.	Chief Inspector of Explosives
Electricity Generation Licence	Energy Regulation Act, 2004 Energy Regulation By-Laws, 2008	Authorises the holder to establish, operate and generate power.	Energy Authority
Bulk Fuel Storage Licence	Liquid Fuels and Gas (Production and Supply) Act, 2004 and Regulations, 2008	Authorises the holder to store liquid fuels and gas for private use.	Department of Environmental Affairs
Permit for the relocation of graves and cemeteries as well as cultural heritage artefacts	Monuments and Relics Act, 1991	Authorises the holder to remove and relocate items of cultural heritage. No person shall, without the prior written consent of the Minister, (a) make any alteration to, or destroy or damage, any monument or relic or any part thereof; or (b) carry out any cultivation or mining project or other work so as to cause, or likely to cause damage to cultural heritage resources.	Minister of Monuments and Relics
Licence to undertake an activity with the potential to result in the exposure to ionising radiation from mining and processing REE	Atomic Energy Act, 2011	To provide an appropriate and internationally acceptable standard of protection and safety for humans and the environment for activities involving the peaceful application of nuclear science technology, without unduly limiting the benefits of the uses of this technology.	Atomic Energy Regulatory Authority (AERA)

20.1.3 International Guidelines and Standards

The project complies with the World Bank criteria by complying with the IFC Standards and the Equator Principles.

The IFC Sustainability Framework expresses its strategic commitment to sustainable development. The Framework encompasses the IFC's Policy and Performance Standards on Environmental and Social Sustainability and Access to Information Policy (IFC, 2012). Table 20.2 provides details on how the ESHIA has been aligned with the IFC Performance Standards.

The following abbreviations are used in Table 20.2 to indicate the level at which the relevant IFC Performance Standards have been addressed in the ESHIA document:

- FC – Fully considered
- PC – Partially considered
- NC – Not considered
- N/A – Not applicable

Note that the project area is still a greenfield site; therefore, all the management plans will be developed when the project is implemented. The purpose of the ESHIA and accompanying Environmental and Social Management Plan (ESMP) has been to identify the potential impacts and propose mitigation and management measures for implementation at project implementation.

Table 20.2: Alignment of the ESHIA with the IFC Performance Standards

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
PS1: ASSESSMENT AND MANAGEMENT OF ENVIRONMENTAL AND SOCIAL RISKS AND IMPACTS			
Objectives	Performance Standard 1 underscores the importance of managing environmental and social performance throughout the life of a project. The objectives of the Performance Standard are To identify and evaluate environmental and social risks and impacts of the project. To adopt a mitigation hierarchy to anticipate and avoid, or where avoidance is not possible, minimise, and where residual impacts remain, compensate/offset for risks and impacts to workers, Affected Communities and the environment. To promote improved environmental and social performance of clients through the effective use of management systems. To ensure that grievances from Affected Communities and external communications from other stakeholders are responded to and managed appropriately. To promote and provide means for adequate engagement with Affected Communities throughout the project cycle on issues that could potentially affect them and to ensure that relevant environmental and social information is disclosed and disseminated.		
Identification of Risks and Impacts	Conduct an environmental and social assessment and establish and maintain an Environmental and Social Management System (ESMS). The ESMS will incorporate the following elements: Policy Identification of risks and impacts Management programmes Organisational capacity and competence Emergency preparedness Stakeholder engagement Monitoring and review	**FC**	The ESHIA phase included comprehensive data collection, impact identification, and the assessment of the potential impact significance both pre- and post-mitigation. To identify and assess impacts posed by the project, data was collected from literature reviews, desktop assessments, seasonal field studies, monitoring data undertaken by Mkango, and technical documents associated with the project design. The findings were then incorporated into the ESHIA to establish the baseline biophysical and socio-economic environment prior to the proposed project, as well as to identify and anticipate the potential risks and impacts likely to arise from the proposed development. The following specialist studies were undertaken to inform the baseline and impact assessment process: Surface water (or hydrology) Groundwater Geochemistry Aquatic biodiversity Floral diversity Faunal diversity

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
			Soils Wetland delineation and functionality Cultural heritage Noise Visibility assessment Radiation Socio-economic Transport and traffic Impact identification was performed by using an input-output model to guide the assessment of potential change/s to the ecological and socio-economic environments (based on the specialist studies listed above), pollution and resource consumption during the establishment, operational, closure and post-closure phases of the project.
Environmental and Social Management System		**FC**	Based on the proposed activities, extent and impacts of the development, the project falls under Category A in terms of the IFC classification: *"Business activities with potential significant adverse environmental or social risks and/or impacts that are diverse, irreversible, or unprecedented."* The ESHIA identifies and quantifies the risks and impacts relating to the project activities. The Environmental, Social and Health Management Plan (ESHMP) is compiled taking into consideration those impacts and how best to mitigate and manage them. The ESHMP includes the management measures aligned with the development of the following plans with the aim of reducing the risks and impacts: Conservation Management Plan Biodiversity Management Plan Storm Water Management Plan Erosion Management Plan Topsoil Management Plan Traffic Management Plan

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
			Alien and Invasive Plant Species Management Plan Plant (Flora) Management Plan Stakeholder Engagement Plan Influx Management Plan Chance Find Procedure Workforce Management Plan Waste Management Plan Fire Management Plan Emergency Preparedness and Response Plans The ESHMP and all mitigation and management measures have been compiled in compliance with Malawian national legislation, policies and plans as well as international conventions, guidelines and standards and should be implemented as the basis of the ESMS for the development.
PS2: LABOUR AND WORKING CONDITIONS			
Objectives	Performance Standard 2 recognises that the pursuit of economic growth through employment creation and income generation should be accompanied by protection of the fundamental rights of workers. The objectives of the Performance Standard are To promote the fair treatment, non-discrimination, and equal opportunity of workers. To establish, maintain, and improve the worker-management relationship. To promote compliance with national employment and labour laws. To protect workers, including vulnerable categories of workers such as children, migrant workers, workers engaged by third parties, and workers in the client's supply chain. To promote safe and healthy working conditions, and the health of workers. To avoid the use of forced labour.		
Working Conditions and Management of Worker Relationship	Project proponents are required to adopt a Human Resources policy that sets out an approach to managing employees that is consistent with PS2 (i.e. provide information on rights in terms of national labour and employment law, and rights related to wages and benefits, and ensure that the information is clear, understandable and explained to each employee). This includes the following:	**FC**	The construction and operational phases of the project will require the employment of unskilled labour. Based on the socio-economic assessment, there is a large pool of unskilled people living in the surrounds of the project from which the project can draw. To enhance the employment and benefits associated with the project, a Local Employment and Procurement Policy is necessary and must be developed as prescribed in the ESHMP, which states the following:

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	Document and communicate to all employees their working conditions and terms of employment (including wages and benefits). Respect collective bargaining agreements. In the absence thereof, reasonable working conditions and terms of employment, which comply with national law, are required. Comply with national law, if it recognises workers' rights to form and join workers organisations and to bargain collectively. Where national law restricts workers organisations, the client should enable alternative means for workers to express grievances and protect their rights. Engage with worker representatives. Ensure an employment relationship based on a principle of equal opportunity and fair treatment. Do not discriminate with respect to aspects of the employment relationship (recruiting, hiring, compensation, working conditions, terms of employment, access to training, promotion, termination, retirement and discipline). Where national law supports this, compliance with the law is required. Where the law does not support this, compliance with PS2 is required. Develop a plan to mitigate the adverse impacts of retrenchment on employees if elimination of a significant number of jobs/lay-off of employees is anticipated. Provide a grievance mechanism for workers to raise workplace concerns. Inform employees of the mechanism when hired, and make it easily accessible. Address concerns promptly, using a transparent and understandable process that provides feedback without retribution. Ensure that it does not impede access to judicial or administrative remedies. Do not employ children in a manner that is economically exploitative, hazardous, interferes with their education, or is harmful to their health or to their physical, mental,		Local employment targets are met in the contractors' Special Conditions of Contract. Local communities understand the project's employment requirements. Skills are transferred, and training is undertaken in the affected communities as far as possible. Mkango employs a grievance mechanism and community relations policy for the effective communication between employer and employees. Employees are made aware of the employment and occupational health and safety procedures in line with the IFC's EHS Guidelines on Occupational Health and Safety. In collaboration with local authorities, Mkango develops and implements an Influx Management Plan to help curb project-induced in-migration that would increase pressure on local natural resources and contribute to their degradation.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	spiritual, moral or social development. Where national laws have provisions for the employment of minors, clients will comply with national law. Under 18s cannot be employed in dangerous work. Do not employ forced labour. This includes involuntary or compulsory labour. Ensure that workers are provided with a safe and healthy work environment that takes account of risks and physical, chemical, biological and radiological hazards. Take measures to prevent accidents, injuries and diseases.		
PS3: RESOURCE EFFICIENCY AND POLLUTION PREVENTION			
Objectives	Performance Standard 3 recognises that increased economic activity and urbanisation often generate increased levels of pollution to air, water, and land, and consume finite resources in a manner that may threaten people and the environment at the local, regional, and global levels. The objectives of the Performance Standard are To avoid or minimise adverse impacts on human health and the environment by avoiding or minimising pollution from project activities. To promote more sustainable use of resources, including energy and water. To reduce project-related greenhouse gas (GHG) emissions. The components considered to achieve these objectives are further detailed below.		
Resource Efficiency	Implement technically and financially feasible and cost-effective measures for improving efficiency in the consumption of energy, water, as well as other resources and material inputs. Where benchmarking data is available, make a comparison to establish the relative level of efficiency. Greenhouse Gases: Consider alternatives and implement technically and financially feasible and cost-effective options to reduce project-related GHG emissions during the design and operation of the project. For projects that are expected to or currently produce more than 25,000 t of CO_2 equivalent annually, quantify direct emissions from the facilities owned or controlled within the physical project boundary, as well as indirect	**FC**	The climate change assessment presents best practice options for consideration to increase energy efficiency and/or lower emissions intensity of its activities in Malawi and reduce emissions. These include the following: Construct PV solar plants for self-generation of power albeit not to cover the entire load but to reduce the demand of fossil fuel generated sources. Purchase hybrid diesel generators and high-efficiency equipment (mills, grinders, etc). Ensure that proper waste management measures are implemented. GHG emissions have been calculated as part of the climate change assessment for the project and assessed by comparing the project's operational impact against

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	emissions associated with the off-site production of energy used by the project. Water Consumption: Adopt measures that avoid or reduce water usage so that the project's water consumption does not have significant adverse impacts on others. Use additional technically feasible water conservation measures within the client's operations to reduce total demand for water resources.		Malawi's current emissions reported to the Intergovernmental Panel on Climate Change (IPCC). The project is estimated to emit approximately 247,167 t of CO_2 equivalent per year, and the emissions impact of the project is relatively minor when compared to that of the national GHG emissions. Based on the assessment, the magnitude of the impact of the project on Malawi's national emissions could be negligible to low. The reported emissions will be lower when actual data is collected and reported on. The initial water consumption of the project will be high; however, as operations proceed, the water will be recycled for process use. Clean and dirty water will be separated accordingly to prevent contamination of clean water resources and decrease demand on freshwater or potable water. A water balance has been developed for the project, and the target is zero discharge of water into the environment. These measures fully comply with the objective to achieve resource efficiency and prevent pollution.
Pollution Prevention	Avoid the release of pollutants, or when not feasible, minimise or control the intensity or load or their release in routine, non-routine or accidental circumstances. Where historical pollution such as land or groundwater contamination exists, determine whether the project proponent is responsible for mitigation measures. To address potential adverse project impacts on existing ambient conditions, consider relevant factors, including the following: Existing ambient conditions The finite assimilative capacity of the environment Existing and future land use The project's proximity to areas of importance to biodiversity	**FC**	Baseline studies conducted for various environmental aspects in the project area assessed existing biophysical and social conditions. The impact assessment has been undertaken relative to the baseline conditions identified. While there are existing anthropogenic disturbances in the area, the ESHIA identifies and sets out mitigation and management of impacts in relation to the proposed project activities. The ESHMP prescribes these measures for mitigation based on the assessed baseline environment, as well as cumulative impacts, unplanned risks and future impacts of the project.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	The potential for cumulative impacts with uncertain and/or irreversible consequences		
	Wastes: Avoid or minimise the generation of hazardous and non-hazardous waste materials. Where generation cannot be avoided but has been minimised, recover and reuse it. Where waste cannot be recovered and reused, treat, destroy and dispose of it in an environmentally sound manner. If hazardous, apply commercially reasonable alternatives for environmentally sound disposal considering the limitations applicable to transboundary movement. When third parties conduct disposal, use contractors that are reputable, legitimate and licensed by regulatory authorities. Comply with all the requirements included in the General EHS Guidelines for Waste Management Facilities, 10 December 2007. Ensure that facilities that generate waste characterise their waste according to composition, source, types of wastes produced, generation rates, or according to local regulatory requirements.	**FC**	The ESHMP is compiled by considering the mitigation hierarchy. Due to the nature of the waste that will be inevitably generated by the project, permits are required by Malawian legislation for the handling and disposal thereof. Mkango is committed to preventing pollution and will make resources available to ensure that all reasonable measures are in place. Mkango will also accept accountability and financial liability for any pollution that may occur as a result of project-related activities. The prescribed waste management measures are cognisant of the provisions of the IFC EHS Guidelines for Waste Management Facilities (2007).
	Hazardous materials: Avoid, or when not feasible, minimise or control the release of hazardous materials resulting from production, transportation, handling, storage and use. Avoid the manufacture, trade and use of chemicals and hazardous materials subject to international bans and phase-outs, and consider the use of less hazardous substitutes.	**FC**	The ESHMP sets out measures for the storage, handling, transportation and disposal of hazardous substances and waste. An Emergency Preparedness and Response Plan has, as part of the ESHMP, been developed and must be implemented.
	Pesticide Use and Management: Formulate and implement an integrated pest management and/or integrated vector management approach targeting economically significant pest	**NC**	The ESHIA has not identified the need for the use of pesticides and the management thereof. Should the need arise to use pesticides during the development of the project, the management plan will be compiled.

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	infestations and disease vectors of public health significance. When pest management activities include the use of chemical pesticides, select chemical pesticides that are low in human toxicity, that are known to be effective against the target species, and that have minimal effects on non-target species and the environment. Design the pesticide application regime to avoid damage to natural enemies of the target pest, avoid the risks associated with the development of resistance in pests and vectors, and where avoidance is not possible, minimise the consequences. Products that fall into the World Health Organisation (WHO) Recommended Classification of Pesticides by Hazard Class Ia (extremely hazardous) or Ib (highly hazardous) will not be purchased, stored, used, manufactured, or traded. Class II (moderately hazardous) pesticides will not be purchased, stored, used, manufactured, or traded, unless the project has appropriate controls on manufacture, procurement, or distribution and/or use of these chemicals. These chemicals should not be accessible to personnel without proper training, equipment, and facilities to handle, store, apply, and dispose of these products properly.		
PS4: COMMUNITY HEALTH, SAFETY AND SECURITY			
Objectives	Performance Standard 4 recognises that project activities, equipment, and infrastructure can increase community exposure to risks and impacts. In addition, communities that are already subjected to impacts from climate change may also experience an acceleration and/or intensification of impacts due to project activities. The objectives of the Performance Standard are To anticipate and avoid adverse impacts on the health and safety of the Affected Community during the project life from both routine and non-routine circumstances. To ensure that the safeguarding of personnel and property is carried out in accordance with relevant human rights principles and in a manner that avoids or minimises risks to the Affected Communities. The components considered to achieve these objectives are further detailed below.		

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
Community Health and Safety Requirements	General: Evaluate the risks to and impacts on the health and safety of the Affected Communities during the project life cycle and establish preventive and control measures consistent with GIIP such as in the WBG EHS Guidelines. Identify risks and impacts and propose mitigation measures that are commensurate with their nature and magnitude.	**FC**	Community health and safety impacts resulting from the project activities have been identified and assessed as part of the ESHIA for each phase of the project (construction, operation and decommissioning), including the following: Increase in sexually transmitted diseases Increase in respiratory tract diseases due to dust Loss of hearing due to noise from blasting operations Human toxicity due to the uptake of REEs from the mining and processing of the ore The ESHMP prescribes mitigation and management measures to avoid community health and safety risks in line with IFC and WHO Health Guidelines for example: Site- and job-specific risk assessments, including similar exposure mapping. Engineering controls and technological developments such as dust collection systems and ventilation systems to reduce on-site particulate matter (PM). Provision of task-specific personal protective equipment (PPE), such as ear defenders, safety glasses, dust masks and breathing apparatus, to reduce or prevent exposure. Regular medical checks for all workers, including blood testing for heavy metals, hearing tests, and respiratory monitoring for indications of silicosis and tuberculosis. Employees who are regularly exposed to hazardous chemicals also receive regular biological and radiation testing. Continuous consultation and monitoring of environmental aspects also allow for the identification of new risks and impacts as well as updates to risk and impact assumptions made during the ESHIA. The ESHMP has

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
			been developed as a "living document", allowing for active management of risks and impacts identified throughout the project's life cycle.
	Hazardous materials management and safety: Prevent or minimise potential for community exposure to hazardous materials released by the project. The safe management of hazardous materials should extend into the decommissioning phase of the project, where remaining wastes, including demolition wastes, must be safely managed according to the waste management requirements of PS3. Exercise care to avoid or minimise community exposure to hazards by modifying, substituting or eliminating the condition or substance causing hazards. Where hazardous materials are part of the project, exercise care when conducting decommissioning activities to prevent exposure to community. Exercise commercially reasonable efforts to control the safety of deliveries of raw materials and transportation and disposal of wastes. Implement measures to avoid or control community exposure to pesticides (see also PS3).	**FC**	Waste management will be undertaken according to both national and international management and safety standards to ensure safe storage, handling, transportation and disposal. The ESHMP prescribes the specific measures that will need to be implemented to restore the biophysical and social environment in the Project area. All waste handling will be undertaken according to the required legal permits, which Mkango must acquire first. Tailings management will be in compliance with the GISTM. The waste management measures aim to protect workers and prevent contamination of the environment and also serve to prevent community exposure to hazardous substances and materials.
	Ecosystem Services: Identify those risks to and potential impacts on priority ecosystem services that may result in adverse health and safety risks to and impacts on Affected Communities or that may be exacerbated by climate change. Avoid adverse impacts, and if these impacts are unavoidable, implement mitigation measures.	**PC**	As part of the wetland study, an assessment of ecosystem services has been conducted. All the wetlands on site are regarded as ecologically important. Despite the degree of modification of these systems, they provide critical ecosystem services including toxicant assimilation, surface water recharge, and flood attenuation. In terms of the communities present, important services such as harvestable resources, cultivation, and water supply are provided.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
			Mitigation measures are set out in the ESHMP as the loss of ecosystem services is unavoidable. A Biodiversity Management Action Plan has also been recommended as part of the ESHMP.
	Environmental health and natural resource issues: Avoid or minimise the exacerbation of impacts caused by natural hazards that could arise from land use changes due to the project. Avoid or minimise the adverse impacts due to project activities on soil, water and natural resources in use by Affected Communities.	**FC**	Impacts on natural resources will be avoided as far as possible. Where unavoidable, mitigation measures have been prescribed in the ESHMP. All waste generated will be appropriately separated and stored prior to disposal, or recycled where possible to prevent land and water contamination. Ongoing rehabilitation as part of the ESHMP and closure plan has been set out, which includes the revegetation of disturbed areas, storm water management, backfilling and reprofiling of the landscape and monitoring of post-closure impacts.
	Community exposure to disease: Prevent or minimise the potential for community exposure to waterborne, water-based, water-related, vector-borne diseases and other communicable diseases that would result from project activities. Health impacts on potentially Affected Communities should be broadly considered and not just restricted to infectious diseases. Where specific diseases are endemic to communities, explore opportunities to improve environmental conditions that could help reduce their incidence. Prevent or minimise transmission of communicable diseases associated with the influx of temporary or permanent labour.	**FC**	It is not expected that waterborne or any other endemic diseases may result specifically from the project and its related activities. All waste generated will be appropriately separated and stored prior to disposal or recycled where possible to prevent land and water contamination. The potential for respiratory tract diseases has been identified, and mitigation measures to minimise these include managing the air quality by dust suppression, wearing masks, and conducting health check-ups as prescribed in the ESHMP. The influx of job seekers and economic opportunists as a result of the project has been identified as a risk. Furthermore, this influx has the potential to increase occurrence and spread of diseases. Mitigation in the ESHMP includes the implementation of human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) and substance abuse prevention campaigns within the construction and operational

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
			workforce, which can be expanded to the broader community at a later stage.
	Emergency preparedness and response: Assess the potential risks and impacts from project activities and inform the Affected Communities of significant potential hazards in a culturally appropriate manner. Assist and collaborate with the community and the local government in their preparations to respond effectively to emergency situations. Where the government lacks capacity, play an active role in preparing for and responding to emergencies associated with the project. Document the emergency preparedness and response activities, resources and responsibilities, and disclose appropriate information in the Action Plan or other relevant documentation to Affected Communities and government agencies.	**FC**	An Emergency Preparedness and Response Plan will be developed for the project. This mainly serves to address impacts related to incidents which have a risk of environmental contamination and in turn affect public health and safety. This plan will ensure that the relevant authorities and affected persons are engaged and that corrective measures are implemented timeously.
Security Personnel	Where direct or contracted workers are retained to provide security and safeguard personnel and property, the risks posed by the security arrangements to those within and outside the project site must be assessed. The principles of proportionality and good international practice must be applied in relation to hiring, rules of conduct, training, equipping, and monitoring of such workers, as well as any applicable laws.	**FC**	The ESHMP considers local procurement of security services. Training and capacity building is provided for in the ESHMP as part of the required Local Procurement Plan.
	When government security personnel provide security, the proponent will assess the risks, ensure that they act in accordance with the above, and encourage the relevant authorities to disclose the security arrangements to the public.	**NC**	

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
PS5: LAND ACQUISITION AND INVOLUNTARY RESETTLEMENT			
Objectives	Performance Standard 5 recognises that project-related land acquisition and restrictions on land use can have adverse impacts on communities and persons that use this land. The objectives of the Performance Standard are To avoid, and when avoidance is not possible, minimise displacement by exploring alternative project designs. To avoid forced eviction. To anticipate and avoid, or where avoidance is not possible, minimise adverse social and economic impacts from land acquisition or restrictions on land use by (i) providing compensation for loss of assets at replacement cost and (ii) ensuring that resettlement activities are implemented with appropriate disclosure of information, consultation, and the informed participation of those affected. To improve, or restore, the livelihoods and standards of living of displaced persons. To improve living conditions among physically displaced persons through the provision of adequate housing with security of tenure at resettlement sites. The components considered to achieve these objectives are further detailed below.		
General Requirements	Consider feasible alternative project designs to avoid or minimise physical or economic displacement.	**FC**	Project alternatives have been considered during the various feasibility phases of the project, in terms of the following: Site layout and infrastructure Mining method Tailings management The mandatory No-Go option has also been considered.
	Compensation and benefits for displaced persons: Offer displaced persons and communities compensation for loss of assets at full replacement cost and other assistance to help them improve or restore their livelihoods/standard of living. Ensure that standards for compensation are transparent and consistent within the project. Offer land-based compensation where livelihoods are land-based or land is collectively owned. Provide opportunities to derive appropriate development benefits from the project.	**FC**	All persons affected by physical or economic displacement as a result of the development will be compensated. The ESHMP prescribes measures to manage any displacement requirements, which include the development of a Resettlement Action Plan (RAP), Livelihood Restoration Plan (LRP), and Grave Relocation Process (GRP) in line with international best practice and Malawian legislation.
	Consultation: Disclose all information and then consult with and facilitate the informed participation of affected persons	**FC**	The RAP will include specific requirements for engagement with affected persons of the displacement. Consultation throughout the life of the project is also included in the ESHMP through continued

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	and communities, including host communities, in the resettlement decision-making processes. Continue consultation during the implementation, monitoring and evaluation of compensation payment and resettlement.		implementation of the grievance mechanism and stakeholder engagement plan. Stakeholder engagement has been undertaken as part of the ESHIA and in compliance with PS1.
	Grievance mechanism: Establish a grievance mechanism consistent with PS1 to receive and address concerns about compensation and relocation, including a recourse mechanism to resolve disputes in an impartial manner.	**FC**	A grievance mechanism is in place for the project, and the ESHMP includes the requirement to continuously implement the grievance mechanism for the facilitation of resolving concerns and grievances about the project's social and environmental performance. This mechanism will also allow for the addressing of grievances relating to the relocation process.
	Where resettlement is unavoidable, carry out a census with appropriate socio-economic baseline data to identify persons who will be displaced, determine who will be eligible for compensation and assistance, and discourage the inflow of people who are ineligible for these benefits. Establish a cut-off date for eligibility. Document and disseminate the cut-off date throughout the project area.	**FC**	The RAP will be developed to international best practice standards. This includes carrying out an asset census where the project activities will displace people and socio-economic infrastructure/land uses to determine who will be eligible for compensation and manage related influx during the implementation of the RAP.
Resettlement Planning and Implementation	Implementation: For Type 1 (acquisition of land rights through the exercise of eminent domain) and Type II (negotiated settlements) Transactions involving physical displacement of people, the client will develop an RAP or resettlement framework based on the social impact assessment that covers the PS requirements. The plan/framework will be designed to: Mitigate negative impacts of displacement. Identify development opportunities. Establish entitlements of all the categories of affected parties (also hosts, poor and vulnerable). The client should also document all transactions to acquire land rights, compensation measures and relocation activities, and establish procedures to monitor	**FC**	This ESHIA identifies physical and economic displacement as one of the consequences of the project development. The ESHMP has prescribed mitigation measures to manage and compensate for such displacement. The most important of this is the development of an RAP and LRP, in collaboration with the relevant stakeholders including regulators. This will serve to ensure that the displacement and compensation process is well managed and that opportunities are identified to improve the livelihoods of those affected. This RAP and LRP will be implemented accordingly.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	and evaluate the implementation of resettlement plans and corrective action.		
Displacement	Physical displacement: When people are to move to another location, the client will Offer choices among feasible options, including cash compensation or replacement housing. Provide relocation assistance suited to the needs of each group. Provide new resettlement sites that offer improved living conditions. Economic displacement: If land acquisition causes loss of income or livelihood (regardless of whether or not the affected people are physically displaced), the following requirements need to be met: Provide prompt compensation for loss of assets or access to assets at full replacement cost. Compensate business owners for cost of re-establishing commercial activities, for net loss income during the period of transition, and for the costs of transfer and reinstallation of the plant, machinery and equipment. Provide replacement property of equal or greater value, or cash compensation at full replacement cost to people with legal rights or claims to land under law. Compensate economically displaced people who are without legally recognisable claims to land for lost assets other than land at full replacement cost. Provide additional targeted assistance and opportunities to improve or at least restore income-earning capacity, production levels and standards of living to economically displaced persons who are adversely affected. Provide transitional support to economically displaced persons based on a reasonable estimate of time required to restore their income-earning capacity, production levels and standards of living.	**FC**	The initial assessment estimates approximately 500 structures that are expected to be physically displaced and will need to be relocated. The placement of infrastructure in the design phase has aimed to minimise relocation, and where possible, infrastructure was moved to avoid cultural heritage resources. Where the displacement cannot be minimised, the ESHMP has included the need for an RAP and GRP, which must include an LRP. The RAP will examine and determine the eligibility criteria and most appropriate compensation options (in kind/in cash) based on legal obligations, specifications of regulating authorities, and outcomes of consultation with affected persons.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
PS6: BIODIVERSITY CONSERVATION AND SUSTAINABLE MANAGEMENT OF LIVING NATURAL RESOURCES			
Objectives	Performance Standard 6 recognises that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development. The objectives of the Performance Standard are To protect and conserve biodiversity. To maintain the benefits from ecosystem services. To promote the sustainable management of living natural resources through the adoption of practices that integrate conservation needs and development priorities. The components considered to achieve these objectives are further detailed below.		
General	The risks and impacts identification process should consider direct and indirect project-related impacts on biodiversity[3] and ecosystem services,[4] and identify any significant residual impacts. As a matter of priority, the client should seek to avoid impacts on biodiversity and ecosystem services. When avoidance of impacts is not possible, measures to minimise impacts and restore biodiversity and ecosystem services should be implemented: Where natural habitats are applicable, the client will retain competent professionals to assist in conducting the risks and impacts identification process. Where critical habitats are applicable, the client should retain external experts with appropriate regional experience to assist in the development of a mitigation hierarchy that complies with this Performance Standard and to verify the implementation of those measures.	**FC**	The ESHIA identified and assessed all the project impacts on a range of aspects including biodiversity and their relation to socio-economic activities. Furthermore, the results of the impact assessment informed the ESHMP mitigation measures, which provide means to avoid and reduce the impacts identified. The ESHMP also emphasises continued stakeholder engagement throughout the life of the project.

[3] The requirements set out in this Performance Standard have been guided by the Convention on Biological Diversity, which defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems."

[4] Ecosystem services are the benefits that people, including businesses, derive from ecosystems. Ecosystem services are organised into four types: (i) provisioning services, which are the products people obtain from ecosystems; (ii) regulating services, which are the benefits people obtain from the regulation of ecosystem processes; (iii) cultural services, which are the non-material benefits people obtain from ecosystems; and (iv) supporting services, which are the natural processes that maintain the other services.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
Protection and Conservation of Biodiversity	Habitat is defined as a "terrestrial, freshwater or marine geographical unit or airway that supports assemblages of living organisms and their interactions with the non-living environment". For the purposes of implementation of this Performance Standard, habitats are divided into (i) modified, (ii) natural, and (iii) critical. Where modified habitats with significant biodiversity values are impacted, the client should minimise impacts and implement mitigation measures, as appropriate. The client shall not significantly convert or degrade natural habitats, unless no viable alternatives within the region exist on modified habitats, consultation has established the views of stakeholders, and the mitigation hierarchy is applied, which will be designed to achieve **no net loss of biodiversity** (where feasible), including the following appropriate actions: Avoiding impacts on biodiversity through the identification and protection of set-asides[5] Implementing measures to minimise habitat fragmentation, such as biological corridors Restoring habitats during operations and/or after operations Implementing biodiversity offsets	**PC**	Disturbance of natural habitat will be unavoidable to develop the project. Current land uses relating to agriculture have altered and degraded the natural habitat. The remaining habitat within the project area will be removed where infrastructure will be placed. Where possible, land disturbance will be avoided or minimised. The ESHMP includes measures to mitigate impacts such as applying wetland buffers, development of a Biodiversity Management Action Plan and an Alien Invasive Management Plan, and implementation of an offset strategy. The latter is considered only after appropriate avoidance, minimisation and restoration measures have been applied. Set-asides have not been identified for the project. A Critical Habitat Assessment would aid in the quantification of biodiversity loss and the required net gain to achieve a no net loss of biodiversity. Habitat fragmentation as a result of the increased vehicular movement, road crossings, contamination of freshwater resources, and deterioration to water quality may occur; however, these will be mitigated by the following: All areas of increased ecological sensitivity must be designated as no-go areas and be off limits to all unauthorised vehicles and personnel. No vehicles or heavy machinery may be allowed to drive indiscriminately within any wetland areas and their associated buffer areas. All vehicles must remain on demarcated roads and within the operational footprint.

[5] Set-asides are land areas within the project site, or areas over which the client has management control, that are excluded from development and are targeted for the implementation of conservation enhancement measures.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	In areas of critical habitat[6], the client will not implement any project activities unless all of the following are demonstrated: No other viable alternatives within the region exist for development of the project on modified or natural habitats that are not critical. The project does not lead to measurable adverse impacts on those biodiversity values for which the critical habitat was designated, and on the ecological processes supporting those biodiversity values. The project does not lead to a net reduction in the global and/or national/regional population of any Critically Endangered or Endangered species over a reasonable period of time. A robust, appropriately designed, and long-term biodiversity monitoring and evaluation programme is integrated into the client's management programme. The project's Mitigation Strategy should be described in a Biodiversity Action Plan and will be designed to achieve **net gains of biodiversity values** for which the critical habitat was designated. For the protection and conservation of biodiversity, the mitigation hierarchy includes biodiversity offsets[7], which may be considered only after appropriate avoidance, minimisation, and restoration measures have been applied.		A 100 m buffer or 1:100 flood line buffer must be demarcated from the edge of the non-directly impacted freshwater resources during the operational phase. A Critical Habitat Assessment, as part of the biodiversity study, was undertaken for the project, and the following areas were identified: Habitats supporting globally significant concentrations of migratory species and/or congregatory species in the Mpoto Lagoon and associated wetlands of the project area. Highly threatened and/or unique ecosystems in the hills in the project area, which are generally threatened through deforestation. Internationally and/or nationally recognised areas of high biodiversity value that in general will likely qualify as Critical Habitat, such as the Mpoto Lagoon and its immediate surrounding wetland which forms part of the Lake Chilwa Ramsar Site. A stand-alone Critical Habitat Assessment will be required to fully comply with the requirements of this standard.

[6] Critical habitats, which support high biodiversity value, are a subset of modified or natural habitats, including (i) habitats of significant importance to Critically Endangered and/or Endangered species; (ii) habitats of significant importance to endemic and/or restricted-range species; (iii) habitats supporting globally significant concentrations of migratory species and/or congregatory species; (iv) highly threatened and/or unique ecosystems; and/or (v) areas associated with key evolutionary processes.

[7] Biodiversity offsets are measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development and persisting after appropriate avoidance, minimisation and restoration measures have been taken.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	Legally Protected and Internationally Recognised Area: In circumstances where a proposed project is located within a legally protected area or an internationally recognised area, the client will treat the habitat as a natural and/or critical habitat, as applicable. Furthermore, the client will Demonstrate that the proposed development in such areas is legally permitted. Act in a manner consistent with any government-recognised management plans for such areas. Consult protected area sponsors and managers, Affected Communities, Indigenous Peoples, and other stakeholders on the proposed project, as appropriate. Implement additional programmes, as appropriate, to promote and enhance the conservation aims and effective management of the area.	**N/A**	The project area does <u>not have</u> any of the following: Biodiversity hotspots Key biodiversity areas Protected areas
	Invasive Alien Species: Intentional or accidental introduction of alien, or non-native, species of flora and fauna into areas where they are not normally found can be a significant threat to biodiversity, since some alien species can become invasive, spreading rapidly and out-competing native species. Therefore, The client will not intentionally introduce any new alien species (not currently established in the country or region of the project) unless this is carried out in accordance with the existing regulatory framework for such introduction. Where alien species are already established in the country or region of the proposed project, the client will exercise diligence in not spreading them into areas in which they have not already been established.	**FC**	During construction activities and associated vegetation clearing and soil disturbance, alien plant species are expected to become established and spread. An alien and invasive plant species management programme will be developed and implemented during the construction, operation and decommissioning phases to manage and curb any spread of these species. During rehabilitation, only indigenous species will be used for revegetation.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
Management of Ecosystem Services	Where a project is likely to adversely impact ecosystem services, as determined by the risks and impacts identification process, the client will conduct a systematic review to identify priority ecosystem services. Priority ecosystem services are defined as follows: Those services on which project operations are most likely to have an impact (Type I Ecosystem Services) and, therefore, which result in adverse impacts on Affected Communities. These impacts should be avoided or minimised, and mitigation measures should be implemented to maintain the value and functionality of these services. Those services on which the project is directly dependent for its operations (Type II Ecosystem Services). These impacts should be minimised and measures that increase the resource efficiency of their operations should be implemented.	**PC**	As part of the wetland study, an assessment of ecosystem services has been conducted. All the wetlands on site are regarded as ecologically important. Despite the degree of modification of these systems, they provide critical ecosystem services including toxicant assimilation, surface water recharge, and flood attenuation. In terms of the communities present, important services such as harvestable resources, cultivation, and water supply are provided. Mitigation measures are set out in the ESHMP as the loss of ecosystem services is unavoidable. A Biodiversity Management Action Plan has also been recommended as part of the ESHMP. A stand-alone Ecosystem Services Assessment has not been undertaken for the project.
Management and Use of Renewable Natural Resources	Clients who are engaged in the primary production of living natural resources, including natural and plantation forestry, agriculture, animal husbandry, aquaculture, and fisheries, will be required To locate land-based agribusiness and forestry projects on unforested land or land already converted. To manage living natural resources in a sustainable manner, through the application of industry-specific good management practices and available technologies. Where such primary production practices are codified in globally, regionally, or nationally recognised standards, the client will implement sustainable management practices to one or more relevant and credible standards as demonstrated by independent verification or certification.	**N/A**	There will not be any harvesting or plantation development involved.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
Supply Chain	Where a client is purchasing primary production (especially but not exclusively food and fibre commodities) that is known to be produced in regions where there is a risk of significant conversion of natural and/or critical habitats, systems and verification practices will be adopted as part of the client's ESMS to evaluate its primary suppliers.	**N/A**	There is no primary production of living natural resources likely to occur on site The project will not involve production and harvesting of fish populations or other aquatic species. It will, however, affect watercourse pathways, which will result in a reduction of flow to these aquatic ecosystems. Clean water will be diverted around the operation to avoid impacting baseflows of river systems in the area and water being received by the Mpoto Lagoon. There is a significant amount of fishing taking place in the project area, and it is assumed that the local communities may use traditional hunting and fishing areas for some level of subsistence. The development of the project is anticipated to affect existing fishing activities. The ESHMP considers mitigation measures which involve a Storm Water Management Plan (SWMP), ensuring the separation of clean and dirty water so as to minimise the impact on freshwater systems in the project area.
PS7: INDIGENOUS PEOPLES			
Objectives	Performance Standard 7 recognises that Indigenous Peoples, as social groups with identities that are distinct from mainstream groups in national societies, are often among the most marginalised and vulnerable segments of the population. The objectives of the Performance Standard are To ensure that the development process fosters full respect for the human rights, dignity, aspirations, culture, and natural resource-based livelihoods of Indigenous Peoples. To anticipate and avoid adverse impacts of projects on communities of Indigenous Peoples, or when avoidance is not possible, to minimise and/or compensate for such impacts. To promote sustainable development benefits and opportunities for Indigenous Peoples in a culturally appropriate manner. To establish and maintain an ongoing relationship based on Informed Consultation and Participation (ICP) with the Indigenous Peoples affected by a project throughout the project's life cycle. To ensure the Free, Prior, and Informed Consent (FPIC) of the Affected Communities of Indigenous Peoples when the circumstances described in this Performance Standard are present. To respect and preserve the culture, knowledge, and practices of Indigenous Peoples.		
Definition	"Indigenous Peoples" is used in a generic sense to refer to a distinct social and cultural group possessing the following characteristics in varying degrees:	**FC**	In terms of the IFC definition, no indigenous people are located within the project area as confirmed by the Social Impact Assessment.

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	Self-identification as members of a distinct indigenous cultural group and recognition of this identity by others Collective attachment to geographically distinct habitats or ancestral territories in the project area and to the natural resources in these habitats and territories Customary cultural, economic, social, or political institutions that are separate from those of the dominant society or culture An indigenous language, often different from the official language of the country or region Ascertaining whether a particular group is considered as Indigenous Peoples for the purpose of this Performance Standard may require technical judgment.		
PS8: CULTURAL HERITAGE			
Objectives	Performance Standard 8 recognises the importance of cultural heritage for current and future generations. The objectives of the Performance Standard are To protect cultural heritage from the adverse impacts of project activities and support its preservation. To promote the equitable sharing of benefits from the use of cultural heritage.		
Internationally Recognised Practices	Comply with national law and host country's obligations under the Convention Concerning the Protection of the World Cultural and Natural Heritage. Protect and support cultural heritage by undertaking internationally recognised practices for the protection, field-based study, and documentation of cultural heritage. Where necessary (see below), retain qualified and experienced experts to assist in any assessments.	**FC**	A Cultural Heritage study was undertaken in terms of the national Malawian legislation (Monuments and Relics Act, 1991) and IFC PS8. The study included a pre-disturbance survey of the project area to identify heritage resources within the wider project area. The ESHMP provides mitigation measures such as no-go buffer zones for the avoidance of cultural heritage resources. The destruction of unavoidable heritage resources will be undertaken according to UNESCO, IFC and Malawian legislation standards.
Chance Find Procedures	The project should be designed and sited to avoid significant damage to cultural heritage. If the proposed location is in areas where cultural heritage is expected to be found, either during construction or operations, a Chance Find Procedure (CFP) must be established as part of the ESHIA. Chance finds must not be disturbed until assessment by a competent specialist is	**NC**	The ESHMP provides for the development of a Conservation Management Plan (CMP) and CFP for potential heritage resources found during construction and operation in the case where they were not detected during the pre-disturbance survey. As part of their induction, construction personnel will be trained on these

Objectives	Requirements	Addressed in ESHIA	Comment on Compliance of this ESHIA
	made and actions consistent with the requirements of PS8 are identified.		procedures. These plans and procedures will be developed by an archaeologist or cultural heritage specialist.
Consultation	Where a project may affect cultural heritage, consult with affected communities who use, or have used within living memory, the cultural heritage for long-standing cultural purposes to identify cultural heritage of importance. Incorporate results of consultation into proponent's decision-making process. Ensure that the consultation involves the relevant national or local regulatory agencies entrusted with the protection of cultural heritage.	**FC**	As part of the heritage study's purpose, in-field consultations were undertaken with community members living in the project area and/or involved in local cultural practices. The ESHMP also presents continued consultation to be undertaken with affected persons as well as the relevant national Malawian authorities. The larger ESHIA stakeholder engagement process has highlighted heritage resources and ensured consultation with affected communities as part of the process.
Removal of Cultural Heritage	Preference is given to preserving cultural heritage in its place, since removal may result in irreparable damage or destruction. Cultural heritage will not be removed unless the following conditions are met: No technically or financially feasible alternatives exist. Overall benefits to the project outweigh the anticipated cultural heritage loss from removal. Removal is conducted by the best available technique.	**PC**	Where possible, cultural heritage will be preserved and left in situ. Infrastructure placement has been cognisant of the location of cultural heritage resources and has aimed to avoid these as far as possible. Should in-situ conservation not be feasible or desirable, a GRP in consultation with the affected communities and next of kin, and in compliance with the relevant Malawian national legislation, must be undertaken. A GRP has not yet been developed for the project. Where identified cultural heritage resources will be directly impacted, a feasibility assessment of the viability of a GRP and/ or compensation must be undertaken to preserve the resource. This must be undertaken with cognisance of Malawian national legislation as well as IFC standards. A CMP with a Community Access Protocol is required by the ESHMP to allow affected persons to access cultural heritage sites remaining in situ.

20.2 SURFACE WATER

Two field assessments were undertaken in the project area: in February 2018 during the wet season, and in September 2018 during the dry season. During the field assessments, the state of all rivers, streams, rivulets and springs was documented. In addition, instantaneous water levels and water velocity were taken using a measuring ruler and a current meter where possible. The data was analysed using standard statistical techniques, and the results are presented in this section.

20.2.1 Hydrological Units

Songwe Hill is located within the Lake Chilwa basin, in south-eastern Malawi. The Lake Chilwa basin is classified as Water Resource Area 2 (WRA 2) out of a total of 18 delineated WRAs in Malawi. In the project area, the main hydrological unit is the transboundary Sombani River. The river swells up to form Mpoto Lagoon 1.3 km north of the project area. Key inflowing rivers contributing approximately 70 % of the inflows into Lake Chilwa include Likangala, Naisi, Sombani, Lingoni, Thondwe, Namadzi and Phalombe from the Malawi part of the catchment, and the Sombani and Mnembo Rivers from the Mozambique part of the catchment.

The Sombani River at Phaloni Hills has an average daily discharge of 2.41 m^3/s, making it the largest inflowing river by discharge contribution into Lake Chilwa. During the wet season field assessment (2018), the measured instantaneous water level for the Sombani River at Phaloni Hills Station was 1.5 m. During the dry season field visits (2018), the instantaneous water level of the Sombani River at Phaloni Hills was estimated at 0.45 m. The Songwe-Phalombe area was receiving substantial amounts of rainfall during the field assessment period.

20.2.2 Water Quality

Surface water quality samples were collected at the streams within and around the project area. Surface water samples were collected in May 2013 at the lagoon, and samples were collected again in 2018 during the dry and wet seasons. Water quality data was benchmarked against the Malawi Maximum Permissible Levels (MPLs) for drinking water and the World Health Organisation (WHO) drinking water quality guidelines.

Elevated levels of fluoride were observed in the Mpoto Lagoon samples from 2013, as well as the samples from September 2018. Although these levels were above the WHO drinking water quality standard (1.5 mg/L), they were within the Malawi MPL for drinking water (6 mg/L). Fluoride in this area is generally high as this was observed in most monitoring boreholes around the project area and was attributed to the historical volcanic activity which released magmatic fluorine as hydrogen fluoride (HF) through volcanic degassing (Digby Wells Groundwater Report, 2018). Thus, elevated levels of fluoride in the surface water could be because of groundwater recharge into the streams.

Iron (Fe) was the only parameter exceeding the Malawi MPL for drinking water at the Mpoto Lagoon (2018 dry season); however, the Fe levels were within the Malawi MPL for drinking water during the wet season sampling (2013 and 2018). This was attributed to dilution as rainfall is prevalent during this period, as opposed to during the winter period where there is limited rainfall. Most of the parameters with set WHO/MPL standards were found to be within these two standards for all the surface water monitoring points.

Another sampling round was conducted in October 2021 to provide baseline water quality conditions for REEs in the surrounding natural water resources including Lake Chilwa, prior to the commencement of the project. Under natural conditions, REEs are only available in small amounts from groundwater sources and the atmosphere.

20.2.3 Flood Line Modelling

Flood lines on river sections were analysed to evaluate the risks associated with the potential flooding or inundation of infrastructure and for the protection of water resources. Songwe Hill comprises several drainage lines emanating from the top of the hill, runoff from these drainages flow towards the Mpoto Lagoon which forms part of the Sombani River. Based on the hydrological assessment, the drainages emanating from the hill have little or no potential for flooding since these are located at the catchment origin. However, the Sombani River and/or Mpoto Lagoon have the potential to flood during very high rainfall events.

The flood line results indicate that all the proposed mine infrastructure, as well as the communities adjacent to the proposed mine and the Mpoto Lagoon, is located outside the modelled 1:50-year and 1:100-year flood-prone zones.

20.3 GROUNDWATER

A groundwater assessment was conducted as part of the ESHIA process, and hydrogeological fieldwork has been conducted since March 2013. A total of 15 locations were visited, including 14 boreholes and a spring. Digby Wells updated the hydrocensus survey in November 2018 including visits to communal water supply boreholes, monitoring boreholes, springs, and hand dug wells. A total of 35 water sites were visited during the hydrocensus.

Groundwater is the main source of drinking water in the area surrounding the proposed mine. Water uses identified during the hydrocensus were the following:

- Domestic uses, livestock watering, and irrigation for the local communities (14 sites, 13 boreholes and a spring)
- Water supply for the mine (1 borehole)

The results show that groundwater contributes 51 % of the total flow of the Sombani River at Phaloni Hills. Aquifer tests were conducted by Mozagua Drilling Company (Pty). The aquifer transmissivity was found to range from 0.22 m²/d to 22.5 m²/d, and the sustainable yield ranges from 0.03 L/s to 3.29 L/s. The boreholes were drilled to depths between 18 mbgl and 75 mbgl. Only one borehole solely intersected the weathered aquifer; the other boreholes penetrated through the weathered aquifer into the deeper aquifer. Therefore, the aquifer properties presented are reflective of the cumulative properties of the shallow, weathered and deep aquifer.

20.3.1 Groundwater Occurrence

The streams from the Songwe Hill area contribute to the total flows of the Sombani River through groundwater contribution as baseflow and direct runoff. The daily data from the gauging station at Phaloni Hills was split into these two components (surface water and baseflow). The results show that groundwater contributes 51 % of the total flow.

20.3.2 Groundwater Levels

The following was concluded from previous studies:

- Measured groundwater levels collected during the hydrocensus survey in 2013 were considered insufficient to define the groundwater flow direction with confidence; thus, further studies took place in 2018.
- Groundwater levels in boreholes drilled in 2018 ranged from 2.1 mbgl to 27.1 mbgl.
- The groundwater level in one monitoring location in 2018 was measured to be 46.4 mbgl; this anomalous deep groundwater level is related to its high topographical location. This monitoring location had a higher topographical elevation resulting in deeper water levels (from surface).
- Groundwater levels in boreholes drilled in 2020 were all less than ~2 mbgl, indicative of high groundwater levels expected for the alluvial plain.

20.3.3 Water Quality

The baseline natural groundwater quality trends were assessed based on groundwater quality analysed in 2013 and 2018. A comparison of the groundwater has been made against the WHO Drinking Water Quality Guideline Limits (2017) and Malawi Bureau of Standards MPLs.

Fluoride is seen to be the most prevalent groundwater contaminant, exceeding the WHO standards for most of the groundwater monitoring points, although within the MBS MPLs. The excess of this constituent in the local groundwater is due to the volcanic nature of the rocks at the project site.

Groundwater quality assessments conducted during 2013 and 2018 are shown to be relatively consistent; therefore, the baseline conditions have not had major alterations over the years. This indicates that agricultural activities undertaken by the local communities do not significantly affect groundwater quality (with the potential exception of one location with the highest topography).

20.4 GEOCHEMISTRY

A waste classification study was carried out for the waste rock (Prime Resources, 2021) and tailings (SGS, 2022) materials. The study included all the major lithologies of waste rock selected from 125 boreholes. The report states that the principal lithologies that comprise the Songwe Hill complex are carbonatite, igneous rock that is predominantly of carbonate minerals (> 50 modal % – calcite, dolomite, ankerite, siderite and magnesite) along with lesser silicates, phosphate minerals, and oxides, fenite and breccia. The minerals identified as likely to exert a strong influence on the drainage chemistry of leachate arising from the waste rock are the following:

- Calcite and dolomite (carbonate, neutralising minerals in high abundance) – Ca, Mg
- Goethite and hematite (oxy-hydroxide iron minerals, known to adsorb metals and metalloid onto their reactive surfaces) – Fe
- Halite (salt, readily soluble, also responsible for releasing trace metals that are within solid solution in the lattice) – Cl, Na

- Apatite (phosphate mineral, weathering is responsible for long term phosphate leaching from rock, uranium is often hosted within apatite and trace concentrations may be liberated) – P, phosphate, U
- Fluorite (soluble, alkaline conditions with the presence of carbonates tend to limit the mobility of released fluorine in the environment) – Ca, F
- Silicate minerals (slower to weather than the more reactive minerals discussed above, impacts long term water chemistry)

The results of the waste rock analysis undertaken by Prime Resources (2021) were subsequently updated by SGS (2022). Six tailings residues, one barren liquid and one waste rock composite sample from the metallurgical test work were analysed. It is recommended that another campaign of tailings and waste rock analysis be undertaken during operations. This will provide an assessment of the actual tailings being produced during operations to account for any potential variability in the ore and processing.

The results of the SGS (2022) analysis have been summarised in the sections below.

20.4.1 Tailings

The six tailings streams characterised were

- Gangue leach neutralisation precipitate
- Causticisation residue
- Rare earth leach residue
- Combined hydrometallurgical purification residue
- Combined front-and back-end hydrometallurgical tails
- Flotation tails

The reactive minerals in the tailings were acid neutralising minerals, carbonates (1.5 % to 57 %), aluminosilicates (1.3 % to 17 %), and goethite (3.7 % to 4.1 %). The carbonate minerals were ankerite, brugnatellite, calcite, dolomite, and pyroaurite. The aluminosilicates were allanite, magnesium aluminium silicate, muscovite and palygorskite. These minerals contribute to the overall neutralisation potential (NP) of the tailings.

The tailings streams were acidic to alkaline (pH 4.4 to 13) in the short term. The acidic tailings streams were rare earth leach residue (pH 4.4) and combined hydrometallurgical purification residue (pH 4.9). Consistent with the mineralogy results, total sulphur in the tailings ranged from 0.14 % to 1.2 %. The sulphur occurred predominantly as sulphate (0.14 % to 1.0 %). Sulphide sulphur ranged from 0 to 0.2 %. The NAG pH ranged from pH 4.3 to 13. All the tailings streams will be non-acid forming (NAF) in the long term except for the rare earth leach residue and combined hydrometallurgical purification residue, which were inconclusive and classified as Uncertain.

The leachates from the tailings streams were highly alkaline (pH 9.1 to 13) except for the rare earth leach residue (pH 4.3) and combined hydrometallurgical purification residue (pH 4.7). The leachates are saline (total dissolved solids (TDS), 3,045 mg/L to 22,516 mg/L) except for the rare earth leach residue (TDS, 838 mg/L) and flotation tails (TDS, 230 mg/L). The potential parameters of concern in the tailings leachates were identified as alkalinity, arsenic (As), calcium (Ca), chloride (Cl), chromium (Cr), fluoride (F), sodium (Na), TDS, and zinc (Zn).

20.4.2 Waste Rock

One composite waste rock sample was characterised. The reactive minerals in the waste rock were acid neutralising minerals, carbonates (1.5 % to 44 %), aluminosilicates (2.4 % to 14 %), and goethite (4.1 %). The carbonate minerals were ankerite and calcite. The aluminosilicates were magnesium aluminium silicate, muscovite, microcline and palygorskite. These minerals contribute to the overall NP of the waste rock.

The waste rock was alkaline (pH 9.5) in the short term. Consistent with the mineralogy, total sulphur in the waste rock was 0.28 %, occurring as sulphates (0.16 %) and sulphides (0.12 %). The NAG pH was pH 9.3, indicating that the waste rock will be NAF in the long term.

The results confirm the 2021 Prime Resources (Pty) Ltd assessment that predicted that the Songwe Hill waste rock is NAF due to the low sulphur content (< 0.2 %, predominantly as sulphate) and high neutralisation potential from calcite, dolomite and aluminosilicate minerals based on assay data.

The leachate from the waste rock was alkaline (pH 9.3) and non-saline (TDS, 291 mg/L). The constituents of concern in the leachate included alkalinity, Cr and F.

The 2021 Prime Resources assessment indicated that the leachates from the waste rock are alkaline (pH, 8.6 to 9.3 for the 1:20 leachate, and pH 8.7 to 9.1 for the 1:4 leachate). The leachate constituents were found to be within the IFC Effluent Standard for Mining, the Malawi Bureau of Standards drinking water specification, the Australian and New Zealand Environment Conservation Council (ANZECC) drinking water for livestock (2000), New Zealand standard, Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000 water quality guidelines, and the United States Environmental Protection Agency (US EPA) maximum contaminant levels used to assess the leachate quality except for Cerium (Ce), La (Lanthanum) and Neodymium (Nd). These rare earth constituents were not analysed in this report but should also be considered potential constituents of concern from the waste rock.

20.4.3 Barren Liquid

The rare earth carbonate barren liquid was very saline (TDS, 35,799 mg/L). The high salinity was mainly from chloride (24,000 mg/L), calcium (5,400 mg/L), sodium (600 mg/L) and zinc (0.045 mg/L to 360 mg/L), all of which exceed the Malawian Water Quality Guidelines (MS 733:2005).

20.5 TERRESTRIAL BIODIVERSITY

20.5.1 Flora

A 2013 study revealed that the Songwe Hill area is rich in plant species diversity with 160 plant species identified within the surveyed area. During the most recent study, a total of 127 plant species were recorded. This included a complex mix of species on the plains (which are under cultivation) lying between Songwe Hill and Mpoto Lagoon.

Species distribution varies throughout the site with no noticeable species dominating the project area. The average percentage vegetation cover of individual species was recorded to provide guidance on the areas vulnerable to disturbance and those more resilient to anthropogenic change.

Only five species of trees which are protected by Malawian legislation were directly observed at selected sampling sites during the dry and wet season surveys. The species included *Pericopsis angolensis, Dalbergia melanoxylon, Pterocarpus angolensis, Cordyla africana,* and *Terminalia sericea.* Two species, namely *Dalbergia melanoxylon* and *Pterocarpus angolensis,* are classified on the International Union for Conservation of Nature (IUCN) Red List as Near Threatened (NT) and Vulnerable (VU), respectively.

A comparison of plant species richness at all sites showed that the Nanzazi River has the highest plant species diversity. Both terrestrial (grasslands, savannah woodland, cultivated fields and a mosaic of shrubs and grass) and aquatic habitats (rivers and open water of Mpoto Lagoon) are the key habitats within and around the project area. The proposed mining pit area is located in a grass patch within the savannah woodland on top of Songwe Hill.

20.5.2 Fauna

Fifteen species of mammals were recorded during the wet and dry season surveys. The results show that the highest number of specimens were encountered at the proposed open pit and the fewest at Changa hill. The proposed mining site is an area of the least disturbance and had good vegetation cover during the wet season compared to the Changa and Phindani hills. This is mainly due to extensive deforestation having taken place by local communities in the other hills. More species were recorded during the wet season compared to the dry season as a result of the increased ground cover and availability of food during the wet season.

Eleven mammal species were recorded during the wet season, with the highest number of specimens encountered at the proposed open pit and the lowest at Changa Hill. The mining site is an area of least disturbance and therefore provided good cover during the wet season. The results show that none of the mammal species recorded are listed under IUCN, and their conservation status is Least Concern (LC).

Only 16 species of birds were recorded in the transects that were conducted along the shoreline of Mpoto Lagoon in the wet season. Species were recorded mainly in the vegetation around the Lagoon and a few in flight above the Lagoon during the boat surveys. All species recorded were of Least Concern on the IUCN Red List. During the dry season, 46 bird species were recorded along the shoreline. Only the species *Ardeola idae* (Madagascar Pond Heron) was recorded as Endangered (EN) on the IUCN Red List. A martial eagle was observed during the PFS in 2013 and in 2018 and is a species of global concern which is listed as Vulnerable (VU) on the IUCN Red List.

None of the amphibian or reptile species recorded in the field is listed under IUCN and the Convention on International Trade in Endangered Species (CITES) as being endangered or requiring any special protection. The key sensitivities present in the project area inform the IFC biodiversity values and critical habitat assessment. No Critical biodiversity areas were identified or delineated in the project area. Lake Chilwa, the Chilwa Wetland Basin, and Mulanje Mountain Forest Reserve, are all located over 10 km away from the project.

20.6 WETLANDS AND AQUATIC BIODIVERSITY

A single wetland ecological field assessment took place during the wet season (February to March 2018). The wetlands associated with the project area are located within the Lake Chilwa catchment, with ephemeral streams and seasonal, temporary and permanent wetlands draining into the Mpoto Lagoon to the north of the project area. During the field study, it was observed that soils near the Lagoon supported hydrophytic plants whilst soils near the edge of the wetland were dry and supported terrestrial vegetation. Six hydro-geomorphic units, as well as several ephemeral drainage lines, which cover over 2,617 ha in total, were identified in the vicinity of the proposed project area. The valleys within the project area have been heavily impacted because of agricultural activities (cultivation and livestock).

Across the two seasons (wet and dry), a total of 485 individual fish belonging to four families (Cichlidae, Clariidae, Nothobranchiidae and Cyprinidae) and eight species were sampled from the aquatic habitats of the project area. The species include *Clarias gariepinus*, *Oreochromis shiranus, Enteromius paludinosus, Enteromius trimaculatus, Astatotilapia calliptera*, *Coptodon rendalli, Nothobranchius kirki* and *Enteromius kerstenii*. The most abundant species in number was the *O. shiranus.* Of these 21 fish species, 15 are classified as being of Least Concern (LC), five are classified as Not Evaluated (NE), while *Nothobranchius kirki* is regarded as Vulnerable (VU) under the IUCN Red list.

A total of 1,113 individual aquatic macro-invertebrates belonging to 38 families were sampled in the project area. Of these invertebrate families, only six contributed over 5 % each to the total collection and together comprised approximately 58 % of the whole sample. Generally, the family Chironomidae (non-biting common midges) was the most, Libellulidae (common skimmers) 12 % of the collected samples, Notonectidae (backswimmers) 10 % of the sample, Aeshnidae (dragonfly nymphs) approximately 8 %, Atyidae (freshwater shrimps) 7 % of the sample, and Dytiscidae (predaceous diving beetles) 6 % of the sample. One species, *Hirudino medicinalis*, a species of leech, is Near Threatened on the IUCN Red List.

20.7 SOILS AND LAND USE

A field survey to include a pedogenic description of representative soil profiles and horizons throughout the proposed mine footprint was carried out in September 2018. The main soil types present in the project area according to the Food and Agricultural Organisation's classification system include eutric fluvisols, eutric gleysols, eutric vertisols and leptosols. The sensitivity of the area to erosion is dependent on various factors such as land use, land cover, and climatic factors. Soils in the Mauze and Songwe Hills are more prone to erosion than the soils within the low-lying areas and wetlands. Anthropogenic activities in the area incite the erosion processes through cultivation on steep slopes, bush clearing, deforestation, and development.

The heavy metals in soil samples were analysed; however, none of the metals recorded was present in high proportions. All soil samples recorded heavy metal values of below the limit of detection, which is 0.01 ppm for As, indium (In), U, and tin (Sn).

The dominant land use units in the project area include community areas made up of houses and plantations, drainage lines and watercourses, grassland, rainfed cultivation, rocky outcrops and hills, woodlands and open water bodies, wetland areas used for rice cultivation, thin forest cover on the uplands and remnants of *Brachystegia* woodlands on the summit of the Mauze Hill.

20.8 RADIATION

A year-long campaign of passive radon monitoring and analysis of environmental media (groundwater, surface water, dust and soil samples) was completed. The aim was to establish the baseline site characteristics related to radionuclide exposure. The potential sources of radiation exposure associated with the project are the TSF, WRD, Type 2 material stockpile, open pit, RWD, processing plant and the topsoil stockpiles. The most significant pathways through which members of the public may be exposed to radiation from the project are defined as follows (International Atomic Energy Agency (IAEA), 2002):

- Atmospheric pathways: radiation exposure through inhalation of airborne gases (e.g., radon, thoron and its progeny) and airborne radioactive particulates associated with the inhalable particulates (PM_{10} and external gamma radiation (cloud shine)
- Atmospheric and associated terrestrial pathways: radiation exposure from ingestion of contaminated soil and foodstuff, as well as external radiation following the deposition of airborne particulates (total suspended particles (TSP) and ground shine (radiation from radioactive material deposited on the ground i.e. dust particulates))
- Aquatic pathways: radiation exposures through ingestion of contaminated surface water and groundwater, foods produced using contaminated irrigation water, fish, and other aquatic biota, food derived from animals drinking contaminated water, as well as external radiation (immersion)

20.8.1 Radiological Baseline

The contaminants of concern are those naturally occurring radionuclides associated with the uranium and thorium decay series. Radionuclides that pose a significant risk to human health are identified from their dose conversion factors and reported half-lives. The analysis results of the environmental media were used to calculate the activity concentrations in a wider spectrum of environmental media using internationally accepted transfer or accumulation factors found in the literature as site-specific factors were not available. The results of the radiological site characterisation baseline are provided in the following sections.

20.8.1.1 Airborne Radon Gas

The environmental radon concentration in the air around the project site was measured over a period of one year (2018-2019) in four campaigns of three months each. The potential radon inhalation dose observed at the monitoring points was calculated using the indoor and outdoor radon inhalation dose conversion factors (NNR, 2013; ICRP, 1996; IAEA, 2011; Eckermann et al., 1988). The results show that radon gas inhalation has the potential to make a significant contribution to the natural background radiation observed at the project site.

20.8.1.2 Surface Water

The potential contribution from external gamma radiation (ground shine and water immersion) was determined to be insignificantly small, with the main contributors being the direct ingestion of water and fish. The total effective dose calculated from all exposure routes at all surface water monitoring points is less than 55 µSv.year^{-1} for all age groups. The public dose limit is 1,000 µSv.year^{-1}.

The doses calculated from the surface water analysis data are relatively low and suggested that the surface water bodies are largely unaffected by naturally occurring radionuclides in the project area. The dose from fish consumption as a bioaccumulation factor from the water was also calculated and found to be relatively low. The total effective dose from all exposure routes at all surface water monitoring points is less than 160 µSv.year^{-1} for all age groups.

20.8.1.3 Groundwater

The doses calculated from the groundwater analysis are more significant than those calculated from the surface water, however, are still relatively low. The results from the groundwater samples result in water ingestion doses of less than 120 µSv.year^{-1} for all age groups. This suggests that the groundwater is largely unaffected by naturally occurring radionuclides at present.

20.8.1.4 Soil and Sediment

The radionuclide activity concentration in the soil can be transferred to crops through root uptake processes. This can then be transferred to animal pasture, implicating animals and animal products, which can then be ingested by humans.

The results of the analysis campaign showed that most of the soil samples result in external gamma radiation doses of less than 100 µSv.year^{-1}. The doses calculated from the soil analysis data resulted in significant doses, whether through external gamma radiation, direct ingestion or the transfer of radioactivity to crops and animal products. Sample SG12, in particular, located on top of the orebody, resulted in the most significant activity doses. The results illustrate the dominance of root and leafy vegetable ingestion and to a lesser extent fruit ingestion.

20.8.2 Public Radiation Protection

A Prospective Radiological Public Safety Assessment was developed as part of the ESHIA process. The purpose of the radiation protection programme is to assess and present safety assessment findings that are consistent with the IAEA Safety Standards, the IFC PSs, as well as the available Atomic Energy Regulations of 2012 promulgated by the AERA in terms of the Atomic Energy Act (2011) in general. The radiological safety assessment is undertaken to provide confidence to stakeholders that an operation, facility or activity does not pose a radiological risk to relevant exposure groups, notably workers or members of the public.

Consistent with the source analysis, the main environmental pathways of concern are the atmospheric, surface water and groundwater pathways. Based on the baseline socio-economic indicators and the biophysical environment surrounding the project, three general receptors were identified to determine their potential for radiation exposure.

The results showed that notwithstanding the close proximity of the receptor locations to the surface mining infrastructure, the total effective doses are still less than the dose limit for all age groups. The maximum contribution from the surface water samples calculated for a conservative set of conditions was less than 100 µSv.year^{-1}. The maximum contribution from the groundwater samples calculated for a conservative set of conditions was less than 155 µSv.year^{-1}. If either of these sources is added to the contribution of the atmospheric pathway, then the total dose is still in the order of 500 µSv.year^{-1}. For all potential receptors the contribution of the project during the operational period is less than the public dose limit of 1,000 µSv.year^{-1}.

20.9 CULTURAL HERITAGE

A cultural heritage assessment was undertaken as part of the ESHIA process in February 2019 in line with the national Malawian legislative framework and IFC PS 8: Cultural Heritage. A follow-up site visit by a cultural heritage specialist was undertaken in May 2021. The purpose of the in-field assessment was to identify previously unknown cultural heritage resources within the project area that may be impacted and undertake informal consultation with informants living in the project area and/or with involvement with local cultural practices.

During the pre-disturbance survey in 2019, the heritage team and a village headman recorded two cemeteries in proximity to the then project layout. Several additional cemeteries were discovered, and the location of these were ground-truthed by the heritage team in 2021. These were expected to be impacted by the changes in the project layout. The 12 cemeteries identified in and near the project site include the following:

- Nazazi Cemetery (BGG-001) – Chiefs and Group Village Heads
- Phindani Cemetery (BGG-022) – Village
- M'mwala Cemetery
- Chitsulo Family Cemetery
- Namalima Group Village Head/Chief Cemetery
- Mangazi Family Cemetery
- Namalima Village Cemetery
- Maloya Cemetery
- Maoni Royal Cemetery
- Maoni Cemetery
- Kathumba Royal Cemetery
- Muhowa Cemetery

Within the project area, 28 cultural heritage resources were identified. Occurrences or scatters of archaeological material representing the Iron Age and historical periods were the largest number of cultural heritage resources identified. One record of a natural feature associated with local oral traditions and two records of tangible material culture associated with intangible or living heritage practices by members of the local community were also found. Archaeological resources were open sites containing material not older than the Early Iron Age. The heritage resources with a High Cultural Significance included the 12 records of cemeteries, Site S13 ("The Road Junction"), which has ongoing cultural practices/living heritage, and Songwe Cave. Of Medium Cultural Significance were records of scattered large pot fragments and a historical iron-smelting site. The project design included avoidance of cemeteries; however, two cemeteries could not be avoided and will need to be relocated through the development of a grave relocation plan in consultation with key stakeholders.

20.10 SOCIAL AND COMMUNITY HEALTH

As part of the ESHIA, a socio-economic and health assessment was conducted and presents an overview of the conditions in the secondary study area (Phalombe District) and the primary study area (Nazombe and Kaduya Traditional Authorities (TAs)). Data on the secondary study area was obtained through desktop reviews, while data on the primary study area was obtained through a combination of desktop research, qualitative data collection, and a sample socio-economic survey.

The Phalombe District is located in the Southern Region of the Republic of Malawi, 81 km south of the commercial city of Blantyre, and is 1,323 km^2 in size. The project site is in TA Nazombe's jurisdiction, specifically Group Village Headmen (GVH) Maoni and Namalima.

The district is vulnerable to floods, particularly in areas of TAs Chiwalo, Nazombe, Nkhulambe, Paramount Mkhumba, Kaduya and Jenala, and 73 % of the total district population is at risk of flooding each year.

The district is also prone to prolonged dry spells which affect all the TAs in the district but very severely affect TAs Chiwalo, Nazombe and Jenala. Approximately 95 % of the total district population is at risk of periods of drought each year.

20.10.1 Socio-Economic Profile

The primary study area is largely inhabited by Malawians (98.4 %) with only 1.6 % Mozambicans. The dominant tribe is the Lhomwe tribe: 94.3 % are Lhomwe, 5.1 % are Chewa, with the Yao and Ngoni represented by 0.3 %. All the survey respondents indicated that they are Christians by religion.

The average number of structures owned by households is three. The most common structures were kitchens, pit latrines, sleeping houses and in a few cases a structure for business, like a shop/grocery store.

There is no secondary or tertiary (university or technical college) school in the immediate area of the project. As a result, only 7.6 % of the household members in surveyed households have completed secondary school education. Literacy in the area is low, with 26 % of the household members not able to read. This affects employment rates as nearly 90 % of the survey respondents did not have any employable skills. Building, driving and carpentry were the skills mentioned by 5 %, 2 % and 1.9 % of the respondents, respectively. The education infrastructures were recorded to be overwhelmed, with too many children compared to the number of teachers and classrooms.

The Phalombe District appears to have a large number of water access points, the majority (80 %) of the households in the project area has a sanitation facility, with 98 % using a pit latrine and 2 % having a flush toilet. The major source of water for domestic use is underground water through boreholes, and surface water is mainly used for irrigation of crops and livestock. Although the water is sourced mainly from boreholes, only 18 % treat it before drinking.

20.10.2 Health

Malaria was the most common disease as reported by 61 % of the respondents, followed by coughs (28 %) and diarrhoea (20 %). The project area is located close to Mpoto Lagoon, which is a habitat for mosquitoes.

The socio-economic profile also identifies cholera, HIV/AIDS, and pneumonia as some of the most common diseases in the district. However, just 7 % of the households reported experiencing pneumonia, and none reported cholera cases for the six months prior to the survey. The study has established that there is a high prevalence of respiratory tract diseases such as coughs, pneumonia, influenza and asthma in the project area.

The average walking time to access health facilities was estimated to be 86 min, with a median of 2 h, and 90 % of the respondents indicated that they were able to obtain medicines prescribed to them for free.

20.10.3 Socio-Economic Activities

Farming is reported as the main income earner by a majority of the households, seconded by fishing. Some households (26 %) reported that they depend on accessing credit. Maize is, as the country's staple food, grown by the majority of households. Other crops include millet, soya, tobacco and vegetables. Vegetables and soya are grown by the communities in the wetlands near Mpoto Lagoon. The wetlands provide for most of the year-round farming. For most households, farming is a supplementary source of food.

Most households have access to land. Only 2.9 % reported having no access to land. High percentages of households mentioned that they had access to improved seeds and fertilisers as a result of the government's programmes.

The Mpoto Lagoon ecosystem is still believed to support livelihoods for a significant number of people as 30 active fishermen were encountered in the area during respective field surveys. The majority of the fish caught from Mpoto Lagoon is consumed at a household level and/or sold directly at local markets. Some of the households (54 %) reported that they owned livestock and poultry and have the land for grazing. The livestock included cattle, goats and pigs, the poultry included chickens and guinea fowl.

20.10.4 Resettlement

The project implementation results in the requirement for physical and economic displacement of communities as well as relocation of cultural heritage resources and graves. Resettlement activities will follow IFC PS5 through the development of an RAP and concurrent stakeholder engagement through the establishment of a Resettlement Working Group composed of representatives of the impacted communities. In April 2022, a preliminary asset and socio-economic survey was undertaken of the project affected persons (PAPs) within the infrastructure areas and proposed exclusion zone.

20.10.4.1 Displacement Impacts and Resettlement Principles

Entitlements for compensation will be based on the eligibility criteria and the various categories of losses identified. Compensation will cover all the assets to be lost at replacement value and will replace any community infrastructure to maintain existing community services. Mkango will compensate the affected businesses, informal traders or enterprise for the cost of reestablishment at a new location. Mkango will seek to further mitigate the effects of the project activities on PAPs by designing and implementing an LRP to ensure that the standard of living of PAPs after compensation and displacement is replaced at least to the standard prior to relocation. The RAP will be conducted in compliance with IFC PS5.

20.10.4.2 Key Tasks for Resettlement Planning

The key tasks required in a resettlement and compensation process are described in this section. These are critical for undertaking successful resettlement and ensuring best practice in the production of an RAP. These include the following:

- **Screening** has been undertaken to provide an understanding of the extent of the resettlement as well as a preliminary analysis of the resettlement and to define the scope for the resettlement process.
- **Consultation** involved public participation through the ESHIA stakeholder engagement process. Engagement with the affected people and stakeholders will be continued throughout the resettlement process. This involves information exchange to build project awareness, capacity building and education of the PAPs, promotion of active participation of the community to discuss their concerns, and discussion and negotiation of options for compensation alternatives.
- **Household surveys** were undertaken in 2018 and more recently in April 2022. This included information on the socio-economic conditions of each PAP and was a preliminary census for a cut-off date, to provide a baseline assessment before the RAP document process is initiated. An asset inventory of all permanent or temporary structures likely to be lost due to the project was also recorded at this time.
- **Identification of host sites** involved identifying and selecting potential resettlement host sites and included consultation with the affected households. This coincides with the development of an LRP, land use planning, and access to natural resources and social infrastructure.
- **Entitlements and compensation** include identifying the households, individuals and communities deemed to be entitled to compensation. The nature of the entitlement varies between each individual and household. The criteria will need to be approved and agreed with all the stakeholders, and an agreement will also need to be reached on the values for compensation.
- **Resettlement planning, schedule, budget and responsibilities** will be provided in the RAP. The planning includes the overall strategy for the resettlement, the phases and means of compensation. A detailed schedule for physical resettlement and payment compensation will be prepared to align with the overall project phases. The management plan is used for planning, implementation, and monitoring of the overall resettlement process. The plan is released for public review, including affected households, local communities, and relevant authorities. It may be released in an abbreviated format that does not include information deemed to be sensitive to the project or the people being affected.

20.11 STAKEHOLDER ENGAGEMENT

Public consultation has been undertaken throughout the ESHIA process; however, Mkango has also taken opportunities to provide regular updates on the status of the project to the community throughout the pre-feasibility, feasibility and bankable feasibility studies.

Engagement was undertaken at the start of the ESHIA process to inform stakeholders of the proposed project and the specialist studies that would be undertaken to understand the biophysical and socio-economic environment. Thereafter, engagement with communities was undertaken prior to undertaking any field activities between 2018 and 2022. Once the draft ESHIA had been finalised, extensive stakeholder engagement was undertaken at a national, regional, district and local level in March and April 2022. The purpose was to provide an update on the project with details of the proposed activities, infrastructure requirements, schedule and status of the project. It served to present the potential environmental and socio-economic impacts and the proposed mitigation and management measures as well as the residual impacts with the implementation of the ESHMP. Meetings were held at a local, district and national level and included separate meetings with the following:

- District authorities
- Group village chiefs
- Traditional authorities
- Members of development committees
- Area executive committee
- Mothers and youth community-based organisations
- Mining action group
- Business community
- Religious leaders
- Phalombe business and religious leaders
- District NGOs and community-based organisations
- Phalombe District Council
- National NGOs

20.12 POTENTIAL ENVIRONMENTAL IMPACTS

The project activities and their potential environmental impacts were assessed based on their biophysical and socio-economic baselines. Potential impacts associated with the proposed activities were identified through a systematic process whereby the activities were assessed for all phases (construction, operation, decommissioning, and closure) of the project. The process identifies and evaluates the likely significance of potential impacts on key receptors and resources.

The project will result in various potential environmental and socio-economic impacts due to the nature of the proposed activities. The most significant potential impacts associated with the project include the following:

- Alteration of the physical and chemical properties of soil resources and loss of topsoil due to increased erodibility, which in turn reduces the land's agricultural potential.
- Alteration of the local natural hydrology as a result of stream diversions required for the establishment of infrastructure.

- Loss of natural habitat in terms of flora and fauna species, and consequently loss of general biodiversity as removal of vegetation and topsoil stripping occurs. This will cause erosion and sedimentation, changing the land use.
- Direct loss of wetlands as some infrastructure will be constructed directly on drainage lines and on the upper boundaries of the catchments.
- Groundwater drawdown as a result of abstraction of water from the wellfield at project start-up for the process plant, thereafter decreasing as water recycling targets are met.
- Potential groundwater and surface water contamination from interaction with the WRD and potential seepage from the TSF.
- Potential exposure to radioactive waste from the mining and processing of REE-bearing ore.
- Direct and indirect impact on cultural heritage resources and graves. A grave relocation process will need to be undertaken to gain access to the project area, resulting in a positive impact.
- Moderate visual impacts due to the establishment of infrastructure as the site changes from rural to industrial.
- Economic and physical displacement during the development of the project as well as disruption of movement patterns and potential influx into the area, leading to increased social ills and increased pressure on available social infrastructure.

In most cases, the negative impacts can be mitigated and will be discussed as part of the various management plans to be developed for the ESHIA. The mitigation measures proposed will reduce the severity of the project impacts on the biophysical and socio-economic environment to an acceptable level with continuous management of these risks. Most of the potential impacts are major to moderate high and some have been reduced to moderate or minor with the implementation of proposed mitigation measures. However, not all the potential negative impacts identified can be avoided.

Positive impacts from the project will include the continuation and expansion of community development programmes, employment opportunities, business and procurement opportunities, as well as royalties and taxes to the Malawian government. The potential positive impacts associated with the project are the following:

- Benefits to the community through job opportunities.
- Business opportunities through procurement and multiplier effects through purchase of supplies by the mine from local and national businesses.
- Establishment of a community development fund to assist with the expansion of community development programmes.
- Restoring the land to pre-mining conditions through the placement of topsoil and revegetation with indigenous species. This is possible through rehabilitation measures and monitoring.

20.13 CUMULATIVE IMPACTS

The development of a mine at Songwe Hill will trigger several other developments in the area, such as new access roads, transmission lines, and changes to the present land uses. There is also the potential for population influx putting pressure on the available land around the mine.

20.14 ENVIRONMENTAL MANAGEMENT AND RECOMMENDATIONS

Detailed environmental and social specialist studies have been undertaken for the ESHIA in compliance with the relevant Malawian Legislation, IFC and other best practice requirements.

20.14.1 Management of Impacts and Issues

An ESHMP was compiled for the project to manage and mitigate identified adverse environmental impacts. The ESHMP is also used to enhance the possible benefits that can result from the development of the project. Where potential negative impacts cannot be avoided, mitigation measures to reduce their significance were proposed along with the necessary environmental and social management and monitoring plans to be implemented.

All Mkango employees, contractors and their associated personnel have a responsibility to ensure that good environmental performance is upheld during the undertaking of their duties. Ultimately, the General Manager of the mine will be responsible for ensuring the implementation of the ESHMP, with specific personnel responsible for environmental and social performance management.

A monitoring plan has been suggested to provide assistance to Mkango to ensure that the mitigation and management measures outlined in the ESHIA are being met and are achieving their objectives. To verify the implementation of the ESHMP, regular ad-hoc site inspections and internal and formal audits should be undertaken. The key environmental aspects which form the monitoring programme are the following:

- Surface water (quality and quantity)
- Groundwater (quality and quantity)
- Air quality and dust
- Biodiversity
- Soils, land use, closure and rehabilitation
- Stockpile management
- Radiation
- Cultural heritage resources
- Waste

Stakeholder engagement was undertaken during the ESHIA process that supports an Informed Consultation and Participation (ICP) process that focuses on an in-depth exchange of views and information with affected communities.

A Rehabilitation and Closure Plan (RCP) was compiled as part of the ESHIA process. The RCP also complies with in-country legislation and World Bank criteria, namely the IFC Performance Standards and Equator Principles. It considered the following GIIP:

- Tailings Management, Good Practice Guide, International Council on Mining and Metals (ICMM, 2021)
- Integrated Mine Closure, Good Practice Guidelines 2nd Edition, International Council of Mining and Metal, 2019 (ICMM, 2019)

Auditing of the ESHMP is imperative to ensure that the activities are undertaken in accordance with the objectives and commitments which have been set out.

20.14.2 Environmental, Social and Health Management Plan

The key recommendations and mitigation measures associated with the potential impacts as a result of the proposed project activities are as follows:

- Ensure continuous monitoring as per the monitoring programme.
- Develop storm water management structures to ensure effective clean and dirty water separation.
- Once operations begin, analyse samples of tailings and waste rock material to update the radiation management programme.
- Undertake training and environmental awareness of mine personnel, contractors and surrounding communities.
- Manage soil erosion and eradication of alien invasive plants timeously.
- Implement buffers around wetlands and cultural heritage resources remaining in situ.
- Undertake concurrent rehabilitation throughout the LOO where possible and maintain topsoil stockpiles for final rehabilitation.
- Conduct a 100 % socio-economic survey of the impacted households in the project site to inform the RAP and LRP.
- Present the result of the ESHIA to stakeholders to obtain further comments and suggestions on the project.
- Maintain relationships with stakeholders and develop a community development strategy of priority development programmes and initiatives as well as recruitment and employment policies.
- Continue to implement the grievance mechanism and continuously update the Stakeholder Engagement Plan in line with the changing socio-economic environment.
- Report and record all monitoring data which should be utilised to identify areas of potential improvements. Periodic internal and external audits of the ESHMP should be undertaken and amendments should be made where necessary in consultation with government authorities.

20.15 WASTE MANAGEMENT

The proposed mining and related activities will result in the generation of mineralised waste (TSF and WRDs) as well as non-mineralised waste (general and hazardous waste), which will require effective waste management.

20.15.1 Tailings

Approximately 20 Mt of tailings will be produced over the LOO and stored in the TSF. The DFS design process was based on the GISTM. The TSF will be constructed in phases over the LOO.

The TSF management measures will consist of

- A 2,000 µm high-density polyethylene (HDPE) liner
- Decant water from the TSF will flow into an RWD with a capacity of 66,000 m^3, lined with a 2,000 µm thick HDPE liner to prevent water loss
- There will be a slurry distribution pipeline along the TSF perimeter, which will measure 4 km

20.15.1.1 Tailings Deposition and Operational Methodology

The proposed depositional methodology for the TSF is by conventional spigot/open-ended discharge behind a fully contained valley-type dam concept. This requires that each phase of the TSF embankment be built to its required height prior to commencing with that phase's associated deposition. Tailings should be deposited into the basin of the TSF by means of open-ended deposition. Prior to the tailings reaching the various toe drains, coarse tailings should be used to cover and further protect the drains. Open-ended deposition shall continue above the covered toe drains to the final elevation of each phase.

Supernatant slurry water and storm water collected on the TSF will be decanted by a floating turret arrangement and pumped back to the plant for reuse as process water. As the pond migrates up the valley, so too does the floating turret. The operational target limit for the pond volume is approximately 5 d of slurry water or a sufficient pond depth (~1.5 m deep) to enable operating and management of the turret.

In the absence of the test work results, the project decision to line the TSF with a single 2,000 µm HDPE liner was made in accordance with the GISTM.

20.15.1.2 TSF Embankment Construction

The TSF will be constructed from the waste rock made available from mining operations; therefore, the test work is relevant to the TSF design. The composite samples have insufficient sulphide present (below the limit of 0.3 %) to sustain long-term acid generation if oxidised. Material forming the embankment shall be compacted in layers to form durable embankments and fills of good, regular appearance with all cross sections having the minimum sizes detailed on drawings and having side slopes not steeper than specified. The sides of the embankments and fills must be compacted to hard durable faces.

20.15.1.3 Return Water Dam

Water from the settled tailings is siphoned off and pumped via return water pumps to the TSF RWD. The water in the RWD will be treated and pumped to the process plant for reuse. All drainage systems for the TSF will flow towards the RWD. Seepage water from the TSF will be collected in a sump and pumped to the RWD.

20.15.2 Waste Rock Dump

The area to the east of the TSF and northeast of the pit was identified as the preferred location for the WRD and Type 2 material stockpile. The material will be co-disposed on the same facility. The waste rock will be disposed of on the southern portion of the facility, with the Type 2 material on the northern portion. The Type 2 material will be placed up against the waste rock, and the interface marked and surveyed.

The WRD will cover a footprint (natural ground) of approximately 36 ha, with a final downstream height of 64 m. The storage capacity of the WRD is of 10.6 Mm^3 or 17.86 Mt of waste. The combined WRD and Type 2 material stockpile will be developed with 7.5 m lifts, 7.5 m wide benches, and intermediate slide slopes of 1V:1.5H.

The waste rock has been shown, from the laboratory testing conducted, to be non-acid generating, owing to the abundance of neutralising carbonate minerals and lack of sulphide minerals.

Geochemical recommendations for the disposal considerations of the Songwe Hill waste rock include the following:

- The anticipated runoff arising from the waste rock is not considered to be of high risk due to its lack of acidity and low concentrations of regulated contaminants; however, there is a potential for the waste rock to release elevated alkaline discharges (high pH) with minor concentrations of REEs. Protection of groundwater resources should be prioritised due to their extensive use in the region. An engineered basal liner of compacted in-situ soil or similar is recommended to restrict potential contamination of groundwater. Civil design work will be required once the geotechnical properties of the selected waste rock dump site(s) have been determined.
- Engineering measures may be necessary to control storm water runoff at the toe of the waste rock facility in catchment paddocks, to prevent uncontrolled runoff. Clean storm water diversion berms/channels will also be required to lead clean water away.
- Infiltration of rainwater and long residence times of rainwater interacting with waste rock should be avoided as the higher leaching ratio of rock to water leads to higher concentrations of potential contaminants (in particular, REEs). Therefore, pooling or ponding of water on top of the waste rock dumps should be limited (for example, waste rock dumps shaped to encourage rainwater runoff into the catchment paddocks below).
- If the intention is to release runoff from the waste rock dumps to the environment, then runoff from the waste rock dumps should first be contained and then be evaporated or analysed before release as part of the water monitoring measures to ensure that water runoff meets the regulatory water quality requirements.
- Should the waste rock be considered for use as acid-neutralising material off site, it is recommended that further kinetic leach testing take place to better understand the long-term contaminant-release profile of the material.

20.15.3 Type 2 Material Stockpile

The Type 2 material storage configuration is such that the ore can be reclaimed in the future for processing, should it be deemed feasible at the time. The Type 2 material stockpile will cover a natural ground footprint of approximately 14.7 ha, with a final downstream height of 75 m. The storage capacity of the Type 2 material stockpile is of 7.45 Mm^3 or 13.1 Mt of material.

Geochemical characterisation of the Type 2 material has shown that it is non-acid forming due to its low sulphur content (0.01%) and high acid neutralisation capacity (380 kg $CACO_3$/t).

20.15.4 General Waste

A 45 m^3/h containerised sewage treatment plant will be provided for the treatment and disposal of the sewage generated by the process plant as well as the mining operations. Sewage reticulation piping and manholes will facilitate the flow of sewage under gravity to a collection manhole located adjacent to the sewage treatment plant. The sewage will be pumped via a submersible pump into the containerised treatment plant. The design is based on a standard activated sludge system, where biochemical oxygen demand is broken down using air and bacteria that grow in this medium. This system provides optimised nitrification and an effluent quality to a standard that complies with the requirements of the National Water Policy for the release of treated effluent back into the environment, in accordance with the Water Resources Act (2013).

All waste generated will be appropriately separated and stored prior to disposal or recycled where possible to prevent land and water contamination. For hazardous waste, additional measures such as the use of drip trays and ensuring that storage areas are bunded will be employed as a precautionary measure to prevent pollution where hazardous waste is handled. A waste yard facility is proposed within the project site, located southwest of the TSF. Skips on site will be implemented and collected as and when required for the disposal of waste off site. Separation of waste will allow for the material to be recycled, reused or disposed of in the appropriate facilities.

20.15.5 Management Measures

An ESMP was created as part of the ESHIA process and provides a description of the mitigation and management options for the identified potential environmental and social impacts associated with the project. The management measures associated with waste disposal, including control of fuel, chemical and hazardous waste are as follows:

- All storage areas for fuels, paints, oils and other hazardous chemicals used at the construction camp and during construction activities should be appropriately bunded, and spill kits should be in place.
- Construction workers should be trained in the use of spill kits, to contain and immediately clean up any potential leakages or spills in timely clean-ups. Monitoring must take place at least for three months after the spill occurred to determine contamination, e.g. as a result of ore handling.
- Maintenance and refuelling of vehicles and machinery should only be undertaken at designated and appropriately designed areas and inspected regularly for leaks.
- Culverts, roads, conveyors, powerlines and river crossings must be maintained, cleared and monitored.
- An SWMP should already be implemented. This should consider all the wetlands and other watercourses adjacent and downstream of the new developments/infrastructure, which should divert storm water and wastewater away from the surface infrastructure and back into the natural watercourses to maintain catchment yield as far as possible. The SWMP should also convey contaminated water to silt traps to limit contamination of the soils and groundwater
- Topsoil and subsoil stockpiles should be monitored and vegetated (if possible) to ensure no runoff, erosion, sedimentation and loss of soil fertility. Stockpiles should be on hardened surfaces to prevent leaching of contaminants into the soil and groundwater.
- Care must be taken to ensure that contamination of the receiving environment as a result of mining activities is minimised as far as possible.
- Chemicals, such as paints and hydrocarbons, should be used in an environmentally safe manner with correct storage as per each chemical’s specific storage descriptions.

- The TSF should be correctly designed to contain all the material safely, and maintenance should be done to ensure tailings do not enter watercourses or downslope areas.
- Monitoring boreholes should be installed to ensure that chemicals and contamination are not making their way into the groundwater and surface water systems.
- Construction of fuel storage facilities as per design requirements (bund walls, storage capacity etc).
- Emergency response plans need to be in place in the event of an accidental spill of fuel or hydrocarbon resulting in environmental pollution.
- Correct PPE should be provided with training of correct use.

21 CAPITAL AND OPERATING COSTS

21.1 CAPITAL COSTS

The purpose of this CAPEX estimate is to provide costs to an accuracy of +15 % to −10 % that can be utilised for the economic analysis of the Songwe Hill Rare Earth Element Project.

21.1.1 Responsibilities

The project's CAPEX estimate breakdown with associated responsibilities consists of the following:

- Bara – Mining
- SENET – Process plant and on-site infrastructure and other supporting infrastructure
- Epoch – Tailings and mine waste management facility
- Mkango – Owner's pre-production costs and logistics
- Digby Wells – Environmental management: resettlement, rehabilitation and closure

21.1.2 Escalation

The capital costs were priced as of the third and fourth quarters (Q3 and Q4) of 2021. These costs were adjusted by 7.5 % to cater for the increase in prices between last year and April 2022, considering that it has been approximately one year since the original costs were received. Due to the worldwide political uncertainty, the increase was higher than expected; therefore, the specific adjustment was made.

21.1.3 Exclusions

The following were not included in this CAPEX estimate:

- Financing costs
- Taxes and duties
- Permits
- Currency fluctuations

21.1.4 Exchange Rates

The costs of the project are reported in the United States dollar. The exchange rates used are shown in Table 21.1.

Table 21.1: Exchange Rates

Currency Conversion	Currency Code	Amount
South African Rand to United States Dollar	ZAR/US$	15.00
British Pound (GBP) to United States Dollar	£/US$	0.7
Euro to United States Dollar	€/US$	0.8
South African Rand to Euro	ZAR/€	17.00
Canadian Dollar to United States Dollar	CAD/US$	1.2
Australian Dollar to United States Dollar	AUD/US$	1.25
Chinese Yuan to United States Dollar	CNY/US$	6.45
Malawian Kwacha to United States Dollar	MWK/US$	833

21.1.5 Scope of the Estimate

The initial CAPEX estimate consists of the direct and indirect costs, including Owner's costs and contingency costs, to be expended during the implementation phase, which shall extend from the approval by Mkango of the DFS and NI 43-101 report until the start of the commercial production.

The sustaining CAPEX estimate, which also consists of the direct and indirect costs and the Owner's costs and contingency costs, covers all the costs to be expended during the period starting at commercial production and extending until the end of the LOO.

The initial CAPEX prepared for the DFS and this report qualifies as a Class 2 estimate as per the Association for the Advancement of Cost Engineering (AACE) Recommended Practice 47R-11. The accuracy of the initial CAPEX estimate is assessed at +15 % to −10 %. The sustaining CAPEX does not qualify as a Class 2 estimate; the accuracy of the sustaining CAPEX is assessed at ± 30 %.

21.1.5.1 Summary of Total CAPEX

The total initial and sustaining CAPEX for the Songwe Hill Project was estimated to be **US$388,790,792**, which includes project execution, EPCM, contingency and sustaining capital costs. The initial capital and sustaining capital costs are summarised in Table 21.2.

Table 21.2: Total CAPEX Summary

Description	CAPEX (US$)	Contingency (US$)	Total CAPEX (US$)
Earthworks	7,470,560	1,120,584	8,591,144
Civil Works – Plant	17,336,477	2,600,471	19,936,948
Civil Works – Infrastructure	1,717,576	257,636	1,975,212
Infrastructure	2,993,326	299,333	3,292,658
Structural Steel	6,239,267	748,712	6,987,979
Plate Work	2,699,408	323,929	3,023,337
Tankage	4,509,659	541,159	5,050,818
Machinery and Equipment	51,550,103	5,155,010	56,705,113
Piping	5,776,188	866,428	6,642,616
Valves	1,763,011	264,452	2,027,463
Electricals	10,505,600	1,050,560	11,556,160
Instrumentation	5,178,489	776,773	5,955,263
Transport	4,389,373	658,406	5,047,778
E&I Installation	6,715,672	1,007,351	7,723,023
SMPP Installation	21,862,300	3,279,345	25,141,645
TOTAL DIRECT FIELD COSTS	**150,707,010**	**18,950,150**	**169,657,160**
Commissioning Spares	243,050	36,458	279,508
2-Year Operational Spares	2,633,275	394,991	3,028,266
Insurance and Critical Spares	2,020,419	303,063	2,323,482
Vendor Services	2,596,685	389,503	2,986,188
First Fills	558,554	83,783	642,337
TOTAL INDIRECT FIELD COSTS	**8,051,983**	**1,207,798**	**9,259,781**
TOTAL FIELD COST	**158,758,993**	**20,157,947**	**178,916,941**

Description	CAPEX (US$)	Contingency (US$)	Total CAPEX (US$)
Project Management (EPCM)	23,318,266	3,497,740	26,816,006
Insurances and Guarantees	3,175,180	0	3,175,180
TOTAL EPCM COSTS	**26,493,446**	**3,497,740**	**29,991,186**
TOTAL PROJECT COST	**185,252,439**	**23,655,687**	**208,908,127**
Mobile Plant and Equipment	4,087,295	613,094	4,700,389
Generator Plant	5,469,482	820,422	6,289,904
PV Solar Plant	21,327,663	3,031,646	24,359,308
Laboratory	0	0	0
Construction Camp	3,567,379	535,107	4,102,486
TSF Phase 1 and RWD	31,225,050	2,420,546	33,645,596
Mining Pre-Production	13,972,675	2,095,901	16,068,576
Other	12,460,340	623,017	13,083,357
TOTAL OTHER COST	**92,109,883**	**10,139,734**	**102,249,617**
TOTAL INITIAL COST	**277,362,322**	**33,795,421**	**311,157,744**
TSF Sustaining Capital – Phases 2 to 5	49,551,380	3,841,192	53,392,572
Mining Sustaining Capital	896,618	134,493	1,031,111
Closure Cost	15,616,797	961,460	16,578,257
Owners Cost	6,028,280	602,828	6,631,108
TOTAL SUSTAINING COST	**72,093,075**	**5,539,973**	**77,633,048**
TOTAL COST	**349,455,397**	**39,335,394**	**388,790,792**

21.1.5.2 Summary of Initial CAPEX

The total initial CAPEX for the Songwe Hill Project was estimated to be **US$311,157,744,** which includes project execution, EPCM and contingency costs. The initial CAPEX is summarised in Table 21.3.

Table 21.3: Initial CAPEX Summary Per Discipline

Description	CAPEX (US$)	Contingency (US$)	Total CAPEX (US$)
Earthworks	7,470,560	1,120,584	8,591,144
Civil Works – Plant	17,336,477	2,600,471	19,936,948
Civil Works – Infrastructure	1,717,576	257,636	1,975,212
Infrastructure	2,993,326	299,333	3,292,658
Structural Steel	6,239,267	748,712	6,987,979
Plate Work	2,699,408	323,929	3,023,337
Tankage	4,509,659	541,159	5,050,818
Machinery and Equipment	51,550,103	5,155,010	56,705,113
Piping	5,776,188	866,428	6,642,616
Valves	1,763,011	264,452	2,027,463

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Electricals	10,505,600	1,050,560	11,556,160
Instrumentation	5,178,489	776,773	5,955,263
Transport	4,389,373	658,406	5,047,778
E&I Installation	6,715,672	1,007,351	7,723,023
SMPP Installation	21,862,300	3,279,345	25,141,645
TOTAL DIRECT FIELD COSTS	150,707,010	18,950,150	169,657,160
Commissioning Spares	243,050	36,458	279,508
2-Year Operational Spares	2,633,275	394,991	3,028,266
Insurance and Critical Spares	2,020,419	303,063	2,323,482
Vendor Services	2,596,685	389,503	2,986,188
First Fills	558,554	83,783	642,337
TOTAL INDIRECT FIELD COSTS	**8,051,983**	**1,207,798**	**9,259,781**
TOTAL FIELD COST	**158,758,993**	**20,157,947**	**178,916,941**
Project Management (EPCM)	23,318,266	3,497,740	26,816,006
Insurances and Guarantees	3,175,180	0	3,175,180
TOTAL EPCM COSTS	**26,493,446**	**3,497,740**	**29,991,186**
TOTAL PROJECT COST	**185,252,439**	**23,655,687**	**208,908,127**
Mobile Plant and Equipment	4,087,295	613,094	4,700,389
Generator Plant	5,469,482	820,422	6,289,904
PV Solar Plant	21,327,663	3,031,646	24,359,308
Laboratory	0	0	0
Construction Camp	3,567,379	535,107	4,102,486
TSF Phase 1 and RWD	31,225,050	2,420,546	33,645,596
Mining Pre-Production	13,972,675	2,095,901	16,068,576
Other	12,460,340	623,017	13,083,357
TOTAL OTHER COST	**92,109,883**	**10,139,734**	**102,249,617**
TOTAL INITIAL COST	**277,362,322**	**33,795,421**	**311,157,744**

21.1.5.3 Summary of Sustaining CAPEX

The total sustaining CAPEX for the Songwe Hill Project was estimated to be **US$77,633,048,** which includes project execution, EPCM and contingency costs. The sustaining CAPEX is summarised in Table 21.4.

Table 21.4: Sustaining CAPEX Summary

Description	CAPEX	Contingency	Total CAPEX
	US$	US$	US$
TSF Sustaining Capital – Phases 2 to 5	49,551,380	3,841,192	53,392,572
Mining Sustaining Capital	896,618	134,493	1,031,111
Closure Cost	15,616,797	961,460	16,578,257
Owner's Cost	6,028,280	602,828	6,631,108
TOTAL SUSTAINING COST	**72,093,075**	**5,539,973**	**77,633,048**

21.1.6 Basis of Estimate, Assumptions and Exclusions

The CAPEX estimate for the Songwe Hill Project has been derived from information collated from the following technical design documents:

- LOO pit production schedule, including stockpiling operations
- LOO processing plan
- Mine haul road designs and layouts
- Mining equipment lists
- Process plant design criteria
- General layouts of the process plant and related infrastructure
- Waste facility and surface water management development schedule and operations
- Process flow diagrams
- Process plant equipment data sheets and lists
- Process plant piping and instrumentation diagrams (P&IDs)
- Process plant line, valve, and instrument lists
- Electrical single-line diagrams and motor lists
- Electrical reticulation routes
- Various discipline material take-offs (MTOs)
- Quotations from vendors on mechanical and/or process equipment
- Quotations from vendors on main construction contracts
- EPCM schedule
- In-house historical databases

The following assumptions were made in the preparation of this estimate:

- The LOO is 20 years.
- There will be a smooth transition between the various project implementation phases.
- Topography, Geotechnical and Materials:
    - A 2 m deep soil improvement was assumed below all the earthworks platforms.
    - All the required fill material was assumed to be available within a 2 km radius, from either necessary excavations or designated borrow pits.
    - No piling allowance has been included in the estimate.
    - For the intermediate and hard rock excavations, 20 % and 15 % of the bulk excavations volume was allowed for, respectively.

- Allowance was made for grading of the PV plants to a maximum gradient of 14 %. This was done to allow for the axial movement of the panels.
- The process water pond and events pond were considered to have double high-density polyethylene (HDPE) liner systems while the raw water pond was considered to have a single HDPE liner system. All the relevant geotextiles and installation of the systems were included.
- The ROM wall was included as a mechanically stabilised earth wall with a gabion face. It was assumed that the gabion rock for that wall face would be locally available, either from site or from commercial sources.
- Excavated material will be non-acid generating.
- No additional topographical studies were made available; therefore, the structural design was not modified.
- The structural design assumptions were not modified after reviewing the geotechnical report that became available after the initial assumptions had been made.

- Construction:

  - The various construction discipline work will be executed as an EPCM contract.
  - The project schedule for the process plant is estimated to have a duration of 30 months from project award. This excludes prior construction of the access roads and resettlement plan implementation.
  - There will be proper communication and cooperation by all the construction contractors.
  - There will be no shortage of skilled trades workers throughout the entire construction phase, including the early works phase. Hence, there is no provision for salary increases potentially necessary to attract skilled trades workers.
  - Labour considers the remoteness of the Songwe Hill Project, i.e. 60 h per week will be paid at regular time, the overtime hours per week will be paid at time and one half (× 1.5), and all public holiday overtime hours per week will be paid at double the base wage (× 2).
  - The construction contractors' facilities will be located within a maximum of 30 min walking distance from any working point for the whole duration of the Songwe Hill Project implementation.
  - The construction site will be accessible 24 h/d and 7 d/week with adequate safety supervision.
  - There will be no work disruption resulting from inadequate accommodation and/or catering services.
  - All unskilled and semi-skilled workers will be recruited locally, and no allowance for accommodation has been made.
  - At least 50 % of the skilled workers will be recruited locally, and no allowance for accommodation has been made.
  - All workers accommodated in the construction camp will be provided with three meals per day.
  - All other workers will be provided with daily lunch while on site.
  - The construction contracts will be of the unit-rate type, cost-plus type, or lump-sum/turnkey type; the estimate does not allow for construction contracts of the time-and-material type.

- All the contractors will provide their own administration offices for the full duration of the construction phase.
- Power from the Escom grid will be made available at least three months before the start of commissioning, and the use of temporary fuel-powered generators will not be required.
- There will be no rework to field-erected and installed equipment and material, resulting from a quality assurance/quality control (QA/QC) inspection.

- Design and Measurement:
  - The mine open-pit access consists of only one ramp.
  - Transfer of tailings to the waste facility will be via piping, and transfer of waste from the open pits will be via haul trucks.
  - Piping was measured from the P&IDs and plant layout drawings
  - Instruments were measured from the P&IDs.
- The fuel cost is US$1.2/L.
- The peak power cost is US$0.1827/kWh (from Escom).
- Transportation of people will be via commercial airlines, i.e. no chartered flights.

The following are excluded from this estimate:

- Taxes and duties (they form part of the financial model)
- Risk provision, including costs pertaining to mitigation plans
- Escalation beyond the April 2022 base date
- Work stoppage resulting from labour disputes
- Work stoppage resulting from community relations disputes
- Any and all scope changes
- Any and all costs beyond commissioning completion
- Delays resulting from the following:
  - Permitting issues
  - Certificate issues
  - Project financing
  - Project approval
  - Agreements with claims owners

21.1.7 Mining Capital Costs

21.1.7.1 Estimating Methodology

The cost estimation for the Songwe Hill Project is based on designs, costs and information as of November 2021. All monetary values are presented in United States dollars (USD) and in real money terms, free of escalation or inflation.

The capital cost estimate has been determined through the application of enquiry quotations, budget quotations, database costs and estimated costs to bills of quantities, material take-offs and estimate quantities. Most of the capital costs are related to the mine design and mine plan, the quantities of which were computationally modelled and scheduled in three-dimensional space. Other costs relate to specific engineering designs, for which drawings have been produced and quantities have been generated from these drawings. This strategy is applicable for a feasibility study.

Some of the budget prices were obtained in South African rands (ZAR). These were converted to USD at an exchange rate of 1 USD = 15 ZAR.

21.1.7.2 Estimate Exclusions

The cost estimate does not make provision for any environmental or closure costs related to the infrastructure or mine plan. No provisions have been allowed for escalation of any costs.

21.1.7.3 Mining Capital Cost Breakdown

Capital cost has been defined as the cost of all infrastructure and constructions for the mining operation within the mine site. Capital costs are all the costs incurred from project initiation to the commencement of ore mining.

21.1.7.3.1 Infrastructure Capital Costs

Table 21.5 is a summary of the mining infrastructure capital costs.

Table 21.5: Mining Infrastructure Capital Costs

WBS	Mining Operations Infrastructure	Capital Cost (US$)	Comment
1.1	Contractors	2,780,395	Includes transportation contractor costs and monthly P&G costs for the established plant infrastructure contractors.
1.2	Site Preparation	241,851	Costs for the terracing for the Mining Contractor's infrastructure area.
1.3	Prefabricated Buildings and Furniture	377,212	Costs for the various prefabricated mining-related buildings and furnishings.
1.4	Local Reticulation and Civil Works	427,000	Cost for power, water and waste water reticulation within the mining infrastructure area.
1.5	Workshop	572,840	Cost for the structural steel building with its civil works and 10 t overhead crane.
1.6	Wash bay	90,457	Cost for a wash bay with its ancillary items including tanks, oil skimmer, bio reactor and pumps.
1.7	Lubrication System	-	Included in Mining Contractor's supply.
1.8	Parking	9,442	Parking with shade netting for light duty vehicles (LDVs).
1.9	Control Room	14,532	A container unit.
1.10	Brake Test Ramp	9,616	–
1.11	Emulsion Silo	7,307	Provision for civil works and fencing. Silo to be provided by Mining Contractor.
1.12	Control and Instrumentation, IT	233,333	Provision for server and computer equipment.
1.13	Explosives Bunker	61,583	Two fenced bunkers.

WBS	Mining Operations Infrastructure	Capital Cost (US$)	Comment
1.14	Surface Vehicles	–	Included in Mining Contractor's supply.
1.15	Pit Dewatering	400,840	Dewatering from the pit into a tank located at the primary crusher.
1.16	Roads and Waste Dump	3,922,562	Truck haul roads from the mining pit to the waste dump, ROM tip, mining infrastructure area and explosives bunker. Construction of the waste dump and low-grade stockpile foundations and ancillary works.
	Total Cost	**9,148,970**	

21.1.7.3.2 Direct Mining Capital Costs

Table 21.6 summarises the direct mining capital costs. This cost is made up of the Mining Contractor's costs prior to the commencement of ore mining as well as the Owner's team costs relating to the mining operation during this period.

Table 21.6: Summary of Direct Mining Capital Costs

WBS	Area	Capital Cost (US$)	Comment
1.1	Mining Contractor		
1.1.1	Site Establishment	979,110	Contractor site establishment
1.1.2	Site Disestablishment	896,618	Contractor disestablishment at end of contract
1.1.3	Time-Related Costs	481,775	Contractor monthly fees
1.1.4	Clear and Grub	803,600	Clear and grub pit area
1.1.5	Waste Mining		
1.1.5.1	Waste Drill and Blast	317,046	Pre-strip
1.1.5.2	Waste Haul	731,553	Pre-strip
1.17	Owner's Cost		
1.17	Manpower	307,000	Owner's team cost prior to ore mining
1.17	Consumables	60,000	Owner's team cost prior to ore mining
	Total Mining Capital Cost	**4,576,702**	

21.1.7.3.3 Indirect Capital Costs

Engineering procurement and construction management costs were provided for by allowing for 12.5 % of the surface infrastructure capital cost.

A contingency of 15 % was provided for all the capital costs. The indirect capital costs are summarised in Table 21.7.

Table 21.7: Summary of Indirect Capital Costs

Area	Costs (US$)
EPCM	1,143,621
Contingency	2,230,394
Total	**3,374,015**

21.1.7.4 Capital Cost Summary

The total capital cost related to mining and the mine support infrastructure is given in Table 21.8.

Table 21.8: Capital Cost Summary

Item	Cost (US$)
Mining Capital Cost	
Site establishment	979,110
Site disestablishment	896,618
Time-related costs	481,775
Clear and grub	803,600
Waste drill and blast	317,046
Waste haul	731,553
Owner’s cost:	
Manpower	307,000
Consumables	60,000
Infrastructure Development	
Terraces	2,152,957
Civil works	1,175,946
Prefabricated buildings	391,744
Services	516,333
Workshops	521,960
Emulsion silo	5,045
Explosives storage	61,583
Surface mining roads	300,787
Pit dewatering infrastructure	400,840
Waste dump footprint and waterways	3,621,775
EPCM	1,143,621
Contingency	2,230,394
Total Capital Cost	**17,099,687**

21.1.7.5 Capital Cost Cash Flow

The capital cost was scheduled according to the implementation schedule. Figure 21.1 shows the monthly capital cost scheduled over time, where the blue bars indicate the monthly spend, and the orange bars indicate the cumulative cost.

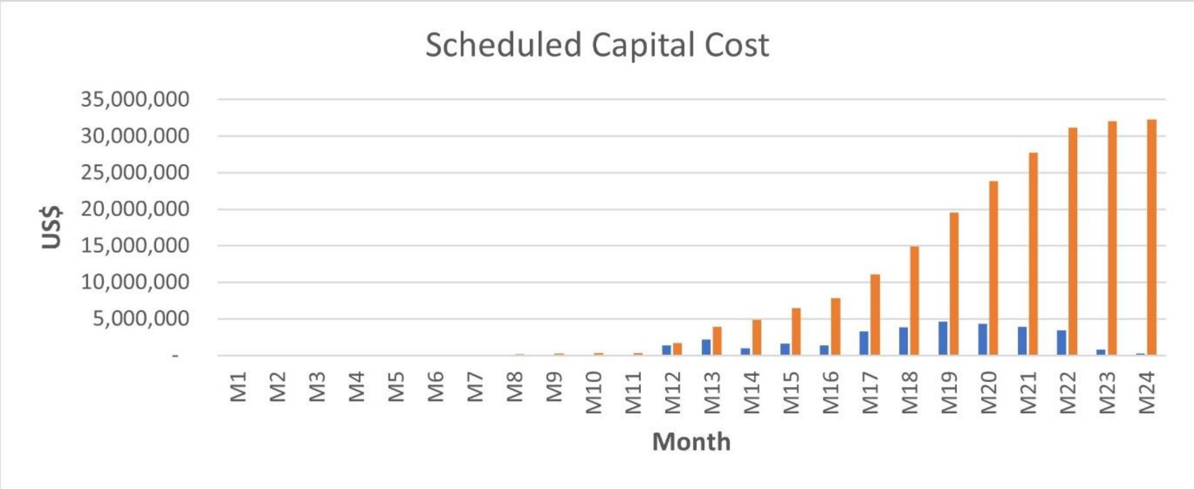

Figure 21.1: Scheduled Capital Cost

21.1.8 Process Plant and Infrastructure Capital Costs

The process plant and infrastructure capital costs are summarised in Table 21.9.

Table 21.9: Process Plant and Infrastructure CAPEX Summary

Description	CAPEX (US$)	Contingency (US$)	Total CAPEX (US$)
Earthworks	7,470,560	1,120,584	8,591,144
Civil Works – Plant	17,336,477	2,600,471	19,936,948
Civil Works – Infrastructure	1,717,576	257,636	1,975,212
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Valves	1,763,011	264,452	2,027,463
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Instrumentation	5,178,489	776,773	5,955,263
Transport	4,389,373	658,406	5,047,778
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TOTAL FIELD COST	**158,758,993**	**20,157,947**	**178,916,941**
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TOTAL EPCM COSTS	**26,493,446**	**3,497,740**	**29,991,186**
TOTAL PROJECT COST	**185,252,439**	**23,655,687**	**208,908,127**

As per the CAPEX summary above, the process plant and related infrastructure are subdivided into various CAPEX categories:

- Main contracts, e.g. earthworks, civil works, SMPP and E&I
- Supply-only contracts, e.g. structural steel, plate work, machinery and equipment, piping, valves, instrumentation, and electrical equipment that will be procured by the EPCM Contractor on behalf of Mkango and free-issued to the respective main contractors for erection/installation
- Supply and install contracts, e.g. prefabricated buildings and assay laboratory

21.1.9 Main Contracts

Main contracts mean contractors performing work on site and include the following:

- Earthworks contract
- Civil works contract
- SMPP works contract
- E&I works contract

All of the main contractors will be responsible for their own supply of construction power as the Escom grid main power switchyard will only be commissioned during the process plant commissioning phase.

21.1.9.1 Earthworks Contract

The main contract scope for the earthworks contract was derived from the calculated BOQ. The quantities, in turn, were derived from earthworks terrace drawings and accompanying long sections. It should be noted that the geotechnical report was not available at the time of making the design assumptions. All the assumptions were however reviewed against the recommendations made in the report once it became available, and no changes were made because of the geotechnical report results.

The earthworks enquiry was issued to suitable contractors in Malawi, surrounding countries, and South Africa, and included the P&G costs and contractual conditions against which tenderers quoted. Fully inclusive wet rates and plant/labour histograms were received from the respective tenderers, and these were compared and adjudicated accordingly.

The earthworks quantities are summarised in Table 21.10.

Table 21.10: Earthworks Quantities

Earthworks	Unit	Quantity
Area 1: Plant Platforms		
Clearing and Stripping of Site	ha	7
Removal of Soil and Excavations	m^3	268,906
Fill and Soil Improvements	m^3	162,303
Area 2: Crushing, Milling and Conveyor Lines		
Clearing and Stripping of Site	ha	1
Removal of Soil and Excavations	m^3	14,688
Fill and Soil Improvements	m^3	39,214
Mechanically Stabilised Earth Wall	m^2	975
Area 3: PV Plants		
Clearing and Stripping of Site	ha	43
Removal of Soil and Excavations	m^3	99,747
Fill and Soil Improvements	m^3	5,397
Road Sub-base	m^3	1,943
Area 4: Ponds, Storm Water Structures and Perimeter Fencing		
Clearing and Stripping of Site	ha	5
Removal of Soil and Excavations	m^3	32,980
Fill and Soil Improvements	m^3	10,653
Area 5: Construction Camp, Fuel Depot and Roadways		
Clearing and Stripping of Site	ha	4
Removal of Soil and Excavations	m^3	56,777
Fill and Soil Improvements	m^3	52,527
Road Sub-base	m^3	3,676

21.1.9.2 Civil Works Contract

The main contract scope for the process plant and peripheral infrastructure civil works was based on a detailed BOQ derived from civil outline drawings, mechanical general arrangement drawings, and the site block plan.

The scope of work for the process plant on- and off-site infrastructure civil works includes the following:

- Reinforced concrete foundations for the support of mechanical equipment, structural steelwork, and plate work
- Reinforced concrete surface beds and bund walls with trenches and sumps to contain spillages within the terraced areas
- Site storm water drainage including a network of concrete lined v-drains
- Reinforced concrete foundations and surface beds for the following:
  - Infrastructure prefabricated buildings
  - Infrastructure pre-engineered steel buildings (workshops and warehouses)
  - Wastewater treatment plant (WWTP)
  - Water pumping stations

- Containerised potable water treatment plant
- Diesel fuel farm
- Backup generators
- Escom switchyard
- Water storage tanks
- Construction camp

- Reinforced concrete foundations for the containerised MCCs and other process electrical infrastructure
- Brickwork for transformer bay buildings
- Sewerage reticulation for the process plant

All the civil materials of construction are included in the Civil Contractor's scope of supply (cement, reinforcement, formworks, mesh, hold-down bolts, bricks, etc.).

The civil works enquiry was issued to suitable contractors based in Malawi, surrounding countries, and South Africa, and included the P&G costs and contractual conditions against which tenderers quoted. Fully inclusive wet rates and plant/labour histograms were received from the respective tenderers, and these were compared and adjudicated accordingly.

The civil works quantities are summarised in Table 21.11.

Table 21.11: Civil Works Quantities

Civil Works	Unit	Quantity
Process Plant and On-Site Infrastructure Civil Works		
Excavation for Restricted Foundations	m^3	18,235
Import and Compact Backfill	m^3	6,021
30 MPa Concrete Structures	m^3	17,584
15 MPa Concrete and Blinding Layers	m^3	580
Reinforcement Steel	t	1,342
Mesh	m^2	22,350
Fencing	m	4,525
Peripheral (MIA) and Off-Site Infrastructure Civil Works		
Excavation for Restricted Foundations	m^3	4,315
Import and Compact Backfill	m^3	800
30 MPa Concrete Structures	m^3	2,838
15 MPa Concrete and Blinding Layers	m^3	96
Reinforcement Steel	t	160
Mesh	m^2	4,016
Number of holes to be drilled (with a diameter of 350 mm and depth of 1,600 mm) for the installation of steel profiles and to be backfilled with concrete		2,200
Number of steel profiles to be rammed to a depth of 1,500 mm		6,931
Fencing	m	13,685

21.1.9.3 SMPP Works Contract

The process plant and peripheral infrastructure SMPP works main contract scope was based on a detailed BOQ derived from general arrangement drawings, P&IDs, and details of the free-issue mechanical equipment.

The SMPP works enquiry was issued to suitable contractors currently based in South Africa and familiar with performing work in Africa. The enquiry included detailed P&G cost lists and contractual conditions against which the tenderers quoted. Fully inclusive rates and plant/labour histograms were received from the respective tenderers, and these were compared and adjudicated accordingly. Mkango will provide accommodation for the expatriate workforce. This will include three meals and laundry services. It must be noted that only a limited number of beds are available and will be allocated proportionally to all the construction contractors. No accommodation will be provided to local employees.

21.1.9.4 E&I Works Contract

The process plant and peripheral infrastructure E&I works main contract scope was based on a detailed BOQ derived from the process plant and infrastructure layout drawings, process plant general arrangement drawings, electrical single-line diagrams, mechanical equipment list, and motor list.

The E&I works enquiry was issued to suitable contractors familiar with construction projects in African countries and to SENET. SENET has its own team that performs site E&I construction work, referred to as SENET's self-build option. The enquiry included P&G cost lists and contractual conditions against which the tenderers quoted. Fully inclusive rates and plant/labour histograms were received from the respective tenderers, and these were compared and adjudicated accordingly. Mkango will provide accommodation for the expatriate workforce. This will include three meals and laundry services. It must be noted that only a limited number of beds are available and will be allocated proportionally to all the construction contractors. No accommodation will be provided to local employees.

The electrical supply reticulation to the respective infrastructure buildings is included in the electrical, control and instrumentation (E, C&I) contract.

21.1.10 Supply-Only Contracts

21.1.10.1 Mechanical Equipment

The mechanical equipment quantities were derived from the equipment lists and process flowsheets and datasheets. The mechanical scope of work for the project is to supply the equipment as detailed in the mechanical equipment list, mechanical data sheets, and mechanical drawings.

Enquiries were prepared, inclusive of equipment data sheets, and sent to equipment vendors/suppliers pre-approved by Mkango. The quotations received were commercially and technically adjudicated.

21.1.10.2 Structural Steel

Quantities were established based on MTOs derived from plant general arrangement drawings produced during the DFS. Unit rates for supply and fabrication were obtained from fabricators and were applied to the MTOs.

The respective rates were applied to the bill of materials for the following equipment:

- Structural steelwork
- Plate work
- Liners
- Grating and flooring
- Handrailing
- Sheeting

Steelwork quantities are given in Table 21.12.

Table 21.12: Process Plant Steelwork Quantities

SMPP Works	Material Grade	Unit	Quantity
Steelwork Structures – Light	S355JR	t	908.07
Steelwork Structures – Medium	S355JR	t	367.15
Steelwork Structures – Heavy	S355JR	t	144.18
Plate Work	S300JR	t	327.88
Take-Up Counterweight	S300JR	t	20.78
Liners	VRN500	t	233.25
Grizzly	VRN500	t	15.53
Liners	Rubber	m^2	400.53
Handrailing	MS	m	5,431.84
Grating	MS	m^2	4,053.54
Number of Stair Treads	MS		1,517.73
Guards	Clearview	m^2	386.30
Guards	VEM6318F	m^2	423.01
Cladding – Roof	MS	m^2	2,185.67
Cladding – Conveyor	MS	m^2	1,387.01
Cladding – Conveyor (2.68m long dog house sheets)	MS	m	780.47
Cladding – Side	MS	m^2	4,159.50
Structural Bolts	GR8.8	t	41.80
Anchor Bolts	GR4.6	t	14.15

21.1.10.3 Plate Work

The plate work scope of work entails shop detailing, supply, manufacturing, inspection, and corrosion protection of plate work in the form of tanks as per the tank schedule. The unit rates for supply and fabrication were obtained from fabricators and were applied to the tank schedule to estimate the plate work cost.

The tank schedules (carbon steel, stainless-steel and FRP) have been developed.

21.1.10.4 Piping and Valves

The piping and valves scope of work entails the supply, manufacturing, inspection, and corrosion protection of the piping and valves as per the BOQs. The unit rates for supply and fabrication were obtained from fabricators and were applied to estimate the piping and valves supply costs.

The pipe MTOs were based on pipe sizes derived from the P&IDs and line transpositions that were done using the plant layout to route the lines. MTOs for all carbon steel, stainless steel, and HDPE piping were forwarded to vendors for pricing. The lengths of overland piping were determined using the overall site layout and geography plans of the area.

A valve list compiled from the P&IDs, detailing each manual valve type, was submitted to vendors for pricing. The actuated valve costs were included in the instrumentation cost estimate. The quotations received were technically and commercially adjudicated, and preferred vendors were selected. The scope of work relating to piping and valves is indicated in the P&IDs.

The piping, fittings and valves BOQs have been developed.

21.1.10.5 Electrical Equipment

The process plant, mining and peripheral infrastructure electrical equipment detailed BOQ was derived from layout drawings, process plant general arrangement drawings, electrical single-line diagrams, mechanical equipment list, and motor lists.

The electrical equipment includes the following:

- MV switchgear
- Step-down transformers
- MCCs
- LV and MV cables
- Cable racking, luminaires, and earthing
- Power factor correction units
- Emergency power system

Electrical equipment supply enquiries were prepared, inclusive of equipment data sheets, and sent to approved equipment vendors/suppliers. The quotations received were commercially and technically adjudicated.

The electrical equipment BOQ has been developed.

21.1.10.6 Process Control (Control and Instrumentation (C&I))

The process plant includes the implementation of a process automation system (PAS). The PAS comprises a SCADA system, PLCs, and instrumentation. The SCADA and PLC equipment will be located in the plant control rooms and the equipment rooms located adjacent to the plant control rooms.

A security system, including CCTV cameras and access control to site, will also be provided.

The communications system, consisting of an office local area network (LAN), satellite link for Internet and email, telephone, and radio systems, will be provided by Mkango.

The PLC and SCADA costs were based on a typical plant configuration with full plant control from a central control room. Provision was also made for a sequel server for constant data logging and trending.

Instrumentation costs were based on instrument and valve lists. The instrumentation BOQ was developed from data derived from the P&IDs, as well as the instrument list and the instrumentation drawings.

Dedicated remote input/output (I/O) panels, located in the specific plant areas, are utilised to connect the field instruments to the PLC. Digital instruments are wired to the remote I/O panel via multipair cables. Analogue instruments are connected to the remote I/O panels via a Profibus PA network.

The C&I equipment BOQ has been developed.

21.1.11 Supply and Install Contracts

The supply and install contracts include the following:

- Prefabricated plant buildings
- Pre-engineered steel and cladded infrastructure buildings
- Mine/plant assay laboratory
- Prefabricated off-site infrastructure and camp buildings

All of the supply and install contractors will be responsible for their own supply of construction power as the Escom grid main power switchyard will only be commissioned during the process plant commissioning phase.

21.1.11.1 Prefabricated Plant Buildings

The following infrastructure buildings will be supplied as prefabricated buildings:

- On-site process plant infrastructure:
  - Change house building
  - Office buildings (two)
  - Gatehouse building
  - Weighbridge control room
  - Process plant control rooms (two)
  - Metallurgical and assay laboratory
  - Clinic
  - Ablution facility
- Off-site infrastructure:
  - Accommodation facility

The prefabricated building package includes the supply and site installation of the buildings, including all the furniture, internal electrical reticulation and fittings, all internal water reticulation, plumbing, sanitary fittings, extraction, and air conditioning.

The Prefabricated Building Contractor has allowed for the relevant P&G costs for the installation of the buildings. Mkango will provide accommodation for the expatriate workforce. This will include three meals and laundry services. It must be noted that only a limited number of beds are available and will be allocated proportionally to all the construction contractors. No accommodation will be provided to local employees.

A supply and installation enquiry package was issued to the market for prefabricated buildings. The vendor was selected based on both technical and commercial adjudications.

The CAPEX for the site clearance and terracing for the infrastructure buildings is included in the earthworks contract.

The CAPEX for the concrete foundations, floor slabs, sewer reticulation and drainage systems is included in the civil works contract.

The CAPEX for the electrical switchgear and MCCs is included in the electrical CAPEX.

The electrical supply reticulation to the respective infrastructure buildings is included in the E, C&I contract.

21.1.11.2 Pre-Engineered Steel Buildings

The following pre-engineered structural steel buildings will be supplied:

- Workshop
- Main store
- Reagents store
- Final product store
- Air buildings
- Blower building

The pre-engineered steel building package includes the design, fabrication, and supply of the steel buildings.

A design, fabrication and supply enquiry package was issued to the market for pre-engineered steel buildings. The vendor was selected based on both technical and commercial adjudications.

The CAPEX for the site clearance and terracing for the pre-engineered steel building is included in the earthworks contract.

The CAPEX for the concrete foundations, floor slabs and drainage systems is included in the civil works contract.

The site installation of the structural steel buildings is included in the SMPP CAPEX.

The CAPEX for the electrical switchgear and MCCs, and all internal electrical reticulation, lighting and fittings is included in the electrical CAPEX.

The electrical supply reticulation to the respective infrastructure buildings is included in the E, C&I contract.

21.1.11.3 Mine/Plant Assay Laboratory

The assay laboratory package includes the supply, installation, and ultimately the operation of the assay laboratory. The supply includes all the laboratory equipment, furniture, and fixtures. This cost is reflected in the OPEX as a monthly allowance.

A second separate package includes the supply of the pre-populated modularised building arrangements. This building includes all internal electrical reticulation and fittings, all internal water reticulation, plumbing, sanitary fittings, and air conditioning. This is reflected in the CAPEX.

The concrete foundations and floor slab will be provided by the Civil Contractor.

The Assay Laboratory Contractor has allowed for the relevant P&G costs for supervision during erection of the contractor-supplied buildings

The supply and install enquiry package was issued to the market for the assay laboratory. The vendor was selected based on both technical and commercial adjudications.

Electrical supply to the laboratory is included in the E, C&I contract.

21.1.11.4 Prefabricated Off-Site Infrastructure and Camp Buildings

The prefabricated building package includes the supply and site installation of the buildings, including all internal electrical reticulation and fittings, all internal water reticulation, plumbing, sanitary fittings, and air conditioning.

The concrete foundations, floor slab and connection to external sewerage reticulation and potable water will be provided by the Civil Contractor.

The Prefabricated Building Contractor has allowed for the relevant P&G costs for the installation of the buildings, including the supply of their own tented construction camp.

A supply and installation enquiry package was issued to the market for prefabricated buildings. The vendor was selected based on both technical and commercial adjudications.

21.1.12 Engineering, Procurement and Construction Management (EPCM)

Engineering, project management and drawing office man-hours are based on the estimated number of man-hours required to complete the detailed design of the project. Unit rates for man-hours represent actual rates currently being charged on similar projects.

Site construction management is based on a highly skilled team of engineers and site staff who will supervise the construction crew’s activities. This part of the estimate assumes that construction will be subcontracted to earthworks, civil works, SMPP and E&I construction companies. This, however, requires a higher level of supervision on the part of the EPCM Contractor and Owner’s representative.

21.1.13 First Fills

The first-fill costs for the ball and regrind mills were developed from first principles. These were defined as those costs incurred prior to commissioning in preparing the circuit to accept ore. These costs included the addition of steel balls (various sizes) to the ball mills and ceramic media to the regrind mill to design charge levels.

The costs for the first fills as required for the balance of the mechanical equipment are included in the respective machinery and equipment CAPEX.

The first-fill costs for the reagents and diesel for the mining fleet are included in the first three months' OPEX allowance.

The first-fill costs for the project are summarised in Table 21.13.

Table 21.13: First-Fill Cost Summary

Description	CAPEX (US$)	Contingency (US$)	Total CAPEX (US$)
Ball Mill	443,748	66,562	510,311
Sulphuric Acid Plant	41,388	6,208	47,596
Sodium Hydroxide	39,226	5,883	45,109
Calcium Chloride	21,148	3,172	24,320
Fine Grind Mill	13,045	1,957	15,002
First-Fill Totals	**558,555**	**83,782**	**642,337**

21.1.14 Contingency

An average contingency of 11 % has been allowed for to cover items that are included in the scope of work but that cannot be adequately defined at this stage due to the level of engineering conducted during the study and a subsequent absence of detailed design and procurement information.

The average contingency of 11 % was derived mathematically and is affected by the design and procurement confidence contingency values that were attributed to each of the respective capital cost categories, i.e.

- Structural Steel and Plate Work; steel price fluctuation – assigned 12 %
- Mechanical Equipment: budget estimate quotations – assigned 10 %
- Piping, Tankage, and Instrumentation: budget estimate quotations – assigned 15 %
- Balance of the Cost Categories: based on level of engineering – assigned 14 %

21.1.15 Vendor Services

The cost for vendor services includes all the items where the presence of the vendor is required during the construction phase in order for guarantees to be honoured. It also includes items where construction supervision is required, particularly for the installation of the large and/or critical equipment items. The costs are based on actual quotes obtained from the respective vendors.

21.1.16 Freight

The freight costs for the project are based on the actual mass of the mechanical equipment, the mass of the structural steelwork as generated in the respective MTOs, and the calculated mass of piping and valves as contained in the respective BOQs. Actual quotes were obtained from local freight forwarders.

Most of the rates utilised in the freighting cost have been obtained from third-party service providers and statutory agencies involved in the management of shipments and documentation. Rates offered by these bodies are subject to change without notice and, therefore, cannot be held as fixed and firm. The contractor will have to negotiate these increases on an ad-hoc basis with Mkango as and when they arise, fully supporting the application with documentary evidence of such increases.

21.1.17 Power Plant

The 132/11 kV switchyard and overhead transmission power line to the plant will be provided by the local Malawian grid power producer – Escom. This includes the switchyard inside the process plant area.

Site preparation of the required terrace area for the 132/110 kV switchyard to be built by others is accounted for in the earthworks CAPEX.

An outline of the electrical power demand is shown in Table 21.14, based on the mechanical equipment list and plant infrastructure.

Table 21.14: Project Electrical Power Demand

Project Load	Continuous Power Demand (kW)	Maximum Start-Up Demand (kW)
Process Plant	20,201	–
Off-Site Infrastructure	1,447	–
Camps	418	–
Ball Mill	3,004 (3,400[a])	4,640
Total	25,071	
[a] Rated		

In addition to the Malawian Escom national power grid, a PV plant will be installed as a secondary source of power. The Escom grid will predominantly be used during the night-time while the PV plant will be used when the solar conditions are favourable. More information on the PV plant is included in Section 18.

21.1.18 Fuel Supply Depot

The diesel fuel storage facilities will hold a 210 m^3 total capacity, which will be operated by the Fuel Supply Contractor.

The CAPEX for the site clearance and fencing for the terrace for the diesel fuel farm and mining fleet refuelling station is included in the earthworks contract.

The CAPEX for the concrete foundations, floor slabs, catch pits and drainage systems is included in the civil works contract.

The CAPEX for the dispensing station control room prefabricated building, furniture, fixtures, internal electrical reticulation and electrical fittings, and the necessary fire protection foam systems, is included in the Fuel Supply Contractor's Scope.

The CAPEX for the electrical switchgear and MCCs is included in the electrical CAPEX.

The electrical supply reticulation to the fuel depot is included in the E, C&I contract.

Erection of the fuel storage tanks and dispensing systems is included in the respective supply contracts. Raw and potable water will be supplied to a central point, and the reticulation thereof will be in the respective supply contracts' scope of works.

21.1.19 Spares

Commissioning spares were allowed for in the CAPEX. The spares costs were obtained from vendor quotations.

Three categories of spares were considered and included in the initial CAPEX and OPEX:

- Commissioning spares
- Two-year operating spares
- Insurance and critical spares

21.1.20 Insurances

The EPCM Contractor will be responsible for the necessary insurance related to workmen's compensation for their supervisory personnel on site.

The EPCM Contractor's subcontractors for the SMPP installation, electrical services installation, and process control installation will be responsible for the workmen's compensation insurance cover for their personnel in their respective engagements.

All risks insurance cover for materials and equipment on site during the execution phase is included in the CAPEX.

Third-party insurance and maintenance of vehicles supplied for use by the EPCM Contractor have been included in the insurances and guarantees portion of the overall CAPEX.

Professional Indemnity (PI) insurance cost allowances have been included in the insurances and guarantees portion of the overall CAPEX.

21.1.21 TSF Costs

The CAPEX associated with the TSF has been determined to a Class 2 AACE accuracy (+15 % to −10 %), based on quantities measured by Epoch and rates sourced from earthworks and liner tender enquiries undertaken and provided by SENET.

The estimated CAPEX has been determined for each phase of the development of the TSF, allowing for the costs to be allocated either to the initial CAPEX budget for the project or to the sustaining CAPEX/OPEX as deemed necessary.

The estimated costs associated with each phase of the TSF, which represent the initial and sustaining TSF CAPEX that occurs over the LOO, are given in Table 21.15. The P&G costs are 31.0 % of the measured works from Teichmann, and 18.8 % of the lining and geotextile supply and installation works from Solmax. An allowance of 10 % of the total measured works was made for contingencies.

Table 21.15: CAPEX for the Songwe Hill TSF

<table>
<tr><th rowspan="2">Description</th><th colspan="6">Amount (US$ million)</th><th rowspan="2">Percentage of Total Works (%)</th></tr>
<tr><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th><th>Phase 4</th><th>Phase 5</th><th>RWD</th></tr>
<tr><td>Site Clearance</td><td>1.27</td><td>0.19</td><td>0.15</td><td>0.11</td><td>0.07</td><td>0.07</td><td>2</td></tr>
<tr><td>Earthworks and Excavations</td><td>10.82</td><td>5.53</td><td>6.49</td><td>6.29</td><td>7.16</td><td>0.45</td><td>43</td></tr>
<tr><td>Drainage</td><td>3.30</td><td>0.12</td><td>0.12</td><td>1.11</td><td>1.18</td><td>0.21</td><td>7</td></tr>
<tr><td>Concrete Structures</td><td>0.83</td><td>0.81</td><td>0.81</td><td>0.81</td><td>0.81</td><td>0.01</td><td>5</td></tr>
<tr><td>Pipe Work</td><td>0.39</td><td>0.09</td><td>0.58</td><td>0.03</td><td>0.03</td><td>0,00</td><td>1</td></tr>
<tr><td>Gabions</td><td>0.17</td><td>0.17</td><td>0.17</td><td>0.17</td><td>0.17</td><td rowspan="4">–</td><td>1</td></tr>
<tr><td>Catwalk</td><td>0.08</td><td>0.08</td><td>0.08</td><td>0.08</td><td>0.08</td><td>0</td></tr>
<tr><td>Warning Signage and Safety</td><td>0.08</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0</td></tr>
<tr><td>Miscellaneous</td><td>0.20</td><td>0.21</td><td>0.26</td><td>0.29</td><td>0.33</td><td>2</td></tr>
<tr><td>Sum of Measured Works</td><td>17.13</td><td>7.20</td><td>8.65</td><td>8.88</td><td>9.83</td><td>0.74</td><td>62</td></tr>
<tr><td>P&G Costs (31.0 % of Measured Works)</td><td>5.44</td><td>2.29</td><td>2.75</td><td>2.82</td><td>3.12</td><td>0.23</td><td>20</td></tr>
<tr><td>Contingencies (10 % of Measured Works)</td><td>1.71</td><td>0.72</td><td>0.86</td><td>0.89</td><td>0.98</td><td>0.07</td><td>6</td></tr>
<tr><td>Total CAPEX per Phase</td><td>24.29</td><td>10.20</td><td>12.26</td><td>12.59</td><td>13.94</td><td>1.05</td><td>88</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>Liner and Geotextile Measured Works</td><td>4.40</td><td>0.93</td><td>0.97</td><td>0.73</td><td>0.75</td><td>0.23</td><td>9</td></tr>
<tr><td>P&G Costs (18.8 % of Measured Works)</td><td>0.83</td><td>0.17</td><td>0.18</td><td>0.14</td><td>0.14</td><td>0.04</td><td>2</td></tr>
<tr><td>Contingencies (10 % of Measured Works)</td><td>0.44</td><td>0.09</td><td>0.10</td><td>0.07</td><td>0.08</td><td>0.02</td><td>1</td></tr>
<tr><td>Total CAPEX per Phase</td><td>5.67</td><td>1.20</td><td>1.26</td><td>0.94</td><td>0.97</td><td>0.29</td><td>12</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>Total CAPEX per Phase</td><td>31.30</td><td>11.40</td><td>13.52</td><td>13.53</td><td>14.91</td><td>1.38</td><td rowspan="2">100</td></tr>
<tr><td>Total CAPEX of Final TSF</td><td colspan="6">84.64</td></tr>
</table>

21.1.22 Other Supporting Infrastructure and Equipment Costs

The proposed infrastructure will support the mining and plant operations and includes the following:

- Raw water management and supply
- Pit dewatering
- Plant access and haul roads
- Plant support and operational vehicles

21.1.23 Raw Water Management and Supply

The raw water management and supply philosophy was derived from the process plant and mining operational requirements as detailed in the process plant and mining water balances, respectively.

Raw water will be supplied to the plant from boreholes located in various areas mainly west of the process plant. This water will be pumped to a water collection tank central to the boreholes' location and then pumped to the raw water pond at the process plant as well as to a collection tank at the accommodation facility for treatment as potable water. From the pond, a stream is filtered and pumped to the filtered raw water tank for the gland water service supply and reagent make-up. A second stream is treated in a reverse osmosis plant for use as potable water. A third stream is used as is for fire water, process water top-up, and crushing dust suppression.

The pumping and piping BOQs associated with these systems were compiled by measuring the relevant piping routes on the overall site plot plan, in conjunction with the project P&IDs. These BOQs (along with the associated pump systems and WWTP) were subsequently issued to the respective vendors via a formal enquiry to obtain rates for the fabrication and supply of the materials/equipment. The CAPEX for the raw water pumping, WWTP and piping is included in the process plant mechanical equipment, piping, and valves CAPEX.

Installation/erection for the raw water supply pumping, piping and WWTP is included in the SMPP contract.

The CAPEX for the site clearance and terracing for the raw water pumping station and WWTP is included in the earthworks contract.

The CAPEX for the concrete foundations, floor slabs, catch pits, sewer reticulation and drainage systems is included in the civil works contract.

The CAPEX for the ablution facility prefabricated building, fixtures, internal sewer reticulation and fittings is included in the infrastructure CAPEX.

The CAPEX for the electrical switchgear and MCCs is included in the electrical CAPEX.

The electrical supply reticulation to the raw water pumping station and WWTP is included in the E, C&I contract.

21.1.24 Pit Dewatering

The pumping requirements to dewater the pits from rainfall and groundwater inflows were estimated following completion of the mine and geohydrology designs. The pit dewatering systems from the pit will feature dedicated diesel pumps, which will pump the water to the highest point into a tank. The water will be gravity fed from that tank to another tank close to the primary crusher, from where it will be pumped to the raw water pond.

The pit dewatering mechanical equipment and all the associated piping to the tank are included in the mining initial CAPEX.

The pump, piping and electrical requirements are included in SENET's initial CAPEX.

21.1.25 Plant Access and Haul Roads

The BOQs for the main site access road, the waste management facility perimeter road, and the mine haul roads have been prepared using the topographical drawings, plant location, waste management facility location, and mine planning designs as a basis for measurement.

Tender documents were drawn up for the design, procurement and construction management of the access roads and sent to suitable contractors for pricing. The quotations received were commercially and technically adjudicated.

The development costs for the access roads are included in the roads CAPEX.

Haul road development costs were derived from in-house database pricing and are included in the mining initial CAPEX (see Section 21.1.7).

21.1.26 Plant Support and Operational Vehicles

The CAPEX for the process plant workshop tools, light support vehicles, and the plant operational vehicles is based on the selected vendor's quotation and is included in the tools and mobile equipment CAPEX.

The process plant light support and operational vehicles are summarised in Table 21.16.

Table 21.16: Plant Support and Operational Vehicles

Description	Quantity
Light Plant Vehicles	8
Mobile Crane 80 t	1
Mobile Crane 20 t	2
Forklift	2
Skid-Steer Loader (Bobcat)	2
Front-End Loader	2
Tractor and Trailer	1
Lorry 10 t	1
Mobile rock breaker	1
Cherry picker	1
16-seater combi	3
32-seater bus	1

21.1.27 Owner's Pre-Production Costs

The Owner's pre-production costs are based on costs that will be incurred from the start of the project implementation phase up to the commissioning and handover to plant operation, including working capital.

The Owner's pre-production costs were estimated at 4 % of the direct field cost. A 10 % contingency has been allowed for to cover items that cannot be adequately defined at this stage.

The Owner's pre-production costs comprise the following:

- General and administration salaries, including the Owner's project team; the health, safety and environmental (HSE) department; the finance department; the procurement department; and the human resources department
- Mining department labour costs prior to commencement of pre-stripping
- Plant and laboratory labour costs prior to commencement of plant commissioning
- Costs associated with the administration of an off-site office
- Training package implementation and contractor engagement
- Vehicle running, insurance and maintenance costs
- Other administrative support costs
- Insurance costs
- Mine licence costs and reclamation bonds

21.1.28 Pre-Production Labour

The pre-production labour cost for the 18-month construction period includes the following:

- Pre-production labour salaries
- Pre-production labour flights
- Dedicated vehicle costs (diesel and maintenance)
- Recruitment costs

21.1.29 Other Pre-Production Costs

The other pre-production costs for the 28-month construction period include the following, which were based on the general and administration costs:

- Facilities maintenance
- Off-site offices and travel
- Supplies and spare parts
- Security
- Other administration
- Environmental and social
- Waste management
- Temporary ablution facilities
- Accommodation and messing facility management
- Potable and construction water supply

21.1.30 Working Capital

The working CAPEX was defined as those fixed and variable costs incurred by the mine from commissioning to the point where the mine is cash flow positive, and the revenue from concentrate sales can pay for the mine's operational costs.

The working CAPEX has been calculated from first principles, estimating a ramp-up period (period for plant to reach design production capacity) of four months. In this calculation, the following costs were considered:

- Operating costs for the whole operation, i.e. mining, process plant, and waste management facility
- General and administration costs
- Mining and process plant assay costs
- Stockholding costs

21.1.31 Environmental Management: Resettlement Costing and Rehabilitation and Closure Costs

Mkango requested Digby Wells to estimate the funding required to complete the resettlement process that may be undertaken to manage the physical and economic displacement impacts associated with the development and operation of the Songwe Hill Project.

The costs are based on eligibility considerations and entitlement measures typically required for resettlement processes within Malawi undertaken in line with International Standards, in particular the IFC Performance Standard 5 (IFC PS 5) on Land Acquisition and Involuntary Resettlement.

As part of the ESHIA, Digby Wells compiled a Mine Closure Plan (CP) and calculated the associated closure cost estimate (CCE) for the proposed Songwe Hill Project. This CP was developed as a desktop study with input from specialists as part of fieldwork and additional verification surveys.

The closure measures set out in the CP are based on a screening-level risk assessment undertaken for the project, which is informed by the relevant biophysical information and available specialist studies. The closure measures developed are then costed in the Digby Wells closure costing model to determine the initial CCE for the project.

A closure-related risk assessment was completed with the aim of informing the rehabilitation and closure measures required to meet the closure objectives and promote sustainable mine closure. The closure cost, including contingency, is estimated to be US$16,578,257 and is included in the sustaining CAPEX. Table 21.17 provides an overview of the CCE.

Table 21.17: Closure Cost Summary

Area and Description	LOO 2038 Cost (US$)
Infrastructure Demolition	
Component 1: Plant, Mining and Related Infrastructures	3,403,537
Component 2: Pit Area	0
Component 3: Waste Rock Dump and Stockpiles	332,715
Component 4: Tailings Storage Facility	0
Component 5: Dams	37,849
Component 6: Linear Infrastructure	99,212
Subtotal	**3,873,313**
Rehabilitation	
Component 1: Plant, Mining and Related Infrastructures	762,276
Component 2: Pit Area	80,155
Component 3: Waste Rock Dump and Stockpiles	912,212
Component 4: Tailings Storage Facility	3,905,730
Component 5: Dams	34,680
Component 6: Linear Infrastructure	46,236
Subtotal	**5,741,288**
Total 1: Demolition and Rehabilitation	**9,614,602**
Monitoring and Maintenance	
Monitoring Costs (Groundwater and Surface Water)	353,994
Monitoring Costs (Vegetation)	25,210
Maintenance Costs (Vegetation)	1,267,811
Specialist Studies (5 % of Total 1)	480,730
Plant Decontamination	509,340
Subtotal	**2,637,085**
Preliminary and General (35 %)	3,365,111
Contingency (10 %)	961,460
Subtotal	**4,326,571**
GRAND TOTAL	**16,578,257**

21.1.32 Closure Framework and Objectives

The initial closure objectives to support the overall closure vision are as follows:

- Rehabilitate disturbed areas to a suitable land capability to ensure the constructive integration and alignment of the rehabilitated site with the surrounding land use mix.
- Ensure that contamination of surrounding areas by mine impacted water is limited as far as possible. Ensure that the mine water is contained or treated if the volume of contaminated water is significant and if it does not meet statutory water quality requirements.
- Remove mine infrastructure that cannot be used by a subsequent landowner or a third party. Where buildings can be used by a third party, arrangements will be made to ensure their long-term sustainable use.
- Clean up all stockpile footprint areas and loading areas and rehabilitate these to a land capability similar to that which existed prior to mining.

- Follow a process of closure that is progressive and integrated into the short- and long-term mine plans and that will assess the closure impacts proactively at regular intervals throughout the project life.
- Rehabilitate the disturbed land to a state that facilitates compliance with applicable environmental quality objectives.
- Landscape the rehabilitated areas in alignment with the surrounding topography to prevent the unnecessary ponding of water and ensure all rehabilitated areas are free draining.
- Physically and chemically stabilise any remaining mining structures (i.e. TSF and WRD), where required, to minimise residual risk post closure.
- Leave a safe and stable environment for both humans and animals.
- Prevent any soil and surface/groundwater contamination by effectively managing water on site, and ensure clean/dirty water separation during the operational period to minimise post-closure contamination potential.
- Reduce the requirement for long-term monitoring and maintenance by establishing stable landforms.
- Comply with local and national regulatory requirements.

The closure measures can be refined or developed further in subsequent updates.

21.1.33 Currency Split

The currency split for the main contracts has been broken down per discipline and is shown in Table 21.18.

Table 21.18: Currency Split

Description	EUR	USD	ZAR
Earthworks	0	6,976,112	7,416,717
Civil Works – Plant	0	17,013,864	4,839,194
Civil Works – Infrastructure	0	1,717,576	0
Infrastructure	0	707,524	34,287,034
Structural Steel	0	0	93,589,009
Plate Work	0	0	40,491,125
Tankage	0	0	67,644,886
Machinery and Equipment	16,431,268	4,521,052	440,415,320
Piping	0	0	86,642,821
Valves	0	0	26,445,164
Electricals	0	10,505,600	0
Instrumentation	0	0	77,677,339
Transport	0	0	65,840,588
E&I Installation	0	6,715,672	0
SMPP Installation	0	21,862,300	0
Commissioning Spares	32,143	16,891	2,873,954
2-Year Operational Spares	143,190	70,664	36,129,649
Insurance and Critical Spares	35,798	10,750	29,567,654

Description	EUR	USD	ZAR
Vendor Services	1,236,250	1,267,384	0
First Fills	0	101,761	6,851,901
Project Management (EPCM)	0	23,318,266	0
Insurances and Guarantees	0	3,175,180	0
Mobile Plant and Equipment	0	245,061	57,633,514
Generator Plant	0	5,469,482	0
PV Solar Plant	0	21,327,663	0
Laboratory	0	0	0
Construction Camp	0	265,044	49,535,023
TSF Phase 1 and RWD	0	31,225,050	0
Mining Pre-Production	0	13,972,675	0
Other	0	12,460,340	0
TSF Sustaining Capital – Phases 2 to 5	0	49,551,380	0
Mining Sustaining Capital	0	896,618	0
Closure Cost	0	15,616,797	0
Owner’s Cost	0	6,028,280	0
TOTAL	**17,878,648**	**256,333,956**	**1,127,880,891**
CURRENCY SPLIT IN PERCENTAGE	**5.5 %**	**73.1 %**	**21.4 %**

21.1.34 Countries of Origin for Procurement Packages

Table 21.19 shows the envisaged countries of origin for the main procurement packages, together with the value, in US dollars, of the respective packages.

Table 21.19: Countries of Origin for Procurement Packages

Package No.	Package Description	Value of Procurement Package (US$)					
		China	Malawi	South Africa	Turkey	India	Italy
CC100	Civil Works		19,740,935				
CC102	Earthworks		7,617,508				
CC103	ROM Wall			139,472			
CC104	HDPE Lining		92,838				
CC105	Acid Proofing		322,613				
CC107	Fencing			1,398,814			
CC108	Pre-Engineered Buildings			768,697			
CC109	Erosion Control		256,756				
CC199	TSF		80,776,429				
CC321	Geotechnical Supervision		98,219				
CON01	Camp			3,302,335			
DW001	Resettlement action plan		15,616,797				
E907, E908, E918	PV Solar			4,271,070			

Package No.	Package Description	Value of Procurement Package (US$)					
		China	Malawi	South Africa	Turkey	India	Italy
EE001, EE901	Electrical			608,963			
EE123	E&I Installation			6,715,672			
EE908	Earthing			47,752			
EE909	MV Switchgear			1,569,348			
EE916	Transformers			547,272			
EE918	LV Cables			1,911,499			
EE918	MV Cables			556,279			
EE921	MCC			4,154,211			
EE928	Luminaires and Poles			299,416			
EE933	Cable Racking			1,061,242			
EE959	Mini Substation			173,403			
EP001	EPCM			23,318,266			
FF001	First Fills			558,554			
GG123	Conveyor Skirting			5,733			
I066	PV Modules	8,641,808					
I067	Inverters	1,545,308					
I068	Mechanical Assembly			959,600			
I069	Trackers – Solar Panels						3,599,371
I070, I750	Instrument Cables			372,924			
I075	Surveillance System			378,458			
I071	Weather Station			88,661			
I072	Plant Controller			152,412			
I073	Collector Substation			206,188			
I084	Generator Plant			5,469,482			
I700	Field Instruments			1,141,565			
I721	Pneumatic Equipment			221,399			
I730	Conveyor Protection			379,073			
I740	Control System			1,564,199			
I765	Security Systems			532,834			
I790	C&I Cable Racking			972,596			
MM001	Ball Mill			4,906,502			
MM002	Apron Feeder				315,368		
MM003	Primary Jaw Crusher			454,888			
MM005	Screens			246,551			
MM006	Vibrating Grizzly Feeders			114,691			
MM007	Rock Breaker			192,741			
MM008	Dust Suppression			274,618			
MM009	Tower Crane	412,666					
MM011	Cyclone Cluster	141,117					
MM013	Pan Feeder					25,412	
MM014	Agitators			1,785,356			
MM015	Hoists			292,684			
MM016	Float Cells			5,095,657			

Package No.	Package Description	Value of Procurement Package (US$)					
		China	Malawi	South Africa	Turkey	India	Italy
MM017	Filter Press	672,004					
MM018	Samplers and Analysers			1,265,935			
MM022	Fine Grinding Cyclone	192,144					
MM023	Regrind Mill	5,036,280					
MM024	Air Compressor	1,804,219					
MM025	SMPP			21,862,300			
MM027	Concentrate Thickener			328,916			
MM028	Tails Thickener			508,313			
MM029	Flocculant Plant			619,661			
MM031	Water Treatment Plant			521,877			
MM033	Hydrometallurgical Thickeners			3,607,371			
MM035	Secondary Cone Crusher			601,676			
MM036	Tertiary Cone Crusher			601,676			
MM039	Hydrometallurgical Filters	4,745,295					
MM041	Plant Buildings			878,332			
MM048, 051, 058	Piping			3,780,962			
MM061	Evaporation Package	3,108,116					
MM062	Sulphuric Acid Plant	10,865,591					
MM063	Trash Screen		61,831				
MM075	Steam Boiler			445,464			
MM076	Off Gas Scrubber			160,399			
MM078	Heat Exchanger			256,525			
MM079	Bagging and Drumming			227,900			
MM081	Ion Exchange Plant			875,656			
MM083	Water Filtration Plant			2,866,667			
MM085	Fire Protection			1,995,226			
MM123	Safety Shower			58,502			
MM457	Pumps			3,298,396			
MM500	Conveyor Belting	168,072					
MM501	Conveyor Pulley			349,331			
MM502	Conveyor Idlers			222,398			
MM503	Drives						442,490
MM504	Belt Scrapers			54,752			
MM505	Take-Ups			3,182			
MM506	Belt Scale			211,617			
MM507	Magnets			70,109			
MM696	Mining Pre-Production			13,972,675			
SEN001	Magnets			14,333			
SEN002	Flame Arresters			17,917			
SEN145	Tools and Mobile Plant			4,087,295			
SS042	Steel and Plate Work			8,932,942			
TRIK	Hydrosphere			60,200			

Package No.	Package Description	Value of Procurement Package (US$)					
		China	Malawi	South Africa	Turkey	India	Italy
TT044, TT45, TT065	Tanks			4,509,659			
VV059	Valves			1,763,011			
	TOTAL	**37,332,623**	**124,583,926**	**156,242,249**	**315,368**	**25,412**	**4,041,861**

21.1.35 Capital Cost Outflow Forecast

The capital cost outflow was scheduled according to the implementation schedule. Figure 21.2 shows the monthly capital cost outflow forecast over time, where the blue bars indicate the monthly spend, and the orange bars indicate the cumulative cost including contingency.

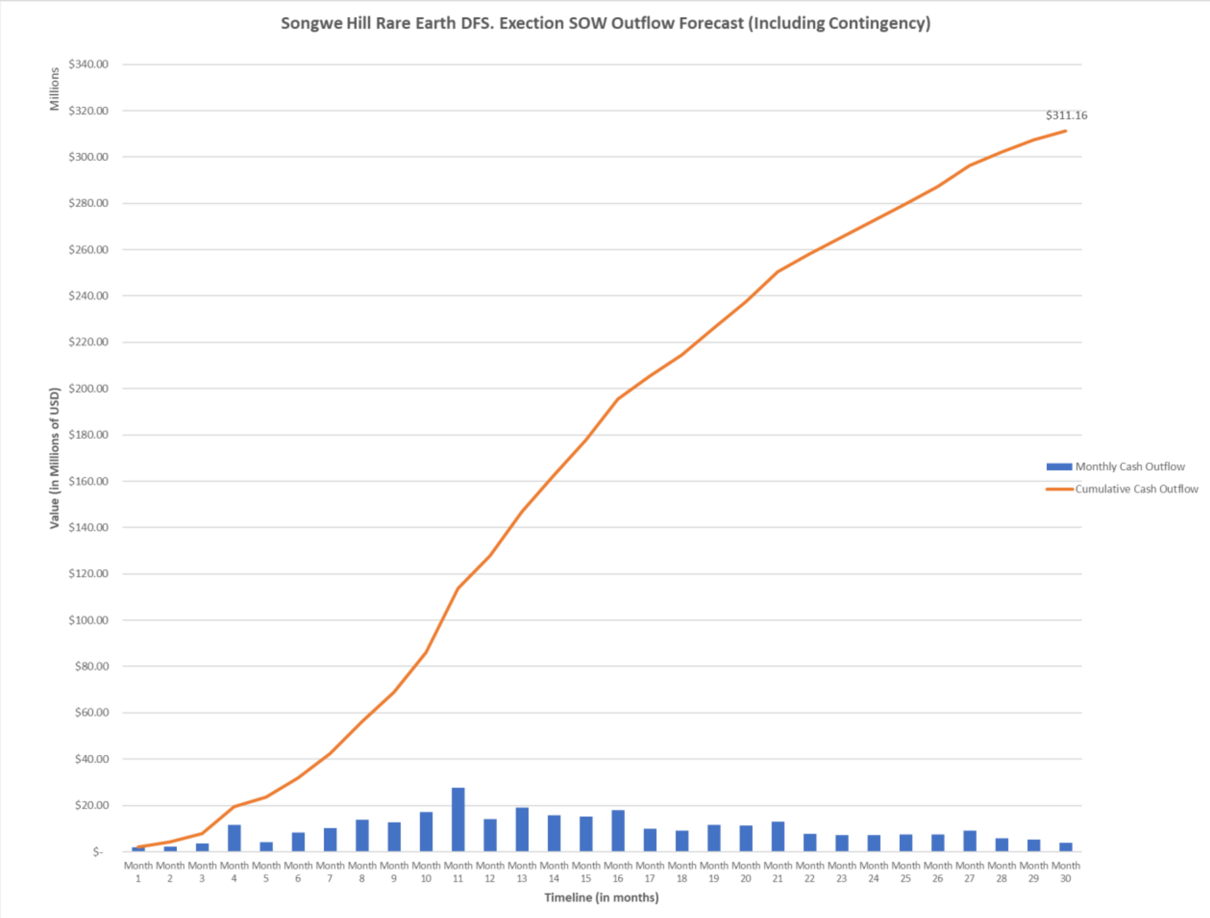

Figure 21.2: Capital Cost Outflow Forecast

21.2 OPERATING COSTS

21.2.1 Summary of Operating Costs

The purpose of this operating cost (OPEX) estimate is to provide operating costs, and the associated general and administration (G&A) costs, to an accuracy of +15 % to −10 % that can be utilised for the economic analysis of the Songwe Hill Rare Earth Element Project.

The project's annual OPEX estimate for the first five years of production consists of the following:

- Mining operating costs estimated by Bara
- Process plant operating costs estimated by SENET
- TSF operating costs estimated by Epoch

The OPEX for the first five years of production for the Songwe Hill Project is summarised in Table 21.20, with the cost distribution shown in Figure 21.3.

Table 21.20: First Five Years of Production OPEX Summary

Description	Cost				Cost Distribution
	US$ million/a	US$/t ROM	US$/t REE	US$/t REO	%
Mining	28,803,976	28.80	4,896.97	4,837.67	19.1
General and Administration	10,663,466	10.66	1,812.90	1,790.95	7.1
Reagents and Consumables	74,306,490	74.31	12,632.86	12,479.89	49.3
Power	25,499,432	25.50	4,335.16	4,282.67	16.9
Maintenance/Spares	2,816,157	2.82	478.78	472.98	1.9
Personnel	2,893,580	2.89	491.94	485.98	1.9
Site Laboratory	1,054,104	1.05	179.21	177.04	0.7
Product Transport	4,236,297	4.24	720.21	711.49	2.8
TSF	409,000	0.41	69.53	68.69	0.3
TOTAL	**150,682,504**	**150.68**	**25,617.56**	**25,307.35**	**100**

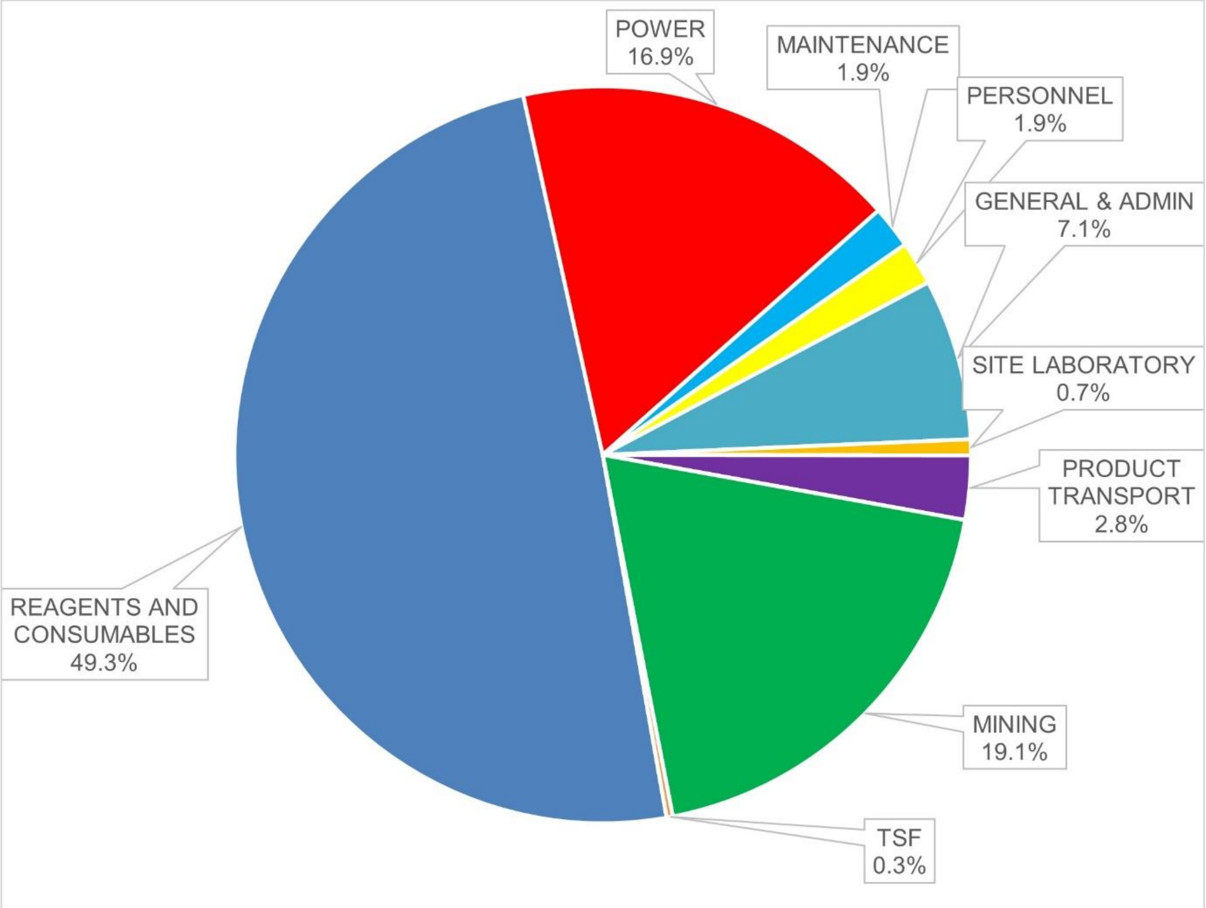

Figure 21.3: OPEX Distribution

The following is a summary of the production over the LOO and for the first five years:

- TREO production:
    - LOO: 4,633.54 t/a
    - First five years: 5,954.1 t/a
- Carbonate production (dry):
    - LOO: 8,424.65 t/a
    - First five years: 10,825.7 t/a
- Carbonate production (wet – to be transported):
    - LOO: 111,232.9 t/a
    - First five years: 14,434.2 t/a

Due to the distinction made between the production profile in the first five years of operation versus the LOO production rates, the OPEX numbers reflect the costs that are expected during the first five years. Due to the fact that varying feed characteristics influence the OPEX, several time-varied inputs have been evaluated over the life of the plant. The OPEX for the entire life of the processing plant given in Section 15 uses an averaged OPEX that differs from that given here for the first five years.

21.2.2 Exchange Rates

The costs of the project are reported in the United States dollar. The exchange rates used are shown in Table 21.1.

21.2.3 Escalation

No escalation has been allowed for in the OPEX estimate.

21.2.4 Exclusions

The following items were excluded from the OPEX estimate:

- Schedule delays, such as those caused by
    - Scope changes
    - Labour disputes
- Receipt of information beyond SENET's control
- Currency fluctuations
- Force majeure
- Contingencies

21.2.5 Mining Operating Costs

21.2.5.1 Definition of Mining Operating Cost

Operating cost has been defined as the costs of all ongoing mining from the time that ore is mined and includes the following:

- The cost of mining the ore and waste material from the open pit, including the cost of manpower and consumables
- The costs of maintaining the surface infrastructure

The operating costs exclude, among other things, the following:

- The cost of processing the ore to saleable products, including the cost of manpower, consumables and bulk supply
- The cost of shared services for the support of the operation, including the cost of on-site labour, infrastructure, camp costs and bulk supply
- The cost of maintaining the tailings dam
- The cost of bulk supply items including power and water

21.2.5.2 Open-Pit Mining Operating Cost

The mine operating cost is based on the use of a mining contractor to conduct the open-pit mining. An enquiry was distributed to a number of potential mining contractors. Contractors were requested to cost the first five years of open-pit mining in detail. Conforming submissions were received from three contractors. Two of the submissions, which were the lowest cost estimates, proposed total costs which were within 1 % of each other. One of these submissions was selected for use as the basis of costing.

The pricing schedule submitted by the contractor is shown in Table 21.21. The rates as shown in the table were applied to the final mining physical schedule to determine the mining cost per period. For the period beyond the first five years, the average rates over the first five years were applied.

In addition to the contractor's cost, costs were estimated for the Owner's team. These costs include the following:

- Management and administration including contract management
- Technical services related to the mining operation
- Allowance for contractors and consultants – this cost includes the grade control drilling contractor
- Infrastructure costs – cost of maintaining the infrastructure provided to the contractor, but for which the mine retains responsibility

The Owner's team manpower and consumables costs were estimated and applied per period (month) in the operating cost estimate.

Table 21.21: Mining Contractor Rates for First Five-Year Mining Period

Schedule A - 5 year Pricing Summary			Year1		Year2		Year3		Year4		Year5		Year1-5	
Item	Item Description	Unit	Quantity	Rate	Quantity	Rate	Quantity	Rate	Quantity	Rate	Quantity	Rate	Quantity	Total cost
1	Fixed charges			0	0	0	0	0	0	0	0			
1.1	Establsihment	1	1	979,910									1	979,910
1.2	De-establishment	1	1								1	896,618	1	896,618
2	Time-related charges	60	12	481,775	12	454,942	12	425,280	12	419,365	12	382,800	60	25,969,934
3	Rates based charges													
3.1	Open Pit mining													
3.1.1	Clear & Grub site, including trees to spoil within 1km	m2	287,000	2.80									287,000	803,600
3.1.2	Waste mining													
3.1.2.1	Waste D&B (127mm diameter Burden & spacing 10m bench 3.7 x 4.4 with PF 0.8, subdrill of 1.1m)	BCM	1,646,238	2.70	685,273	2.70	182,892	2.70	1,398,921	2.70	1,073,047	2.70	4,986,371	13,463,202
3.1.2.2	Waste haul	BCM	1,646,238	6.23	685,273	6.23	182,892	5.77	1,398,921	7.84	1,073,047	6.00	4,986,371	32,998,568
3.1.3	Ore mining													
3.1.3.1	Ore D&B (115mm diameter Burden & spacing 10m bench 3.7 x 4.4 with PF 0.8, subdrill of 1.1m)	BCM	774,351	2.70	1,941,444	2.70	2,006,200	2.70	759,722	2.70	999,845	2.70	6,481,562	17,500,217
3.1.3.2	Ore haul	BCM	774,351	7.38	1,941,444	7.84	2,006,200	6.92	759,722	6.46	999,845	6.74	6,481,562	46,459,722
4	Road works													
4.1	Haul road construction: Placement and compaction of selected and approved material for road and terrace layerworks (includes crushing & screening from opencast material- free issue)													
	Haul road subgrade, rip to depth of 200mm and compact to 90% MODASHTO density, Min CBR 6%	m2	51,400	0.43									51,400	22,205
	Haul road subbase, G6 material, 300mm layer, compact to 93% MODASHTO density, min CBR 15%	m3	22,100	9.10									22,100	201,110
	Haul road base, G5 material, 200mm layer, compact to 95% MODASHTO density, min CBR 45%	m3	9,300	10.20									9,300	94,860
	Haul road surface course, G4 material, 300mm layer, compact to 98% MODASHTO density, min CBR 80%	m3	9,000	11.15									9,000	100,350
5	Waste dump and stockpile earthworks													
5.1	Clear and Grub site, including trees with 1km freeaul	m2	780,000	1.28									780,000	998,400
5.2	Remove topsoil to average depth 200mm and stockpile with 1km.	m2	780,000	1.52									780,000	1,185,600
5.3	Bulk excavation in in class A material. Material used for backfill, stockpile, fill, construction of embankments or disposed within 1km.	m3	12,000	3.25									12,000	39,000
5.4	Base preperation for insitu material to (rip to depth of 200mm and compact to 90%)	m2	780,000	0.56									780,000	436,800
6.5	Construct compacted embankment walls, fills and terraces with material from opencast works, by spreading, shaping, and compacting - material available from borrow or from excavation in Pit	m3	18,000	7.80									18,000	140,400

21.2.5.3 Summary of Mining Operating Costs

The mining OPEX has been updated based on the planned movements and the selected Mining Contractor's budgetary offer.

The mining OPEX estimate includes the following items:

- Mining Contractor's costs
- Mining Contractor's overhead costs and charges
- Fuel costs
- Grade control drilling costs
- Mine Owner's team manpower costs

21.2.5.4 Basis of Estimate

21.2.5.4.1 Mining Contractor's Costs

Bara was commissioned by Mkango to complete the mining and mining infrastructure aspects relating to the DFS and the NI 43-101 report.

Bara's scope of work comprised the following:

- Project management of mining scope
- Geotechnical analysis and excavation design
- Mine design
- Mine layout and production scheduling
- Waste dump designs
- Mine services infrastructure
- Capital cost estimates for mining
- Operating cost estimates for mining
- Project scheduling
- Reporting
- Ore reserve statement

21.2.5.4.2 Manpower – Owner's Team

Bara estimated the full complement of skilled and semi-skilled workers. The summary and split between personnel employed by the project owner and the contractor are shown in Table 21.22. The Paterson job grading system has been used.

Table 21.22: Summary of Manpower by Employer

Employer	Complement
Mine	**21**
Skilled (Paterson Band C and above)	15
Semi-skilled (Paterson Band A and B)	6
Contractor	**129**
Skilled (Paterson Band C and above)	48
Semi-skilled (Paterson Band A and B)	81
Total	**150**

Table 21.23 shows the personnel estimated to be employed by the mine (Mkango). Bara's estimates excluded the manpower costs associated with whichever mining contractor is ultimately responsible for building the mine.

Table 21.23: Mining Manpower OPEX

Description	Shifts per Day	Complement per Shift	Cost to Company (US$/month)
Contract Manager	1	1	15,000
Technical Manager	1	1	15,000
Surveyor	1	1	7,500
Surveyor Assistant	1	1	1,000
Senior Geologist	1	1	12,000
Geologist	1	2	7,500
Geological/Grade Control Technician	2	2	3,000
Geotechnical Engineer	1	1	12,000
Geotechnician	1	2	3,000
Mine Planner	1	2	7,500
General Worker (Cleaner, Water Pump Attendant, Surveyor)	1	5	1,000
Total	**0**	**21**	**20,109,000**
Total cost (US$/t processed over LOO)			**1.11**

21.2.6 Process Plant Operating Costs

21.2.6.1 Summary of Process Plant Operating Costs

The process plant operating costs are summarised in Table 21.24, and the distribution of the cost is shown in Figure 21.4.

Table 21.24: Process Plant OPEX Summary

Description	Cost			
	US$/a	US$/t ROM	US$/t REE	US$/t REO
Personnel	2,893,580	2.89	585.52	485.98
Power	25,499,432	25.50	5,159.84	3,639.85
Maintenance/Spares	2,816,157	2.82	569.85	401.99
Reagents and Consumables	74,306,490	74.31	12,632.86	12,479.89
Site Laboratory	1,054,104	1.05	213.30	177.04
TOTAL	**117,011,928.48**	**117.01**	**14,180.51**	**19,652.33**

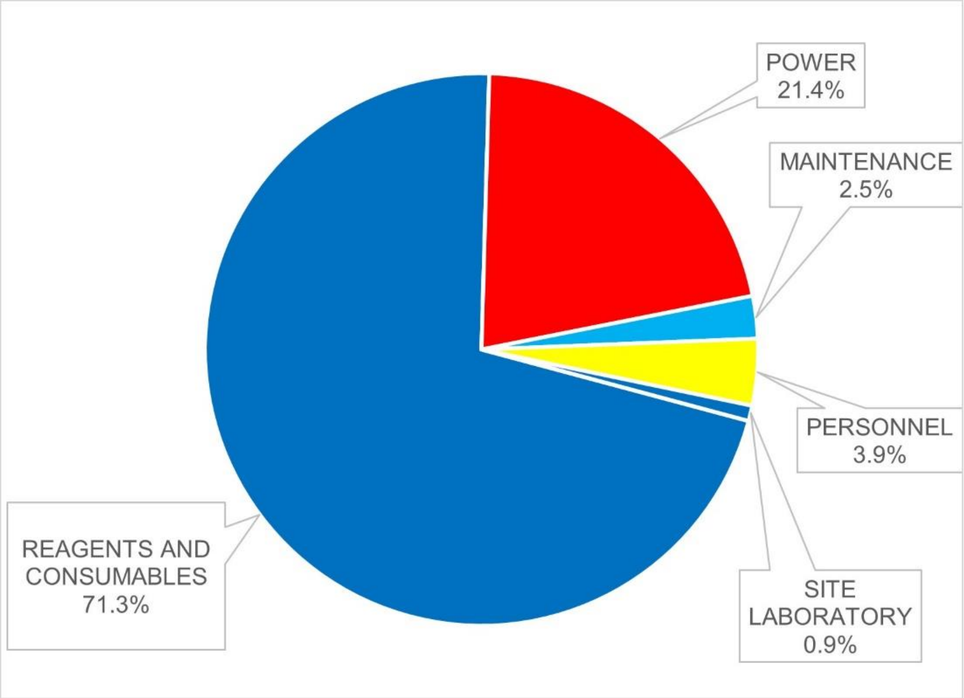

Figure 21.4: Plant OPEX Distribution

21.2.6.2 Basis of Estimate

The process plant operating costs were compiled from a variety of sources, notably

- Reagent consumptions calculated from first principles where required
- Test work data regarding reagent consumptions and operating conditions
- Supplier quotations on reagents and consumables
- SENET's in-house experience and database where applicable
- Client input

The following are the main cost elements of the process plant:

- Reagents and consumables
- Power (includes fuel farm)
- Plant operating and maintenance labour
- Maintenance parts and supplies

21.2.6.2.1 Reagents and Consumables

The reagents and consumables costs were calculated by using vendor supply costs together with the consumptions of the respective reagents or consumables calculated by a mass balance that was based upon test work results. The reagents and consumables supply costs are shown in Table 21.25. The large quantities of reagents make this section of the OPEX sensitive to transport costs. Fixing long-term reagent supply and transport contracts will be critical to decreasing the OPEX. Current reagent and transport costs are very high but have been used for the current base case. There is, however, scope to reduce this considerably once global reagent flows return to some form of stability in the wake of Covid-19.

Table 21.25: Reagents and Consumables Supplied Costs

Consumable	Requirement (t/a)	Cost (US$/t)	Freight Cost (US$/t)	Cost per Annum (US$/a)
Concentrator Plant				
Primary Jaw Crusher Liner		1,608.00		32,160
Secondary Cone Crusher Liner		1,010.00		20,200
Tertiary Cone Crusher Liner		1,010.00		20,200
Ball Mill Liner				442,575
Grinding Media		14,500.00	137	146 370
Fine Grinding Media		4,100.00	137	41,000
Flotation Reagents	3,122.98		267	25,685,919
Flocculant	50.00	2,320.00	267	129,350
Concentrator Total				**26,476,773**
Hydrometallurgy Plant				
Sulphur	16,585.41	325.00	267	9,818,564
Hydrated Lime	16,111.11	135.00	137	4,382,222
Sodium Hydroxide	19,102.02	450.00	447	17,134,512
Calcium Chloride	26,338.52	207.00	267	12,484,457
Ammonium Bicarbonate	10,513.35	118.00	267	4,047,641
Barium Chloride	400.52	665.00	267	373,280
Ammonium Sulphate	780.00	149.00	267	324,480
Sodium Sulphide	13.43	408.00	267	9,068
Flocculants	33.08	2,574.26	267	93,989
Hydrometallurgy Total				**47,168,212**
TOTAL CONSUMABLES COST				**74,306,490**

Crusher Liners

The primary, secondary and tertiary crusher liner costs were escalated from costing received for the PFS. Annual costs were calculated by estimating the number of liner changes per annum using the abrasion indices obtained from metallurgical tests and the expected liner life for a given throughput. The estimated delivered costs were received from liner suppliers.

Mill Liners

The ball mill liner costs were based on estimating the liner consumption by using the abrasion index results obtained from test work. Equipment suppliers used the test work data to simulate the expected wear rates. Annual costs were calculated by assuming a mill reline every eight months. The current pricing for a set of rubber liners for the ball mill was obtained from a liner supply vendor and used in the cost estimate based on the number of liner changes per annum for a given throughput. The delivered costs were received from liner suppliers.

Mill Grinding Media

The grinding media costs were obtained by estimating the consumption in the ball mill based on Bond's estimating method and using the standard method abrasion index results that were obtained from laboratory tests. Mill suppliers used the test work data to estimate the expected mill grinding media consumptions. In addition, the mill throughputs and quotations for 100 mm balls were obtained from suppliers. Quotations obtained from reagent suppliers, together with the consumption, were then used to estimate the grinding media costs.

Fine Grinding Media

The fine grinding mill media consumption was estimated by the equipment supplier using fine grinding test work, ore properties, and design parameters. This cost was seen to be relatively low compared with the ball mill media.

Flotation Reagents

The flotation regime was determined and optimised during bench-scale and pilot plant testing campaigns, and reagent consumptions for optimal flotation performance were established and documented.

Pricing was obtained for all the flotation reagents from local and international suppliers, including suppliers that were identified by Mkango's consultant Pendant Holdings. The best prices were selected, and the cost of transport to site was estimated from information supplied by reagent suppliers and specialist logistics companies.

Flocculant

Flocculant consumption was determined by test work during the flotation piloting campaigns, and market pricing was used to calculate the total cost. SENET compared the cost of Chinese flocculant supply to the database pricing from previous projects, and it was seen to be in line with what was expected. The cost of transport to site was estimated from information supplied by reagent suppliers and specialist logistics companies.

Sulphur

The consumption of sulphur was calculated from the amount of sulphuric acid required by the acid regeneration process in the SENET mass balance and confirmed by the ANSTO test work. The hydrochloric acid requirement in the gangue and rare earth leaches drove the demand for sulphuric acid in acid regeneration. Suppliers of acid plants who were approached provided efficiencies of sulphur use, after which the final sulphur requirement per annum was estimated. Pricing was estimated from quotations received from suppliers, and the transport costs to site were estimated from information supplied by reagent suppliers and specialist logistics companies.

Hydrated Lime

Hydrated lime is consumed in several unit operations in the hydrometallurgical plant. The consumption was calculated from the SENET mass balance and confirmed with test work. An estimation was made from first principles on the lime requirement for the hydrometallurgical tails neutralisation. Pricing was estimated from quotations received from suppliers, also considering product availability. Transport costs to site were estimated from information supplied by reagent suppliers and specialist logistics companies.

Sodium Hydroxide

Sodium hydroxide is used both in the flotation plant and in the hydrometallurgical plant. The base-case process design has been used for the purposes of this OPEX. The sodium hydroxide requirement is heavily dependent on three variables:

1. Mass loss in gangue leach
2. Sodium hydroxide addition rate per unit mass of dry feed to caustic conversion
3. The percentage of the bleed stream taken from the caustic conversion thickener overflow to remove impurities

The current base case includes sodium hydroxide consumption to offset a bleed stream of approximately 25 % to 30 % of the solution overflowing from the caustic conversion thickener.

It is important to note that potential process changes could significantly impact the sodium hydroxide consumption. Sodium hydroxide consumption has been the focus of numerous test work campaigns. Test work results on both the caustic conversion process and the subsequent regeneration processes were incorporated into the SENET mass balance to determine annual consumptions. Meetings with international reagent supply chain experts indicated that sodium hydroxide pricing has recently entered a period of steep increase, likely due to global market imbalances and supply chain constraints. Enquiries were submitted to the market nevertheless, and transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies to produce the final annual cost.

It must, however, be emphasised that reagent prices and transport costs will likely stabilise at lower levels in the near future. Furthermore, this current process is immensely sensitive to sodium hydroxide pricing due to the high concentrations required to drive the caustic conversion process.

Calcium Chloride

Calcium chloride is used with sulphuric acid to make the acid regeneration process work. Sulphuric acid is added to supply the acid, and calcium chloride is added to balance the sulphate and calcium in solution. Calcium chloride consumption was calculated from the SENET mass balance and confirmed with test work. Pricing was estimated from quotations received from suppliers; however, concerns have been raised by several global suppliers about the quantity of reagent required by the process. This is something that will require investigation as the reliable supply of calcium chloride will have to be ensured. Transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies.

Ammonium Bicarbonate

Ammonium bicarbonate is used to precipitate the rare earth product. Consumption was determined by test work and incorporated into the SENET mass balance. Pricing was estimated from quotations received from suppliers. Transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies.

Barium Chloride

Barium chloride is used to remove radium from the rare earth leach solution. Consumption was determined via test work and incorporated into the SENET mass balance. Pricing was estimated from quotations received from suppliers for use in the OPEX. Transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies.

Ammonium Sulphate

Ammonium sulphate is also added as a reagent to remove radium from solution, by acting as a source of sulphate. Consumption was determined by test work and incorporated into the SENET mass balance. Pricing was estimated from quotations received from suppliers for use in the OPEX. Transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies.

Sodium Sulphide

Sodium sulphide is used to remove lead and zinc from the rare earth leach solution. Consumption was determined by test work and incorporated into the SENET mass balance. Pricing was estimated from quotations received from suppliers for use in the OPEX. Transport costs were estimated from information supplied by reagent suppliers and specialist logistics companies.

21.2.6.2.2 Power

The average continuous fixed power consumption was determined by taking into account the installed power rating of each of the equipment in the plant and infrastructure, excluding standbys, and the projected running times. The fixed power draw includes the absorbed operating loads associated with the process plant equipment as detailed in the mechanical equipment list and on-site infrastructure, including the following buildings:

- Sewage Treatment Plant
- Fuel Farm
- Change House
- Plant Offices
- Laboratory
- Administration Building
- Weighbridge
- Control Room
- Gatehouse
- Warehouse
- Reagents Stores
- Ball Storage and Bunker
- Workshop

The Songwe Hill process design is energy intensive due to the need to elevate temperatures in several unit operations. Flotation is operated at 50 °C, gangue leach at 80 °C, caustic conversion at 90 °C to 100 °C, and the caustic evaporation requires large amounts of saturated steam. The thermal load of the processing plant is approximately 10 MW, including all the thermal recovery systems such as heat exchangers. Electrical energy is used to power an arrangement of steam boilers that provide low-pressure saturated steam for heating purposes.

The Songwe Hill Project will have access to the Malawian national grid and solar PV as a secondary source. The grid (approximately 25 MW) will be predominantly in use during night-time and in the event that the conditions for solar PV are insufficient. Furthermore, in the event that the grid is not available, there are provisions for six 1.6 MW (five running and one standby, equal to 8 MW) backup generators to supply only the essential load during this scenario.

Power Supply Options

Three power supply options have been evaluated for the Songwe Hill Project:

1. Grid only
2. Grid and PV
3. Grid, PV and Wind Turbines

The use of solar PV has been proven to offer lower operating costs for projects by reducing the power purchased from the grid. Furthermore, the renewable energy component significantly reduces the carbon footprint of the mine.

The addition of wind energy could also be considered, which can further decrease the cost of energy and Scope 2 grid emissions.

A wind energy yield assessment was undertaken based on mesoscale meteorological data, which has been used to estimate the long-term energy production for the proposed wind turbines at Songwe Hill. The wind energy yield assessment is, however, still subject to high uncertainty as no site-measured data is available for analysis.

It is recommended that a detailed energy yield analysis and uncertainty assessment be conducted following the collection of a sufficient period of high-quality on-site data. On-site measurement is required for at least twelve months.

A comparison of the energy balance and the cost of energy is shown in Figure 21.5 and Figure 21.6, respectively, for the three different power supply options. This report 's cost of energy is based on grid with PV. By adding the wind energy component, the overall excess energy at 6.8 % is a marginal increase of 4.2 % compared to the grid with the PV excess energy of 2.6 %. The overall grid energy consumption, however, further decreases by an average of 15 % (16 % during the off-peak time and 13 % during the peak time, using the relevant tariffs for these periods), resulting in a further 19.8 % reduction in the cost of energy from US$0.138/kWh for a grid with PV to US$0.111/kWh for a grid with PV and wind energy.

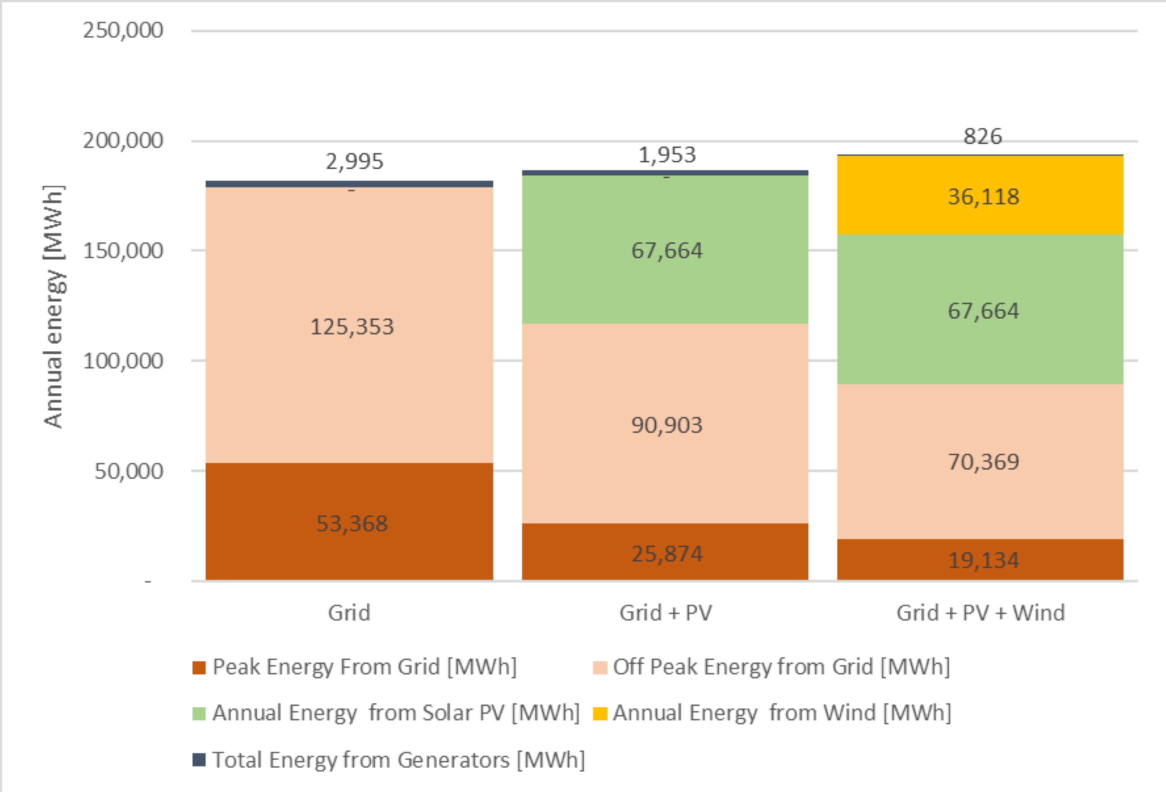

Figure 21.5: Energy Balance for the Three Different Energy Options

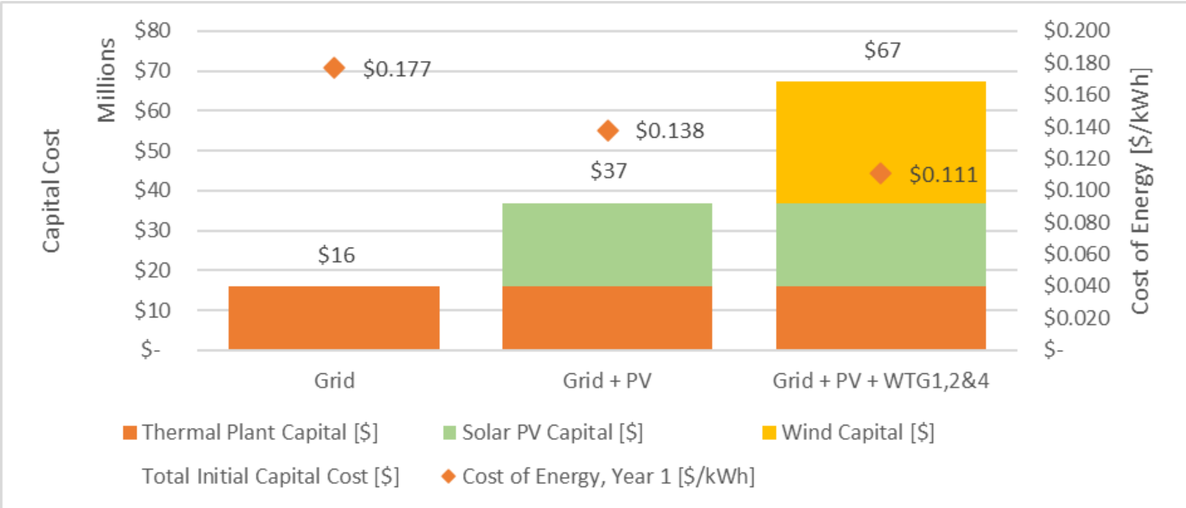

Figure 21.6: Cost of Energy and Initial CAPEX for the Three Different Energy Options

A trade-off between the three options was done, considering annual diesel cost, electricity cost, and initial CAPEX. Option 2 has been chosen as the base-case option to be presented in the OPEX, and Option 3 has been included as a potential opportunity although further detailed investigation is required.

Table 21.26 shows the trade-off between the three optimised power options evaluated by SENET and the SENERGY business unit. The base case used in the overall power cost is Option 2, comprising grid energy and a solar plant. Option 3 is potentially more economical over the life of the project but requires further detailed study to determine the cost of wind turbines with a higher degree of accuracy.

Table 21.26: Power Options Trade-Off

Option	Levelised Cost of Power (US$/kWh)	Diesel Cost (US$/a)	Electrical Power Cost (US$/a)	Total Power Cost (US$/a)
1: Grid	0.177	828,100	31,877,694	32,705,794
2: Grid + PV	0.138	554,878	24,944,555	25,499,432
3: Grid + PV + Wind	0.111	255,695	20,254,718	20,510,413

Thermal Generation

A fuel farm with emergency diesel generator sets has been sized for an assumed duration of grid power unavailability. The diesel cost in Malawi has been determined from TOTAL to be US$1.124/L of fuel.

The backup diesel generators are configured to operate in a prime operating mode. Six backup generators have been allocated to allow for an n+1 redundancy.

The diesel generator parameters are provided in Table 21.27.

Table 21.27: Diesel Generator Sets

Item	Description
Prime Rated Power	2,000 kVA/1,600 kWe at 0.8 pf
Total Generation Capacity	8.0 MW/10 MVA at 0.8 pf, Prime
Rated Voltage	11 kV
Fuel Consumption, 100 % Load	0.248 L/kWh
Fuel Consumption, 75 % Load	0.251 L/kWh

Table 21.28 shows the summary for the power draw per plant area.

Table 21.28: Power Draw Summary

Plant Area	Description	Operating Power (kW)
1000	Administration, Mining, Buildings, Workshop, Canteen, Stores	2,357
2100	Primary Crushing	148
2200	Secondary Crushing	186
2300	Tertiary Crushing	281
2400	Milling and Classification	3,731
2500	Fine Grinding and Classification	1,358
3100	Pre-Float Rougher Flotation	517

Plant Area	Description	Operating Power (kW)
3200	Pre-Float Cleaner Flotation	39
3300	Rougher Flotation	923
3400	Cleaner Flotation	377
3500	Scavenger Flotation	407
3600	Cleaner Scavenger Flotation	397
3700	Concentrate Thickening and Filtration	121
3800	Tails Thickening and Filtration	592
3900	Tailings Storage Facility and Return Water	48
4100	Gangue Leach	202
4200	Caustic Conversion	174
4300	Cerium Oxidation	385
4400	Rare Earth Leach	106
4500	PLS Purification	119
4600	Uranium Ion Exchange	417
4700	Rare Earth Carbonate Precipitation	221
4800	Hydrometallurgical Tails Neutralisation	117
5100	Gangue Leach Liquor Neutralisation	131
5200	Acid Regeneration	138
5300	Caustic Evaporation	130
5400	Causticisation	164
5500	Scrubbing	5
6100	Caustic Make-Up	48
6100	Modifier M7	35
6100	Modifier M4P	36
6200	Frother	16
6300	Collector	37
6300	PAX	3
6400	Flocculant	30
7100	Lime Make-Up	49
7200	Sodium Sulphide	15
7200	Barium Chloride	15
7200	Calcium Sulphate	17
7300	Ammonium Bicarbonate	22
7400	Calcium Chloride	20
7600	Steam Plant	10,310
7600	Hot Water	7
8100	Air Services	669
8400	Process Water	76
	Process Water RO Plant	380
8500	Raw Water	158
8500	Gland Water	15
8600	Potable Water	116
	TOTAL	**25,863**

21.2.6.2.3 Plant Operating and Maintenance Labour

The estimated annual plant operating and maintenance labour cost was estimated at **US$2,893,580.** The cost was derived from first principles where the actual labour complement for each plant area and maintenance function was identified, and the required number of personnel and their levels were established. The complement derived was then benchmarked against other operations of similar size and complexity.

The operating and maintenance labour cost was broken down as follows:

- Management
- Finance and Administration
- Health, Safety, Security, Environment and Community
- Operations/Production
- Maintenance
- Metallurgy
- Laboratory

The following costs were excluded as they will be included in the G&A operating costs:

- Camp food and catering facility
- Expatriate travel
- Safety supplies
- Training
- Consultants' fees

The labour schedule was developed assuming a six-weeks-on and three-weeks-off roster for expatriate personnel and two 12-hour, two-shift cycles for Malawian national personnel.

The salaries for expatriate personnel and Malawian national personnel were based on remuneration rates in line with market rates internationally and in Malawi, considering the scenario of both qualified and unqualified labour availability in the mine locale. Expatriate personnel will be employed in some managerial and supervisory positions. The rest of the positions will be occupied by Malawi nationals local to the mine site.

Table 21.29 shows the labour cost summary.

Table 21.29: Process Plant Labour Cost Summary

Description	Concentrator Plant Employees	Hydrometallurgical Plant Employees	Total Cost (US$/a)
Subtotal Management	6		1,245,000
Subtotal Finance and Administration	77		272,969
Subtotal HSSEC	8		378,804
Subtotal Operations/Production	44	44	534,083
Subtotal Maintenance	25	23	256,168
Subtotal Metallurgy	6	5	206,557
Total Labour	**166**	**72**	**2,893,580**

21.2.6.2.4 Maintenance Parts and Supplies

The plant maintenance parts and supplies annual costs for the Songwe Hill Project were estimated at **US$2,816,157**. Plant maintenance and supplies costs refer to the costs of operating spares, lubricants and other maintenance-related consumables for the plant. It has been assumed that the plant will experience a moderate amount of wear. An average annual cost was calculated using the maintenance cost factors as shown in Table 21.30 for the various commodities. The annual maintenance cost is estimated by multiplying the total initial capital cost with a maintenance factor that has been determined by previous projects and observations on running plants. The total maintenance, parts and supplies OPEX is shown in Table 21.31.

Table 21.30: Plant Maintenance Cost Factors

Description	Maintenance Factor (%)
Mechanical Equipment Cost	5.0
Piping and Valves	2.5
Electricals	2.5
Instrumentation	1.0

Table 21.31: Plant Maintenance, Parts and Supplies OPEX

Description	Unit	Quantity
Machinery and Equipment		
Mechanical Equipment Capital Cost	US$	47,953,584
Factor	%	5.0
Total Annual Cost	US$	2,397,679
Piping and Valves		
Piping and Valves Capital Cost	US$	5,373,198
Factor	%	2.5
Total Annual Cost	US$	53,732
Electricals		
Electrical Infrastructure Capital Cost	US$	9,772,651
Factor	%	2.5
Total Annual Cost	US$	244,316
Instrumentation		
Instrumentation Capital Cost	US$	4,817,199
Factor	%	1.0
Total Annual Cost	US$	120,430
Maintenance Parts and Supplies Cost	**US$/a**	**2,816,157**
Maintenance Parts and Supplies Cost	**US$/t ROM**	**2.82**

21.2.7 TSF Operating Costs

The OPEX associated with the TSF has been estimated at US$8.18 million over the LOO, based on a tailings dam design and costing study completed by Epoch.

Epoch proposed a five-phase design, construction and expansion programme over the life of the project to distribute the CAPEX, but also to continuously provide a sufficient storage facility for the solid tailings.

The moisture accompanying the process plant tailings will return to the plant via a return water dam and be used as processed water, purified by a reverse osmosis plant where required.

The OPEX of US$0.34 to US$0.49 million per annum comprises the following:

- US$0.2 million per annum for operational management, comprising a team leader/manager, a supervisor, unskilled labour, and a spares workshop. This team shall be responsible for the following:
    - Day-to-day depositional management
    - Maintenance of the pool wall
    - Maintenance of and repairs to the slurry delivery pipeline and valves
    - Monitoring and cleaning of the drains
    - Monitoring of the seepage collection sump pump
    - General maintenance (cleaning trenches)
    - Monitoring of various components (freeboard, drain flows, water returns, rainfall, tonnes deposited, etc.)
- US$0.08 to US$0.23 million per annum for pipeline and valve replacement costs and maintenance as the TSF and pipeline expand over the LOO
- US$0.06 million per annum for quarterly inspections, monitoring and quarterly reports by the design engineer

22 ECONOMIC ANALYSIS

A discounted cash flow model prepared by Mkango was reviewed by SENET and a third party. This model incorporates the LOO plan figures, economic assumptions as to the USA inflation rates, and the rare earth oxide and carbonate prices as outlined in Section 19.2. The escalation/de-escalation technique has been employed to ensure that the quantum and timing of any taxes payable are calculated correctly. The financial evaluation has been undertaken on an after-tax, unleveraged basis.

A range of discount rates were used to determine the NPV; the NPVs are set at 01 July 2022.

A sensitivity analysis shows the impact on the NPV and IRR to changes in the metal prices, CAPEX, and OPEX.

22.1 RARE EARTH PRICE ASSUMPTIONS

Base case long-term rare earth price assumptions were derived from Adamas Intelligence's base case pricing scenario outlined in Section 19.2.

Two additional pricing scenarios were also analysed, based on Adamas Intelligence's upside and downside cases.

22.2 MALAWIAN FISCAL REGIME

Malawi follows a tax concession regime. The prevailing taxation regime for mining companies in Malawi includes the following provisions, which were incorporated into the financial model where applicable:

- The corporate income tax (CIT) is 30 %.
- Exploration, development and capital costs can be expensed against profit in the year incurred or carried forward to be expensed against future assessable income over the LOO.
- Mine-specific expenditure is subject to an annual allowance according to the expected LOO.
- Mine start-up expenditure is allowed a 100 % tax depreciation in the year incurred.
- The mineral royalty is at a rate of 5 % of the revenue; the revenue represents the royalty base.
- Losses arising from mine expenditure and revenue expenditure can be carried forward up to 10 years.
- Resource rent tax is 15 % on after-tax project resource rent. The determination of the after-tax project resource rent is provided in the Sixteenth Schedule of the Taxation Act whereby the adjusted assessable income is in excess of the adjusted deductions of the year.
- The legislated thin capitalisation ratio – the debt-to-equity ratio for a mining project – is 3 to 1 (3:1) for the first five years and 1.5 to 1 (1.5:1) thereafter.
- The debt deduction limit – allowable interest for tax deduction purposes – is limited to the proportion of the legislated debt-to-equity ratio (3:1) for the first five years and 1.5:1 thereafter.
- Contributions to a qualifying mine closure fund in respect of the mining project are deductible as an expenditure in carrying on the activities of the project; where the mine

closure fund pays out to the company to enable the company to make expenditures, the payment is treated as a receipt in relation to the activities.

- Upon effective change of control of the mining project, the amount by which the value of the assets exceeds the value of the liabilities of the project shall be included as income – taxable income.
- Only 50 % of the corporate social responsibility (CSR) contributions towards the construction of a public hospital or school is allowable for deduction. Any donations made to charitable or non-profit organisations as listed in the gazette are allowable for deduction.
- Community development expenditure arising from a community development agreement (CDA) with qualifying communities affected by operations is 0.45 % (minimum) of the company's gross sales revenue; this CDA expenditure's deductibility for tax purposes has not yet been legislated.
- The Government shall have the right, but not the obligation, to acquire directly or through a Government nominee, without cost, a free equity ownership interest of up to 10 % in the mining project based on the large-scale mining licence; this shall be on election of the Government to require this free equity ownership interest.
- The free equity ownership interest shall not affect the entitlement of the Government to receive taxes, royalties, ground rents, fees or any levy or compensation payable to it.
- Management fees and services fees paid to an affiliate, interest payments to project lenders, financing costs (non-arm's length) are subject to transfer pricing regulations if paid to related parties. If paid to a non-resident, non-resident tax (NRT) at 10 % shall apply subject to double taxation agreements.
- NRT is payable on income derived by way of interest, payment for independent services, or dividends.
- The company is liable for the payment of fringe benefit tax where fringe benefits are provided to its employees; fringe benefit tax is 30 % of the computed taxable value of the fringe benefits.
- Various rates of withholding tax shall apply before making payments for goods and services specified in the principal Act's Fourteenth Schedule.
- The input VAT at 16.5 % is offset and claimed against the zero-rated output VAT on exports.
- The deduction of realised foreign exchange losses is restricted to unrealised gain that will remain after all the assets and liabilities are disposed of on the last day of the year of assessment – Section 28(5) of the Taxation Act.
- Capital gains realised on the disposal or transfer of shares attract a 15 % non-resident tax subject to double taxation agreements; for residents, there is a provisional tax of 30 %.
- An advance pricing agreement (APA) can be entered into with the Commissioner General on the basis that particular conditions, including conditions of fact, are satisfied; such an agreement shall not be for longer than five successive years.
- Tax on dividends shall be deducted as withholding tax at 10 % for residents and as non-resident tax at 10 % for non-residents.
- Direct importation of specialised goods for use in mining (machinery, plant and equipment) is duty free; import duty, excise duty, and import VAT are not charged on these imported specialised items under customs procedure Code 4000.481.

- Import duty and excise duty are not charged on reagents and consumables except for an import VAT of 16.5 %.
- Duties on all other imports are subject to the customs and excise tariff orders from the authorities in line with the relevant tariff heading.

22.3 MINERAL RESOURCE AND MINERAL RESERVE ESTIMATES

The Feasibility Study for the Songwe Hill Rare Earth Project based on the NI 43-101 Mineral Resource Estimate prepared by MSA entitled “NI 43-101 Technical Report – 23 January 2019 Mineral Resource Estimate” was filed on 03 February 2020. The Report's Mineral Resource Estimates, as previously announced, are summarised in Table 22.1.

Table 22.1: Measured, Indicated and Inferred Mineral Resource Estimate

	0.5% TREO cut off grade			Base Case 1.0% TREO cut off grade			1.5% TREO cut off grade		
	Million tonnes	TREO %	TREO tonnes	Million tonnes	TREO %	TREO tonnes	Million tonnes	TREO %	TREO tonnes
Resource Categories									
Measured	13.34	1.26	167,573	8.81	1.50	131,929	3.67	1.86	68,278
Indicated	24.30	1.06	258,092	12.22	1.35	165,469	3.13	1.79	55,805
Total Measured & Indicated	**37.64**	**1.13**	**425,665**	**21.03**	**1.41**	**297,398**	**6.80**	**1.83**	**124,084**
Total Inferred	59.65	1.02	608,194	27.54	1.33	366,154	5.92	1.75	103,414

NOTE: TREO – Total Rare Earth Oxides including yttrium; In situ – no geological losses applied

This report supports the declaration of a Mineral Reserve Estimate for the project as summarised below and outlined in Sections 15.3.3 and 15.5.

The work reported in this report has demonstrated that a portion of the resources stated in the Mineral Resource statement can be viably mined, processed and sold and will support a sustainable mining and processing operation.

Applying the mining modifying factors, process recovery, operating costs and product prices, the project is shown to be profitable and viable. This work supports the declaration of Mineral Reserves under NI 43-101.

Although the Qualified Person was not responsible for the completion of the processing, tailings storage, environmental and financial modelling sections of this report, the QP has relied on the specialists in these fields for completion of their respective sections. The QP has reviewed the sections completed by others and has found no reason not to accept their work. The results of the DFS have shown that the mining inventory included in the study, which is derived from only Measured and Indicated Mineral Resources, can be viably mined based on the techno-economic assumptions documented in this report.

In estimating the Mineral Reserves, only material from the Measured and Indicated Mineral Resources has been included in the inventory. Mineral Reserves resulting from Measured Mineral Resources have been considered as Proven Mineral Reserves while those generated from Indicated Mineral Resources are categorised as Probable Mineral Reserves. Table 22.2 shows a summary of the total Mineral Reserves.

Table 22.2: Mineral Reserve Summary as at 31 December 2021

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

NOTE:

- Type 2 material, which is mineralised material with a grade above the cut-off grade but with an Mn:Mg ratio of greater then 3.5, is stockpiled on site for possible future processing. This material is excluded from both the ROM ore inventory and any Mineral Reserve estimate.
- Inferred resources are not considered as ore in the mine plan and as such are treated as waste and not included in the ROM ore inventory.

The following modifying factors were used to convert the Mineral Resource Estimate to the Mineral Reserve Estimate: Mining recovery – 95 %; mining dilution – 9 %; TREO recovery – 39.6 %; product price – US$68.2/kg TREO; operating cost – US$30.2/kg TREO recovered.

Indicated Mineral Resources are inclusive of Mineral Reserves. Mineral Resources that are not Mineral Reserves do not have demonstrated economic viability. The financial valuation is based on the mining of the ROM Type 1 ore (high grade and medium grade), 18,246,334 t of estimated Mineral Reserves only.

22.4 MINING AND PROCESSING ASSUMPTIONS

The mining and processing inputs to the financial model are based on those as outlined in Section 16.6 and summarised below. Table 22.3 to Table 22.5 are sourced from the Songwe Hill financial model.

Table 22.3: Summary of Mining and Processing Inputs and Results – Average over First Five Years

Item	Unit	Value
Mining		
Average yearly ore mined	kt	2,186
Average TREO grade mined	%	1.19
Average yearly waste mined	kt	3,667
Average strip ratio (waste:ore)		1.68
Processing		
Average yearly flotation plant feed	kt	1,000.8
Average head TREO grade	%	1.50
Flotation TREO concentrate grade	%	15.05
Average TREO recovery to concentrate	%	74.10
Average yearly flotation concentrate feed to hydrometallurgical plant	kt	74.06
Average NdPr oxide hydrometallurgical recovery to carbonate	%	85.26

Item	Unit	Value
Average Ce oxide hydrometallurgical recovery to carbonate	%	20.88
Average yearly TREOs in carbonate product	kt	5,954
Average carbonate TREO grade	%	55
Average yearly carbonate production	t/a	10,826
NOTE: The first 5 years refer to the 60 months from the start of processing in September 2025. Mining excludes the first 5 months of mined and stockpiled ore prior to the start of processing (819,437 t at 1.00 % TREO).		

Table 22.4: Summary of Mining and Processing Inputs and Results – LOO

Item	Unit	Value
LOO	Years	18
Mining		
Average yearly ore mined	kt	1,481.5
Average TREO grade mined	%	1.16
Average yearly waste mined	kt	3,310.5
Average strip ratio (waste:ore)		2.2
Processing		
Average yearly flotation plant feed	kt	1,000.80
Average head TREO grade	%	1.16
Flotation TREO concentrate grade	%	11.64
Average TREO recovery to concentrate	%	74.10
Average yearly flotation concentrate feed to hydrometallurgical plant	kt	74.06
Average NdPr oxide hydrometallurgical recovery to carbonate	%	85.26
Average Ce oxide hydrometallurgical recovery to carbonate	%	20.88
Average yearly TREOs in carbonate product	t	4,633.56
Average carbonate TREO grade	%	55.00
Average yearly carbonate production (dry basis)	t	8,424.65

Table 22.5: Summary of Mining and Processing Inputs and Results – Total LOO

Item	Unit	Value
Mining		
Total LOO ore production	kt	18,147.8
Waste mined	kt	40,553.9
Strip ratio (waste:ore)		2.2
Total LOO plant feed	kt	18,127.0
Average yearly plant feed	kt	982.0
Processing		
Tonnes to hydrometallurgical plant	kt	1,341.4
Contained REOs in carbonate product	kt	83.4
Total carbonate production (dry basis)	t	151,644

22.5 CAPITAL AND OPERATING COSTS

The capital and operating cost inputs to the financial model (see Table 22.6 to Table 22.8) are those as outlined in Section 21.

Table 22.6: Capital Costs

Item	Unit	Value
Total real development capital	US$ million	277.4
Contingency	US$ million	33.8
Total Real Development Capital Including Contingency	**US$ million**	**311.2**
Sustaining capital and reclamation	US$ million	77.6
Total Real Capital Expenditure	**US$ million**	**388.8**

Table 22.7: Operating Costs – Average over First Five Years

Item	Unit	Value
Mining	US$/kg TREO	4.8
Beneficiation – Milling and Flotation	US$/kg TREO	7.9
Hydrometallurgical Plant	US$/kg TREO	10.8
G&A and Other	US$/kg TREO	1.8
Total Operating Costs	**US$/kg TREO**	**25.3**

Table 22.8: Operating Costs – Average over LOO

Item	Unit	Value
Mining	US$/kg TREO	3.9
Beneficiation – Milling and Flotation	US$/kg TREO	10.2
Hydrometallurgical Plant	US$/kg TREO	13.8
G&A and Other	US$/kg TREO	2.2
Total Operating Costs	**US$/kg TREO**	**30.1**

22.6 DISCOUNTED CASH FLOW VALUATION ANALYSIS

Based on the preceding assumptions, the discounted cash flow valuation analysis for the base case gave the following results:

- NPV at 10 % (nominal) (7.3 % real) of US$559 million as at 1 July 2022
- IRR of 31.47 % (nominal) (28.26 % real)

Table 22.9 and Table 22.10 summarise selected financial inputs and the corresponding results. All costs are quoted in real June 2022 United States dollars (US$).

Table 22.9: Summary of Selected Financial Inputs and Corresponding Results – Post-Tax Valuation

Item	Unit	Value
Project cash flow post-tax (nominal) (including royalty)	US$ million	2,083.3
Payback period from project start	Years	5.0
Payback period from start of production	Years	2.56
Post-tax NPV at 10 % (nominal) discount rate	US$ million	559.0
Post-tax IRR (nominal)	%	31.47

Table 22.10: NPVs of Songwe Hill Project[1]

Financial Evaluation	Nominal Discount Rate (%)	Real Discount Rate (%)	Adamas Intelligence Base Case Post-Tax NPV (US$ million)	Adamas Intelligence Upside Case Post-Tax NPV (US$ million)	Adamas Intelligence Downside Case Post-Tax NPV (US$ million)
	8.0	5.37	719.3	1,007.2	431.6
Base Case	**10.0**	7.32	559.0	801.4	316.5
	12.0	9.27	435.0	641.1	228.5
Nominal IRR			31.47 %	39.20 %	22.70 %
Real IRR			28.26 %	35.80 %	19.71 %
[1] As at 1 July 2022					

22.7 SENSITIVITY ANALYSIS

The sensitivity chart (see Figure 22.1) shows the nominal NPV at a 10 % variation for the base case due to changes in revenue, capital and operating costs, holding all other inputs constant. The project is most sensitive to the metal prices and more sensitive to OPEX than to CAPEX. The revenue sensitivity assumes that all rare earth metal prices change by the same percentage and that the tolling rate does not change with rare earth prices.

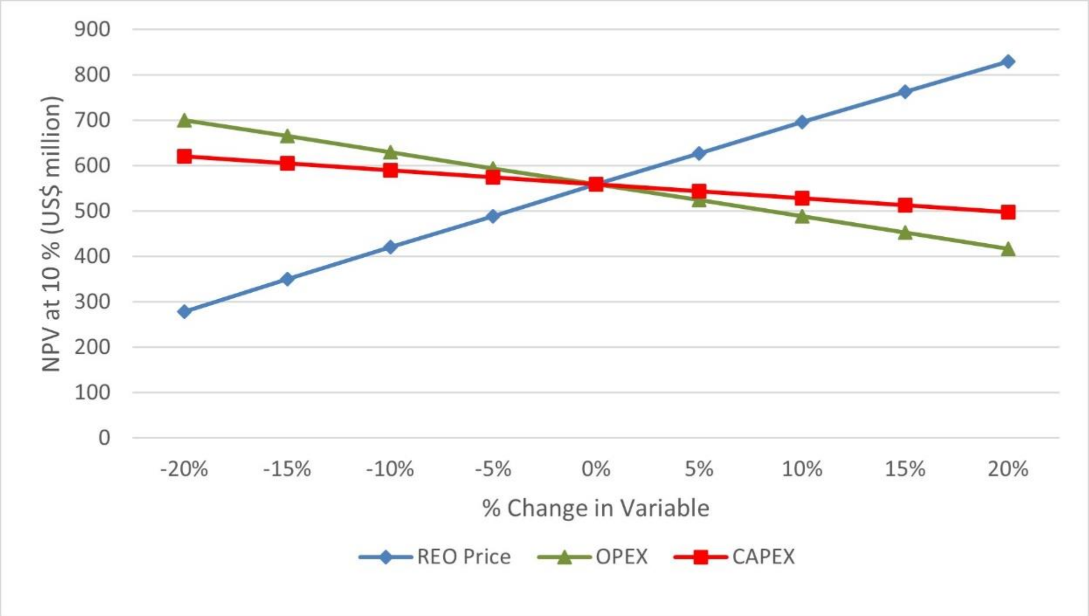

Figure 22.1: NPV at 10 % Nominal Sensitivity Analysis

Figure 22.2 shows the nominal annual cash flows over the life of the project.

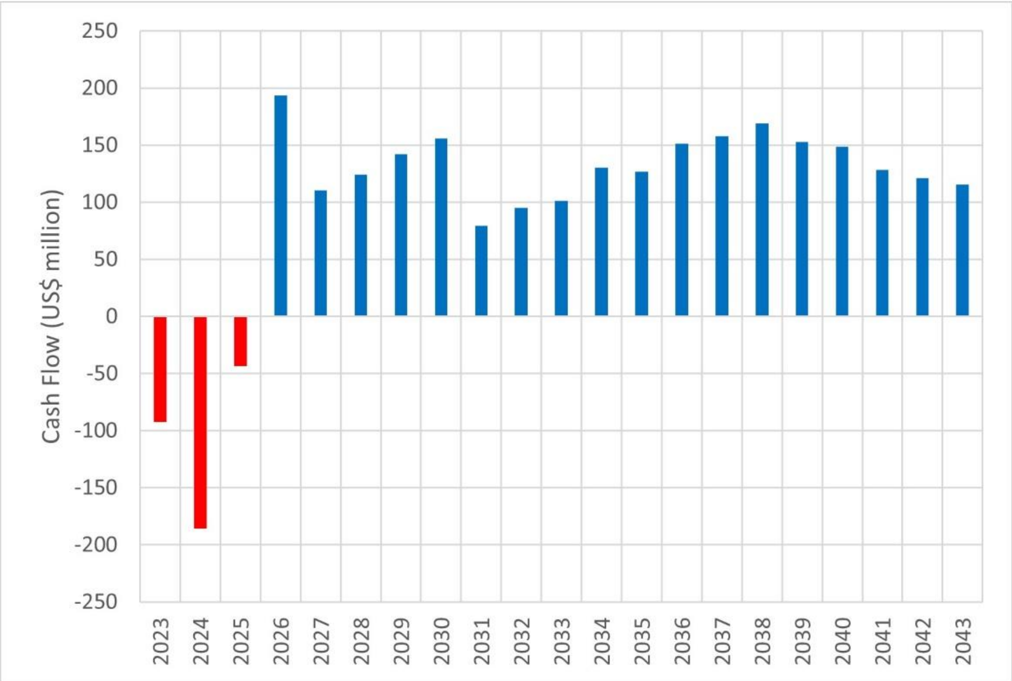

Figure 22.2: Annual Cash Flow (Nominal)

The maximum negative cash flow of US$186 million (nominal) occurs in 2024 as shown in the cumulative cash flow graph (see Figure 22.3).

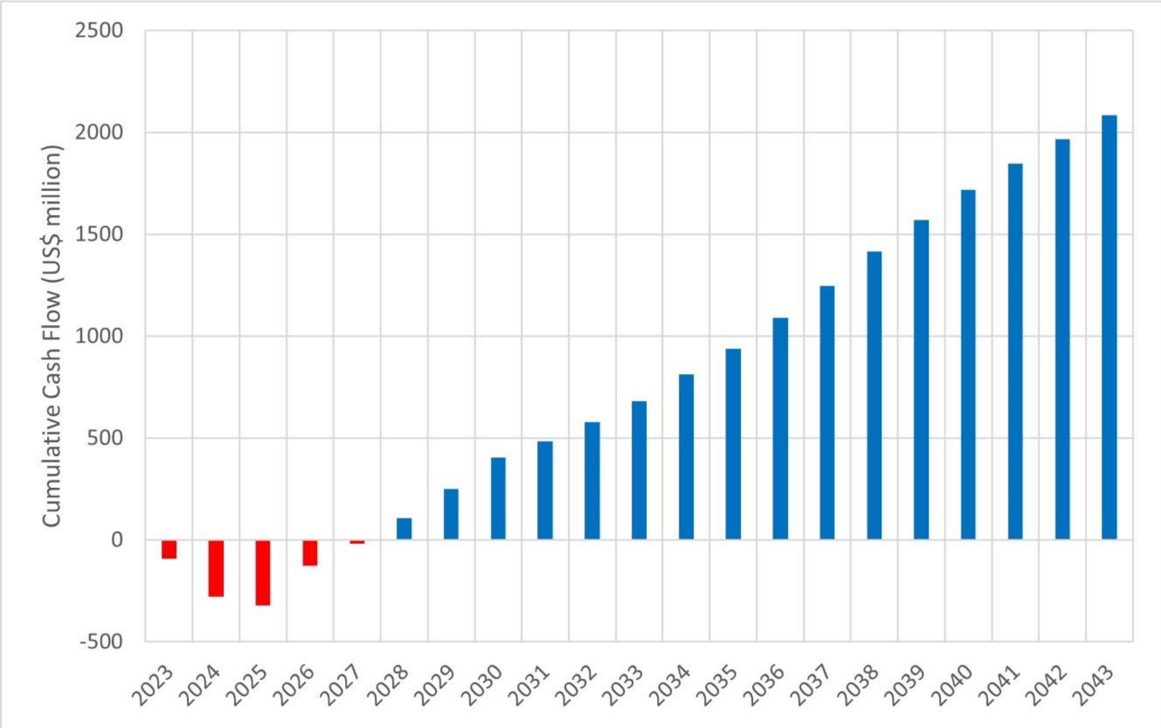

Figure 22.3: Cumulative Annual Cash Flow (Nominal)

Table 22.11 to Table 22.13 show the matrices of the NPV for percentage variations in revenue (all metals), OPEX, and CAPEX.

Table 22.11: Sensitivity of NPV (Nominal) to Changes in Metal Prices (All Metals)

		Revenue						
		NPV (US$ million)						
Nominal Discount Rate: -->	**558.97**	**0.0 %**	**9.0 %**	**10.0 %**	**11.0 %**	**12.0 %**	**13.0 %**	**14.0 %**
Change in Metal Prices	20 %	2,891.18	931.78	830.08	740.53	661.44	591.41	529.22
	15 %	2,690.93	858.10	763.04	679.36	605.47	540.05	481.98
	10 %	2,489.54	783.89	695.51	617.73	549.07	488.30	434.37
	5 %	2,287.01	709.15	627.49	555.64	492.23	436.14	386.38
	0 %	2,083.34	633.88	558.97	493.09	434.97	383.58	338.01
	-5 %	1,878.53	558.08	489.96	430.08	377.28	330.62	289.26
	-10 %	1,672.58	481.44	420.14	366.27	318.81	276.88	239.76
	-15 %	1,465.48	404.00	349.53	301.69	259.58	222.42	189.54
	-20 %	1,257.25	326.03	278.42	236.65	199.92	167.54	138.93

Table 22.12: Sensitivity of NPV (Nominal) to Changes in OPEX

		OPEX NPV (US$ million)						
Nominal Discount Rate: -->	558.97	0.0 %	9.0 %	10.0 %	11.0 %	12.0 %	13.0 %	14.0 %
Change in OPEX	20 %	1,680.30	478.81	417.16	363.01	315.32	273.23	235.97
	15 %	1,781.06	517.79	452.83	395.76	345.48	301.07	261.74
	10 %	1,881.82	556.55	488.28	428.28	375.39	328.65	287.24
	5 %	1,982.58	595.21	523.63	460.68	405.18	356.11	312.63
	0 %	2,083.34	633.88	558.97	493.09	434.97	383.58	338.01
	-5 %	2,184.10	672.54	594.32	525.49	464.77	411.04	363.39
	-10 %	2,284.86	711.20	629.66	557.90	494.56	438.51	388.77
	-15 %	2,385.62	749.86	665.01	590.30	524.35	465.97	414.16
	-20 %	2,486.38	788.53	700.35	622.71	554.14	493.44	439.54

Table 22.13: Sensitivity of NPV (Nominal) to Changes in CAPEX

		CAPEX NPV (US$ million)						
Nominal Discount Rate: -->	558.97	0.0 %	9.0 %	10.0 %	11.0 %	12.0 %	13.0 %	14.0 %
Change in CAPEX	20 %	1,996.76	570.65	497.36	432.97	376.25	326.17	281.85
	15 %	2,018.40	586.46	512.76	448.00	390.93	340.53	295.89
	10 %	2,040.05	602.27	528.16	463.03	405.61	354.88	309.93
	5 %	2,061.69	618.07	543.57	478.06	420.29	369.23	323.97
	0 %	2,083.34	633.88	558.97	493.09	434.97	383.58	338.01
	-5 %	2,104.98	649.68	574.38	508.12	449.65	397.93	352.05
	-10 %	2,126.63	665.49	589.78	523.15	464.33	412.28	366.09
	-15 %	2,148.27	681.29	605.18	538.18	479.01	426.63	380.13
	-20 %	2,169.92	697.10	620.59	553.21	493.69	440.98	394.17

Table 22.14 shows the effect on the NPV at 10 % for a two-way variation in OPEX and CAPEX.

Table 22.14: Sensitivity of NPV at 10 % (Nominal) to Two-Way Variation in OPEX and CAPEX

		NPV at 10 % (Nominal) (US$ million) Change in OPEX								
	558.97	20.00 %	15.00 %	10.00 %	5.00 %	0 %	-5.00 %	-10.00 %	-15.00 %	-20.00 %
Change in CAPEX	20 %	355.54	391.22	426.67	462.01	497.36	532.70	568.05	603.39	638.74
	15 %	370.94	406.62	442.07	477.42	512.76	548.11	583.45	618.80	654.14
	10 %	386.35	422.03	457.47	492.82	528.16	563.51	598.85	634.20	669.54
	5 %	401.75	437.43	472.88	508.22	543.57	578.91	614.26	649.60	684.95
	0 %	417.16	452.83	488.28	523.63	558.97	594.32	629.66	665.01	700.35
	-5 %	432.56	468.24	503.69	539.03	574.38	609.72	645.07	680.41	715.76
	-10 %	447.96	483.64	519.09	554.44	589.78	625.12	660.47	695.81	731.16
	-15 %	463.37	499.05	534.49	569.84	605.18	640.53	675.87	711.22	746.56
	-20 %	478.77	514.45	549.90	585.24	620.59	655.93	691.28	726.62	761.97

22.8 FREE CASH FLOW FORECASTS

Table 22.15 shows the DCF model for the Songwe Hill Project in nominal terms.

Table 22.15: Cash Flow Model – Songwe Hill Project

Item	Unit	Total	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Mining and Processing Plan																							
Waste	t	12,119,018	0	0	1,997,038	362,915	407,238	2,083,956	2,006,151	1,709,896	1,232,559	975,136	603,905	538,777	172,964	21,318	7,166	0	0	0	0	0	0
Measured and Indicated Tonnes	t	35,324,364	0	0	4,498,713	5,265,602	4,922,070	2,093,824	2,990,099	2,185,224	1,616,365	1,994,636	1,934,959	2,567,231	2,497,746	2,104,389	653,507	0	0	0	0	0	0
Indicated Tonnes	t	11,258,330	0	0	1,894,124	409,481	497,148	1,297,221	478,751	577,111	801,076	680,228	1,111,137	553,992	979,290	1,524,293	454,479	0	0	0	0	0	0
Stripping ratio W:O		2.23	0.00	0.00	3.31	1.32	1.24	2.54	1.59	2.94	5.50	5.36	3.73	2.24	2.22	1.41	1.16	0.00	0.00	0.00	0.00	0.00	0.00
Total Ore	t	58,701,712	0	0	8,389,874	6,037,998	5,826,456	5,475,000	5,475,001	4,472,230	3,650,000	3,650,000	3,650,000	3,660,000	3,650,000	3,650,000	1,115,152	0	0	0	0	0	0
Type 1 Ore	t	18,147,781	0	0	1,948,115	2,599,084	2,605,299	1,547,300	2,114,563	1,133,694	561,507	573,650	772,402	1,129,056	1,133,520	1,514,106	515,486	0	0	0	0	0	0
Type 1 Ore Processed	t	18,127,011	0	0	412,830	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	1,000,800	700,581
Grade processed	%	1.16%	0.00%	0.00%	1.49%	1.46%	1.46%	1.50%	1.55%	1.46%	1.07%	1.01%	1.00%	1.11%	1.11%	1.11%	1.09%	1.09%	1.09%	0.94%	0.88%	0.88%	0.88%
REO entering processing	t	210,672	0	0	6,134	14,593	14,568	15,015	15,497	14,618	10,698	10,072	10,055	11,080	11,113	11,136	10,938	10,928	10,928	9,455	8,831	8,831	6,182
REO in flotation concentrate	t	156,095	0	0	4,545	10,813	10,794	11,125	11,482	10,831	7,927	7,463	7,450	8,209	8,234	8,251	8,104	8,097	8,097	7,006	6,543	6,543	4,580
REO in mixed chemical carbonate	t	80,957	0	0	2,429	5,777	5,767	5,944	6,135	5,787	4,235	3,988	3,981	4,386	4,400	4,409	4,330	4,326	4,326	3,743	3,496	3,496	
REO Value In Carbonate (Nominal)																							
Total	**US$**	**10,501,870,263**	**0**	**0**	**218,697,382**	**520,839,338**	**526,732,236**	**546,888,764**	**597,239,022**	**604,691,791**	**478,706,147**	**481,271,047**	**507,211,407**	**589,580,851**	**623,282,907**	**640,156,935**	**644,517,421**	**660,006,543**	**676,506,706**	**599,985,387**	**574,381,314**	**588,740,846**	**422,434,220**
Carbonate basket discount (nominal)	US$	2,835,504,971	0	0	59,048,293	140,626,621	142,217,704	147,659,966	161,254,536	163,266,784	129,250,660	129,943,183	136,947,080	159,186,830	168,286,385	172,842,372	174,019,704	178,201,767	182,656,811	161,996,054	155,082,955	158,960,029	114,057,239
Total Revenue After Discount (Nominal)	**US$**	**7,666,365,292**	**0**	**0**	**159,649,089**	**380,212,717**	**384,514,532**	**399,228,798**	**435,984,486**	**441,425,008**	**349,455,487**	**351,327,865**	**370,264,327**	**430,394,021**	**454,996,522**	**467,314,562**	**470,497,717**	**481,804,776**	**493,849,896**	**437,989,332**	**419,298,359**	**429,780,818**	**308,376,980**
Royalty	US$	383,318,265	0	0	7,982,454	19,010,636	19,225,727	19,961,440	21,799,224	22,071,250	17,472,774	17,566,393	18,513,216	21,519,701	22,749,826	23,365,728	23,524,886	24,090,239	24,692,495	21,899,467	20,964,918	21,489,041	15,418,849
Net Revenue (nominal)	US$	**7,283,047,028**	**0**	**0**	**151,666,635**	**361,202,081**	**365,288,806**	**379,267,358**	**414,185,262**	**419,353,757**	**331,982,713**	**333,761,471**	**351,751,111**	**408,874,320**	**432,246,696**	**443,948,834**	**446,972,832**	**457,714,537**	**469,157,401**	**416,089,866**	**398,333,441**	**408,291,777**	**292,958,131**
OPERATING COSTS (US$) (REAL)																							
Mining OPEX																							
TSF costs	US$	7,464,250	0	0	204,500	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	409,000	306,750
Mining cost (Bara)	US$	327,229,346	0	0	34,705,344	29,621,997	27,290,569	28,225,435	26,329,843	23,723,733	21,393,945	21,541,247	21,326,073	21,407,052	21,101,607	20,855,724	10,489,043	2,969,682	2,969,682	3,404,864	3,589,369	3,589,369	2,694,770
Milling/ flotation OPEX																							
Milling/flotation total	**US$**	**837,720,539**	**0**	**0**	**19,319,362**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**46,229,239**	**32,504,121**
Hydrometallurgical Plant OPEX																							
Hydrometallurgical plant total	**US$**	**1,142,511,536**	**0**	**0**	**26,623,620**	**63,861,128**	**63,854,165**	**63,975,533**	**64,106,459**	**63,867,886**	**62,803,604**	**62,633,608**	**62,628,824**	**62,907,160**	**62,916,186**	**62,922,288**	**62,868,639**	**62,865,834**	**62,865,834**	**62,466,057**	**62,296,563**	**62,296,563**	**43,751,585**
Total processing	US$	**1,999,469,473**	**0**	**0**	**46,470,033**	**111,144,470**	**111,137,507**	**111,258,876**	**111,389,802**	**111,151,228**	**110,086,947**	**109,916,951**	**109,912,166**	**110,190,502**	**110,199,529**	**110,205,631**	**110,151,981**	**110,149,177**	**110,149,177**	**109,749,400**	**109,579,906**	**109,579,906**	**77,046,283**
G&A/Other (real)																							
G&A	US$	99,613,244	516,131	1,548,392	4,645,177	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308	5,161,308
Concentrate transport	US$	59,242,110	0	0	1,725,014	4,103,756	4,096,545	4,222,248	4,357,850	4,110,756	3,008,460	2,832,393	2,827,437	3,115,715	3,125,064	3,131,384	3,075,818	3,072,913	3,072,913	2,658,857	2,483,309	2,483,309	1,738,369

Item	Unit	Total	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Community Development Agreement (0.45 %)	US$	25,587,646	0	0	667,125	1,550,043	1,529,347	1,549,142	1,650,504	1,630,341	1,259,185	1,235,055	1,269,878	1,440,099	1,485,287	1,488,291	1,461,881	1,460,501	1,460,501	1,263,707	1,180,272	1,180,272	826,215
Total G&A and other costs	US$	184,443,000	516,131	1,548,392	7,037,316	10,815,107	10,787,199	10,932,698	11,169,662	10,902,405	9,428,954	9,228,756	9,258,623	9,717,122	9,771,659	9,780,982	9,699,007	9,694,722	9,694,722	9,083,872	8,824,889	8,824,889	7,725,892
Total cash operating costs (real)	**US$**	**2,518,606,069**	**516,131**	**1,548,392**	**88,417,193**	**151,990,574**	**149,624,275**	**150,826,008**	**149,298,307**	**146,186,367**	**141,318,845**	**141,095,954**	**140,905,863**	**141,723,677**	**141,481,795**	**141,251,337**	**130,749,031**	**123,222,581**	**123,222,581**	**122,647,136**	**122,403,164**	**122,403,164**	**87,773,695**
Cash costs (nominal)	**US$**	**3,386,874,295**	**529,034**	**1,626,780**	**95,215,647**	**167,769,155**	**169,286,134**	**174,911,929**	**177,468,770**	**178,113,893**	**176,487,873**	**180,614,750**	**184,880,703**	**190,602,589**	**195,034,217**	**199,584,441**	**189,363,582**	**182,924,614**	**187,497,729**	**191,287,675**	**195,679,840**	**200,571,836**	**147,423,105**
Earnings before interest, taxes, depreciation, and amortisation	**US$**	**3,896,172,733**	**-529,034**	**-1,626,780**	**56,450,988**	**193,432,926**	**196,002,672**	**204,355,429**	**236,716,491**	**241,239,865**	**155,494,840**	**153,146,721**	**166,870,408**	**218,271,731**	**237,212,479**	**244,364,394**	**257,609,249**	**274,789,924**	**281,659,672**	**224,802,191**	**202,653,601**	**207,719,941**	**145,535,026**
% margin			na	na	35%	51%	51%	51%	54%	55%	44%	44%	45%	51%	52%	52%	55%	57%	57%	51%	48%	48%	47%
Earnings before interest and taxes	US$	3,412,228,423	-52,199,641	-109,461,530	16,769,376	185,578,199	187,184,156	195,312,891	227,443,999	231,731,287	144,407,238	141,776,691	155,210,270	206,313,487	222,907,734	229,693,358	242,561,279	259,353,605	261,355,434	203,971,201	181,275,672	178,975,984	102,067,732
CAPEX (including sustaining CAPEX)																							
Total real development CAPEX	US$	**388,790,791**	**89,548,925**	**175,448,281**	**52,938,947**	**49,101**	**11,530,890**	**49,101**	**49,101**	**49,101**	**13,962,328**	**49,101**	**49,101**	**49,101**	**13,367,976**	**49,101**	**49,101**	**49,101**	**14,727,780**	**49,101**	**49,101**	**8,338,229**	**8,338,229**
Total CAPEX (real)	**US$**	**388,790,791**	**89,548,925**	**175,448,281**	**52,938,947**	**49,101**	**11,530,890**	**49,101**	**49,101**	**49,101**	**13,962,328**	**49,101**	**49,101**	**49,101**	**13,367,976**	**49,101**	**49,101**	**49,101**	**14,727,780**	**49,101**	**49,101**	**8,338,229**	**8,338,229**
Total CAPEX (nominal)	US$		91,787,648	184,330,350	57,009,456	54,198	13,046,143	56,942	58,365	59,824	17,437,034	62,853	64,424	66,035	18,427,903	69,378	71,112	72,890	22,410,059	76,580	78,495	13,663,159	14,004,738
Depreciation (real)	**US$**	**388,790,791**	**50,410,348**	**102,638,668**	**36,848,322**	**7,115,995**	**7,794,283**	**7,797,352**	**7,800,625**	**7,804,132**	**8,878,157**	**8,882,249**	**8,886,713**	**8,891,623**	**10,376,954**	**10,383,091**	**10,390,106**	**10,398,289**	**13,343,845**	**13,356,120**	**13,372,487**	**17,541,601**	**25,879,830**
Depreciation (nominal)	US$	483,944,310	51,670,607	107,834,750	39,681,612	7,854,727	8,818,516	9,042,538	9,272,492	9,508,577	11,087,602	11,370,030	11,660,137	11,958,244	14,304,745	14,671,036	15,047,971	15,436,318	20,304,238	20,830,989	21,377,929	28,743,957	43,467,294
Cash flow (nominal - with inflation)	**US$**	**2,083,337,636**	**-92,293,170**	**-185,908,341**	**-23,013,226**	**179,351,419**	**105,134,238**	**124,480,442**	**142,236,008**	**155,961,592**	**79,197,434**	**95,254,701**	**101,303,090**	**130,608,309**	**126,866,131**	**151,050,081**	**157,734,632**	**168,947,456**	**152,651,010**	**148,961,684**	**128,561,176**	**120,959,293**	**115,678,960**
Cash flow (real - without inflation)	**US$**	**1,474,565,464**	**-90,042,117**	**-176,950,235**	**-21,370,069**	**162,483,533**	**92,923,347**	**107,339,095**	**119,658,209**	**128,004,942**	**63,415,632**	**74,412,820**	**77,207,622**	**97,114,576**	**92,031,277**	**106,902,250**	**108,910,330**	**113,807,219**	**100,321,489**	**95,509,154**	**80,418,579**	**73,817,942**	**68,873,667**

22.9 CONCLUSIONS

A discounted cash flow model prepared by Mkango was reviewed by SENET and incorporates the LOO plan figures, economic assumptions as to the USA inflation rates, and the rare earth oxide and carbonate prices as outlined in Section 19.2. The escalation/de-escalation technique has been employed to ensure that the quantum and timing of any taxes payable are calculated correctly. The financial evaluation has been undertaken on an after-tax, unleveraged basis.

A range of discount rates were used to determine the NPV; the NPVs are set at 01 July 2022.

The prevailing taxation regime for mining companies in Malawi was incorporated into the financial model where applicable.

This report supports the declaration of a Mineral Reserve Estimate for the project as summarised below and outlined in Sections 15.3.3 and 15.5.

The work reported in this report has demonstrated that a portion of the resources stated in the Mineral Resource statement can be viably mined, processed and sold and will support a sustainable mining and processing operation.

Applying the mining modifying factors, process recovery, operating costs and product prices, the project is shown to be profitable and viable. This work supports the declaration of Mineral Reserves under NI 43-101.

In estimating the Mineral Reserves, only material from the Measured and Indicated Mineral Resources has been included in the inventory. Mineral Reserves resulting from Measured Mineral Resources have been considered as Proven Mineral Reserves while those generated from Indicated Mineral Resources are categorised as Probable Mineral Reserves. Table 22.16 shows a summary of the total Mineral Reserves.

Table 22.16: Mineral Reserve Summary as at 31 December 2021

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

NOTE:

- Type 2 material, which is mineralised material with a grade above the cut-off grade but with an Mn:Mg ratio of greater then 3.5, is stockpiled on site for possible future processing. This material is excluded from both the ROM ore inventory and any Mineral Reserve estimate.
- Inferred resources are not considered as ore in the mine plan and as such are treated as waste and not included in the ROM ore inventory.

The following modifying factors were used to convert the Mineral Resource Estimate to the Mineral Reserve Estimate: Mining recovery – 95 %; mining dilution – 9 %; TREO recovery – 39.6 %; product price – US$68.2/kg TREO; operating cost – US$30.2/kg TREO recovered.

Indicated Mineral Resources are inclusive of Mineral Reserves. Mineral Resources that are not Mineral Reserves do not have demonstrated economic viability. The financial valuation is based on the mining of the ROM Type 1 ore (high grade and medium grade), 18,246,334 t of estimated Mineral Reserves only.

The discounted cash flow valuation analysis for the base case gave the following results:

- NPV at 10 % (nominal) (7.3 % real) of US$559 million as at 1 July 2022
- IRR of 31.47 % (nominal) (28.26 % real)

Table 22.17 and Table 22.18 summarise selected financial inputs and the corresponding results. All costs are quoted in real June 2022 United States dollars (US$).

Table 22.17: Summary of Selected Financial Inputs and Corresponding Results – Post-Tax Valuation

Item	Unit	Value
Project cash flow post-tax (nominal) (including royalty)	US$ million	2,083.3
Payback period from project start	Years	5.0
Payback period from start of production	Years	2.5
Post-tax NPV at 10 % (nominal) discount rate	US$ million	559
Post-tax IRR (nominal)	%	31.47

Table 22.18: NPVs of Songwe Hill Project[1]

Financial Evaluation	Nominal Discount Rate (%)	Real Discount Rate (%)	Adamas Intelligence Base Case Post-Tax NPV (US$ million)	Adamas Intelligence Upside Case Post-Tax NPV (US$ million)	Adamas Intelligence Downside Case Post-Tax NPV (US$ million)
	8.0	5.37	719.3	1,007.2	431.6
Base Case	**10.0**	7.32	559.0	801.4	316.5
	12.0	9.27	435.0	641.1	228.5
Nominal IRR			31.47 %	39.20 %	22.70 %
Real IRR			28.26 %	35.80 %	19.71 %
[1] As at 1 July 2022					

23 ADJACENT PROPERTIES

There are no adjacent properties relevant to the project.

24 OTHER RELEVANT DATA AND INFORMATION

24.1 PROJECT SCHEDULE

The project implementation schedule has been compiled to ensure that the engineering, procurement and construction management activities are aligned for successful project execution.

24.1.1 Schedule Basis – Source Information

The Songwe Hill execution schedule was developed based on the scope of work, deliverables list, SENET register, and the Procurement Operating Plan (POP) utilised during the DFS.

All the available Construction Contractor, Mkango and vendor schedule information has been incorporated into the execution schedule.

Outcomes from schedule reviews, planning workshops and experience from the recent DFS schedule history have been incorporated. The logic for activity relationships in the schedule is based on a joint consultation process between all the discipline engineers and other relevant parties on the project.

24.1.2 Schedule Levels and Structure

The Songwe Hill execution schedule is a Level 4 detailed schedule, which is structured by project phase, process area, and engineering discipline.

24.1.3 Project Key Dates/Milestones

The project schedule assumes that there will be a seamless advancement between the various phases of the project evolution. It is also recognised that this is a moderately aggressive schedule and that it will require diligent progress monitoring and coordination of all the parties involved. The overall Songwe Hill execution schedule duration is 30 months (615 d).

The project milestones are given in Table 24.1.

Table 24.1: Overall Project Key Dates

Milestone Description	Month
Project Start	Month 1
Escom Power Grid and Switchyard Installation Completed	Month 23
Concentrator Plant Construction and Commissioning Phase Completed	Month 22
Hydrometallurgical Plant Construction and Commissioning Phase Completed	Month 30
TSF Construction Completed	Month 16
PV Modules Order Placed	Month 6
PV Modules Mounting Completed	Month 19
Final PV Modules Testing Completed	Month 23
Project Completed	Month 30

24.1.4 Long-Lead Equipment

Placing the purchase orders for the long-lead equipment is crucial not only to ensure that the equipment is on site in time to allow for a seamless construction sequence and a successful project execution but also to obtain the certified information from the supply vendors on their equipment to complete the detailed engineering phase of the project. The long-lead equipment has been identified for the project and is as follows:

- Concentrator Plant:
  - Ball Mill
  - Apron Feeder
  - Primary Jaw Crusher
  - Primary Mill Cyclone Cluster
  - Agitators
  - Flotation Cells
  - Secondary Cyclone Cluster
  - Fine Grinding Mills
- Hydrometallurgical Plant:
  - Filter Press
  - Caustic Evaporators
  - Sulphuric Acid Plant
  - Uranium Ion Exchange Plant

24.1.5 Project Execution Schedule Summary

The project execution schedule has been developed, and a summary project execution schedule is shown in Figure 24.1.

SP0803 - Songwe Hill
Execution Schedule
Executive Summary

ID	Task Name	Duration
1	SP0803 - Songwe Hill Execution Schedule	636 days
2	Overall Project Milestones	636 days
3	Project start	1 day
4	Escom Power Grid requirement	1 day
5	Complete Concentrator construction & commissioning phase	1 day
6	Complete Hyromet construction & commissioning phase	1 day
7	Complete TSF construction	1 day
8	PV Modules Order Placed	1 day
9	PV Modules Mounting Completed	1 day
10	Final PV Modules Testing Complete	1 day
11	Project complete	1 day
12	Design & Engineering	251 days
13	Tailings Storage Facility	20 days
15	Process Plant - SENET	251 days
2272	PV System Design & Engineering	30 days
2292	Procurement (Including Fabrication & Delivery to site)	431 days
2293	De-Risking Procurement Packages	431 days
2619	Concentrator	285 days
3202	Hydromet	355 days
3724	PV System Procurement	191 days
3800	Contractors & Consultants	252 days
3849	Construction	545 days
3850	Contractor mobilisation	231 days
3859	Infrastructure	325 days
3940	Tailings Storage Facility	210 days
3965	Tower Crane	63 days
3968	Concentrator	328 days
4525	Hydromet	407 days
4982	PV System Construction	163 days
5011	Mining	385 days
5041	Commissioning	288 days
5042	PV System Commissioning	104 days
5066	Concentrator	55 days
5071	Hydromet	116 days

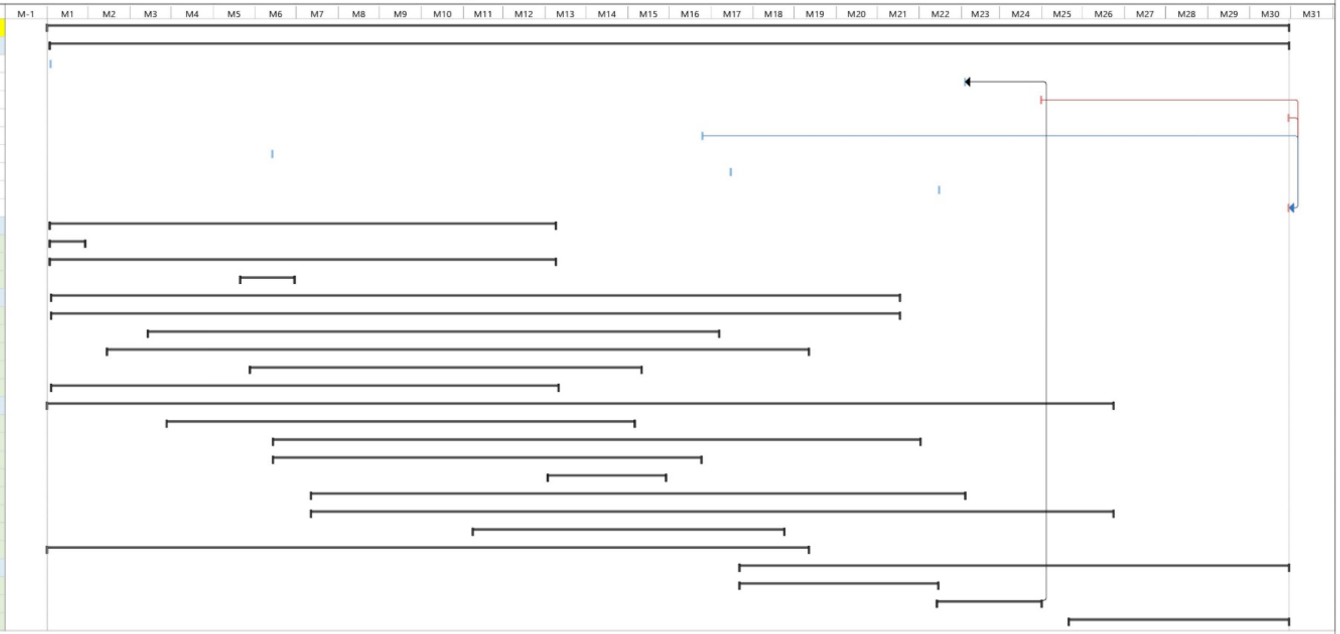

Figure 24.1: Project Schedule Summary

24.1.6 Critical Path

The primary critical path (items with no float) runs through the following sequence of tasks:

- Concentrator plant:
  - Project award
  - Process design
  - Order placement – ball mill
  - Fabrication and delivery to site
  - Construction of mill and associated equipment and final commissioning
- Hydrometallurgical plant:
  - Project award
  - Process design
  - Order placement – sulphuric acid plant
  - Fabrication and delivery to site
  - Construction of acid plant and associated equipment and final commissioning

24.1.7 Schedule Assumptions

The following assumptions have been made in developing the schedule:

- All the test work will be completed and no additional test work will be required.
- Various de-risking procurement packages will have been identified to ensure that no undue risk is placed on the project due to the long-lead mechanical items.
- The construction work permit application (by Mkango) will be approved prior to the start of bulk earthworks construction.
- Relocation of protected trees and plants (by Mkango) will be completed prior to the start of bulk earthworks construction.
- Grave relocations will be completed prior to the start of bulk earthworks in the respective areas.
- All the Mkango information will be available as scheduled.
- Squad check will allow for one round of reviews. Where documents are rejected, the rework of documents has not been catered for in the schedule.
- Decisions to be made by Mkango shall be forthcoming, in accordance with the dates as scheduled, where activities require Mkango's approval/consent/direction.
- Integrated change management procedures will be adhered to.

24.1.8 Rainfall

The rainfall period is estimated to last for a period of six months from November to April. The most rainfall experienced during a 31 d period was recorded in January with a total accumulation of 210 mm. The assumption is that a total of 17 d will be lost due to rain during the construction phase of the project.

24.2 RISKS

The purpose of conducting the project risk assessment was to identify and evaluate the risks associated with the Songwe Hill Project as presented in this report. The risk assessment addresses project implementation issues including any external factors such as political risk, resource risk, financial risk (including taxation and revenues), and government legislation risk that might have an impact on the success of the project.

The risk assessment is based on the SENET Project Risk Management Plan and, in addition to highlighting and quantifying areas of risk, it establishes the baseline upon which measures that are installed to eliminate, mitigate or transfer risk, can be evaluated. Risks were assessed as follows:

- Identification and analysis of risk
- Evaluation of the likelihood of specific risks occurring
- Evaluation of the consequences of risk occurrence
- Selection of a risk rating using the risk scoring definitions given in Table 24.2
- Production of risk assessment tables by likelihood and severity as shown in Table 24.3

Table 24.2: Risk Scoring Definitions

Score	Description	Definition
High 5	Likelihood	An event that is extremely or very likely to occur.
	Severity	The occurrence of this event will impact the project's cost (and/or schedule), cause sustained production interruption or delay/reduction in cash flow that leads to negative cash flow.
Medium 3–4	Likelihood	An event that has a 50-50 chance of occurring.
	Severity	The occurrence of this event will cause noticeable cost (and/or schedule) increases and substantial reduction in production, resulting in reduced, but adequate cash flow for project/plant production costs.
Low 1–2	Likelihood	An event that is unlikely or very unlikely to occur.
	Severity	The occurrence of this event will cause small or no cost (and/or schedule) increases that, in most cases, can be absorbed by the project, minor delays in production, or a reduction in cash flow that is easily recoverable within the next operating month.

Table 24.3: Risk Scoring Matrix

Risk Level is at the intersection of Likelihood and Severity		Severity (Impact)			
		Very Low	Low	Medium	High
Likelihood (Probability)	High				
	Medium				
	Low				
	Very Low				

A Hazard and Operability (HAZOP) Study Stage 1 was completed in May 2021, and a HAZOP Study Stage 2 was completed in July 2021.

24.2.1 General Risks

The general risks associated with the Songwe Hill Project are listed in Table 24.4.

Table 24.4: General Risks

Risk	Description	Severity	Likelihood	Mitigating Factor
Currency Exchange Rate Fluctuations	Specifically related to the strength of the euro and United States dollar, the currencies in which commodity prices are generally quoted. Risk of these currencies gaining or losing value, which will affect commodity prices and project CAPEX and OPEX.	Medium	High	Possible purchase of forward cover and hedging.
Rare Earth Metals Price Fluctuations	Risk of the low-value overproduced rare earth metals price decreasing in value, which will have a negative effect on the project economics	Medium	Low	The project has shown favourable economics. The sensitivity of the rare earth metals price is investigated in detail in the financial section (Section 22). The economics of using REEs is robust, and these segments will continue to fuel strong demand growth into the foreseeable future.
Country Risk	Specifically including political unrest, economic policy changes, legislative and fiscal changes	Medium	Low	Political risk insurance on all loans.
Logistics	• The Songwe Hill Project is remotely located, with some limitations to road accesses during the rainy season. The control of the logistics and the cost implications will be fundamental in maintaining reasonable operating costs. • The import of project equipment and essential commodities, such as diesel fuel, explosives materials, plant reagents and consumables, is highly dependent on an efficient logistics system.	Medium	Medium	• Mkango has a project implementation plan that considers the potential logistics challenges such as the rainy season. A construction period of 23 months has been estimated and is considered adequate with respect to logistics. Mkango will appoint a reputable transporter with experience in mine projects and operations to ensure minimal logistics problems during construction and the operation of the mine. • Mkango will have one month's worth of reagents and consumables, ensuring enough of a buffer to mitigate any logistics challenges.

Risk	Description	Severity	Likelihood	Mitigating Factor
Fuel price fluctuations and supply	• Specifically related to diesel: the risk of the fuel price increasing would affect the operating cost. • The large quantities of fuel required for the mining fleet and emergency power plant pose a potential risk of supply shortages.	High	Medium	• Close liaison with selected fuel supplier is envisaged. • Possibility of using two fuel suppliers to reduce the risk of supply shortage. The fuel storage capacity also ensures a buffer for any potential supply shortages.
Raw water supply	Risk of insufficient raw water supply to the plant from the boreholes in the wellfield because of, for example, flow dynamics of the underground river system from which the borehole water is pumped.	Low	Low	The plant will use the tailings return water and reuse most of the filtrate water in the hydrometallurgical process as part of the raw and process water supply.
Global COVID-19 pandemic	Disruption caused by the COVID-19 pandemic. This disruption could be to construction activity as well as the supply of plant and equipment.	Medium	Medium	Construction activities will be prioritised and scheduled according to manpower and equipment availability.

24.2.2 Resource Risks

The resource risks associated with the Songwe Hill Project are listed in Table 24.5.

Table 24.5: Resource Risks

Risk	Description	Severity	Likelihood	Mitigating Factor
Cavities	Known cavities in Songwe Hill are likely due to karst-type dissolution of matrix carbonate in the host carbonatite. There is a risk of the total volume of void spaces in the resource zone being greater than the 2.5 % represented in the drilled length.	Low	Low	A 4 % loss due to cavities has been applied to the Mineral Resource Estimate.
Geological and domain interpretation	Small-scale lithological variation makes it difficult to accurately distinguish the different rock types through visual assessment.	Low	Low	• Assessment of the relationship between calcium grade and rare earths grade has shown that the application of a 15 % calcium threshold in the resource estimation provides a reasonable distinction between carbonatite (> 15 % Ca, high RE grade) and non-carbonatite (< 15 % Ca, low RE grade) domains. This geochemical distinction makes visual assessment redundant. • The 3D-modelled carbonatite domain shows a good match

Risk	Description	Severity	Likelihood	Mitigating Factor
				with the geological map in terms of observed carbonatite at surface, supporting the veracity of the geological model that informs the block model.
Tonnage risk	Risk of rock density variation not being adequately understood due to complex lithological variation.	Low	Low	• During Stage 3 resource drilling (2018), the density of every sample of drill core was measured. • The density of drill core samples from Stages 1 and 2 (2011–2012) was re-measured to check the results and to ensure that the density measurement methodology was homogenised across Stages 1 to 3 of the resource drilling. • The density block model shows that appreciable differences in density generally occur between broad zones, not over short distances.

24.2.3 Mining Risks

The mining risks associated with the Songwe Hill Project are listed in Table 24.6.

Table 24.6: Mining Risks

Risk	Description	Severity	Likelihood	Mitigating Factor
Low or variable ROM grade from mining operation	Low ROM grade from mining operation from excessive dilution	Medium	Medium	• Ensure sound design of mining method. • Plan based on industry average performance, not best in class. • Carry out trial mining and correct equipment selection.
	Grade control system not implemented properly or ineffectual in controlling ROM grade	Medium	Medium	• Ensure sound design of mining method. • Plan based on industry average performance, not best in class. • Apply industry-appropriate grade control standards. • Ensure that grade control is the responsibility of Mine Owner and not contractor. • Incentivise operational staff (contractor) appropriately.

Risk	Description	Severity	Likelihood	Mitigating Factor
Loss of production from open pit	Lost days due to bad weather	Low	High	• Design for additional mining capacity to allow for lost days. • Negotiate additional capacity with the Mining Contractor.
	Pit slope failure	High	Low	• Ensure sound geotechnical design of pit. • Re-assess slope design during development of mine, incorporating all newly available geotechnical data.
	Pit flooding, ingression of groundwater or rainwater	Medium	Low	• Ensure sound storm water design. • Ensure sound design of pit dewatering systems. • Complete detailed groundwater study as part of the FEED, to determine pit inflows over time.
	Poor contractor performance	Medium	Medium	• Consider relevant experience and competence of contractor during contractor selection. • Ensure good contract management and early detection of issues. • Involve Mine Management in short- and medium-term planning.
Waste dump stability	Slope failure on waste dump or stockpile	Medium	Low	Complete engineering geotechnical work during FEED programme and revise designs based on field data and laboratory test results.

24.2.4 Process Plant Risks

The process plant risks associated with the Songwe Hill Project are listed in Table 24.7.

Table 24.7: Process Plant Risks

Risk	Description	Severity	Likelihood	Mitigating Factor
Freight costs	The process consumes large quantities of reagents that are sourced internationally. Disturbances in international logistics can severely impact the overall operating costs.	High	Medium	• Enter into long-term contracts with transport companies. • Ensure that the financial model is robust.
Availability of electrical power	The process consumes large quantities of electrical energy for the heating of process streams and evaporation. The local electrical grid has experienced shortages before.	High	Medium	• SENET has included the efficient recycle of energy in the process design, as well as a solar plant to supplement grid power during daytime. • Diesel emergency power generation is available if

Risk	Description	Severity	Likelihood	Mitigating Factor
				neither the solar nor the grid power is available. The emergency diesel power plant capacity is however only enough to operate essential plant and equipment.
Reagent costs	Due to the high consumption of reagents such as sodium hydroxide and calcium chloride, a change in reagent costs or consumptions would have a significant impact on the financials.	High	Medium	• Contracts with suppliers would mitigate price fluctuations. • Proper process analysis and control would optimise reagent consumption.
Build-up of impurities in the process	The maximum amount of water and reagents are reused/recycled on the plant, but a gradual build-up of impurities would negatively impact process performance.	Medium	Medium	• SENET has included purification steps and water treatment packages to mitigate the risk of unwanted impurity build-up. • There is a bleed stream of sodium hydroxide to protect the integrity of the caustic conversion and rare earth leach process. • During further studies, options will be evaluated for the treatment of barren rare earth carbonate precipitation liquor to produce reusable or saleable by-products.
Poor flotation performance	The Songwe Hill ore can be divided into two types: Type 1 ore is amenable to flotation whilst Type 2 material exhibits poor flotation performance.	Medium	Low	An optimised flotation regime for Type 1 ore has been developed in conjunction with a mine plan that selectively targets Type 1 ore areas for processing, whilst stockpiling Type 2 material.
Geotechnical report received from Zutari and the related earthworks and civil works quantities for the CAPEX	• Recommendations to increase the base sizes for the hydrometallurgical filtration area and flotation ring beams would result in an increase in concrete quantities • Recommendations for the raft foundations to be completely rigid, or if not possible, that piling be used, would have cost implications. • Possible potential on-site borrow pits for material sourcing exist. These will require further investigation and might not yield the required quality or volumes for the engineered fill; thereby	Low	Low	• The Zutari report is comprehensive. Borrow pits testing and investigation not completed yet. • Zutari recommended that future geotechnical studies be undertaken.

Risk	Description	Severity	Likelihood	Mitigating Factor
	requiring the possible importation of material from commercial sources.			

24.2.5 TSF Risks

The TSF risks associated with the Songwe Hill Project are listed in Table 24.8.

Table 24.8: TSF Risks

Risk	Description	Severity	Likelihood	Mitigation or Management Measures
Geotechnical test work on soils from geotechnical site investigation incomplete	Design assumptions may prove to be non-conservative and fail to satisfy minimum slope stability criteria of the tailings dam.	Medium	Low	• Once completed, use the geotechnical laboratory test work on the samples from the geotechnical site investigation to validate and confirm the design assumptions used in the DFS. • If warranted, flatten the side slopes accordingly to increase slope stability.
Geotechnical test work on tailings incomplete	The design assumption for dry density may differ from the test results and implicate the storage capacity of the TSF.	Medium	Low	• Once completed, use the geotechnical laboratory test work on the tailings to validate and confirm the design assumptions used in the DFS. (Test work is currently under way.) • If warranted, TSF storage capacity can be increased by repositioning the TSF main embankment.
Geochemical test work	The design assumption for the TSF lining system may prove to be inadequate.	Low	Low	Geochemical and radionuclide test work is required to provide a more accurate assessment of any risk posed by the tailings.
TSF and embankment failure due to external, side slope erosion	Side slope surface erosion due to surface water runoff.	High	Low	The TSF shall be rehabilitated during the LOO, which should mitigate erosion of the embankment outside slopes.
Overtopping due to non-compliance with the operating procedures	The TSF pond spilling over the crest of the embankment wall.	High	Low	Adequate freeboard and emergency spillways have been incorporated into the design.

24.2.6 Sustainable Development Risks

The sustainable development risk assessment identified the key risks and the measures that can be implemented to mitigate or reduce each risk. These are outlined in Table 24.9.

Table 24.9: Sustainable Development Risks

Risk	Description	Severity	Likelihood	Mitigation or Management Measures
Licence and permitting	The environmental permitting process is ongoing and needs to be completed before the environmental permit can be issued by the authorities.	Medium	Medium	Ensure regular interaction with the authorities to identify and address any potential issues throughout the permitting process.
Water contamination	The transportation of sediment and contaminated water from dirty water areas of the project area (i.e. WRD, Type 2 material stockpile and open pit) into the natural environment impacting wetland areas and aquatic systems including the Mpoto Lagoon.	High	Medium	• Implement the SWMP. • Direct all contaminated water into the storm water control dams to avoid discharge into the environment. • Implement industry best management practices. • Conduct regular monitoring of storm water management structures and biomonitoring of the natural environment.
Air quality and noise	Air quality and noise exceeding Malawi and WHO guidelines, respectively	High	Medium	• Implement a minimum buffer between the mining operations and any sensitive receptor locations to protect the health of residents of nearby villages. Households within the fence line will be relocated, reducing the number of receptors surrounding the project. • Put into place a Blasting Assessment and Management Plan.
Geochemical test work	Available test work for the waste rock determined the contamination potential to be low and largely inert.	Low	Low	Continue undertaking analysis of waste rock and tailings material throughout the operation to determine any changes in the geochemistry of the waste material.
Decantation	It is unlikely that the open pit will decant due to its position on the hill.	Low	Medium	• Place additional boreholes around the pit to determine any changes in water levels and impacts from pit dewatering. The groundwater table is unlikely to be intersected until the last two years of mining. • Conduct a detailed geochemical pit lake quality study to calculate the long-term water qualities in the pit.

Risk	Description	Severity	Likelihood	Mitigation or Management Measures
Socio-economic studies and resettlement	The establishment of the project will result in the physical and economic displacement of 451 households, impacting land availability and livelihoods.	High	Medium	• Socio-economic baseline studies have been completed, as well as a preliminary asset survey of the communities within the proposed exclusion zone. • Develop and implement an RAP. • Continue engagement with community members (local and traditional leaders) as well as implementation of the grievance mechanism.
Radiation	Potential to liberate radionuclides associated with RE ore. Deposition of waste products in the WRD and TSF could mobilise radionuclides and could impact community health.	Medium	Medium	• Continue with baseline radon and thoron monitoring prior to construction activities. • Implement concurrent rehabilitation of the WRD and side walls of the TSF to reduce dust mobilisation. • Implement the closure plan to provide a cover over the TSF and WRD. • Undertake a radionuclide deportment campaign every two years to determine changes to the baseline. • Update the public radiation protection report with any updated information on the TSF and groundwater plume migration study.
Biodiversity	Baseline wet and dry season surveys have been undertaken in the project area. However, vegetation clearing will be required for the establishment of project infrastructure as well as diversion of a stream for construction of the process plant.	Medium	Low	• Limit vegetation clearing to designated areas only. • Implement the SWMP. • Monitor alien invasive plant establishment on site. • Conduct biomonitoring of the project area with a focus on the Mpoto Lagoon.
Pressure on social infrastructure	Increased pressure on social infrastructure due to an influx of people and potential conflict due to competition for resources.	Medium	Medium	Develop and implement influx management measures.
Community expectations	Public consultation required to document community expectations and implementation of the Community Development Plan.	High	Medium	• Ongoing consultation and interaction with communities and stakeholders. • Management of community expectations through clear communication on plans to improve livelihoods of the people.

Risk	Description	Severity	Likelihood	Mitigation or Management Measures
Occupational and community health	Increase in social ills during construction and operations	Medium	Medium	Develop and implement Community and Occupational Health Impact Management Plan.
Climate change	Climate change may affect a wide range of aspects associated with the project, such as reliable water supply, storm water management, disruption of operations, food supply, worker health and safety, as well as community health and safety.	High	Medium	• Develop and implement a climate-change adaptation strategy for Mkango. • Undertake vulnerability risk assessments at all Mkango's operations and host communities. • Develop and implement plans that respond to material climate risks. • Improve efficiencies in the use of natural resources (energy and water). • Implement community awareness and resilience strategies. • Undertake a climate change risk assessment of the project.
Blasting	Blasting in the open pit will result in noise and air quality impacts on nearby receptors. A minimum 500 m blast radius has been implemented as part of the project design.	High	Low	Implement controlled blast technology to reduce the negative effects of blasting.

24.3 OPPORTUNITIES

The opportunities that have been identified for the Songwe Hill Project are outlined in Table 24.10.

Table 24.10: Opportunities

Opportunity	Description
Inferred Resources	During the DFS, a pit optimisation that included Inferred resources was conducted. This exercise demonstrated that the ore tonnage could be increased from 18 Mt to 28 Mt by including Inferred resources in the ore stream. Infill drilling and sampling data from the pit will allow some, or all, of these Inferred resources to be upgraded to Measured or Indicated resources and support the inclusion of this material in the mine plan.
Underground Mine	The Songwe Hill deposit is open at depth, and desktop study work has been completed for a potential underground mine. This presents an opportunity for the life of the Songwe Hill Project to be extended beyond the life of viable open-pit mining.
Optimisation of sodium hydroxide bleed stream	Further test work would confirm the percentage of the caustic conversion thickener overflow solution that must be bled out of the process to prevent impurity build-up. This could significantly decrease the fresh sodium hydroxide consumption.

Opportunity	Description
Regenerating sodium hydroxide with membrane technology	Currently, sodium hydroxide is being regenerated by evaporation and causticisation. Replacing this system with an electrolytic membrane process could significantly decrease process complexity, reagent consumption, OPEX and CAPEX. A detailed investigation is required to weigh membrane technology against the current evaporation/causticisation design.
Producing ammonium and calcium/sodium salts from barren rare earth carbonate precipitation liquor	There is an opportunity to treat the barren rare earth carbonate precipitation liquor, which contains sulphate, ammonium and chloride, to produce reusable or saleable salts of ammonium and chloride by steam stripping. There are several options for doing this, but a trade-off needs to be done on the potential benefit versus the additional costs.
Simplifying the flotation circuit to exclude cleaning and cleaner-scavenger flotation	Test work has shown that the recovery of rare earth elements in the flotation circuit could be increased by accepting a lower rare earth grade in the flotation concentrate. Currently, the target is to have a high-grade flotation concentrate, sacrificing recovery. This is a potential opportunity to optimise the flotation circuit towards a higher-recovery philosophy.
Decreasing power consumption	The Songwe Hill plant consumes large amounts of energy, primarily to heat up process streams. Further optimisation of the flotation circuit to achieve the target grade and recovery at a lower temperature would decrease the plant power consumption considerably.
Decreasing reagent costs	The OPEX is heavily sensitive to reagent consumptions and reagent costs. There are several reagents that dominate the overall consumables section of the OPEX, such as the flotation collector, sulphur, sodium hydroxide and calcium chloride. Decreasing the collector consumption in the flotation circuit, and decreasing the sulphuric acid, sodium hydroxide and calcium chloride consumption (or regenerating it as previously discussed) will have a significant impact on the OPEX.
Upgrading the Songwe Hill site access gravel road to a tar road	The Songwe Hill Project is remotely located, with some limitations to road accesses during the rainy season. With the high volume of traffic expected to site daily, it might be cost effective to consider tarring the 15 km gravel road to ensure that heavy vehicles can reach the site during the rainy season and eliminate potential delays.
Ensuring that Escom grid power is available on site as early as possible during construction	Although all the contractors are responsible for supplying their own diesel generators during the construction phase, having grid power available would mean cost savings. It would also minimise noise and air pollution.
Optimising the construction schedule	Ordering long-lead items as early as is practically possible, even prior to detailed engineering, could improve the project schedule.
Wind energy opportunity	Refer to Section 24.3.1 for details of wind energy.

24.3.1 Wind Energy Opportunity

The addition of wind energy would further decrease the cost of energy and Scope 2 grid emissions.

A wind energy yield assessment was undertaken based on mesoscale meteorological data, which has been used to estimate the long-term energy production for the proposed wind turbines at Songwe Hill. The wind energy yield assessment is, however, still subject to high uncertainty as no site measured data is available for analysis.

A comparison of the energy balance and the cost of energy is shown in Figure 24.2 and Figure 24.3, respectively, for three different power supply options. This report's cost of energy is based on grid with PV. By adding the wind energy component, the overall excess energy at

6.8 % is a marginal increase of 4.2 % compared to the grid with PV excess energy of 2.6 %. The overall grid energy consumption, however, further decreases by an average of 15 % (16 % during the off-peak time and 13 % during the peak time, using the relevant tariffs for these periods), resulting in a further 19.8 % reduction in cost of energy from US$0.138/kWh for a grid with PV to US$0.111/kWh for a grid with PV and wind energy.

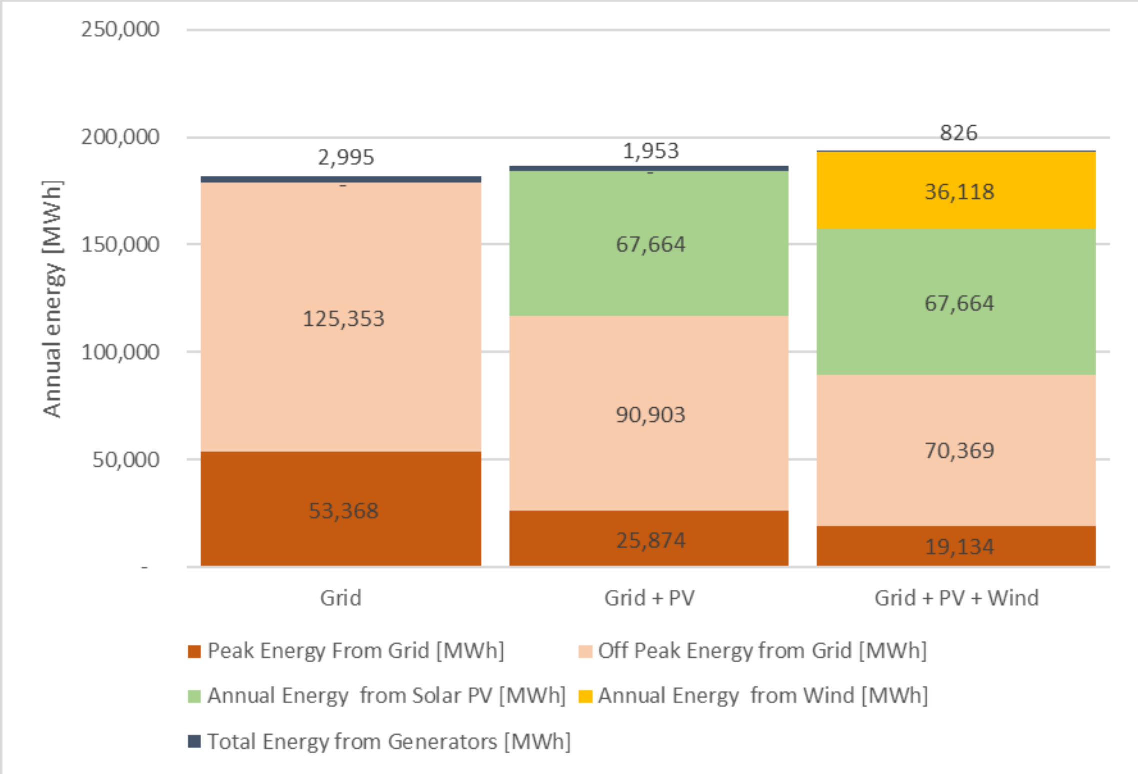

Figure 24.2 :Energy Balance for Three Different Energy Options

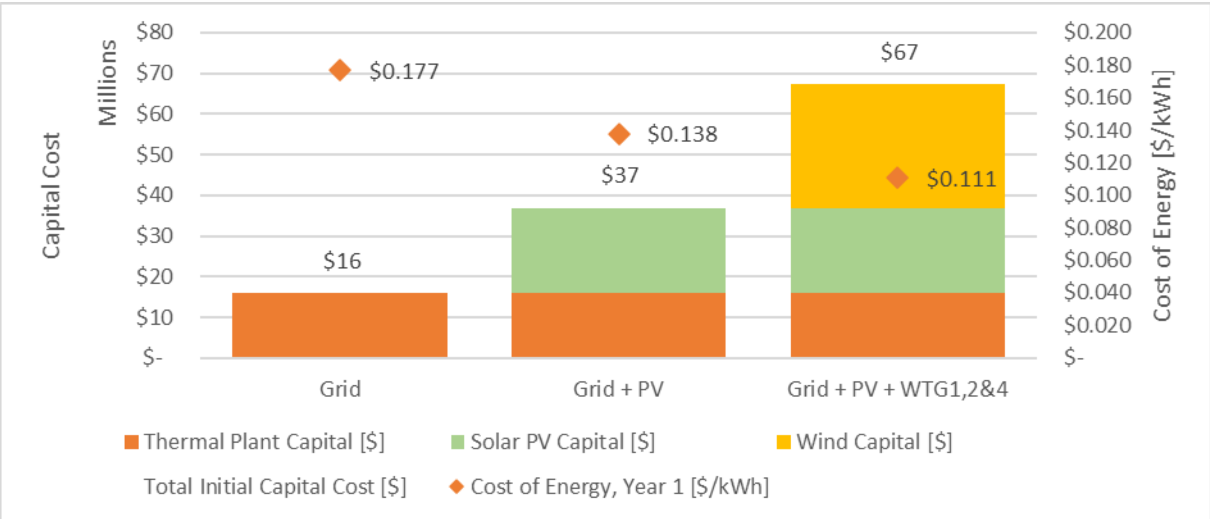

Figure 24.3 : Cost of Energy and Initial CAPEX for Three Different Energy Options

24.4 HUMAN RESOURCE ELEMENT

24.4.1 Introduction

The Mkango human resource element is a vital component of ensuring the operational success of the Songwe Hill Project. Significant consideration has been given in the recruitment strategy to ensure a seamless transition between commissioning and normal operation. Mkango also recognises the necessity for the operation to employ a sustainable localisation plan within the Songwe Hill mine area and nationally, and as such part of the policy is to recruit locally as far as practicable and implement a skills development plan for nationals with focus on those local to the mine site.

In order to effectively manage the operations at Songwe Hill, a labour schedule was drawn up to include labour for mining, process plant and administration duties. This section will describe the labour complement that will be required for the Songwe Hill Project, inclusive of expatriates, African national employees, and local Malawian employees.

24.4.2 Overall Mine Management Structure

Figure 24.4 shows the overall management structure proposed for the Songwe Hill Project. The mine management will be structured into five main departments: the process plant; mining; finance and administration; health, safety, security, environmental and community (HSSEC); and the maintenance departments. All the respective departmental managers will report to a general manager, who will be responsible for the mine's overall operation.

The department managers will have the overall responsibility for managing the technical and non-technical business disciplines within the mine. The general mine management labour complement is shown in Figure 24.4.

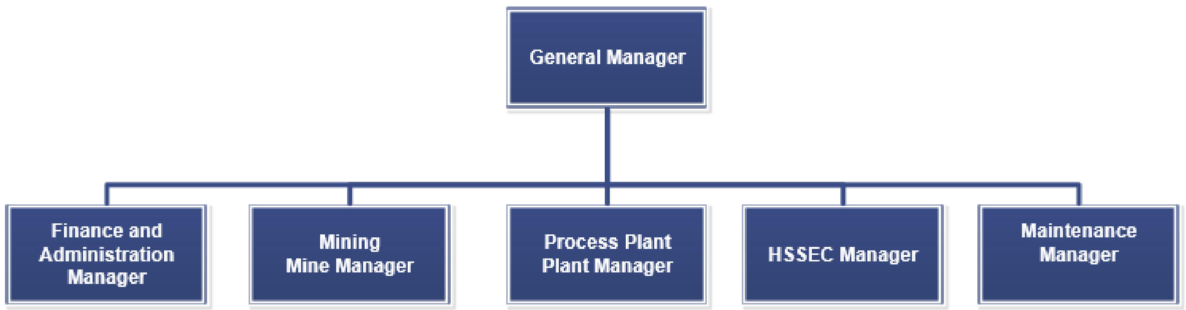

Figure 24.4: Overall Mine Management Structure

The process plant department will include a labour complement for the following:

- Process plant production
- Assay laboratory

The mining department will include a labour complement for the following:

- Mining operations
- Mining technical services

The finance and administration department will include a labour complement for the following:

- Human resources
- Finance and accounting management
- Procurement and logistics
- Information technology (IT) and control
- Facilities engineering

The HSSEC department will include a labour complement for the following:

- Health and safety
- Security
- Environment
- Community relations

The maintenance department will include a labour complement for the following:

Mechanical (concentrator and hydrometallurgical plants)
Electrical, and control and instrumentation (concentrator and hydrometallurgical plants)
Planning
Riggers, mobile and tower cranes

Table 24.11 gives a summary of the total labour complement while Figure 24.5 shows the overall labour distribution as a percentage per department.

Table 24.11: Total Labour

Department	Number of Employees	Percentage of Distribution
Mining	150	35 %
Process Plant – Production	98	23 %
Process Plant – Laboratory	39	9 %
Finance and Administration	82	19 %
HSSEC	9	2 %
Maintenance	49	12 %
Total	**427**	**100 %**

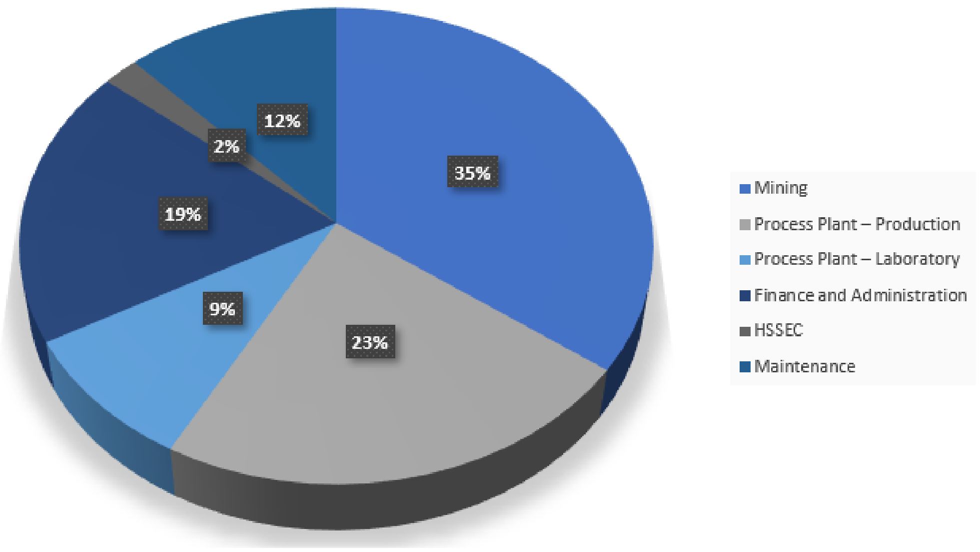

Figure 24.5: Total Labour Distribution

24.4.3 Department Structure

Each department will be headed by an experienced manager, with line managers reporting to them. A total of 299 people will be employed directly by Mkango. The mining contractor will employ 128 people. The people directly employed by Mkango will comprise 192 national staff members and 107 international expatriate staff members.

In developing the manpower requirements for the Songwe Hill Project, the following assumptions were made:

- Mining labour and supervisory staff will work on a two 12-hour shift operation per day, seven days a week. Technical and maintenance staff for mining will work the day shift only and will be on standby after hours on a rotational basis.
- Local process plant operators and supervisory staff will work on a two 12-hour shift operation per day, seven days a week. Technical and maintenance staff for the process plant will work a 12-hour day shift only and will be on standby after hours on a rotational basis.
- Management, general and administration staff will work on a 9-hour shift operation per day, five days a week.
- Expatriates will work on an eight-weeks-on and three-weeks-off work cycle.

25 INTERPRETATION AND CONCLUSIONS

Since Mkango has become involved in the Songwe Hill Project, considerable effort has been made and expenditure has been incurred to certify what is now a significant rare earth resource and reserve at Songwe Hill. This report confirms the extensive amount of exploration, tests and study work carried out on the project. It is believed that the level of accuracy used herein is sufficient to consider this report to be definitive with its demonstration of a viable rare earth resource at Songwe Hill that will exploit the current reserve over an 18-year life of operations.

The Mineral Resource Estimates for Songwe Hill are reported at a cut-off grade of 1.0 % TREO and classified into the Measured, Indicated and Inferred categories as summarised in Table 25.1.

Table 25.1: Mineral Resource Estimates

Category	Tonnage (Mt)	TREO %	TREO (kt)
Measured	8.81	1.50	131.9
Indicated	12.22	1.35	165.5
Measured & Indicated	**21.03**	**1.41**	**297.4**
Inferred	27.54	1.33	366.2
NOTE: TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3 in situ – no geological losses applied.			

Table 25.2 shows a summary of the total Mineral Reserves Estimate.

Table 25.2: Mineral Reserve Estimate

Category	Tonnage (Mt)	TREO %	TREO (t)
Proven Mineral Reserves	8.160	1.28	104,183
Probable Mineral Reserves	9.988	1.07	106,801
Total Ore Reserves	**18.147**	**1.16**	**210,984**
NOTE: Totals might not add up due to rounding.			

This report has demonstrated that based on the operating and pricing outlook assumed in the DFS, the Songwe Hill REE deposits can be economically mined using the open-pit method and processed using flotation and hydrometallurgy processes at an annual rate of approximately 1 Mt/a with a view to producing an average of 5,954 t of TREO in MREC per year for the first five years and 4,081 t of TREO in MREC per year in Years 6 to 18.

The DFS is based on selling the MREC rather than the separate products. As a result, a 27 % discount was applied to the forecasted value of the rare earths contained in the MREC (discount equivalent to approximately US$22.07/kg (real 2022 US dollars) of TREO in MREC for the first full five years of production to reflect the discount that would be applied for the MREC product versus the value of the underlying separate rare earth oxides.

This report indicates a US$559.0 million post-tax NPV, using a 10 % nominal discount rate, and a 31.5 % post-tax IRR for 100% of Songwe.

25.1 MINERAL RESOURCE

On behalf of Mkango, MSA has completed a Mineral Resource estimate for Songwe Hill.

The Mineral Resource was reported as Measured, Indicated and Inferred Mineral Resources as shown in Table 25.3. The Mineral Resource was estimated using the CIM Best Practice Guidelines (2003) and is reported in accordance with the 2014 CIM Definition Standards, which have been incorporated by reference into NI 43-101.

Table 25.3: Songwe Hill, Measured, Indicated and Inferred Mineral Resources above 1 % TREO Grade, 23 January 2019

Category	Tonnage (Mt)	TREO (%)	TREO Tonnage (kt)
Measured	8.81	1.50	131.9
Indicated	12.22	1.35	165.5
Total Measured and Indicated (M&I)	**21.03**	**1.41**	**297.4**
Inferred	27.54	1.33	366.2
NOTES: 1. All tabulated data has been rounded, and as a result minor computational errors may occur. 2. Mineral Resources, which are not Mineral Reserves, have no demonstrated economic viability. 3. Quantities reported are the total quantities for the project regardless of ownership.			
TREO = La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, and Y_2O_3			

The mineralisation is associated with a steep-sided carbonatite intrusion-breccia complex. The rare earth elements are mainly associated with the carbonatite, although mineralisation occurs in the brecciated and fenite type rocks as well, but at a lower grade.

The Mineral Resource was estimated based on the results of exploration programmes completed by Mkango. The drilling was on an average grid of approximately 30 m by 30 m in the areas with closely spaced drilling, approximately 50 m by 50 m away from the core of the deposit, and wider than a 50 m grid close to the extents of the deposit.

The drilling exploration and sampling were guided by comprehensive standard operating procedures, and in the opinion of the relevant QPs, conforms to good exploration practice.

The Mineral Resource has been categorised into three domains based on the carbonatite proportion per block:

- > 0.75 carbonatite = Carbonatite
- < 0.75 and > 0.25 carbonatite = Mixed
- < 0.25 carbonatite = Fenite

25.2 ENVIRONMENTAL

Detailed environmental and social specialist studies have been undertaken for the ESHIA, and these comply with Malawian legislation and IFC best practice requirements. Environmental and social baseline studies commenced in 2018 and have been updated alongside updates to the project design and placement of infrastructure. Environmental studies included detailed wet and dry season fieldwork, providing a comprehensive understanding of the current environmental and social baseline of the project area.

Social studies included household surveys, comprising questionnaires completed by the community surrounding Songwe Hill to establish a socio-economic and health baseline for the area. Updated socio-economic and asset surveys were undertaken of the households within the proposed exclusion zone in April 2022 as part of the initial work which will form part of the resettlement action plan.

Dust monitoring has been in place since 2016, providing an uninterrupted record of the dust fallout regime of the area. A weather station was installed on site in August 2014 providing on-site, local data for input into the ESHIA. After the significant amount of work completed on the environmental and social aspects, the environmental risks and current legislative environment are well understood.

A Stakeholder Engagement Plan and grievance mechanism are in place on site to record and document engagement activities with the community and any grievances that may arise as a result of project activities. Communication and stakeholder management are essential for building sustainable relationships based on transparency and trust. Stakeholder consultations have been taking place regularly since November 2014, and most recently, in March 2022, the results of the ESHIA process were shared with stakeholders through comprehensive engagement at local, district and national levels which included community members, government authorities and non-governmental organisations (NGOs).

Environmental and social risks exist but these can be managed through comprehensive consultation especially around resettlement and heritage impacts associated with the project. A number of recommendations should be undertaken as part of the project’s implementation to ensure that the project is socially and environmentally acceptable and complies with international good practice guidelines. The ESHIA has been undertaken to comply with IFC Performance Standards to ensure that the process is acceptable to the developer, authorities, and other key stakeholders. The project has the potential to provide benefits to the local community, industry, and the country if positive impacts are enhanced and potential negative impacts are mitigated against. The project is committed to ensuring environmental and social compliance, and leaving a positive legacy.

26 RECOMMENDATIONS

SENET recommends the execution of a front-end engineering design (FEED) study prior to project execution stage.

Through a well-defined and executed FEED phase, the following can be achieved:

- Reduced technical, schedule and cost risks
- Faster time to achieve plant/process start-up, commissioning and handover
- Reduced EHS and compliance risks
- Improved risk identification and mitigation
- Orders of long-lead items can be finalised
- Vendor drawings and data can be demanded, taking the detailed design to the next level of accuracy.

The following early works activities should be completed before the site construction activities start in order to minimise potential delays:

- Complete additional geotechnical studies as per the Zutari recommendation.
- Commission sufficient water boreholes in the wellfield to supply water to the accommodation camp, site offices and facilities as well as the water required for construction purposes.
- Construct the accommodation camp and facilities prior to construction start date.
- Identify aggregate source.
- Complete the RAP and specifically the relocation of houses prior to construction start date.

The following are recommendations related to the environmental and social aspects of the project for Mkango to integrate throughout the project:

- Ensure continuous engagement and two-way dialogue with communities in the vicinity of the project and other key stakeholders, including government and administrative authorities, traditional authorities, group village heads, local chiefs, and community-based organisations, as well as international and local non-governmental organisations.
- Ensure management of waste by engineering and constructing waste facilities in compliance with good international industry practice. Infrastructure has been sited and designed to mitigate against potential negative impacts from dust, radiation, noise and water pollution. Design measures to manage contaminants and waste include clean and dirty water diversion berms, trenches, dams, HDPE lining of the TSF, and other technological measures that together contribute to the reduction of potential negative impacts. Monitoring of these measures through the ESMP must be undertaken throughout the project lifecycle to ensure that they are fit for purpose and appropriately manage any potential negative environmental and social risk.
- Design a wellfield in the alluvial material around the project for water provisioning for the project. Surface water runoff and precipitation during the wet season will also be captured, stored and used to contribute to the mine's water demands. This alongside the project's aim to achieve high recycling rates will alleviate the potential impacts on groundwater abstraction.

- Ensure that the resettlement activities as a result of the physical and economic displacement of communities required by the project will follow the IFC PS5 through the development of a Resettlement Action Plan and concurrent stakeholder engagement.
- Ensure that the relocation of cultural heritage resources will follow the IFC PS8.

The radiation protection programme assessed and presented radiological baseline and safety assessment findings consistent with the IAEA Safety Standards, the IFC PSs, as well as the available Malawi Atomic Energy Regulations of 2012 promulgated by the AERA in terms of the Atomic Energy Bill (Act 16 of 2011).

The following TSF recommendations are proposed:

- Prior to the commencement of the detailed design, a geotechnical engineer should be appointed to retrieve appropriate samples from test pits on site for the triaxial test work of the in-situ material.
- For consideration and evaluation during the detailed design of the TSF,
    - The possible further optimisation of the TSF drainage system should be assessed.
    - The validity of the basin geotextile should be assessed.
    - A more comprehensive detailed dam break analysis should be undertaken to more accurately define the potential inundation extent of the TSF

It is recommended that opportunities to reduce reagent consumptions and negotiate prices with reliable reagent suppliers or distributors with long-term contracts be investigated in order to optimise the OPEX and mitigate price fluctuations.

It is also recommended that a detailed energy yield analysis and uncertainty assessment be conducted to further optimise the energy requirements.

27 REFERENCES

A. Nxumalo, S. S. 2022. *Geotechnical Interpretative Report Songwe Hill – Rare Earth,* Pretoria: Zutari (Pty) Ltd.

Anon. 2022. *Geotechnical Investigation,* Lilongwe: Geoconsult Pty Ltd.

ASTM International ASTM D1739-98. 2017. *Standard Test Method for Collection and Measurement of Dustfall (Settleable Particulate Matter)*.

Ball, S.M.J. 2004. Stocks and exploitation of East African blackwood. Dalbergia melanoxylon.

Broom-Fendley, S. et al. 2017. Geology, geochemistry and geochronology of the Songwe Hill carbonatite, Malawi. Journal of African Earth Sciences, Volume 134, pp. 10-23.

Burrough P. A., and McDonnell R. A. 1998. *Principles of Geographical Information Systems*: Oxford University Press, London.

Castor, S.B. 2008: The Mountain Pass rare-earth carbonatite and associated ultrapotassic rocks, California. Canadian Mineralogist, v. 46, 779-806.

CDA. 2013. *Dam safety guidelines 2007.* 2013 edition ed. s.l.: Canadian Dam Association.

CDA. 2019. *Application of Dam Safety Guidelines to Mining Dams.* s.l.: Canadian Dam Association.

Chakhmouradian, A. and Zaitsev, A.N. 2012. Rare earth mineralization in igneous rocks: sources and processes. Elements, 8, 347-353.

Chao, E.C.T., Back, J.M., Minkin, J.A., and Yinchen, R. 1992. Host-rock controlled epigenetic hydrothermal metasomatic origin of the Bayan Obo REE-Fe-Nb ore deposit, Inner Mongolia. P.R.C. Applied Geochemistry, 7, 443-458.

Chapola, L. S. 2001. Seismology in Malawi. Bulletin of the International Institute of Seismology and Earthquake Engineering. 35:57-69.

Chindandali, P. R. 2016. Seismic Observation and Seismicity of Malawi. Seismology Section, Geological Survey Department of Malawi.

CITES. "Convention on International Trade in Endangered Species of Wild Fauna and Flora" 2013 http://www.cites.org/eng/resources/pub/checklist11/Appendices.pdf.

Cole, K., 1993. Paper 1: Considerations of Risk and Reliability, Ground Engineering. *Building over Abandoned Shallow Mines,* Volume 1, pp. 35-37.

Digby Wells Environmental. 2021. *Environmental, Social and Health Impact Assessment for the Songwe Hill Rare Earth Project, Malawi, Groundwater Impact Assessment,* prepared by Digby Wells Environmental, dated September 2021.

Digby Wells Environmental. 2021. *Digby Wells Type 2 Ore charaterisation 2021*, Songwe SP0803 Type 2 material ABA and Sulphur specification

Digby Wells Environmental. 2022. *Environmental, Social and Health Impact Assessment of the Songwe Hill Rare Earth Elements Project*. MKA5076. May 2022.

Dips 7.0. Rocscience User's Manual.

Dixey, F., Campell Smith, W. and Bissett, C.B. 1937 (revised edition 1955). The Chilwa Series of Southern Nyasaland. Bulletin, Geological Survey Department, Nyasaland, 5, 1-71.

Doroshkevich, A.G., Viladkar, S., Ripp, G.S., Burtseva, M.V. 2009. Hydrothermal REE Mineralization in the Amba Dongar Carbonatite Complex, Gujarat, India. Canadian Mineralogist, 47, 1105-1116.

DWAF. 2007. A practical field procedure for identification and delineation of wetlands and riparian areas (updated). Pretoria: Department of Water Affairs and Forestry.

Eby, G.N., Roden-Tice, M., Krueger, H.L., Ewing, W., Faxon, E.H., and Woolley, A.R. 1995. Geochronology and cooling history of the northern part of the Chilwa Alkaline Province, Malawi. Journal of African Earth Sciences, 20, 257-288.

Eckermann, K. F., A. B. Wolbarst, and A. C. B. Richardson. 1988. Federal Guidance Report No 11, Limiting Values of Radionuclide Intake and Air Concentrations and Dose Conversion Factors for Inhalation, Submersion and Ingestion, Oak Ridge National Laboratories, Oak Ridge, Tennessee.

Edwards, M. 2021. *Songwe Hill Rare Earth Geophysical Survey,* Jersey: Digby Wells Environmental.

EN 1990:2002, 2005. *Eurocode – Basis of Structural Design Annex C*.

Environmental Affairs Department. 2002. Environmental and Natural Resources Management Policies, Laws and Institutional Framework in Malawi, Volume 1: A Resource Book for District Level Managers. Ministry of Mines, Natural Resources and Environment, Government of Malawi. ISBN Number: 99908-26-23-4

Equator Principles. 2020. The Equator Principles. https://equator-principles.com/app/uploads/The-Equator-Principles_EP4_July2020.pdf

Garson, M.S. 1962. The Tundulu carbonatite ring-complex in southern Nyasaland. Memoir, Geological Survey Department, Nyasaland, 2, 1-248.

Garson, M.S. 1965. Carbonatites in southern Malawi. Bulletin of the Geological Survey of Malawi, 15, 1-128.

Garson, M.S. 1966. Carbonatites in Malawi. In: Tuttle, O.F. and Gittins, J. (Eds.), Carbonatites. John Wiley, New York, 33-71

Garson, M.S. and Walshaw, R.D. 1969. The geology of the Melanje area. Bulletin of the Geological Survey of Malawi, 21, 1-157.

Giere, R. 1996. Formation of rare earth minerals in hydrothermal systems. In Rare Earth Minerals: Chemistry Origin and Ore Deposits. In Jones, A.P., Wall, F., and Williams, C.T., (Eds.). Rare Earth Minerals: Chemistry Origin and Ore Deposits. Chapman and Hall. 105-150.

Government of Malawi. 2018. Malawi Population and Housing Census – Main Report. National Statistics Office. May 2019. https://malawi.unfpa.org/sites/default/files/resource-pdf/2018%20Malawi%20Population%20and%20Housing%20Census%20Main%20Report%20%281%29.pdf

Hall, M and Swinden, S. 2012. The MSA Group. NI43-101 Technical Report and Mineral Resource Estimate for the Songwe Hill REE Project, Phalombe District, Republic of Malawi.

Holley et al. 2006. Geotechnical design for open pits at Tanjianshan, China.

Hornig-Kjarsgaard, I. 1998. Rare earth elements in sovitic carbonatites and their mineral phases. Journal of Petrology, 39, 2105-2121.

Howard, G., Bartram, J. and World Health Organisation. 2003. Domestic Water Quantity, Service Level and Health. World Health Organisation. WHO/SDE/WSH/03.02 p.33 https://apps.who.int/iris/handle/10665/67884

Hunting Geology and Geophysics Limited, 1985: Airborne Geophysical Survey: Government of Malawi: Report on Field Operations and Processing; Hunting Geology and Geophysics Limited, 1985.

IAEA. 2002. Monitoring and Surveillance of Residue from the Mining and Milling of Uranium and Thorium, Safety Report Series No.27, International Atomic Energy Agency, Vienna.

IAEA. 2011. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards: General Safety Requirements, *IAEA Safety Standards Series No. GSR Part 3 (Interim)*, International Atomic Energy Agency, Vienna, Austria.

ICRP. 1996. Age Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients, *ICRP Publication 72 Volume 26 No. 1*, Pergamon Press, Oxford.

International Electrotechnical Commission. IEC 60034-30-1, *Rotating electrical machines - Part 30-1: Efficiency classes of line operated AC motors (IE code)*.

International Electrotechnical Commission. IEC 60076 (All Parts), *Power Transformers.*

International Electrotechnical Commission. IEC 60529, *Degrees of protection provided by enclosures (IP Code)*.

International Electrotechnical Commission, IEC 61215 (All Parts), *Terrestrial photovoltaic (PV) modules - Design qualification and type approval.*

International Electrotechnical Commission. IEC 61439-2, *Low-voltage switchgear and controlgear assemblies - Part 2: Power switchgear and controlgear assemblies*.

International Electrotechnical Commission, IEC 61730 (All Parts), *Photovoltaic (PV) module safety qualification.*

International Finance Corporation. 2007. Environmental, Health and Safety Guidelines for Waste Management Facilities. December 10, 2007. https://www.ifc.org/wps/wcm/connect/5b05bf0e-1726-42b1-b7c9-33c7b46ddda8/Final%2B-%2BWaste%2BManagement%2BFacilities.pdf?MOD=AJPERES&CVID=nPtj.3h

International Finance Corporation. 2012. Performance Standard 5: Land Acquisition and Involuntary Resettlement. January 1, 2012. World Bank Group. https://www.ifc.org/wps/wcm/connect/75de96d4-ed36-4bdb-8050-400be02bf2d9/PS5_English_2012.pdf?MOD=AJPERES&CVID=jqex59b

IUSS. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Japan International Cooperation Agency and Metal Mining Agency of Japan. 1989. Report on the Cooperative Mineral Exploration in the Chilwa Alkaline Area Republic of Malawi, Phases I (March 1987), II (March 1988), III (March 1989), Consolidated Report (March 1989).

Kjarsgaard, B.A., and Hamilton, D.L. 1989. The genesis of carbonatites by immiscibility. In: Bell, K. (Editor), Carbonatites: Genesis and Evolution. Unwin Hyman, London, pp. 388-404.

Kijko, A. 2021. *Deterministic and Probabilistic Seismic Hazard Analysis Songwe Hill Mine,* Centurion: Natural Hazard Assessment Consultancy CC.

Knight, J., Stratford, D. and Grab, S.W. 2016. Landscape–climate–human interactions in southern Africa. In: Knight, J. and Grab, S.W. (eds) Quaternary environmental change in southern Africa: physical and human dimensions. Cambridge University Press, 412-431.

Lehmann, B., Nakai, S., Höhndorf, A., Brinckmann, J., Dulski, P., Hein, U.F. and Masuda, A. 1994. REE mineralization at Gakara, Burundi: Evidence for anomalous upper mantle in the western Rift Valley. Geochimica et Cosmochimica Acta, 58: 985-992

Levy et al. 2017. Addressing rainfall data selection uncertainty using connections between rainfall and streamflow. *Scientific Reports,* p. 219.

Lewis, T.A. 1953. Geological report on Songwe ring-structure (E.P.L.2/1952). London Nyasaland Mining Corporation, Ltd. (unpublished)

Local Authority Performance Assessment (LAPA) Tool. 2018. District Council's Performance Assessment (LAPA) for 2018-2019 Fiscal Year. Final Report. Ministry of Local Government and Rural Development (MLGD) and DAI-Local Government Accountability Program (LGAP), Lilongwe, Malawi. August 2020. https://pdf.usaid.gov/pdf_docs/PA00XGSR.pdf

Malawi. 2012. UN Map of Malawi (Map No. 3858 Rev4), published April 2012

Malawi Bureau of Standards (MBS). 2005. MS 173, Acoustics – Noise Pollution – Tolerance Limits Malawi Bureau of Standards. PO Box 946. Blantyre. http://www.arso-oran.org/wp-content/uploads/2014/09/Catalogue-of-Malawi-Standards-2011.pdf

Malawi Bureau of Standards (MBS). 2005. MS 214, Drinking water – specification. Malawi Bureau of Standards. PO Box 946. Blantyre. http://www.ndr.mw:8080/xmlui/bitstream/handle/123456789/1183/Drinking%20Water%20-%20Specification.pdf?sequence=1

Malawi Bureau of Standards (MBS). 2005. MS 733:2005 (First edition) Borehole and shallow well water quality – Specification. Malawi Bureau of Standards. PO Box 946. Blantyre.http://www.ndr.mw:8080/xmlui/bitstream/handle/123456789/1171/Borehole%20and%20shallow%20well%20water%20quality%20%E2%80%93%20Specification.pdf?sequence=1#:~:text=MS%20214%2C%20Drinking%20water%2D%20Specif,other%20sources%20of%20ground%20water.

Mariano, A.N. 1989. Nature of economic mineralization in carbonatites and related rocks. In Bell, K., (Ed), Carbonatites: Genesis and Evolution. Unwin Hyman, London. 149-176.

Marinos, P. G., Marinos V and Hoek E. 2005. The Geological Strength Index (GSI): A Characterization Tool for assessing Engineering Properties for Rock Masses. Bull Eng Geol Environ 64, pp 55-65.

Marsh, J. W., J. D. Harrison, and D. Laurier. 2010. Dose Conversion Factors for radon: Recent Developments, Health Physics, 99(4), 511 - 516.

Martin, J. E. 2006. Physics for Radiation Protection: A Handbook. Second Edition, Completely Revised and Enlarge, Wiley-VCH, Weinheim.

McCartney, M. 2007. Technical Note : Hydrology of the Lake Chilwa wetland, Malawi: IWMI.

Mitchell, R.H., 2005: Carbonatites and Carbonatites and Carbonatites. The Canadian Mineralogist, 43, 2049-2068.

Nagoli, J., Green, E., Mulwafu, W., & Chiwona-Karltun, L. 2017. Coping with the Double Crisis: Lake Chilwa Recession and the Great Depression on Chisi Island in Colonial Malawi, 1930-1935. Human ecology: an interdisciplinary journal, 45(1), 111–117. https://doi.org/10.1007/s10745-016-9882-1

National Statistical Office. 2008. 2008 Population and Housing Census. National Statistical Office. P.O. Box 333, Zomba, Malawi. September 2008. https://unstats.un.org/unsd/demographic-social/census/documents/malawi/malawi_report.pdf and http://www.nsomalawi.mw/index.php?option=com_content&view=article&id=87%3Astatistical-yearbook-2008&catid=2&Itemid=95

Necsa. 2013. Report on the Pre-feasibility Radiological Baseline Study performed at Songwe Hill: Mkango Resources; Malawi, Digby Wells Project Number MKA1657, South African Nuclear Energy Corporation, Pretoria.

NNR. 2013. Regulatory Guide: Safety Assessment of Radiation Hazards to members of the Public from NORM Activities, edited, National Nuclear Regulator, Pretoria.

Oberholzer, B. 2005. Guideline for involving visual and aesthetic specialists in EIA processes: Edition 1. CSIR Report No ENV-S-C 2005 053 F. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs and Development Planning, Cape Town.

O Gutu et al. 2016. *Modelling trends and variation in climate of the Serengeti-Mara Ecosystem,* s.l.: Researchgate, University of Hohenheim.

Rafundisani, M. 2020. *Surface Water Impact Assessment Report,* s.l.: Digby Wells.

Remote Exploration Services Ltd. 2010. Results Report: Songwe Geophysical Surveys, Songwe Hill, Malawi. Unpublished Report for Mkango Resources Ltd.

Remote Exploration Services Ltd. 2011. Updated Songwe digital elevation model and geophysical investigation, Unpublished Report for Mkango Resources Ltd.

Rivett, M. O. et al. 2020. Paleo-Geohydrology of Lake Chilwa, Malawi is the Source of Localised Groundwater Salinity and Rural Water Supply Challenges. *Applied Sciences,* 10(6909), pp. 1-36

Robinson, K. R. 1977. Iron Age Occupation North and East of the Mulanje Plateau, Malawi. Department of Antiquities No. 17. Lilongwe: Department of Antiquities.

RocData 4.0. Rocscience User's Manual.

SAICE. 2010. *Site Investigation Code of Practice.* 1st ed. s.l.: South African Institution of Civil Engineering – Geotechnical Division.

SENET. 2018. *Mkango Rare Earth Contours.dwg,* Johannesburg: s.n.

SENET. 2019*. Standard Specification Songwe Hill, SP0803, Design Criteria, Site Conditions*, 25/10/2019.

SLIDE 6.0. Rocscience User's Manual.

Smith, M.P., Henderson, P. 2000: Preliminary fluid inclusion constraints on fluid evolution in the Bayan Obo Fe-REE-Nb deposit, Inner Mongolia, China. Economic Geology, 95. 1371-1388.

Sneller et al. 2000. Maximum Permissible Concentrations and Negligible Concentrations for Rare Earth Elements (REEs).

South African Bureau of Standards. SANS 1507 (All Parts), *Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V)*.

South African Bureau of Standards. SANS 10142-1, *The wiring of premises – Part 1: Low-voltage installations*.

Statham P. 2014. Standard Work Procedure – Topsoil Management. Health, Safety and Environmental Standard.

SWedge 6.0. Rocscience User's Manual.

Tallaksen, L., and Van Lanen, H. 2004. Hydrological Drought: Processes and Estimation Methods for Streamflow and Groundwater.

The MSA Group. 2015. Mkango Resources Limited, Songwe REE Project, Malawi NI 43-101 Pre-Feasibility Report.

The MSA Group. 2019. Mkango Resources Limited, Songwe Hill Rare Earth Element (REE) Project, Phalombe District, Republic of Malawi, NI 43-101 Technical Report – 23 January 2019 Mineral Resource Estimate.

UNESCO. 2015. Ecological Sciences for Sustainable Development: Lake Chilwa Wetland. http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/africa/malawi/lake-chilwa-wetland/

U.S. Army Corps of Engineers. 1997. *Engineering and Design: Introduction To Probability and Reliability Methods,* Washington, DC: s.n.

U.S. Army Corps of Engineers. 2010. Corps of Engineers wetlands delineation manual. Wetlands Regulatory Assistance Program. Engineer Research and Development Center. https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/7627/

Wall, F. and Mariano, A.N. 1996. Rare earth minerals in carbonatites: a discussion on the Kangankunde Carbonatite, Malawi. In: Jones, A.P., Wall, F., and Williams, C.T., (Eds.) Rare Earth Minerals: Chemistry, Origin and Ore Deposits. Chapman and Hall, 193-225.

Wallace, M.E. and Green, D.H. 1988. An experimental determination of primary carbonatite magma composition. Nature, 335, 343-346.

Watkinson, D.H., and Wyllie, P.J. 1971. Experimental study of the join NaAlSiO 4-CaCO3-H2O and the genesis of alkalic rock-carbonatite complexes. Journal of Petrology, 12, 357-378.

Woolley, A.R. and Garson, M.S. 1970. Petrochemical and tectonic relationship of the Malawian carbonatite-alkaline province and the Lupata-Lebombo volcanics. In: T.N. Clifford and I.G. Gass (Eds.), African Magmatism and Tectonics. Oliver and Boyd, Edinburgh. 237-262.

Woolley, A.R. 1987. Lithosphere metasomatism and petrogenesis of the Chilwa Province of alkaline igneous rocks and carbonatites, Malawi. Journal of African Earth Sciences, 6, 891

Woolley, A.R. and Jones, G.C. 1987. The petrochemistry of the northern part of the Chilwa alkaline province, Malawi. Geological Society, London, Special Publications, 30, 335.

Woolley, A.R. and Kempe, D.R.C. 1989. Carbonatites: nomenclature, average chemical compositions, and element distribution. In: Bell, K. (Editor), Carbonatites: Genesis and Evolution. Unwin Hyman, London, pp1–14.

Woolley, A.R. 1991. The Chilwa Alkaline Igneous Province of Malawi: a review. In: Kampunzu, A.B. and Lubala, R.T. (Eds.), Magmatism in Extensional Structural Settings: the Phanerozoic African Plate. Springer-Verlag, Berlin, 377-409.

Woolley, A.R. 2001. Alkaline Rocks and Carbonatites of the World Part 3: Africa. The Geological Society, London. 372 pp.

Woolley, A.R., and Kjarsgaard, B.A. 2008. Paragenetic types of carbonatite as indicated by the diversity and relative abundances of associated silicate rocks: evidence from a global database. Canadian Mineralogist, 46 (4), 741-752.