



**HYDROLOGICAL ASSESSMENT FOR THE KOKOSEB
EPL 4818 PROJECT, ERONGO REGION, NAMIBIA**

VERSION 1

04 JULY 2025

PROJECT NO. UVO-005

HYDROLOGIC CONSULTING

Email: info@hydrologic.consulting | Phone: +27 72 239 0974

HYDROLOGICAL ASSESSMENT FOR THE KOKOSEB EPL 4818 PROJECT, ERONGO REGION, NAMIBIA

Prepared For

UMVOTO AFRICA (PTY) LTD

Prepared By

HYDROLOGIC CONSULTING (PTY) LTD

PROJECT NO. UVO-005

VERSION 1

04 July 2025

TABLE OF CONTENTS

1	INTRODUCTION.....	1
1.1	SCOPE OF WORK	1
1.2	REGIONAL SETTING AND LAYOUT	1
1.2.1	<i>EXPERTISE OF PRIMARY AUTHOR AND DECLARATION OF INDEPENDENCE.....</i>	<i>4</i>
2	BASELINE ENVIRONMENT.....	5
2.1	RAINFALL	5
2.1.1	<i>DESIGN RAINFALL DEPTHS.....</i>	<i>5</i>
2.1.2	<i>FREQUENCY ANALYSIS.....</i>	<i>7</i>
2.2	EVAPORATION	9
2.3	AVERAGE CLIMATE	9
2.4	TERRAIN.....	10
2.5	HYDROLOGY	11
2.6	SOILS AND LAND-COVER	11
3	APPLICABLE GUIDANCE	15
3.1	SURFACE WATER-SPECIFIC GUIDANCE.....	15
3.1.1	<i>WATER RESOURCES MANAGEMENT ACT 11 OF 2013 (GOVERNMENT GAZETTE NO. 5367).....</i>	<i>16</i>
3.1.2	<i>COMMENCEMENT OF WATER RESOURCES MANAGEMENT ACT 11 OF 2013 (GOVERNMENT GAZETTE NO. 8187)</i>	<i>17</i>
3.1.3	<i>IFC ENVIRONMENTAL, HEALTH AND SAFETY GUIDELINES – MINING (2007)</i>	<i>18</i>
3.1.4	<i>GN 704</i>	<i>19</i>
4	HIGH-LEVEL EVALUATION OF FLOOD POTENTIAL.....	21
4.1	ASSESSMENT OF FLOODING	21
4.1.1	<i>FLOODING ON FLOW PATHS (>5KM²)</i>	<i>21</i>
4.1.2	<i>BUFFERING APPROACH TO FLOOD SENSITIVITY</i>	<i>22</i>
4.2	RIPARIAN BUFFER.....	27
5	HYDROLOGICAL IMPACTS AND MITIGATION MEASURES	28
5.1	METHOD OF ASSESSING IMPACTS	28
5.1.1	<i>DETERMINATION OF SIGNIFICANCE</i>	<i>28</i>
5.2	PROJECT PHASES	31
5.3	IDENTIFIED IMPACTS	31
5.3.1	<i>EROSION OF SOILS.....</i>	<i>31</i>
5.3.2	<i>POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT</i>	<i>32</i>
5.3.3	<i>DECREASE IN RUNOFF.....</i>	<i>34</i>
5.3.4	<i>ALTERED DRAINAGE</i>	<i>35</i>
5.3.5	<i>FLOODING.....</i>	<i>36</i>
5.4	ASSUMPTIONS, UNCERTAINTIES AND GAPS IN KNOWLEDGE	37
6	SURFACE WATER MONITORING.....	38
6.1	MONITORING PROGRAMME.....	38
7	RECOMMENDATIONS AND CONCLUSION.....	41

8 REFERENCES	43
APPENDIX A: FLOOD MODELLING.....	44

LIST OF FIGURES

FIGURE 1-1: REGIONAL SETTING	2
FIGURE 1-2: LAYOUT.....	3
FIGURE 2-1: WEATHER STATIONS AND MEAN ANNUAL PRECIPITATION.....	6
FIGURE 2-2: AVERAGE MONTHLY CLIMATE	10
FIGURE 2-3: TERRAIN AND HYDROLOGY	12
FIGURE 2-4: VEGETATION AND SOIL RUNOFF POTENTIAL	13
FIGURE 2-5: LAND-COVER.....	14
FIGURE 4-1: FLOOD SENSITIVITY	24
FIGURE 4-1: MAXIMUM FLOOD DEPTH (1:100 RI)	25
FIGURE 4-1: MAXIMUM FLOOD VELOCITY (1:100 RI).....	26
FIGURE 5-1: ECC IMPACT METHODOLOGY – PART 1	29
FIGURE 5-2: ECC IMPACT METHODOLOGY – PART 2.....	30
FIGURE 6-1: POSSIBLE SURFACE WATER SAMPLING LOCATIONS	39

LIST OF TABLES

TABLE 2-1: CHIRPS AVERAGE MONTHLY RAINFALL DISTRIBUTION (MM)	5
TABLE 2-1: COMPARISON OF AMS DATA	8
TABLE 2-2: DESIGN STORM DEPTH	9
TABLE 2-2: FAO AQUASTAT AVERAGE MONTHLY REFERENCE EVAPOTRANSPIRATION	9
TABLE 5-1: EROSION OF SOILS (CONSTRUCTION PHASE)	31
TABLE 5-2: EROSION OF SOILS (OPERATION AND DECOMMISSIONING PHASE)	32
TABLE 5-3: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (CONSTRUCTION PHASE)	33
TABLE 5-4: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (OPERATION PHASE).....	33
TABLE 5-5: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (DECOMMISSIONING PHASE)	34
TABLE 5-6: DECREASE IN RUNOFF (CONSTRUCTION PHASE).....	34
TABLE 5-7: DECREASE IN RUNOFF (OPERATION AND DECOMMISSIONING PHASE)	35
TABLE 5-8: ALTERED DRAINAGE (CONSTRUCTION PHASE).....	35
TABLE 5-9: ALTERED DRAINAGE (OPERATION AND DECOMMISSIONING PHASE)	36
TABLE 5-10: FLOODING (CONSTRUCTION, OPERATIONAL AND DECOMMISSIONING PHASE)	37
TABLE 6-1: SAMPLING COORDINATES	38
TABLE 6-2: MONITORING PARAMETERS	40

ACROYNYS

Abbreviation	Full Term
AMS	Annual Maximum Series
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station Data
COP30	Copernicus 30m Digital Surface Model
DSM	Digital Surface Model
ECC	Environmental Compliance Consultancy (Pty) Ltd
EIA	Environmental Impact Assessment
EMA	Environmental Management Act
EPL	Exclusive Prospecting Licence
ESIA	Environmental and Social Impact Assessment
ET ₀	Reference Evapotranspiration
FAO	Food and Agriculture Organization (of the United Nations)
HEC-RAS	Hydrologic Engineering Center - River Analysis System
IFC	International Finance Corporation
IMERG	Integrated Multi-satellite Retrievals for GPM
OSM	OpenStreetMap
RI	Recurrence Interval
SAF	Sampling Adjustment Factor
SANRAL	South African National Roads Agency Limited
SWAT	Soil and Water Assessment Tool
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers

1 INTRODUCTION

Umvoto Africa (Pty) Ltd has appointed Hydrologic Consulting to undertake a hydrological assessment of the proposed Kokoseb EPL 4818 Project, located in the Erongo Region, Namibia.

Umvoto requires specialist input into the environmental and social impact assessment (ESIA) being conducted by Environmental Compliance Consultancy (Pty) Ltd (ECC) for the project. This assessment aims to evaluate the impacts on sensitive receptors that the proposed project will have regarding hydrology (surface water) during construction, operation, and decommissioning.

This report outlines the hydrological baseline, followed by a hydrological (surface water) impact assessment.

1.1 SCOPE OF WORK

The scope of work was achieved by undertaking the following:

- Baseline Assessment – sourcing of baseline climatic and hydrological data. This included the interrogation of rainfall data, site-specific design rainfall (depth/duration/frequency), evaporation, soils, and land use, as well as a regional and local hydrological assessment.
- Flooding Assessment – a high-level assessment of possible flooding from the larger ephemeral rivers on the site was undertaken to define the 1:50 and 1:100 flood extents. A buffering approach to flow accumulation (defined by available terrain data) was also undertaken as a qualitative approach to considering flooding for lesser watercourses or flow paths.
- Hydrological Impact Assessment – this was undertaken using an impact assessment methodology developed to enable effective communication of the potential consequences or impacts of activities on the hydrological (surface water) environment; and
- A technical report detailing the achieved scope of work (this report).

The above scope of work is based on a desktop assessment of the site.

1.2 REGIONAL SETTING AND LAYOUT

The proposed mine (hereafter also referred to as the Project) is located at 21° 10' 34" S and 15° 17' 17" E. The regional setting of the site is illustrated in **Figure 1-1**, while the layout of the site is presented in **Figure 1-2**. The following proposed infrastructure locations were considered in this assessment:

- Opencast pit;
- Waste rock dump; and
- Processing plant.

The position of the proposed infrastructure is presently approximate (for the waste rock dump and processing plant in particular).

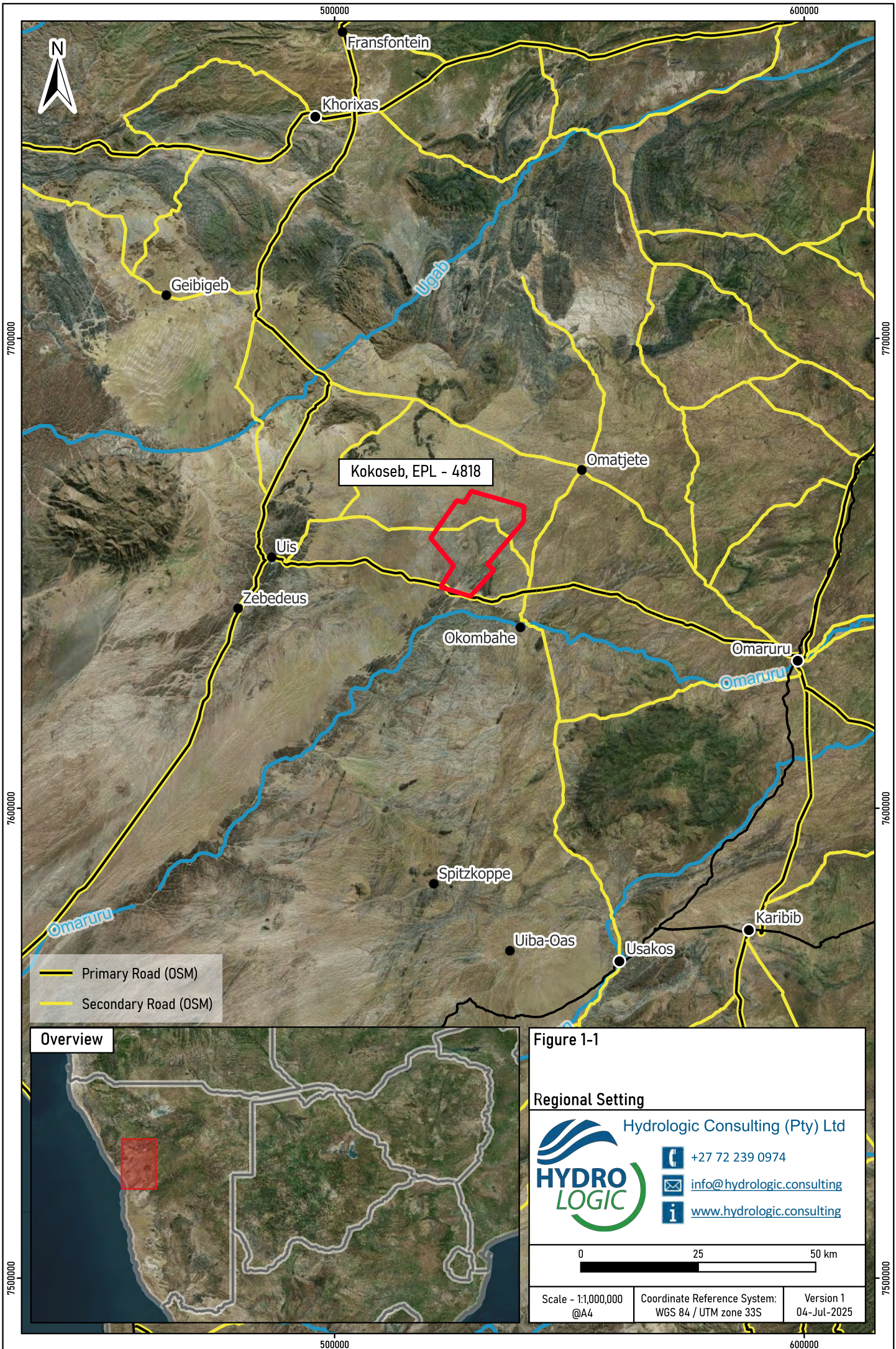


Figure 1-1

Regional Setting

Hydrologic Consulting (Pty) Ltd

HYDRO LOGIC

+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 25 50 km

Scale - 1:1,000,000 @A4	Coordinate Reference System: WGS 84 / UTM zone 33S	Version 1 04-Jul-2025
-------------------------	--	-----------------------



Legend

- Boundary (Kokoseb, EPL - 4818)
- Locality (OSM)
- Rivers (OSM)
- 20m Contour (COP30 Derived)

Layout

- Pit
- Processing Plant (Approximate)
- Waste Rock Dump (Approximate)

Roads (OSM)

- Primary
- Secondary
- Tertiary

Figure 1-2

Layout

Hydrologic Consulting (Pty) Ltd

HYDRO LOGIC

+27 72 239 0974

info@hydrologic.consulting

www.hydrologic.consulting

0 5 10 km

Scale - 1:200,000 @A3

Coordinate Reference System: WGS 84 / UTM zone 33S

Version 1 04-Jul-2025

1.2.1 EXPERTISE OF PRIMARY AUTHOR AND DECLARATION OF INDEPENDENCE

Mr Mark Bollaert has over 17 years of experience working as a consulting hydrologist in both the United Kingdom and South Africa, since completing his Master of Science (MSc) degree in Hydrology at the University of KwaZulu-Natal. Mark has supplemented his tertiary education with professional qualifications, which represent his ongoing effort toward maintaining a professional approach and continuing in his professional development. These include qualifications from the UK (Chartered Scientist, Chartered Environmentalist and Chartered Water and Environmental Manager) and South Africa (Professional Natural Scientist in Water Resources).

In terms of the requirement to be independent, Hydrologic Consulting and affiliated consultant Mr Mark Bollaert declare that other than fair remuneration for the work undertaken, he has no business, financial, or personal interest in the proposed activity or application and that there are no circumstances that may compromise his objectivity.

2 BASELINE ENVIRONMENT

Baseline information in this section includes discussions on the rainfall, evaporation, design event rainfall, soils and land cover, as well as local terrain and regional and local catchment hydrology.

The Atlas of Namibia (2022) provided much of the data presented in this section.

2.1 RAINFALL

Rainfall data for the site was not readily available and required consideration of alternate datasets. The first of these datasets was sourced from the Atlas of Namibia (2022) and provided a *Climate Hazards Group InfraRed Precipitation with Station data* CHIRPS¹ derived estimate of annual rainfall for the site and its surroundings. This data is illustrated in **Figure 2-1**.

Average monthly CHIRPS rainfall data for the site were subsequently extracted and presented in **Table 2-1**.

TABLE 2-1: CHIRPS AVERAGE MONTHLY RAINFALL DISTRIBUTION (MM)

Month	Rainfall (mm)
Jan	35
Feb	44
Mar	45
Apr	18
May	1
Jun	0
Jul	0
Aug	0
Sep	1
Oct	4
Nov	11
Dec	13
Total	172

* Estimates sourced at the centre of the site.

2.1.1 DESIGN RAINFALL DEPTHS

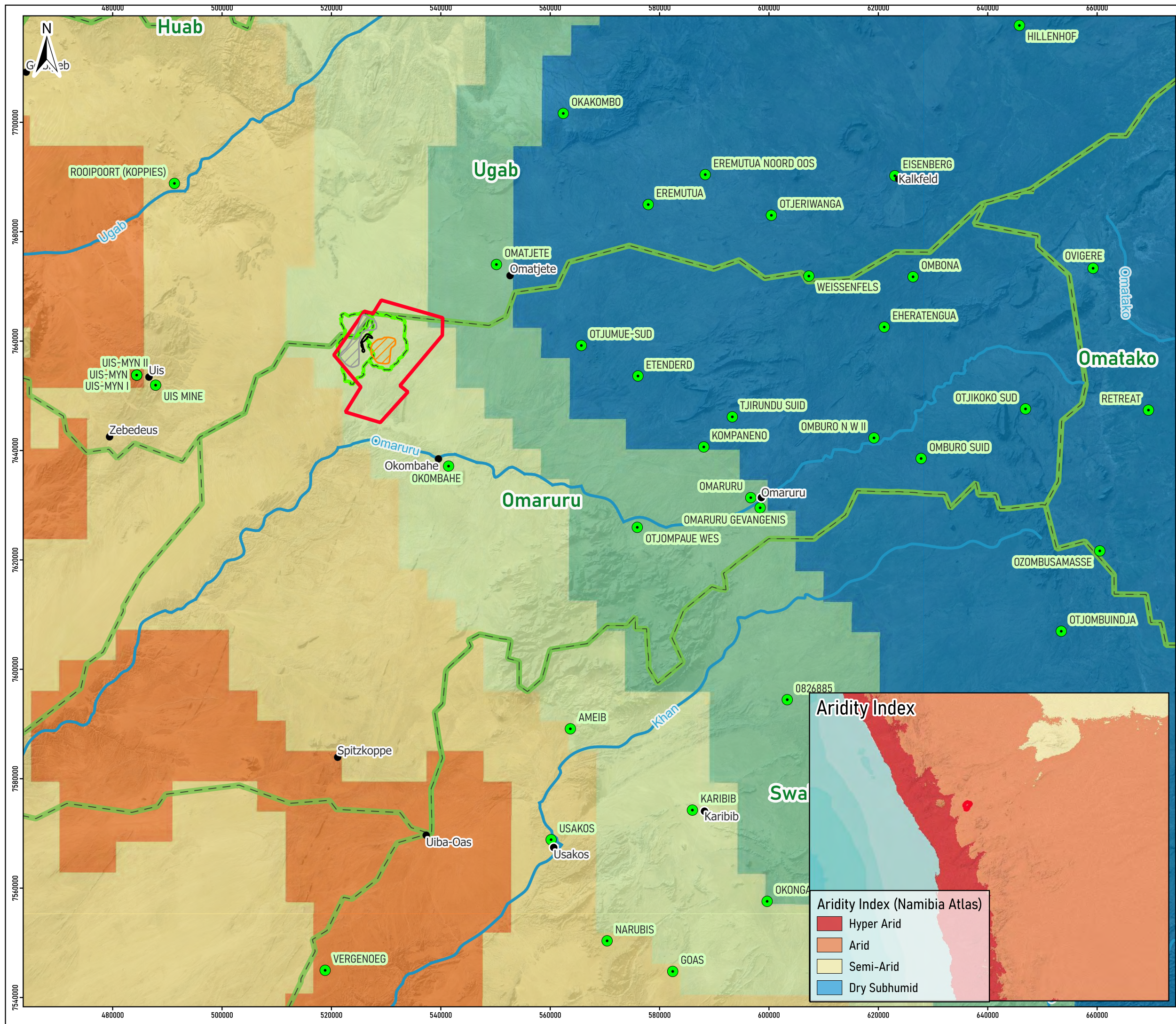
For the assessment of flooding, design rainfall was the most important climatic variable to consider as it is the driver behind peak flows.

DAILY RAINFALL – KUNZ (2004)

Kunz (2004) provides the means to extract observed daily rainfall (gauge) data up to the year 2001 from rainfall stations within Southern Africa. In considering **Figure 2-1**, there are many rainfall stations in the region of the site. In reviewing these stations, none are within 10km of the site.

Of the stations within 100km of the site, the highest record length was 16 years. Etenderd (0870403 W) located approximately 41km to the east of the site had a 16-year record from 1968 to 1986.

¹ CHIRPS: Rainfall Estimates from Rain Gauge and Satellite Observations | Climate Hazards Center - UC Santa Barbara ([ucsb.edu](https://climate.geos.udel.edu/research/CHIRPS/))



Legend

Boundary (Kokoseb, EPL - 4818)

Raingauge (Kunz, 2004)

Non-Perennial River (Nambias Atlas)

River Basin (Nambias Atlas)

Dams (Nambias Atlas)

Containing Catchment (COP30 Derived)

Layout

Pit

Processing Plant (Approximate)

Waste Rock Dump (Approximate)

Mean Annual Precipitation (mm, Nambias Atlas)

<= 50

50 - 100

100 - 150

150 - 200

200 - 250

> 250

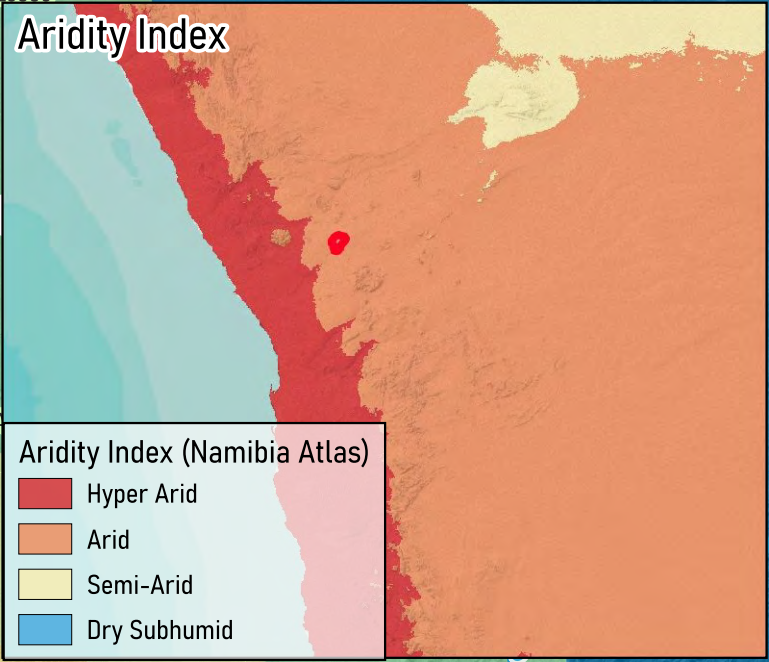


Figure 2-1

Mean Annual Precipitation

+27 72 239 0974

info@hydrologicconsulting

www.hydrologicconsulting

0102030 km

Scale - 1:650,000 @A3

Coordinate Reference System: WGS 84 / UTM zone 33S

Version 1 04-Jul-2025

DAILY RAINFALL – CHIRPS

CHIRPS² (*Climate Hazards Group InfraRed Precipitation with Station data*) is the rainfall dataset used by the Atlas of Namibia (2022) to provide monthly rainfall estimates for the country (at any location). CHIRPS is a 35+ year quasi-global rainfall data set spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present, CHIRPS incorporates climatology, satellite imagery, and in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. This data has seen increasing use (globally) due to its ability (when compared to alternative remotely sensed rainfall datasets) to better predict monthly rainfall depths.

DAILY RAINFALL - IMERG

IMERG³ (Integrated Multi-satellite Retrievals for GPM) combines estimates from the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement Mission (GPM) satellites over the years spanning from 2000 to 2020 (the dataset used). This data includes estimates of daily rainfall at the site and is recommended by SWAT (Soil & Water Assessment Tool) developed by the United States Department of Agriculture (USDA) Agricultural Research Service and Texas A&M University's Blackland Research & Extension Center. SWAT is a physical, conceptual hydrological modelling tool that has been used by Hydrologic Consulting in past projects to simulate river flows. The linkage with SWAT provides some credibility to the use of IMERG in describing daily rainfall at an otherwise unmonitored location.

2.1.2 FREQUENCY ANALYSIS

A frequency analysis using the three sources of daily rainfall obtained for this study was performed. Frequency analysis is achieved by selecting the highest recorded rainfall record in each year (i.e. the annual maximum series or AMS). For the analysis, the water year, which runs from October to September was used to extract the AMS with the following the result (see **Table 2-2**). The table clearly shows how Kunz (2004) observations are higher than IMERG and CHIRPS, with CHIRPS seeing lower estimates than IMERG. With a brief overlapping period between Kunz (2004) and CHIRPS, it is likely that CHIRPS is underestimating rainfall despite the location at which the Kunz (2004) data originated from (approximately 41km east of the site).

Where rainfall records are available, estimates of design rainfall for a particular Recurrence Interval (RI) can be estimated, although extrapolation of RI events beyond twice the record length (e.g. 50 years of data used to define the 1:100 year event) is not recommended (SANRAL, 2013).

The AMS based on daily data is, however, insufficient to estimate the 24-hour rainfall for the site with a sampling adjustment factor (SAF) needed to correct the underestimation of fixed time interval maxima (daily rainfall) relative to maxima of a moving time window (24-hour rainfall). A factor of 1.16 was used to scale the daily rainfall to 24-hour rainfall. With the 24-hour rainfall AMS series completed, a frequency analysis was undertaken utilising the 'best fit' distribution identified by the 'goodness-of-fit' per the Kolmogorov-Smirnov method.

Three different datasets of rainfall data were evaluated; Kunz (2004) only, Kunz (2004) with IMERG and, Kunz (2004) with a modified CHIRPS dataset (scaled according to Kunz 2004 to 220% higher than the original value). All three

² <https://www.chc.ucsb.edu/data/chirps>

³ [IMERG: Integrated Multi-satellite Retrievals for GPM | NASA Global Precipitation Measurement Mission](#)

approaches to the frequency analysis gave results that approximated 100mm for the 24-hour, 1:100 RI design rainfall event.

TABLE 2-2: COMPARISON OF AMS DATA

Water Year	KUNZ (2004)	CHIRPS	IMERG
1967-68	71		
1968-69	12		
1969-70			
1970-71	36		
1971-72	69		
1972-73	25		
1973-74	56		
1974-75	41		
1975-76	81		
1976-77	45		
1977-78	55		
1978-79	54		
1979-80	33		
1980-81	43	9	
1981-82	41	30	
1982-83	48	18	
1983-84	31	24	
1984-85	67	19	
1985-86	43	15	
1986-87		15	
1987-88		40	
1988-89		16	
1989-90		21	
1990-91		12	
1991-92		18	
1992-93		18	
1993-94		26	
1994-95		14	
1995-96		11	
1996-97		14	
1997-98		23	
1998-99		15	
1999-00		24	
2000-01		21	40
2001-02		43	16
2002-03		40	26
2003-04		16	54
2004-05		19	42
2005-06		18	56
2006-07		15	18
2007-08		16	30
2008-09		19	31
2009-10		15	25
2010-11		18	30
2011-12		17	22
2012-13		21	19
2013-14		15	26
2014-15		15	19
2015-16		9	10
2016-17		29	23
2017-18		22	19
2018-19		8	15
2019-20		9	24
2020-21		7	26
2021-22		20	25
2022-23		7	18
2023-24		14	35

Of these three, the scaled CHIRPS dataset was marginally higher at 102mm compared to 99mm for the other two datasets. The availability of a longer record set (rainfall gauge) would improve the accuracy of the above analysis.

Table 2-3 presents the design rainfall depths as determined according to the scaled CHIRPS dataset.

TABLE 2-3: DESIGN STORM DEPTH

Recurrence Interval (Years)	Scaled CHIRPS - Rainfall Depth (24-hour) (mm)
2	45.6
5	64.4
10	77.1
20	89.4
50	105.7
100	118.2
200	130.8

It is important to note, that no allowances for climate change have been made. A risk analysis using the expected life of a structure or process will indicate the relevance of considering climate change (i.e. as the expected life increases the influence of climate change increases).

2.2 EVAPORATION

Estimates of Reference Evapotranspiration (ET₀) were sourced from the Food and Agriculture Organisation's (FAO's) AQUASTAT Tool. The resulting average monthly and annual total ET₀ estimates are presented in **Table 2-2**. ET₀ is noted as being estimated at 2,489mm. By comparison, the Atlas of Namibia (2022) indicates a Potential Evapotranspiration estimate of 2,509mm.

TABLE 2-4: FAO AQUASTAT AVERAGE MONTHLY REFERENCE EVAPOTRANSPIRATION

Month	Reference Evapotranspiration (ET ₀) (mm)
Jan	236
Feb	187
Mar	186
Apr	164
May	167
Jun	169
Jul	184
Aug	208
Sep	219
Oct	261
Nov	255
Dec	253
Total	2,489

* Estimates sourced at the centre of the site.

2.3 AVERAGE CLIMATE

Average climate data was derived from the FAO's Aquastat platform (reference evapotranspiration and temperature) and from CHIRPS. The average monthly data are presented together in **Figure 2-4**. While evapotranspiration is shown as significantly exceeding rainfall, this represents the maximum reference evapotranspiration (ET₀) that could occur, assuming no limitations are placed on evapotranspiration demand. The

combination of rainfall, evapotranspiration and temperature results in a dry, hot, arid desert climate according to the Köppen-Geiger climate classification⁴.

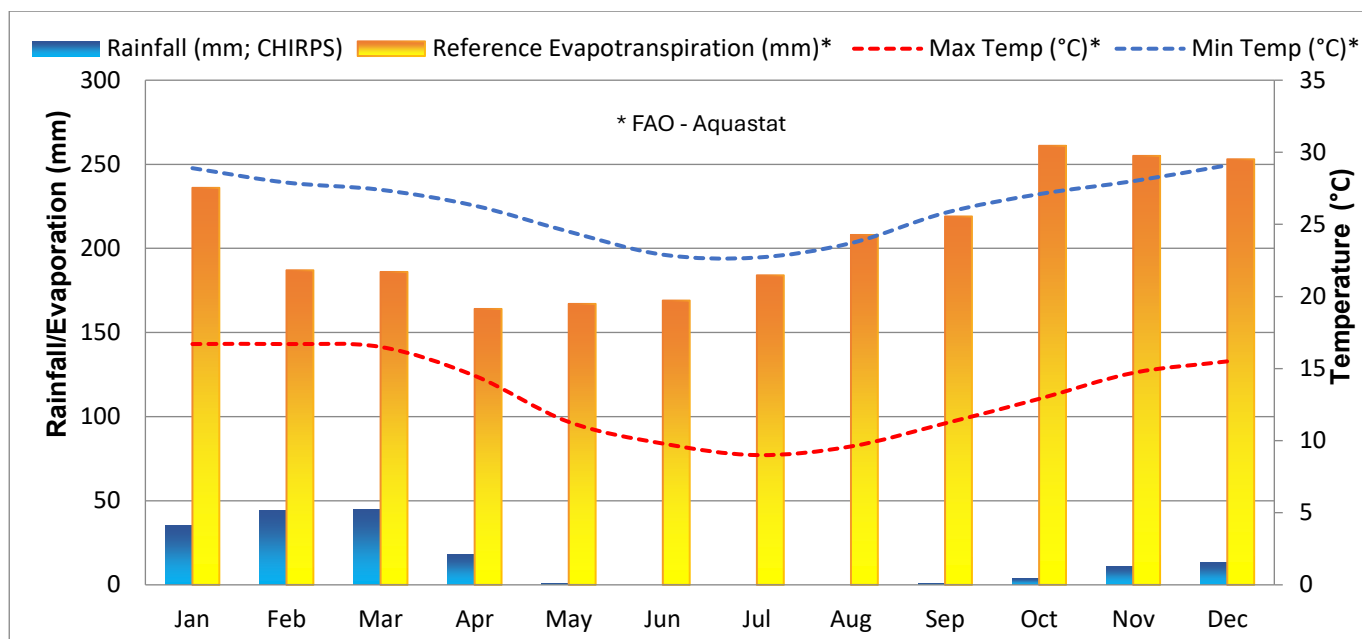


FIGURE 2-2: AVERAGE MONTHLY CLIMATE

2.4 TERRAIN

In assessing the terrain of the site, a single dataset was used in the form of 30m digital surface model (DSM) COP30⁵ data. The 30m DSM provides a coarse estimate of the terrain due to the accuracy/detail of the dataset.

COP30 was selected from among alternative (freely available) 30m terrain datasets due to previous evaluation of this dataset by Hydrologic, which involved the comparison of 30m terrain datasets to higher detail/accuracy terrain data and aerial imagery, with COP30 being found to perform the better (among the available 30m datasets). This is not to say that COP30 is the ideal 30m DSM (when compared to alternate options) in all aspects of terrain variability found at and around the site; however, a single continual dataset was needed on which to base this study.

20m contours were subsequently derived from the COP30 data for use in mapping. **Figure 2-3** presents the terrain of the site with elevation on the site approximating 780m AMSL. Slope (derived from COP30) is also illustrated in **Figure 2-3**, with a variation in slope noted given the undulating nature of the site. Slopes are typically mild, falling below 10%.

⁴ [Namibia - Summary | Climate Change Knowledge Portal \(worldbank.org\)](https://climateknowledgeportal.worldbank.org/namibia/)

⁵ [Copernicus Digital Elevation Model - Copernicus Contributing Missions Online](https://copernicus.digital-elevation-model.com/)

2.5 HYDROLOGY

Figure 2-1 illustrates the regional hydrological setting of the project, while **Figure 2-3** presents the local hydrology of the mine.

The project is within the greater Omaruru Catchment, which drains to the Atlantic Ocean. The Omaruru Catchment's primary river is the Omaruru River, which passes approximately 3.4km to the south of the site (and approximately 14.3km south of the proposed infrastructure on the site).

The Omaruru River is ephemeral, only flowing after periods of rain. Tributaries to the Omaruru River were available using OpenStreetMaps (OSM) data and are illustrated in **Figure 2-3** (although easier to identify in **Figure 2-1**). Four ephemeral river reaches (per OSM data) with the Leeu and Xamgudomi labelled watercourses. Per Namibia's 1:50,000 topographical map data, there are, however, many defined ephemeral rivers intersecting the site. These are referred to in more detail in **Section 4**.

To better understand the possible influence of the ephemeral rivers on the site, a flow path analysis which considered contributing areas was used with thresholds of 1km², 5km² and 10km². These differing classifications enable a distinction in areas on the site where flows could potentially be more concentrated following rainfall.

A containing catchment representative here catchments draining to individual flow paths was delineated. This containing catchment encompasses the area of works on the site.

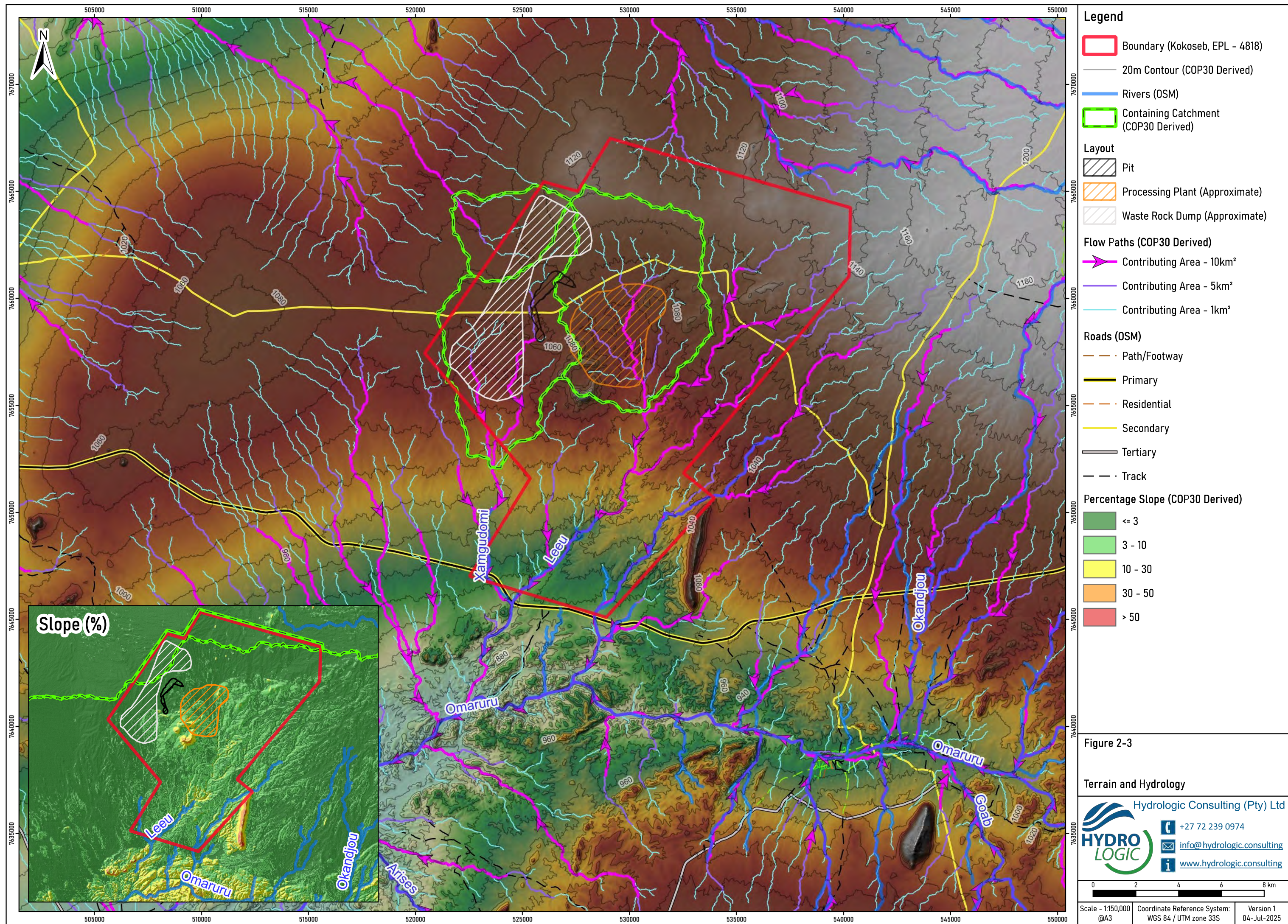
2.6 SOILS AND LAND-COVER

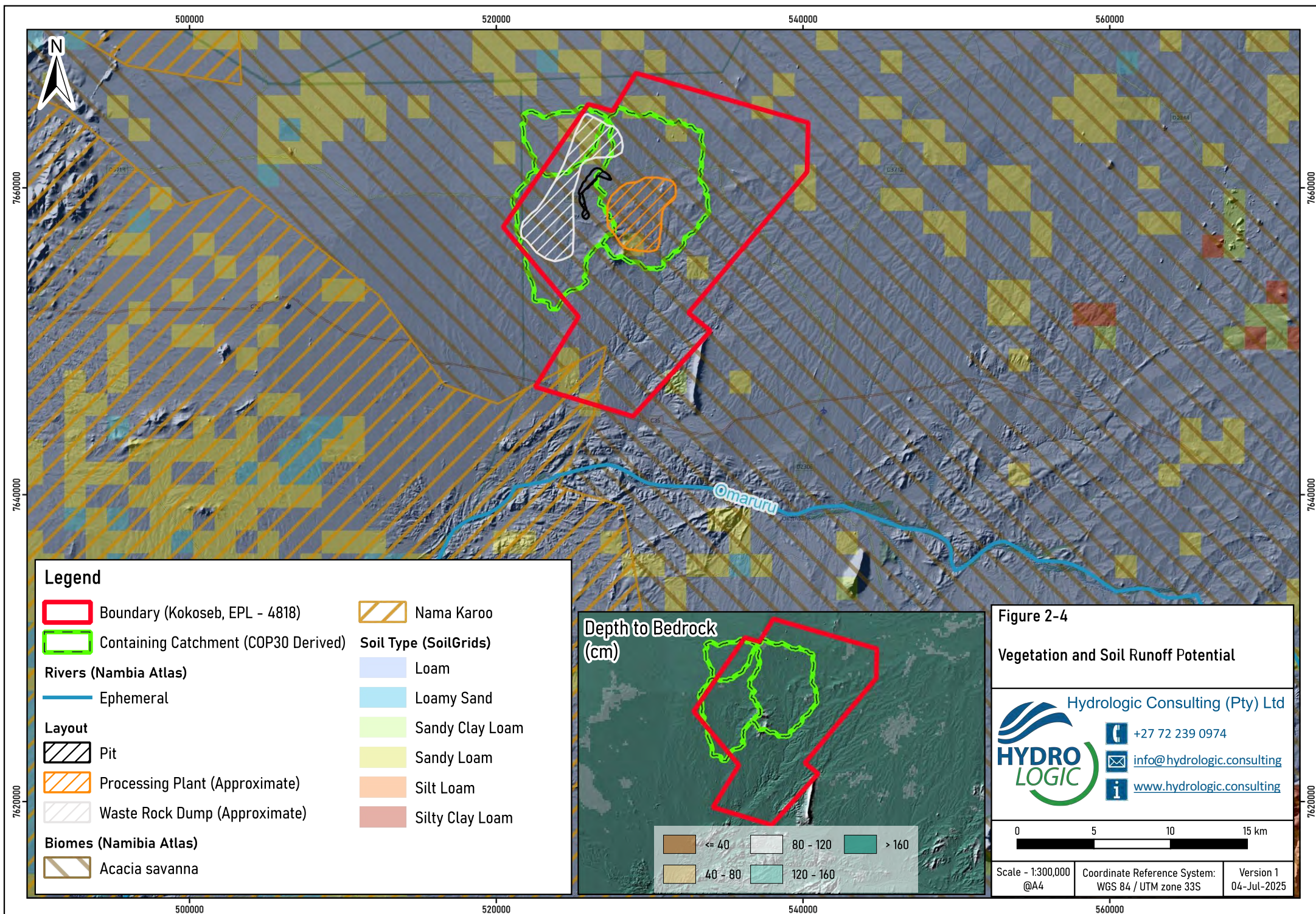
A soil texture class and depth to bedrock for the site and containing catchment were identified from the Atlas of Namibia (2022) and are presented in **Figure 2-4**. This figure illustrates a depth to bedrock that is shallower in regions of more mountainous terrain, as is expected. Soil texture over the site is predominantly classified as 'loam'.

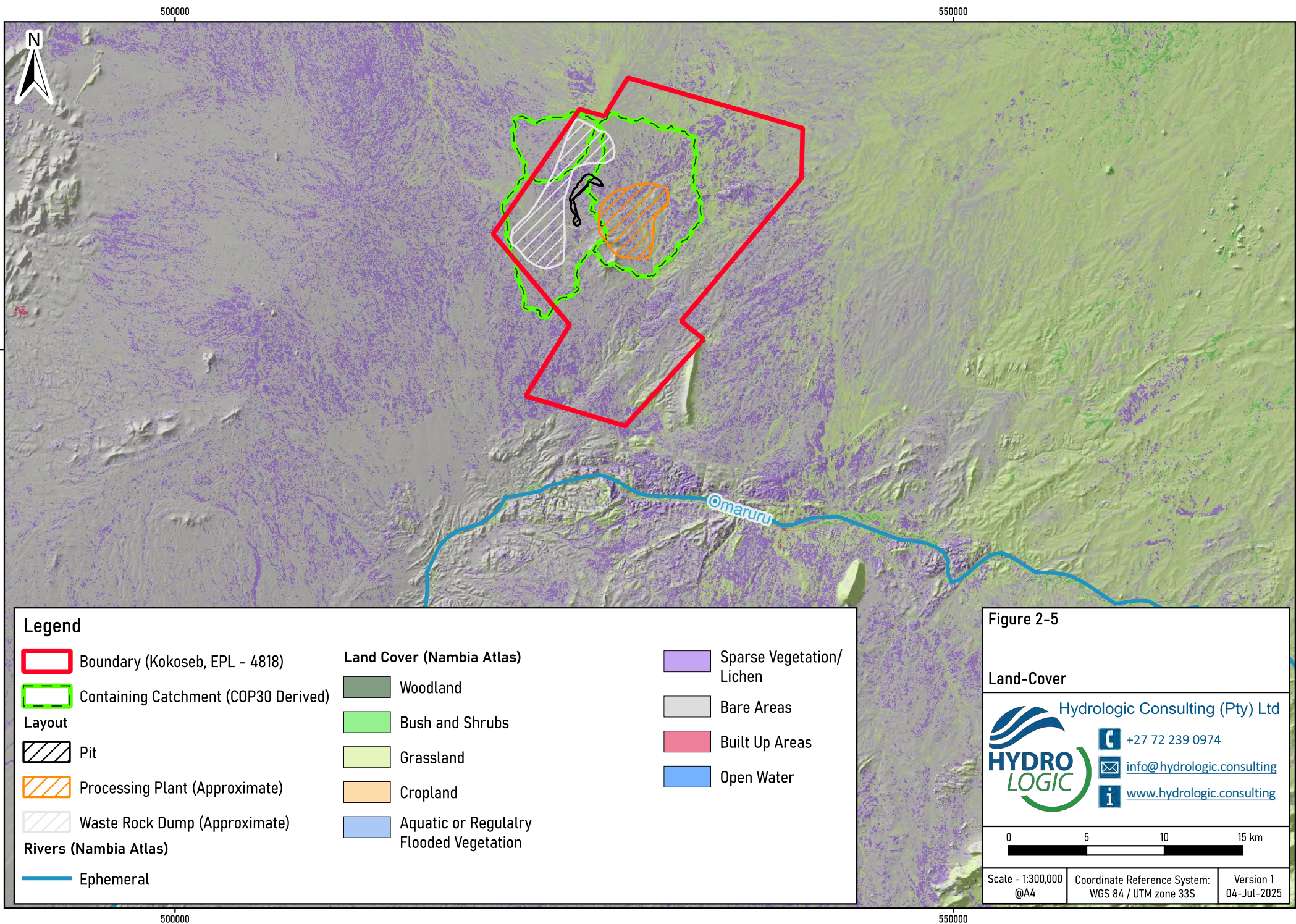
The natural vegetation of the site is classified per the Atlas of Namibia (2022) as being Acacia Savannah.

The land-cover of the site as defined by the Atlas of Namibia (2022) is a mix of Bare Areas, Sparse Vegetation and Grassland.

Figure 2-4 presents the soil and vegetation coverage of the containing catchment while **Figure 2-5** presents the land-cover of the containing catchment.







3 APPLICABLE GUIDANCE

Environmental Compliance Consultancy (Pty) Ltd (ECC) has previously published a “Best Practice Guide – Environmental Principles for Mining in Namibia”⁶. Within this document, the following legislative and regulatory frameworks are identified (focus on the surface water environment):

- THE CONSTITUTION OF THE REPUBLIC OF NAMIBIA, 1990 (AMENDED 1998) states that “*the maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilisation of living natural resources on a sustainable basis*”.
- MINERALS (PROSPECTING AND MINING) ACT, NO. 33 OF 1992 which indicates that that a licence holder should apply “good mining practices” concerning environmental protection, natural resource conservation, and the removal of accessory works or other goods that were erected, constructed or brought onto the land for the mining activities.
- MINERALS POLICY OF NAMIBIA, 2002, which stipulates that mine closure should be properly planned and “form part of an integrated land use strategy involving engagement with communities”, and encourages the alternative use of land through rehabilitation, as well as the use of remaining infrastructure for ongoing economic benefits.
- ENVIRONMENTAL MANAGEMENT ACT, NO. 7 OF 2007, which provides a framework for conducting environmental assessments as well as the implementation of monitoring and auditing measures.
- NAMIBIA’S ENVIRONMENTAL ASSESSMENT POLICY FOR DEVELOPMENT AND ENVIRONMENTAL CONSERVATION, 1994 states that the proponent is required to enter into a binding agreement (based on the procedures and recommendations contained in the EIA report) to ensure that the mitigation and other measures recommended in the EIA are accepted by all parties and fulfilled. This agreement should address the construction, operational, and decommissioning phases in the mine closure process, as applicable, as well as its monitoring and auditing.
- WATER RESOURCES MANAGEMENT ACT, NO. 11 OF 2013 (Government Gazette No. 5367 and 8187), which includes aspects such as the licensing of water use, prevention of water pollution, protection of water resources, efficient use of water, water conservation measures, and the safety of dams.
- BIODIVERSITY-RELATED LEGISLATION Some key principles endorsed in Namibia include: the protection of sensitive habitats; the maintenance of species and ecological processes, such as surface hydrology and groundwater movement; the prevention of secondary impacts and unnecessary collateral damage; monitoring; the avoidance of adverse impacts on biodiversity, wherever possible; and rehabilitation where avoidance is not possible.

3.1 SURFACE WATER-SPECIFIC GUIDANCE

Mining operations will alter the natural environment, thereby affecting the generation of stormwater on the site. It is of particular importance to identify the effect the mining operations will have on stormwater production and to manage this water accordingly. Volumes of stormwater generated are expected to increase as a result of both mining operations and the reduction of natural vegetation. The quality of the stormwater generated is expected to

⁶ ECC Best Practice Guide – Environmental Principles for Mining in Namibia

decrease due to the nature of mining operations. The ultimate objective of stormwater management on a mine is to ensure that no dirty water (contaminated through mining operations) enters the natural environment.

The following presents published legislation and/or guidance that should be considered concerning the development of the Project.

3.1.1 WATER RESOURCES MANAGEMENT ACT 11 OF 2013 (GOVERNMENT GAZETTE NO. 5367)

The Act provides legislation related to the management, protection, development, use and conservation of water resources; to provide for the regulation and monitoring of water services.

Per the Act a “watercourse” is defined as:-

- (a) a river or spring, including the base flow of an ephemeral river when there is no surface flow;
- (b) a natural channel in which water flows regularly or intermittently;
- (c) an estuary, wetland, lake or dam into which, or from which, water flows;
- (d) any collection or body of water declared under section 5(s) to be a watercourse; and includes the water in, and the bed and banks of, the watercourse.

Some specific guidance arising from this act includes the following.

Per Clause 68 (Pollution Control):

- (1) A person may not by any act or omission cause a water resource to be polluted, either directly or indirectly, unless authorised to do so by or under this Act or any other law, and in accordance with that authorisation.

Per Clause 69 (Obligation to provide and operate systems for discharge of effluent, wastewater and waste):

- (5) A lessor of land or premises where any industrial, mining or other activity is carried on by the lessee, that may cause water pollution, is responsible to remedy the effects of any pollution caused by such activity in the event that the lessee fails to remedy the effects of such pollution.

Per Clause 92 (Obstruction of a watercourse)

- (1) A person may not engage in any construction work or other activity that causes, or is likely to cause, the natural flow conditions of water in, to or from a watercourse to be modified, unless the Minister has granted prior written approval for the work or activity to be carried out.

Per Clause 100 (Prevention of flood risk)

- (1) A person may not engage in any construction work or other activity that causes, or is likely to cause, the natural flow conditions of water in, to or from a watercourse to be modified, unless the Minister has granted prior written approval for the work or activity to be carried out.
 - (d) by notice in writing given specifically to any person, or by regulation, prohibit the growing of crops, the building of structures or the placing of deposits on land located between a watercourse and any protective dykes, embankments or levees;

- (e) consult with any regional council or local authority in determining the geographic extent of floodplain areas in its region or local authority area, as the case may be, and assist any such councils in regulating the development and use of land within a floodplain area; or
- (f) prescribe measures for the control and management of storm and flood risk within local authority areas.

3.1.2 COMMENCEMENT OF WATER RESOURCES MANAGEMENT ACT 11 OF 2013 (GOVERNMENT GAZETTE NO. 8187)

The Act extends the Water Resources Management Act 11 of 2013 and includes the definition of a “riparian area” as:

- the historically, occasionally or seasonally flooded banks and floodplains along both sides of a watercourse.

Per Clause 138 (Prohibition on removal of riparian species, filling or excavation of riparian zone or erection of structural development within riparian zone without licence). A person may not:

- (a) remove any riparian species;
- (b) fill or excavate a riparian zone; or
- (c) erect any structural development within a riparian zone, without a licence issued by the Minister

Per Clause 141 (Conditions relating to licence to remove riparian species, fill or excavate riparian zone or erect structural development within riparian zone).

Subject to regulation 140(4)(a) and (b), a licence to remove riparian species, fill or excavate a riparian zone or erect a structural development within a riparian zone is subject to the following conditions:

- (a) where there is a reasonable threat to the ecological integrity of any body of water a person may not
 - i. remove riparian species from the riparian zone of that body of water;
 - ii. excavate or fill the riparian zone of the body of water; or
 - iii. erect any structural development within the riparian zone the body of water;
- (b) a person may not remove a protected plant species;
- (c) a person may not erect any structural development on the stream or river bank;
- (d) a buffer zone of 100 metres from the stream or river bank must be maintained to protect streams and river banks from soil erosion and reduces flooding;
- (e) a person may not remove rocks, sand or gravel within 100 metres of the riparian zone from the stream or river bank;
- (f) a licence holder who removes rocks, sand or gravel must ensure that such removal does not expose the roots of indigenous trees in any watercourse;
- (g) precautionary measures to prevent damage to riverbanks or riparian zones and prevent the pollution or reduction of water resource quality must be implemented by the licensee;
- (h) the licence excludes the right of access to private properties, and if applicable, the holder of the licence must separately obtain permission from a particular landowner; and

- (i) the Minister or his or her authorised representative reserves the right to carry out periodic inspections to determine whether the conditions of the licence are adhered to.

There is, however, no guidance on the design requirement of stormwater containment facilities or diversions. For this International Finance Corporation (IFC) and South African guidelines have been considered.

3.1.1.3 IFC ENVIRONMENTAL, HEALTH AND SAFETY GUIDELINES – MINING (2007)

The IFC Environmental, Health and Safety Guidelines - Mining (2007), indicate that the following should be applied:

- Stormwater should be separated from process and sanitary wastewater streams in order to reduce the volume of wastewater to be treated prior to discharge.
- Surface runoff from process areas or potential sources of contamination should be prevented.
- Where this approach is not practical, runoff from process and storage areas should be segregated from potentially less contaminated runoff.
- Runoff from areas without potential sources of contamination should be minimized (e.g. by minimizing the area of impermeable surfaces) and the peak discharge rate should be reduced (e.g. by using vegetated swales and retention ponds).
- Where stormwater treatment is deemed necessary to protect the quality of receiving water bodies, priority should be given to managing and treating the first flush of stormwater runoff where the majority of potential contaminants tend to be present.
- When water quality criteria allow, stormwater should be managed as a resource, either for groundwater recharge or for meeting water needs at the facility.
- Oil water separators and grease traps should be installed and maintained as appropriate at refuelling facilities, workshops, parking areas, fuel storage and containment areas.
- Sludge from stormwater catchments or collection and treatment systems may contain elevated levels of pollutants and should be disposed in compliance with local regulatory requirements, in the absence of which disposal has to be consistent with protection of public health and safety and conservation and long term sustainability of water and land.

Furthermore, the IFC Environmental, Health and Safety Guidelines for Mining (2007) identifies the following:

- Dirty Water Areas include beneficiation plants, workshops (where oil is handled), residue disposal facilities, haul roads, opencast pits, and pollution control dams.
- Separation of clean and dirty water areas is required, while minimising runoff, avoiding erosion of exposed ground surfaces, avoiding sedimentation of drainage systems and minimising exposure of polluted areas to stormwater.

From exploration onwards, the management strategies include:

- Reducing exposure of sediment-generating materials to wind or water (e.g. proper placement of soil and rock piles);

- Divert run-off from undisturbed areas around disturbed areas - including areas that have been graded, seeded, or planted. Such drainage should be treated for sediment removal;
- Reducing or preventing off-site sediment transport (e.g. use of settlement ponds, silt fences);
- Stormwater drains, ditches and stream channels should be protected against erosion through a combination of adequate dimensions, slope limitation techniques and use of rip-rap and lining. Temporary drainage installations should be designed, constructed and maintained for Recurrence Intervals (RIs) of at least a 25-year/24-hour event, while permanent drainage installations should be designed for a 1:100-year/24-hour event. Design requirements for temporary drainage structures should additionally be defined on a risk basis considering the intended life of diversion structures, as well as the RI of any structures that drain into them.

From construction onwards, recommended management strategies include:

- Establishing riparian zones;
- Timely implementation of an appropriate combination of contouring techniques, terracing, slope reduction / minimization, runoff velocity limitation and appropriate drainage installations to reduce erosion in both active and inactive areas;
- Access and haul roads should have gradients or surface treatment to limit erosion. Road drainage systems should be provided;
- Facilities should be designed for the full hydraulic load, including contributions from upstream catchments and non-mined areas;
- Stormwater settling facilities should be designed and maintained according to internationally accepted good engineering practices, including provision for capturing of debris and floating matter. Sediment control facilities should be designed and operated for a final Total Suspended Solids (TSS) discharge of 50 mg/l and other applicable effluent guidelines, taking into consideration background conditions and opportunities for overall improvement of the receiving water body quality.

From operations onwards, recommended management strategies include:

- Final grading of disturbed areas, including preparation of overburden before application of the final layers of growth medium, should be along the contour as far as can be achieved in a safe and practical manner;
- Re-vegetation of disturbed areas including seeding should be performed immediately following application of the growth medium to avoid erosion.

3.1.4 GN 704

The principles of the South African National Water Act (Act 36 of 1998), and more particularly Government Notice 704 (GN 704) provide a thorough and useful reference to the management of the mine's stormwater. GN 704 deals with the separation of clean and dirty water and governs the management thereof. These regulations conform to international best practices.

GN 704 was established to provide regulations on the use of water for mining and related activities aimed at the protection of water resources. There are important definitions in the regulation which provide useful background to the management of stormwater.

- **Clean water system:** This includes any dam, other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of unpolluted water.
- **Dam:** This includes any settling dam, slurry dam, evaporation dam, catchment or barrier dam and any other form of impoundment used for the storage of unpolluted water or water containing waste (i.e. polluted water).
- **Dirty area:** This refers to any area at a mine or activity which causes, has caused or is likely to cause pollution of a water resource (i.e. polluted water).
- **Dirty water system:** This includes any dam, other form of impoundment, canal, works, pipeline, residue deposit and any other structure or facility constructed for the retention or conveyance of water containing waste

The three main principles in GN 704 of particular applicability to this project are set out in the following:

- Condition 4, which defines the area in which mine workings or associated structures may be located concerning a watercourse and its associated flooding. The 50-year flood-line and 100-year flood-line are used for defining suitable locations for mine workings (prospecting, underground mining or excavations) and associated structures respectively. Where the flood-line is less than 100 metres away from the watercourse, then a minimum watercourse buffer distance of 100 metres is required for both mine workings and associated structures
- Condition 6, which deals with the capacity requirements of clean and dirty water systems. Clean and dirty water systems must be kept separate and must be designed, constructed, maintained and operated such that these systems do not spill into each other more than once in 50 years.
- Condition 7, which describes the measures which must be taken to protect water resources. All dirty water or substances which cause or are likely to cause pollution of a water resource either through natural flow or by seepage.

4 HIGH-LEVEL EVALUATION OF FLOOD POTENTIAL

As per **Section 3.1.2**, numerous activities (including fill and excavation) are prohibited within riparian zones without a licence. A buffer zone of 100 metres from the stream or river bank is applicable. This implies that flooding is relevant, given the relationship between riparian zones and flood zones, as well as the use of a 100m river buffer, which is a simple buffering distance often used in the absence of simulated flood extents. Flooding is consequently the focus of this section.

4.1 ASSESSMENT OF FLOODING

The approach to the assessment of flooding adopted two strategies:

1. Flow paths (ephemeral rivers) with a larger contributing area ($>5\text{km}^2$) that intersected or were adjacent to proposed areas of works were identified for flood analysis. This resulted in approximately 37km of ephemeral river being identified for flooding analysis. A simulation of the flooding on these watercourses was consequently adopted to illustrate the 1:50 year recurrence interval (RI) and 1:100 year RI flooding estimated as occurring at this time. The details within this model were limited, and the simulation results should be considered a high-level estimate.
2. For the remaining rivers (or flow paths) on the site, a threshold catchment area analysis had been previously undertaken per **Figure 2-3**, with three flow path classifications produced. A buffering approach to these defined flow paths was subsequently undertaken to suggest possible exclusion or flood risk areas.

4.1.1 FLOODING ON FLOW PATHS ($>5\text{KM}^2$)

Since the modelling of flooding is (as undertaken) an approximation of reality, various assumptions and limitations are relevant (when considering the results presented in this section). These have been highlighted at various places in this report and are also outlined in **Appendix A**.

To undertake a high-level estimate of flooding on the flow paths of relevance (those with contributing catchments greater than 5km^2 which approached areas of works), it was first necessary to estimate the flood flow (peak flow) that would be possible for the specific events of interest (1:50 and 1:100 RI events).

A hydrological (PCSWMM) model was subsequently developed, which evaluated 49 subcatchments connected by hypothetical channels. Each subcatchment had its hydrological parameters informed by site-specific datasets including soils (loam) and land-cover (largely bare). The output of PCSWMM was ten 24-hour design hydrographs for the 1:50 and 1:100 RI events of interest.

HEC-RAS 6.6 was selected to model flood hydraulics (the movement of floodwaters over the surface resulting from the design hydrograph estimates) using a 2D model approach. HEC-RAS is designed to perform one-dimensional and two-dimensional calculations for a full network of natural and constructed channels. The software is used worldwide and has undergone thorough testing (USACE, 2016, 2018).

Flood modelling utilised the 30m (COP30) terrain data and provided a coarse estimate of the flow paths (ephemeral rivers) of interest. The resulting flooding is consequently not highly accurate, with more spread of flooding anticipated (had a more detailed terrain dataset been used).

The availability of continuous DSM data allowed for the adoption of a 2D flood model approach using HEC-RAS. Unlike a 1D approach (using cross-sections), which samples the DSM at set cross-section locations, a 2D model approach uses a continuous model grid. The advantage of a 2D model is, consequently, its ability to account for more variation in the topographic data since no gaps are present in the model geometry (as is the case with cross-sections).

No river crossings or hydraulic controls were considered. No significant crossings or hydraulic controls are expected based on a review of aerial imagery (ephemeral river crossings appear to be drifts or small culverts).

The results of the flood modelling are presented in the following figures:

- **Figure 4-1** - This figure illustrates that for the 1:50 RI and 1:100 RI flood events, the flood response is similar, with flooding for the 1:100 RI event (yellow colour) barely visible given the overlapping 1:50 RI event results (green colour).
- **Figure 4-2** - This figure illustrates the maximum depth of flooding for the 1:100 RI event. The pixelization in the figure is indicative of the underlying 30m DSM data. This pixelization should advise the reader of the high-level approach to flood modelling adopted. According to the figure, flood depths exceed 1m in some places.
- **Figure 4-3** - This figure illustrates the maximum flood velocity. As with depth, pixelization is present. According to the figure, flood velocities exceed 1m/s in certain areas.

Flooding is a risk to the operation that is likely to require flood protection for the pit and plant (potentially through exclusion zones or through mitigation by way of channels/berms). The stormwater management plan for the site will provide a level of (flood) protection commensurate with the plan's design level (i.e. a 1:100 RI design will protect against up to the 1:100 RI flood).

4.1.2 BUFFERING APPROACH TO FLOOD SENSITIVITY

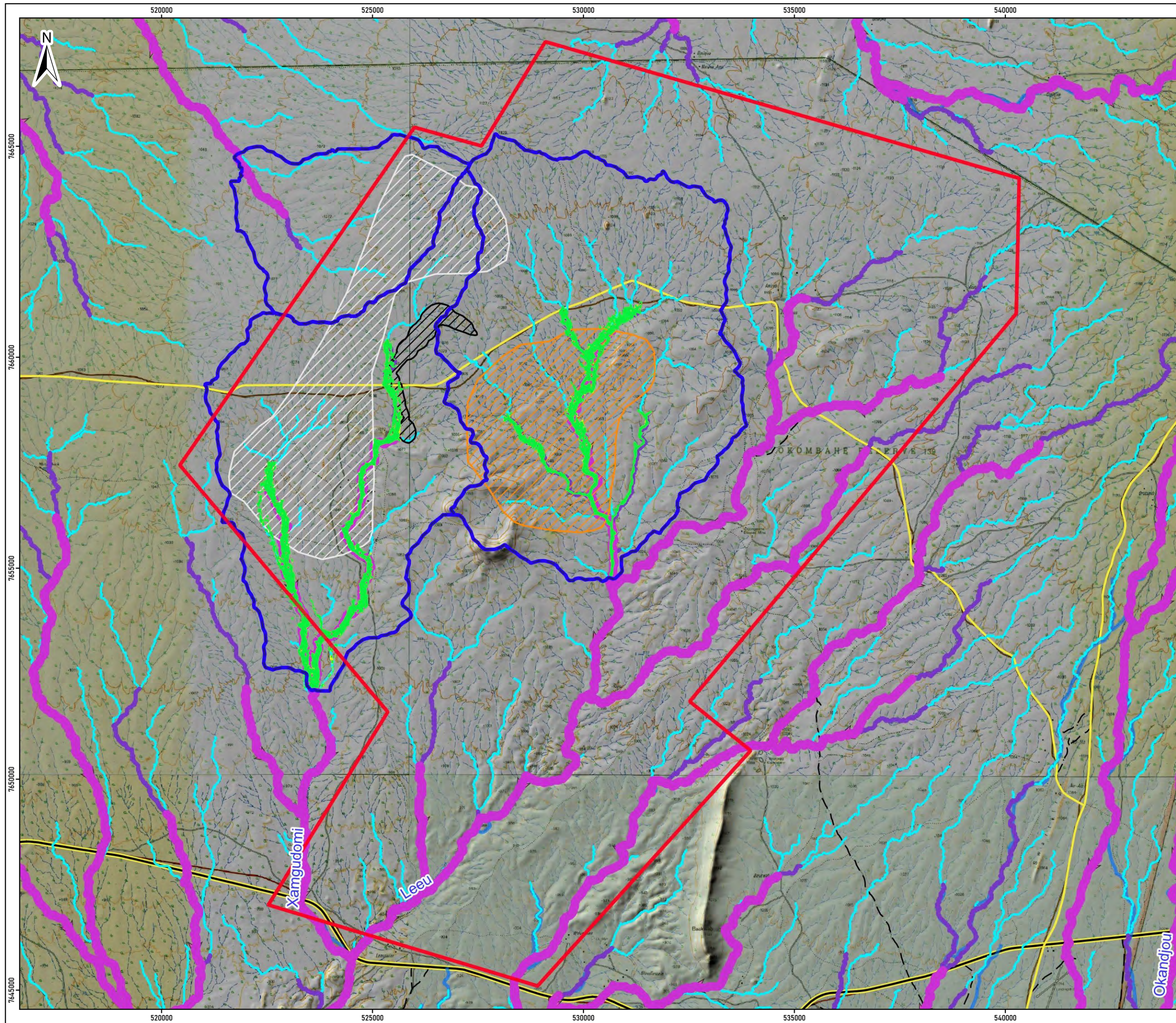
To account for the variability in flooding that could be produced from a smaller catchment area ($< 5\text{km}^2$), the flow path analysis outlined in **Section 2.5** considered contributing areas with thresholds of 1km^2 , 5km^2 and 10km^2 . These contributing areas would be associated with an increase in potential flood risk (respectively).

To account for this increasing flood risk, a buffering approach was implemented along the defined flow paths. It should be noted that due to the available terrain data (30m cell size), the results of the flow path analysis have the potential for error (due to the coarse terrain data used). Nevertheless, a simple buffering analysis provides some indication of areas of possible flood risk (as well as areas in which stormwater would be concentrated. Where works intersect flow paths (whether illustrated in this report or as evidenced by on-site observations), flood protection or stormwater management may be necessary.

The evaluation of flooding based on flow paths used the following classification (this classification is simplistic as river floodplains vary along a particular river reach):

- Contributing area $> 1\text{km}^2$: A 25m buffer was applied;
- Contributing area $> 5\text{km}^2$: A 50m buffer was applied; and
- Contributing area $> 10\text{km}^2$: A 100m buffer was applied.

Figure 4-1 presents the results of the buffering workflow. The buffer classification used in the above is not precise. It is instead a simplistic approach that attempts to illustrate greater flood risk as flood peak potential increases (based on contributing area alone). It is interesting to note the modelling of flooding compared to the applicable buffer distances. In places, modelled flooding exceeds buffer distances, while in other locations it is less than the buffer distance. Inaccuracies in both the flood modelling (primarily due to the available terrain data) and in the flow path position (likewise due to the terrain data), make any conclusion on buffer distance to flood extent untenable.



Legend

- Boundary (Kokoseb, EPL - 4818)
- Pit
- Processing Plant (Approximate)
- Waste Rock Dump (Approximate)
- Containing Catchment (COP30 Derived)

Flood Results

- Inundation Boundary (1:50 RI Event; High-Level)
- Inundation Boundary (1:100 RI Event; High-Level)

Flow Path Analysis

- 100m Flow Path Buffer (>10km²; COP30 Derived)
- 50m Flow Path Buffer (>5km²; COP30 Derived)
- 25m Flow Path Buffer (>1km²; COP30 Derived)

Figure 4-1

Flood Sensitivity

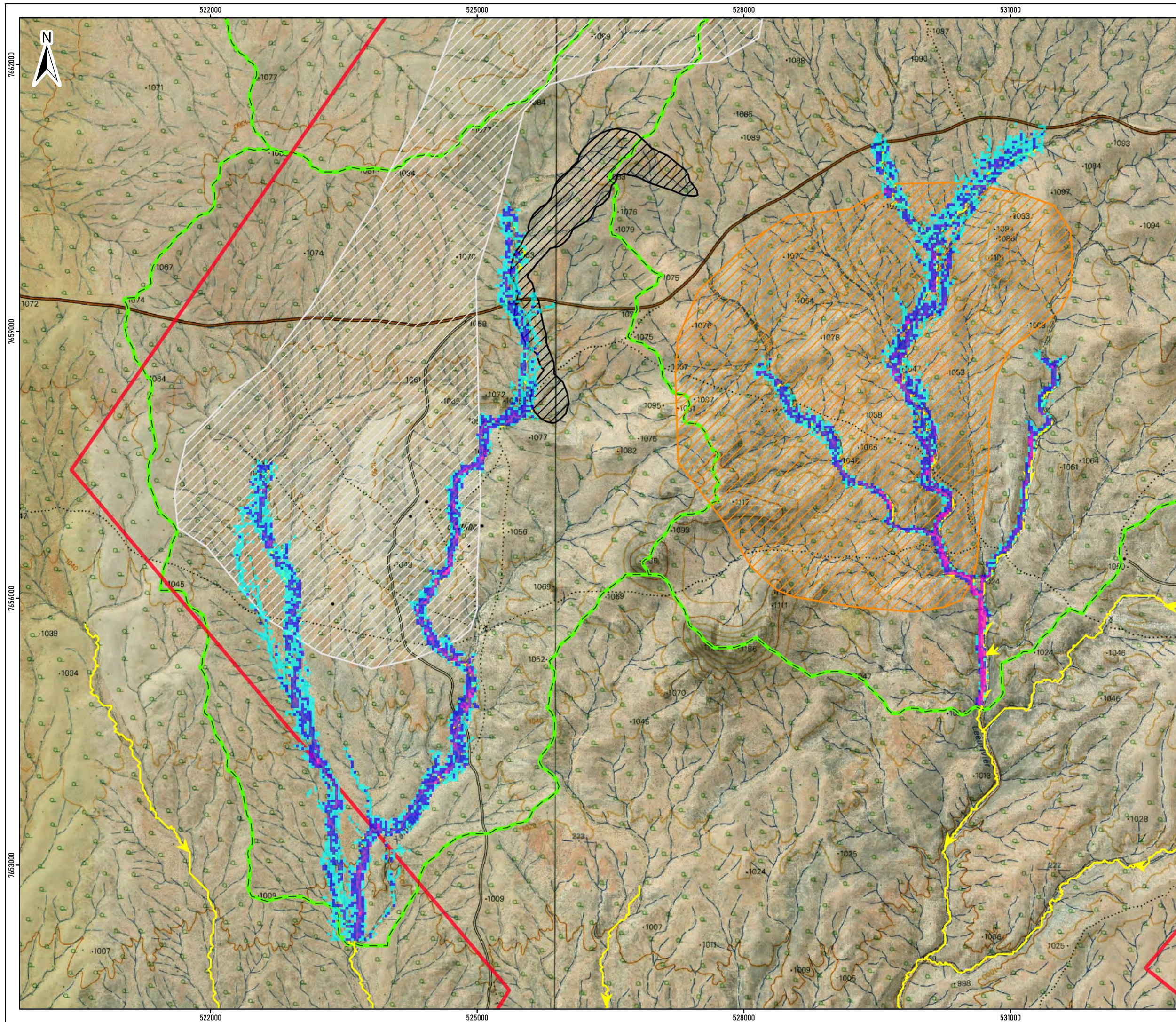


Hydrologic Consulting (Pty) Ltd

+27 72 239 0974

info@hydrologic.consulting

www.hydrologic.consulting



Legend

- Boundary (Kokoseb, EPL - 4818)
- Containing Catchment (COP30 Derived)

Layout

- Pit
- Processing Plant (Approximate)
- Waste Rock Dump (Approximate)
- Flow Paths - Contributing Area 5km²

Max. Depth (m)

- ≤ 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- > 1.5

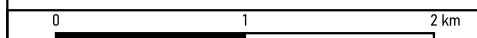
Figure 4-2

Maximum Flood Depth (1:100 RI)

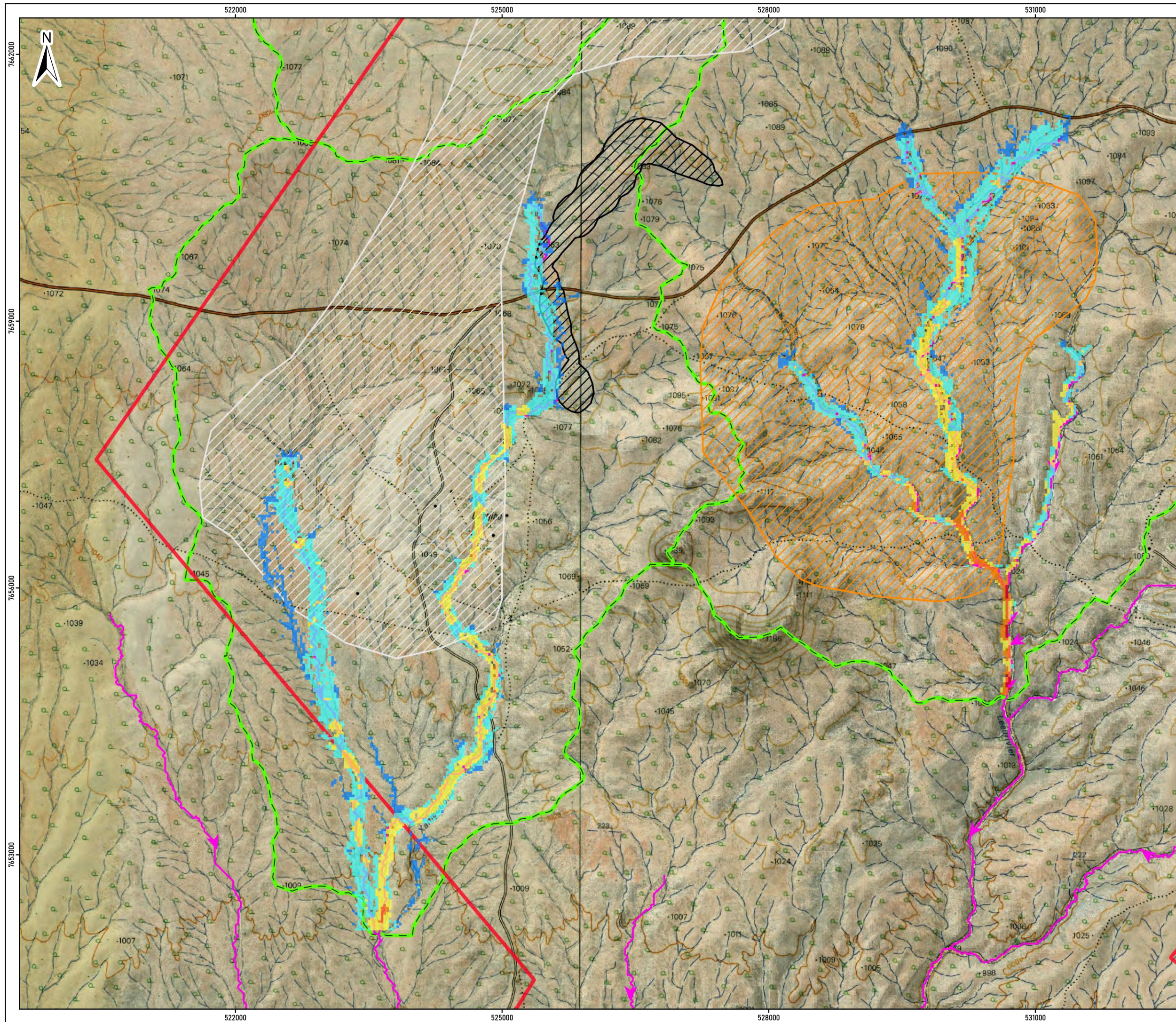
Hydrologic Consulting (Pty) Ltd

HYDRO LOGIC

+27 72 239 0974
info@hydrologicconsulting
www.hydrologicconsulting



Scale - 1:40,000 @A3 Coordinate Reference System: WGS 84 / UTM zone 33S Version 1 04-Jul-2025



Legend

Boundary (Kokoseb, EPL - 4818)

Containing Catchment (COP30 Derived)

Layout

Pit

Processing Plant (Approximate)

Waste Rock Dump (Approximate)

Flow Paths - Contributing Area 5km²

Max Velocity (m/s)

<= 0.5

0.5 - 1.0

1.0 - 1.5

1.5 - 2.0

>2.0

Figure 4-3

Maximum Flood Velocity (1:100 RI)

Hydrologic Consulting (Pty) Ltd

HYDRO LOGIC

+27 72 239 0974

info@hydrologicconsulting.com

www.hydrologicconsulting.com

0 1 2 km

Scale - 1:40,000 @A3

Coordinate Reference System: WGS 84 / UTM zone 33S

Version 1 04-Jul-2025

4.2 RIPARIAN BUFFER

The 100m buffer is relevant to determining the riparian zone, which is defined by the Water Resources Management Act 11 of 2013 as:

- The historically, occasionally or seasonally flooded banks and floodplains along both sides of a watercourse.

Wherein a watercourse is defined as:

- a river or spring, including the base flow of an ephemeral river when there is no surface flow; or
- a natural channel in which water flows regularly or intermittently.

While the buffer distance (25m to 100m) presented in **Section 4.1.2** is intended to provide some variability in assessing flood sensitivity to the site, from a legislative perspective, the 100m buffer still applies to all watercourses.

The 1:50,000 topographical map dataset for Namibia includes various watercourses, whether perennial or non-perennial (including ephemeral watercourses). These watercourses have consequently been understood to qualify as riparian zones. As such, a 100m buffer zone is relevant given the applicability of Clause 141 of the Water Resources Management Act 11 of 2013, which outlines the conditions relating to a licence to remove riparian species, fill or excavate the riparian zone or erect structural development within the riparian zone.

As illustrated in **Figures 4-2** and **4-3**, the site is characterised by a high density of defined watercourses and riparian area density is consequently high. An exemption to mine on the site is, consequently, likely required.

5 HYDROLOGICAL IMPACTS AND MITIGATION MEASURES

An impact is essentially any change (positive or negative) to a resource or receptor brought about by the presence of the project component or by the execution of a project-related activity.

The potential impacts of the project have been evaluated using a recognised risk assessment methodology provided by ECC. This methodology was developed to enable communication of the potential consequences or impacts of activities on the hydrological (surface water) environment as set out in the Environmental Management Act, No. 7 of 2007.

5.1 METHOD OF ASSESSING IMPACTS

ECC provided their impact assessment methodology as outlined in **Figures 5-1** and **5-2**. The assessment of impact concludes with a scoring of the impact, ranging from 1 (low) to 12 (major), based on the intersection of impact sensitivity and impact significance. Sensitivity is a single variable with three options, which rank sensitivity from 1 to 3. Significance considers a combination of factors.

5.1.1 DETERMINATION OF SIGNIFICANCE

The significance of an impact was determined by evaluating the nature (N), frequency (F), duration (D) reversibility (R) and probability (P) which are collectively considered under the heading “Nature and Characteristics -of the Impact”. The magnitude of the change (M) is the final factor which influences impact significance.

To calculate the rating of significance (from 1 to 4), the following formula was applied:

$$\text{Significance} = \frac{(E + D + R + P) \times N}{4} \times M$$

All variables in the above except for nature (N) are ranked 1 to 5 in the ECC methodology. Nature (N) is either +1 (beneficial) or -1 (adverse). The resulting significance rating is between -25 and +25. The translation of this scoring to an ECC significance rating of between 1 and 4 requires the division of the rating by 6.25.

With significance calculated, it was possible to compare the impact rating to the sensitivity rating to arrive at the final impact scoring (1 to 12; low to major).

ECC IMPACT PREDICATION AND EVALUATION METHODOLOGY

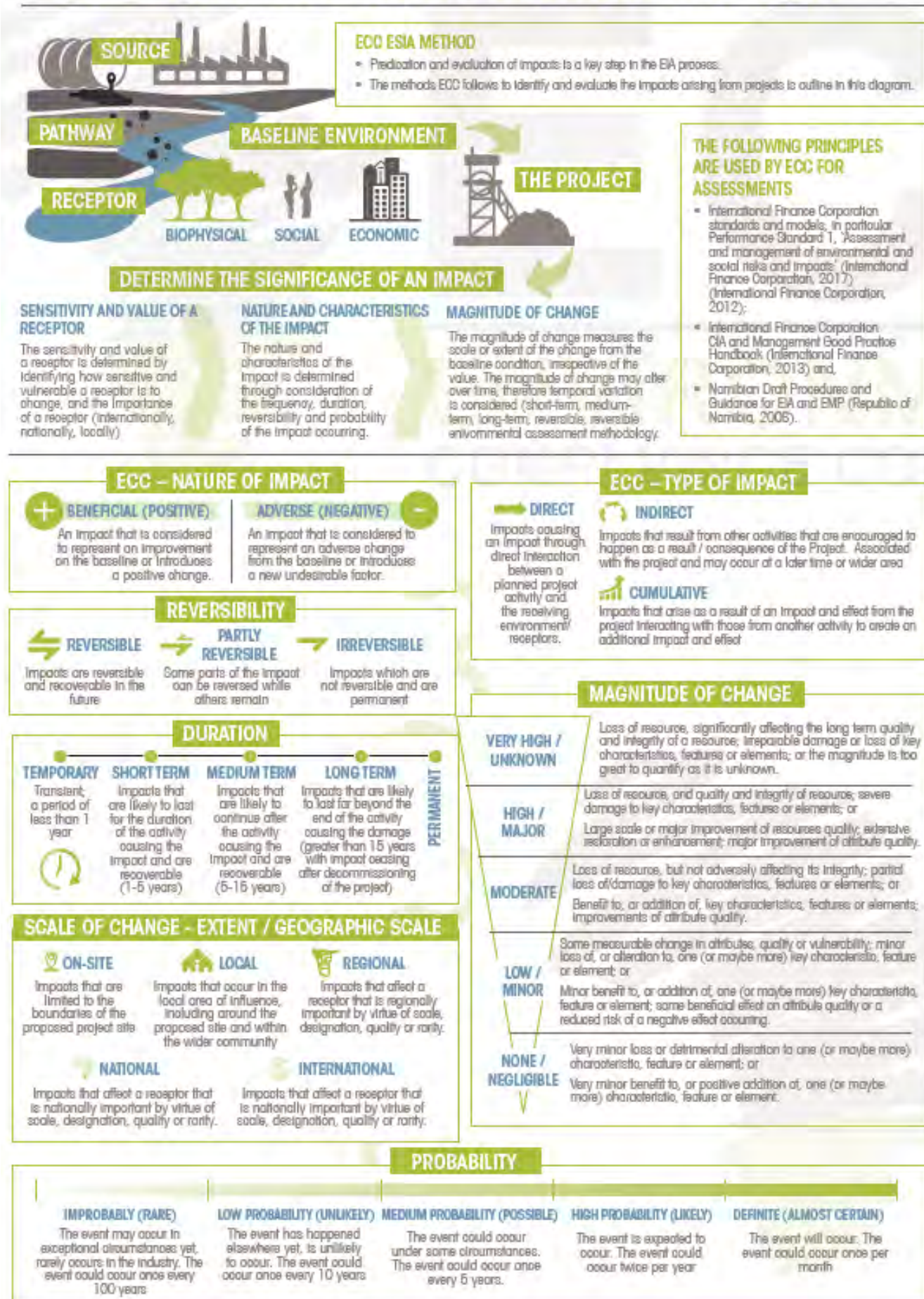


FIGURE 5-1: ECC IMPACT METHODOLOGY – PART 1

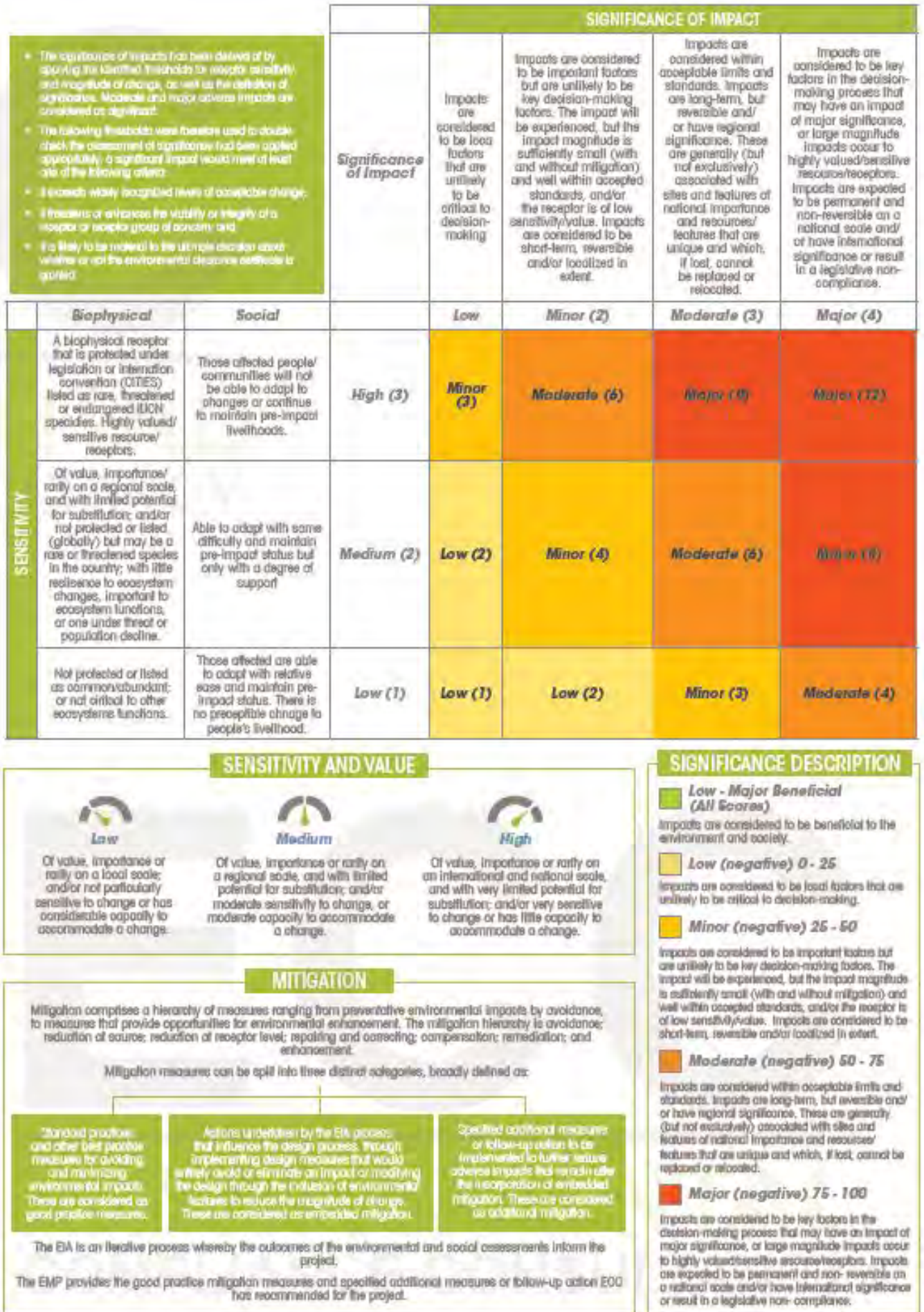


FIGURE 5-2: ECC IMPACT METHODOLOGY – PART 2

5.2 PROJECT PHASES

This impact assessment has been developed on the understanding that the project is comprised of the following phases:

- Construction – surface infrastructure will be built on land cleared for that purpose;
- Operation – the mining operation will commence inclusive of opencast pit and waste rock dump development; and
- Decommissioning – all operations will cease with certain surface infrastructure removed and disturbed areas rehabilitated.

Impacts are assessed collectively for the project, and include those of the proposed opencast pits, waste rock dumps, processing plant and haul roads.

No alternatives are relevant to this report.

5.3 IDENTIFIED IMPACTS

The impacts reviewed in this report present the impact and mitigation options. The scoring of the impact (per the following tables) is based on the pre-mitigation scoring. The proposed mitigation will reduce the impact in most instances.

5.3.1 EROSION OF SOILS

Eroded soils have the potential to cause sedimentation of downstream watercourses. The construction or expansion of infrastructure will lead to new areas being disturbed, resulting in the potential for soil erosion to occur during periods of rainfall. Conversely, the decommissioning of this infrastructure will also result in the same. If not mitigated, erosion could continue during the operational phase, although it is expected that soils would settle to a degree, reducing the potential volume of erosion for any given rainfall event. The decommissioning phase (inclusive of rehabilitation) may have an overall positive impact on any existing erosion without formal erosion mitigation in place, although there could also be some increase in erosion due to earthworks.

Disturbed areas should consequently be stabilised, with erosion control methods used where stabilisation is not possible. A rehabilitation plan for the site should be developed, inclusive of topsoil replacement where possible. A re-vegetation strategy, including maintenance/aftercare, should likewise be developed for disturbed areas. The arid nature of the site may mean re-vegetation is challenging. Naturally occurring plant species should be prioritised.

TABLE 5-1: EROSION OF SOILS (CONSTRUCTION PHASE)

Impact Name	Erosion of Soils		
Phase	Construction		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Likely
Type of Impact	Direct	Magnitude	Moderate
Extent	Local	Reversibility	Partly Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Minor
Sensitivity			Low

Scoring	Low
Mitigation Measures	
- Implement a stormwater management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guidelines or possibly South African GN704. - Suitable erosion control should be utilised. - The disturbed footprint should be minimised as far as practically possible. - Clearing of vegetation and associated excavation should be kept to a minimum, particularly in areas where soils are unstable. - Construction should, where possible, be scheduled to take place during the dry season when rainfall and associated erosion potential are at their lowest. For construction periods exceeding six months, construction should be scheduled to minimise soil exposure (before the addition of hardstanding or rehabilitation) during the dry season whenever possible. - All disturbed areas must be rehabilitated (as soon as practically possible) to represent the previous undisturbed environment (soil, land-cover, slope) to limit the impact on receiving water resources (by limiting soil erosion). - Disturbed areas or areas rehabilitated with soils should be stabilised as soon as possible using plants (e.g. grass) or other mechanical methods (e.g. profiling or erosion control blankets). - Where erosion is nevertheless likely to occur, it is recommended to use settling facilities or silt fences. - Rehabilitation should include topsoil replacement, re-vegetation and maintenance/aftercare for disturbed areas.	

TABLE 5-2: EROSION OF SOILS (OPERATION AND DECOMMISSIONING PHASE)

Impact Name	Erosion of Soils		
Phase	Operation and Decommissioning		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Likely
Type of Impact	Direct	Magnitude	High
Extent	Local	Reversibility	Partly Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Minor
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Maintain a stormwater management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guidelines or possibly South African GN704. - Suitable erosion control should be utilised. - The disturbed footprint should be minimised as far as practically possible. - Clearing of vegetation and associated excavation should be kept to a minimum, particularly in areas where soils are unstable. - All disturbed areas must be rehabilitated (as soon as practically possible) to represent the previous undisturbed environment (soil, land-cover, slope) to limit the impact on receiving water resources (by limiting soil erosion). - Disturbed areas or areas rehabilitated with soils should be stabilised as soon as possible using plants (e.g. grass) or other mechanical methods (e.g. profiling or erosion control blankets). - Where erosion is nevertheless likely to occur, it is recommended to use settling facilities or silt fences. - Rehabilitation should include topsoil replacement, re-vegetation and maintenance/aftercare for disturbed areas.			

5.3.2 POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT

The operation of earthmoving machinery or maintenance of vehicles on site during construction, operation, and decommissioning (including the possible storage or handling of hydrocarbons) poses a potential source of hydrocarbon contamination to the surface water environment. An emergency response plan for unforeseen hydrocarbon spills should be developed.

A stormwater management plan is a necessary part of the development of the expansion (as per the Water Resources Management Act 11 of 2013 and IFC guidance) and will form an integral mitigation measure concerning the management of dirty areas. These will include management of runoff from waste rock dumps and the processing plant. The pit is less likely to need management due to its self-contained nature (as it relates to runoff).

Important. This section only considers the surface water impact from the proposed surface activities. It is expected that the groundwater specialist assess the potential impact of possible seepage of contaminated groundwater into surface water resources.

TABLE 5-3: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (CONSTRUCTION PHASE)

Impact Name	Pollutants Entering the Surface Water Environment		
Phase	Construction		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Likely
Type of Impact	Direct	Magnitude	Moderate
Extent	Local	Reversibility	Partly Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Minor
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Implement a stormwater management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guideliens or possibly South African GN704. - Keep activity within the managed dirty water footprint where possible. - Store hydrocarbons off site where possible, or otherwise implement hydrocarbon storage with adequate bunding. - Handle hydrocarbons carefully to limit spillage. - Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited. - Use drip trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor) - Refuel vehicles away from watercourses/waterbodies. - Designate a single location for refuelling and maintenance away from watercourses/waterbodies. - Keep spill kits on site to deal with any hydrocarbon leaks and use catch pans for parked mining vehicles. - Remediate the soil on the site which has been contaminated by hydrocarbon spillage. This may require removal of the soil from the site. - Undertake surface water monitoring where possible to enable change detection related to contaminants originating from the site.			

TABLE 5-4: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (OPERATION PHASE)

Impact Name	Pollutants Entering the Surface Water Environment		
Phase	Operation		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Likely
Type of Impact	Direct	Magnitude	High
Extent	Regional	Reversibility	Partly Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Minor
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Maintain a stormwater management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guideliens or possibly South African GN704. - Keep activity within the managed dirty water footprint where possible. - Store hydrocarbons off site where possible, or otherwise implement hydrocarbon storage with adequate bunding. - Handle hydrocarbons carefully to limit spillage. - Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited. - Use drip trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor) - Designate a single location for refuelling and maintenance away from watercourses/waterbodies. - Keep spill kits on site to deal with any hydrocarbon leaks and use catch pans for parked mining vehicles. - Remediate the soil on the site which has been contaminated by hydrocarbon spillage. This may require removal of the soil from the site. - Clean up material on the mine (ore) that is spilt during transport (and is not within a managed dirty water area)			

- Undertake surface water monitoring where possible to enable change detection related to contaminants originating from the site.

TABLE 5-5: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (DECOMMISSIONING PHASE)

Impact Name	Pollutants Entering the Surface Water Environment		
Phase	Decommissioning		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Likely
Type of Impact	Direct	Magnitude	High
Extent	Local	Reversibility	Partly Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Minor
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Maintain a management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guidelines or possibly South African GN704. - Keep activity within the managed dirty water footprint where possible. - Store hydrocarbons off site where possible, or otherwise implement hydrocarbon storage with adequate bunding. - Handle hydrocarbons carefully to limit spillage. - Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited. - Use drip trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor) - Designate a single location for refuelling and maintenance away from watercourses/waterbodies. - Keep spill kits on site to deal with any hydrocarbon leaks and use catch pans for parked mining vehicles. - Remediate the soil on the site which has been contaminated by hydrocarbon spillage. This may require removal of the soil from the site. - Undertake surface water monitoring where possible to enable change detection related to contaminants originating from the site.			

5.3.3 DECREASE IN RUNOFF

An increase in runoff could be expected due to the proposed construction of infrastructure, which will increase impermeable hardstanding and compaction from the movement of machinery and use of laydown areas. The necessary introduction of a stormwater management plan (which will adopt a containment philosophy), the nature of the mining (opencast pits), and a focus on reusing all dirty water on site will, however, likely result in a net reduction in runoff.

A decrease in runoff is a typical impact associated with the containment of dirty areas on mines, and the mitigation of this impact is often not practical or possible with a reduction in mean annual runoff as an expected outcome.

However, based on the scale of the operation to the Omaruru River, the reduction in runoff to the Omaruru River is expected to be minor.

Important. This section only considers the surface water impact from the proposed surface activities. It is expected that the groundwater specialist will assess the potential impacts of any dewatering (if relevant).

TABLE 5-6: DECREASE IN RUNOFF (CONSTRUCTION PHASE)

Impact Name	Decrease in Runoff		
Phase	Construction		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation

Nature	Adverse	Probability	Unlikely
Type of Impact	Direct	Magnitude	None/Negligible
Extent	On-Site	Reversibility	Reversible
Duration	Short Term	Confidence	High
Significance (Pre-mitigation)			Low
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Keep the contained dirty area to a minimum, thereby limiting this impact. - Where relevant, discharge excess water of an acceptable quality back into the surface water environment (river).			

TABLE 5-7: DECREASE IN RUNOFF (OPERATION AND DECOMMISSIONING PHASE)

Impact Name	Decrease in Runoff		
Phase	Operation and Decommissioning		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Definite
Type of Impact	Direct	Magnitude	Low/Minor
Extent	Local	Reversibility	Irreversible
Duration	Permanent	Confidence	High
Significance (Pre-mitigation)			Minor
Sensitivity			Low
Scoring			Low
Mitigation Measures			
- Keep the contained dirty area to a minimum, thereby limiting this impact. - Where relevant, discharge excess water of an acceptable quality back into the surface water environment (river).			

5.3.4 ALTERED DRAINAGE

The alteration/removal of watercourses is an unavoidable impact due to the establishment of the opencast pits and waste rock dumps. Not all rivers are expected to be altered simultaneously, assuming a sequential pit and waste rock dump development is undertaken; the impact will occur during construction, and operation (effectively ongoing development) and remain in the decommissioning phase.

The assumed sequential opencast pit and waste rock dump development mining approach may allow for the reinstatement of watercourses. The re-establishment of the watercourses altered/removed by the mining operation would require an approach that attempts to replicate the pre-development hydrology (soils, vegetation and geomorphology). The diversion or removal of a watercourse would require a licence application to the Department of Water Affairs, from which more specific details with regard to the required rehabilitation or reinstatement of the watercourse (post-mining) would be provided.

TABLE 5-8: ALTERED DRAINAGE (CONSTRUCTION PHASE)

Impact Name	Altered Drainage		
Phase	Construction		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Definite
Type of Impact	Direct	Magnitude	Low
Extent	On-Site	Reversibility	Reversible
Duration	Short Term	Confidence	Moderate
Significance (Pre-mitigation)			Low
Sensitivity			Medium

Scoring	Low
Mitigation Measures	
- The minimal extent of watercourses/flow paths reasonably possible should be disturbed. - Altered watercourses should be modified in such a way that allows upstream areas to route back into the natural watercourse downstream of works. - Ideally, the pre-existing hydrology (surface water environment) should be replicated or re-instated where practicable.	

TABLE 5-9: ALTERED DRAINAGE (OPERATION AND DECOMMISSIONING PHASE)

Impact Name	Altered Drainage		
Phase	Operation and Decommissioning		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Definite
Type of Impact	Direct	Magnitude	High
Extent	On-Site	Reversibility	Reversible
Duration	Permanent	Confidence	Moderate
Significance (Pre-mitigation)			Moderate
Sensitivity			Medium
Scoring			Moderate
Mitigation Measures			
- The minimal extent of watercourses/flow paths reasonably possible should be disturbed. - Altered watercourses should be modified in such a way that allows upstream areas to route back into the natural watercourse downstream of works. - Ideally, the pre-existing hydrology (surface water environment) should be replicated or where practicable.			

5.3.5 FLOODING

Flood risk is largely an impact on the proposed mine, rather than the environment, as with the other impacts identified in this report. This flood risk (from rivers and flow paths) is expected to be present during the construction, operational, and decommissioning phases due to the existence of infrastructure and works that could be flooded, as well as the presence of personnel who might be caught in floodwaters.

Various locations over the proposed mine are intersected by rivers/flow paths identified in **Section 4**, which also outlines the flood risk from select flow paths (with a contributing area > 5km²). Additional flood risk is also present in the form of surface water flooding (i.e., flooding from runoff before it enters a defined river). This risk will largely be managed through a suitably designed stormwater management plan (not assessed in this study).

The consequences of flooding are potentially severe, particularly in the location of the proposed processing plant and pit, which will need to manage this flood risk. Failure to do so may negatively impact production, with loss of life being the most severe potential consequence of flooding. The addition of flood defences and their design (i.e. to the 1:100 RI event) will dictate the level of protection afforded to the site.

Flooding also has possible feedback to **Section 5.3.2** (Pollutants Entering the Surface Water Environment), if flooding results in exposed pollutants (due to the Project) becoming entrained in flood waters.

Important. It should, however, be noted that the potentially severe impact of flood risk is not adequately conveyed by the impact table below since the probability and duration of extreme flooding is low while sensitivity is low, resulting in the impact appearing less significant than may be warranted.

TABLE 5-10: FLOODING (CONSTRUCTION, OPERATIONAL AND DECOMMISSIONING PHASE)

Impact Name	Flooding		
Phase	Construction, Operation, and Decommissioning		
Significance (Factors)			
Attribute	Pre-mitigation	Attribute	Pre-mitigation
Nature	Adverse	Probability	Rare
Type of Impact	Cumulative	Magnitude	Very High/Unknown
Extent	Local	Reversibility	Irreversible
Duration	Temporary	Confidence	High
Significance (Pre-mitigation)			Moderate
Sensitivity			Medium
Scoring			Moderate
Mitigation Measures			
- Maintain a stormwater management plan that is consistent with good practice guidelines such as the IFC EHS Mining Guidelines or possibly South African GN704, which would provide a secondary benefit of flood protection. - Where works/infrastructure is at risk of flooding, acceptable flood protection measures should be adopted. - Consider the results of the flood modelling presented in Section 4 in the development of the site. - Flood buffers have been presented in Section 4. Works should ideally not take place in these defined buffer areas, or within the 1:100 year flood-line (although this is a high-level estimate of flooding)			

5.4 ASSUMPTIONS, UNCERTAINTIES AND GAPS IN KNOWLEDGE

- Flooding and pollutants entering the surface water environment are poorly represented in the impact assessment (due to the probability of occurrence and extent/duration, respectively).
- The impact assessment undertaken within this study is based on a desktop assessment.
- The proposed mining operation includes an opencast pit, haul roads, a waste rock dump and a processing plant. This impact assessment is, however, a collective assessment. This results in some impacts being diluted by the generalised assessment (compared to an assessment focusing on a particular facility or process)

6 SURFACE WATER MONITORING

Regular surface water quality monitoring is a typical recommendation to enable detection of changes resulting from potential contamination of surface water by unexpected leaks, spills, or operational oversights. In the case of the proposed mine, local water resources are ephemeral. It may consequently be challenging to undertake regular surface water monitoring. Monitoring may, however, be possible in some locations during periods of rainfall, and this section suggests locations where water may be more abundant.

Surface water monitoring points have consequently been proposed, as shown in Figure 6-1, where more substantial rivers or flow paths are present, with upstream and downstream monitoring locations (from proposed works) preferred.

Table 6-1 presents the coordinates of these points.

TABLE 6-1: SAMPLING COORDINATES

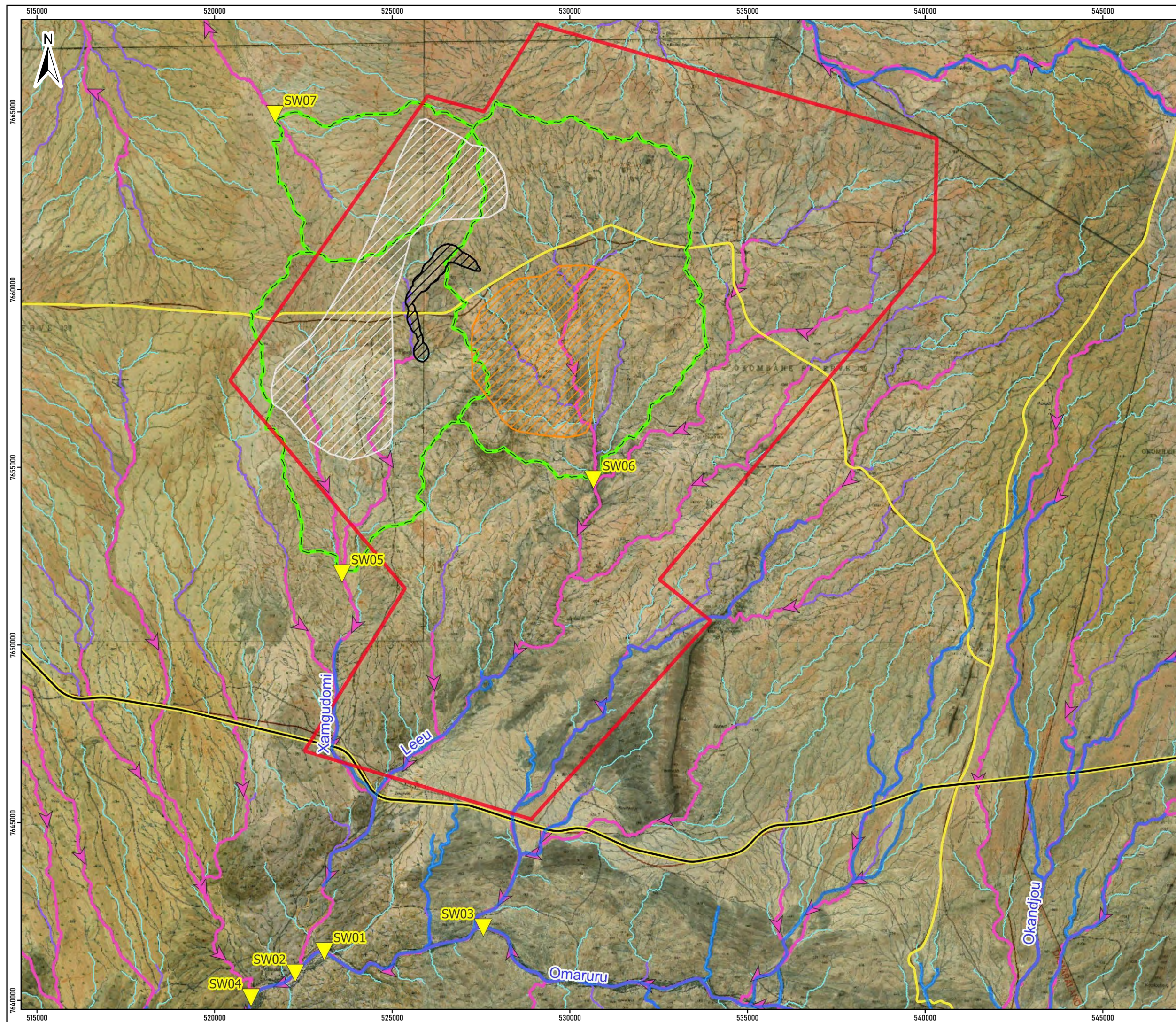
Month	Coordinates	Comment
SW01	21° 19' 46" S, 15° 13' 21" E	Captures the area of works influence on the Omaruru River
SW02	21° 20' 5" S, 15° 12' 53" E	Captures the area of works influence on the Omaruru River
SW03	21° 19' 24" S, 15° 15' 57" E	Extends to the full site (on the Omaruru River)
SW04	21° 20' 28" S, 15° 12' 10" E	Extends to the full site (on the Omaruru River)
SW05	21° 14' 0" S, 15° 13' 38" E	Captures the area of works (localised)
SW06	21° 12' 33" S, 15° 17' 44" E	Captures the area of works (localised)
SW07	21° 7' 0" S, 15° 12' 32" E	Captures the area of works (localised)

Sampling locations within the site boundary and as close as possible to the area of works are preferred due to the potential for dilution, the further away a sample point is located, and the possibility of influence from other land uses, limiting the potential for change detection resulting from the water quality changes at the site alone.

6.1 MONITORING PROGRAMME

Sampling should ideally take place every quarter, although the frequency of streamflow due to the ephemeral nature of rivers means that monitoring may be irregular. Any water that will be discharged into the natural environment must be tested and comply with the relevant water quality limits and regulations. Any mine intending to discharge waste or effluent water should also apply for a discharge permit under the Water Resources Management Act 11 of 2013 (Clause 66 and 67).

Parameters that need to be monitored should include (but are not limited to) those in **Table 6-2**. This table can be refined through the focus on contaminants of concern if presently known or as they become identified over time. For example, if a potential contaminant is consistently below effluent limits, its monitoring can be reduced or excluded in favour of more relevant contaminants. Alternatively, known parameters of concern should be added to **Table 6-2** (which is not exhaustive in its list of monitoring parameters).



Legend

Boundary (Kokoseb, EPL - 4818)

Containing Catchment (COP30 Derived)

Possible Surface Water Monitoring Point

Rivers (OSM)

Layout

Pit

Processing Plant (Approximate)

Waste Rock Dump (Approximate)

Roads (OSM)

Primary

Secondary

Flow Paths

Contributing Area - 10km²

Contributing Area - 5km²

Contributing Area - 1km²

Figure 6-1

Possible Surface Water Monitoring Locations

Hydrologic Consulting (Pty) Ltd

+27 72 239 0974

info@hydrologic.consulting

www.hydrologic.consulting

02 km5 km

Scale - 1:100,000 @A3

Coordinate Reference System: WGS 84 / UTM zone 33S

Version 1 04-Jul-2025

TABLE 6-2: MONITORING PARAMETERS

Infield measurements		
pH	Electrical conductivity	Total suspended solids (TSS)
Laboratory analysis		
Alkalinity as CaCO ₃	Chromium	Nitrate
Aluminum	Cobalt	pH
Ammonium	Copper	Phosphate
Arsenic	Cyanide	Potassium
Barium	Fluoride	Selenium
Bicarbonate	Iron	Silver
Boron	Lead	Sodium
Cadmium	Lithium	Sulphate
Calcium	Magnesium	Tin
Chloride	Manganese	Thorium
Chrome	Mercury	Total dissolved solids (TDS)
Chrome VI	Nickel	Uranium
		Zinc

Where possible, bi-annual surface water monitoring report should be completed and, as a minimum, include the following:

- Comparison of water samples to differentiate seasonal variations and general trends due to the historic mining activities;
- Comparison of water samples to standards and guidelines set by the Namibian Authorities; and
- Analysis of parameters over time to establish trends.

7 RECOMMENDATIONS AND CONCLUSION

Umvoto Africa (Pty) Ltd appointed Hydrologic Consulting to undertake a hydrological assessment of the proposed Kokoseb EPL 4818 Project, located in the Erongo Region, Namibia.

Baseline information, including rainfall, evaporation, design event rainfall, soils, vegetation and land-cover, as well as site terrain, flooding and regional and local catchment hydrology, has been considered for the proposed mine.

Applicable Guidance

The primary guidance applicable to this assessment is as follows:

- Environmental Management Act, No. 7 of 2007, which provides a framework for conducting environmental assessments as well as the implementation of monitoring and auditing measures.
- Water Resources Management Act, No. 11 of 2013, which includes aspects such as the licensing of water use, prevention of water pollution, protection of water resources, efficient use of water, water conservation measures, and the safety of dams.
- IFC Environmental, Health and Safety Guidelines – Mining (2007) guides the management of surface water with regards to mining, including the management of stormwater (and by association the management of flooding).

Flood Modelling

The approach to the assessment of flooding adopted two strategies:

1. Flow paths (ephemeral rivers) with a larger contributing area (>5km²) that intersected or were adjacent to proposed areas of works were identified for flood analysis. This resulted in approximately 37km of ephemeral river being identified for flooding analysis. A simulation of the flooding on these watercourses was consequently adopted to illustrate the 1:50 year recurrence interval (RI) and 1:100 year RI flooding estimated as occurring at this time. The details within this model were limited, and the simulation results should be considered a high-level estimate.
2. For the remaining rivers (or flow paths) on the site, a threshold catchment area analysis had been previously undertaken, with three flow path classifications produced. A buffering approach to these defined flow paths was subsequently undertaken to suggest possible exclusion or flood risk areas.

The 100m buffer is relevant to defining the riparian zone, which is defined by the Water Resources Management Act 11 of 2013 as historically, occasionally, or seasonally flooded banks and floodplains along both sides of a watercourse. The 1:50,000 topographical map dataset for Namibia includes various watercourses over the site. These watercourses have consequently been understood to qualify as riparian zones. As such, a 100m buffer zone is applicable, given Clause 141 of the Water Resources Management Act 11 of 2013. The result is that most of the site is expected to be associated with riparian areas due to the drainage density (of defined watercourses). An exemption to mine on the site is, consequently, likely required.

Identified Impacts

Flooding and pollutants entering the surface water environment are the two primary impacts, whether or not indicated by the impact assessment. Both impacts are not well represented in the impact assessment (due to the probability of occurrence and extent/duration, respectively). In the case of flooding, the primary impact is not from the project but to the project.

Surface Water Monitoring

Regular surface water quality monitoring is a typical recommendation to enable detection of changes resulting from potential contamination of surface water by unexpected leaks, spills, or operational oversights. In the case of the proposed mine, local water resources are ephemeral. It may consequently be challenging to undertake regular surface water monitoring. Monitoring may, however, be possible in some locations during periods of rainfall and monitoring locations were recommended where water may be more common.



Jonathan Southwood
BSc, Professional Land Surveyor (GPrLS 1539)
Author/Mapping



Mark Bollaert
MSc, CSci, CEnv, C.WEM, PrSciNat
Author/Project Manager/Reviewer

DISCLAIMER

Although Hydrologic Consulting (Pty) Ltd exercises due care and diligence in rendering services and preparing documents, Hydrologic Consulting (Pty) Ltd accepts no liability, and the client, by receiving this document, indemnifies Hydrologic Consulting (Pty) Ltd and its members, managers, agents and employees against all actions, claims, demands, losses, liabilities, costs, damages and expenses arising from or in connection with services rendered, directly or indirectly by Hydrologic Consulting (Pty) Ltd and by the use of the information contained in this document.

8 REFERENCES

Atlas of Namibia, 2022, “*Atlas of Namibia: its land, water and life*”, Namibia Nature Foundation, Windhoek. URL: <https://atlasofnamibia.online/>

Kunz, R., 2004, “*Daily Rainfall Data Extraction Utility*”. Institute for Commercial Forestry, Pietermaritzburg, South Africa.

Rossman, L., 2008. “*Stormwater Management Model user’s manual, version 5.0*”, 271. Retrieved from <http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=P10011XQ.txt>.

SANRAL., 2013, “*Drainage Manual - Sixth Edition*”, The South African National Roads Agency Limited, Pretoria

USACE (United States Army Corps of Engineers). 2016. “*HEC-RAS River Analysis System – 2D Modelling User Manual*”, Institute for Water Resources, Davis, California.

USACE (United States Army Corps of Engineers), 2016, “*Benchmarking of the HEC-RAS Two-Dimensional Hydraulic Modeling Capabilities*”, Davis, California

USACE (United States Army Corps of Engineers), 2018, “*HEC-RAS Verification and Validation Tests*”, Davis, California

APPENDIX A: FLOOD MODELLING

A.1 HYDROLOGICAL MODEL

A hydrological model was required to first be developed for the contributing catchment routing through the current double culvert.

A.1.1 HYDROLOGICAL MODEL CHOICE

PCSWMM is a model package that makes use of the USEPA Storm Water Management Model (SWMM), which is a computer program that computes dynamic rainfall-runoff from developed urban and undeveloped or rural areas (Rossman, 2008).

The SWMM model suited application to this study since it could account for:

- Time-varying rainfall;
- Rainfall interception in depression storage;
- Infiltration of rainfall into unsaturated soil layers;
- Routing of overland flow;
- Dynamic wave flow routing of flood waters; and
- Capture and retention of rainfall/runoff.

The hydrological modelling as it pertains to the development of stormwater management plans and flooding assessments using SWMM has been undertaken for many thousands of studies throughout the world (Rossman, 2008), including South Africa and was well suited to deriving the upstream inflows and effective rainfall as input into the hydraulic component of this study.

A.1.2 HYDROLOGICAL MODEL DOMAIN

The 30m DSDM formed the basis of the hydrological model domain, informing the partitioning of subcatchments, the accumulation of flow and some parameterisation of the model (e.g. subcatchment slope). Subcatchments of interest were derived through geoprocessing of the available elevation data. Sequential computations of flow direction, flow accumulation and stream definition based upon a contributing area of 200ha were then used to delineate subcatchments with a total subcatchment area of 91km² being modelled.

A.1.3 SUBCATCHMENT PARAMETERISATION

Land cover parameters were estimated according to the soil texture type and land-cover (**Section 2.6**), the 30m DSM (Section 2.4) and satellite imagery, for each of the 49 subcatchments. These were used to populate model attributes relating to depression storage, surface roughness, infiltration loss, slope and impervious areas.

A.1.4 DESIGN RAINFALL

In assessing flooding, it was necessary to define the associated rainfall that would cause this flooding. A hypothetical storm consequently needed to be developed which utilised the depth-duration-frequency (DDF) data (see Section 2.2). This hypothetical storm is the design rainfall that will produce the highest degree of flooding at each location independent of catchment response time (which is the index of the rate at which stormflow moves through a catchment). To calculate the hypothetical storm, the 24-hour 1:100 year RI rainfall depth for various durations (e.g. 5 minutes, 30 minutes and 2 hours) was transformed into a synthetic rainfall distribution or design hyetograph using the methodology outlined in Roads Authority of Namibia (2014).

When considering the catchment area upstream, it was not necessary to include an areal reduction factor that considers the difference between the design rainfall estimate for a point versus that over a large catchment (since larger catchments are less likely to experience high-intensity storms over the full catchment area).

A.1.5 DESIGN HYDROGRAPHS

The 1:50 and 1:100 year RI design hydrographs were extracted from the PCSWMM model at ten locations (for application on the river reaches to be modelled). It is, however, also the specific hydrological characteristics of the subcatchments upstream of the crossing, which lead to one of the largest uncertainties concerning the flood modelling undertaken. The parameterisation of these subcatchments has utilised site-specific datasets, however, some inaccuracy is expected with the potential for the peak flows and design hydrographs to vary in reality. Lack of calibration due to an absence of observed flows means that the PCSWMM model results couldn't be verified.

A.2 HYDRAULIC (FLOOD) MODELLING

The hydraulic model developed for modelling flood-lines needed to utilise available terrain data in the form of the 30m DSM.

A.2.1 HYDRAULIC MODEL CHOICE

HEC-RAS 6.6 was selected to model the hydraulic flooding on the two rivers of interest. HEC-RAS is designed to perform one-dimensional and two-dimensional hydraulic calculations for a full network of natural and constructed channels. The software is used worldwide and the 1D component of the model has been thoroughly tested through numerous case studies. The 2D component to the HEC-RAS model is a more recent addition having been released in 2015 although robust benchmarking (USACE, 2016) and verification and validation tests (USACE, 2018) have been performed to prove the 2D component of the model works as intended.

A.2.2 TOPOGRAPHIC DATA

The 3m DSM data (detailed in Section 2.3) provided the available terrain data for the hydraulic model build. This terrain data is coarse (in detail) and improvement in its detail would increase the accuracy of the flood modelling.

A.2.3 COMPUTATIONAL MODEL MESH

In developing a 2D HEC-RAS model, it was necessary to first delineate the model boundary. The model boundary was then used to define the model grid, with a 90m model mesh spacing selected to maximise spatial detail while limiting unnecessary model complexity.

The computational model mesh is the primary element making up the HEC-RAS 2D model. This mesh contains the data about the terrain of the underlying elevation data, the presence of linear features and surface roughness.

One of HEC-RAS's major advances to hydraulic modelling has been the addition of a subgrid. The subgrid extracts the detail available in the underlying terrain (i.e. the 30x30m DSM) into a hydraulic properties table for each cell and cell face in the model mesh. This includes variables such as the elevation/volume relationship per cell and the cross-section, elevation/area, and wetted perimeter for each cell face. This results in HEC-RAS models being able to use a larger cell size while still representing much of the underlying terrain, thereby producing an improved model result.

Aside from added hydraulic detail, the visual benefit from HEC-RAS using a subgrid, is that a more representative result of the expected flooding is possible since HEC-RAS will show only partial flooding for a mesh cell (where applicable).

A.2.4 BOUNDARY CONDITIONS AND BREAKLINES

Upstream and downstream boundaries were defined for the model using a normal depth slope. This 'normal depth' is estimated according to the river bed slope.

The two inflow hydrographs were applied to the upstream ends of the relevant river reach within the hydraulic model, despite being representative of the accumulated flows at the downstream end of the respective reach. This is common practice, whereby the design hydrographs for a point at the end of a modelled river reach are applied to a point upstream and results in some conservatism (where more flooding is conservative).

Breaklines were used to represent linear features that may otherwise have been missed by the application of a consistent model mesh (e.g. 90m mesh).

A.2.5 ROUGHNESS VALUES

A single Manning's n value of 0.05 was used across the model to approximate a fairly bare terrain with sporadic tree/bush cover.

A.2.7 MODEL RUN

More accurate full momentum equations were used in the running of the model. A stable model run was achieved.

A.2.8 ASSUMPTIONS AND LIMITATIONS

Various assumptions were required in the development of the hydraulic model with resultant limitations in the accuracy of the modelled flooding. They included the following:

- *PCSWMM parameterisation* – Design hydrographs estimated using PCSWMM are accurate given the potential for large deviations in their estimation to significantly influence resulting flooding.
- *Rainfall depth* – estimated rainfall depths are assumed accurate.
- *Accuracy of terrain datasets* – the 30m DSM was assumed accurate whereas it is known to be a coarse dataset. Lidar (for example) would improve on the detail of the 30m DSM by at least 900 times.
- *Culvert Dimensions* – no culverts were included (or known to exist).
- *Mesh detail* – the default mesh utilised a 90m mesh size. While one of HEC-RAS's major strengths is the use of a subgrid, the obstructing or routing influence of linear features that are smaller than the mesh resolution will not be well defined.
- *Breaklines* – To compensate for mesh detail, linear features (and ridges in particular) were digitised as breaklines and then applied to the model mesh. The application of these breaklines is assumed correct/sufficient.
- *Roughness values* – The selected Manning's 'n' value was representative of the area it covered, including being representative regardless of the depth of flooding.
- *Model calibration* – no calibration of the model was undertaken as there is no observed data for calibration purposes.
- *Software Performance* - The software and methods utilised are assumed accurate with regards to their utilisation of input data and the processes they simulate.
- *Climate Change* – climate change was not included in the assessment of flooding.