APPENDIX D: GROUND WATER IMPACT ASSESSMENT, NATURE STAMP 2022

GEOHYDROLOGICAL ASSESSMENT

FOR THE PROPOSED RENEWSTABLE® SWAKOPMUND PROJECT,

SWAKOPMUND DISTRICT, ERONGO REGION, NAMIBIA

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FINAL REPORT

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Acronyms

GIS	Geographical Information Systems
GPS	Global Positioning System
MAP	Mean Annual Precipitation

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Specialist Details & Declaration

This report has been prepared in accordance with Section 13: General Requirements for Environmental Assessment Practitioners (EAPs) and Specialists as well as per Appendix 6 of GNR 982 – Environmental Impact Assessment Regulations and the National Environmental Management Act (NEMA, No. 107 of 1998 as amended 2017) and Government Notice 704 (GN 704). It has been prepared independently of influence or prejudice by any parties.

The details of Specialists are as follows –

Table 1 Details of Specialist

Specialist	Task	Qualification and accreditation	Client	Signature
Bruce Scott-Shaw NatureStamp	Fieldwork, Assessments & report	PhD, Hydrology	SLR	Date: 05/06/2022
Nick Davis Isikhungusethu Environmental Services	Review	BSc, BSc Hon, MSc Hydrology	NatureStamp	Date: 08/06/2022

Details of Authors:

Bruce is a hydrologist; whose focus is broadly on hydrological perspectives of land use management and climate change. He completed his MSc under Prof. Roland Schulze in the School of Bioresources Engineering and Environmental Hydrology (BEEH) at the University of KwaZulu-Natal, South Africa. Throughout his university career he has mastered numerous models and tools relating to hydrology, soil science and GIS. Some of these include ACRU, SWAT, SWAT-MODFLOW ArcMap, Idrisi, SEBAL, MatLab and Loggernet. He has some basic programming skills on the Java and CR Basic platforms. He has spent most of his spare time doing field work for numerous companies and researchers. Bruce has completed his PhD which focuses on rehabilitation of alien invaded riparian zones and catchments using indigenous trees. Bruce has worked on numerous groundwater projects, which has included micrometeorological work, borehole testing, borehole siting, groundwater modelling, EIAs and wetland mapping. Bruce has presented his research around the world, where most recently he represented South Africa in Cambodia on surface water and groundwater model.

Details of Reviewer: Nicholas Davis is a hydrologist whose focus is broadly on hydrological perspectives of land use management, climate change, estuarine and wetland systems. Throughout his studies and subsequent work at UKZN he has mastered several models and programs such as ACRU, HEC-RAS, ArcMap, QGIS, Indicators of Hydrologic Alteration software (IHA) and Idrisi. He has moderate VBA programming skills, basic UNIX and python programming skills.

1. INTRODUCTION

1.1 Project Background and Description of the Activity

HDF Energy proposes to develop an energy plant in Swakopmund, using their trademarked Renewstable technology. Electricity will be generated by PV arrays and delivered to Swakopmund town during the day. A portion of the generated energy will be transformed into Hydrogen (H2) and stored on site in high-capacity fuel cells for night-time delivery.

A desalination plant will be built nearby to produce ultra-pure water (81m^3/day) for use in their process and cleaning solar panels. The water will be transported to the power plant via a 315 mm pipeline within a servitude of 50 m running next to an existing road.

SLR (South Africa) was commissioned by HDF Energy to do an Environmental Impact Assessment (EIA) as part of an application for environmental clearance in terms of the Environmental Management Act, 7 of 2007. Potgieter Consultancy CC was contracted by SLR to conduct a terrestrial biodiversity study for the EIA.

The coastal towns of Walvis Bay, Swakopmund and Henties Bay are supplied with fresh water from the Central Namib Water Supply Scheme based at Swakopmund. The scheme is managed by NamWater and abstracts groundwater from wellfields in the Omaruru and Kuiseb Rivers, which are the nearest sources of potable water to the towns (Christelis and Struckmeier, 2011). Shortfalls in the water supply capabilities at the NamWater well-fields are supplemented by desalinated water from the Orano (previously known as Areva) desalination plant. Swakopmund is located next to the dune belt of the Namib Desert. Petric gypsisols and rock outcrops are the dominant soils which are encountered in the area (Mendelsohn et al., 2003).

The key requirements for this study are as follows:

1. Desktop Geohydrological assessment.
2. Hydrocensus (investigation of boreholes within 5 km).
3. Groundwater monitoring programme.
4. Reporting (report & maps in pdf format).

The receiving environment as of February 2021 can be seen in Figure 1 with the layout of the proposed development and associated infrastructure in Figure 2.

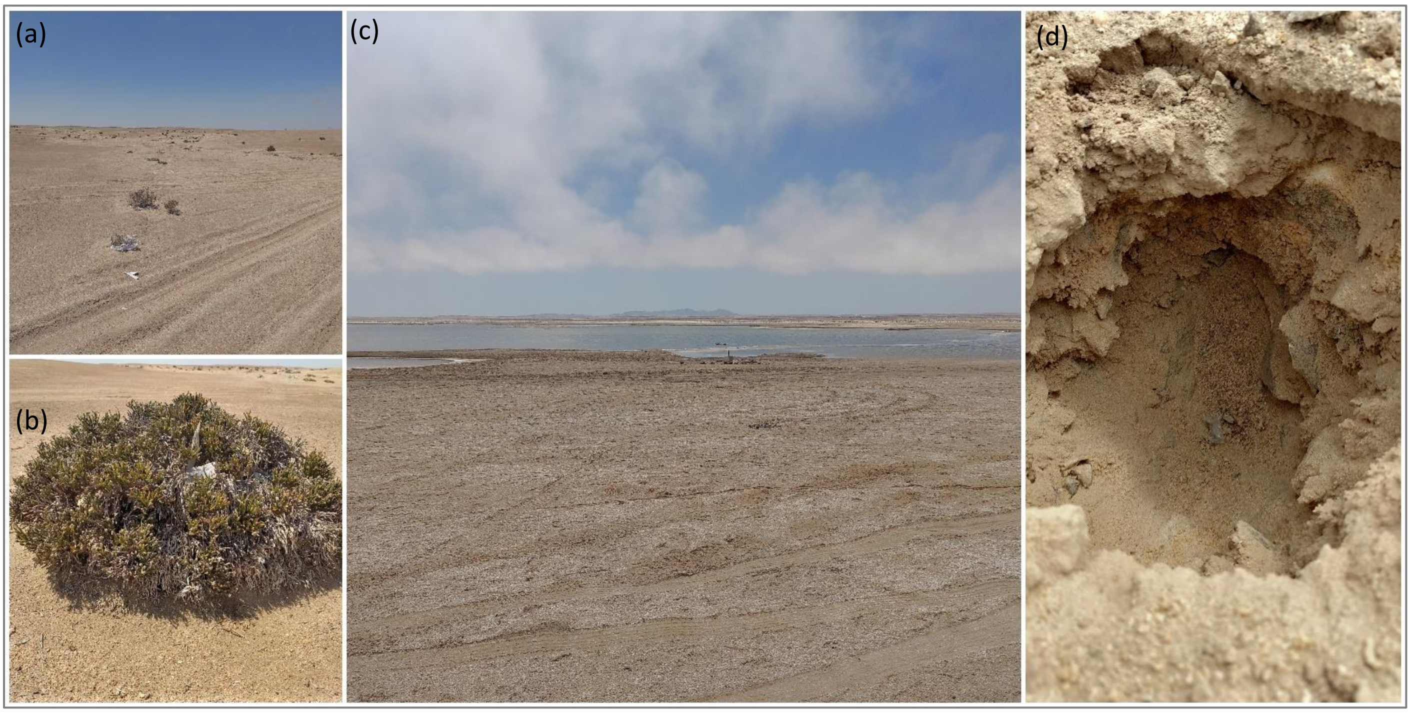

Figure 1 The receiving environment of the proposed HDF Energy Renewstable Facility (a), *Psilicaulon salicornioides* (b), the desalinisation plant location (c) and the typical soil characteristics at the site (d)

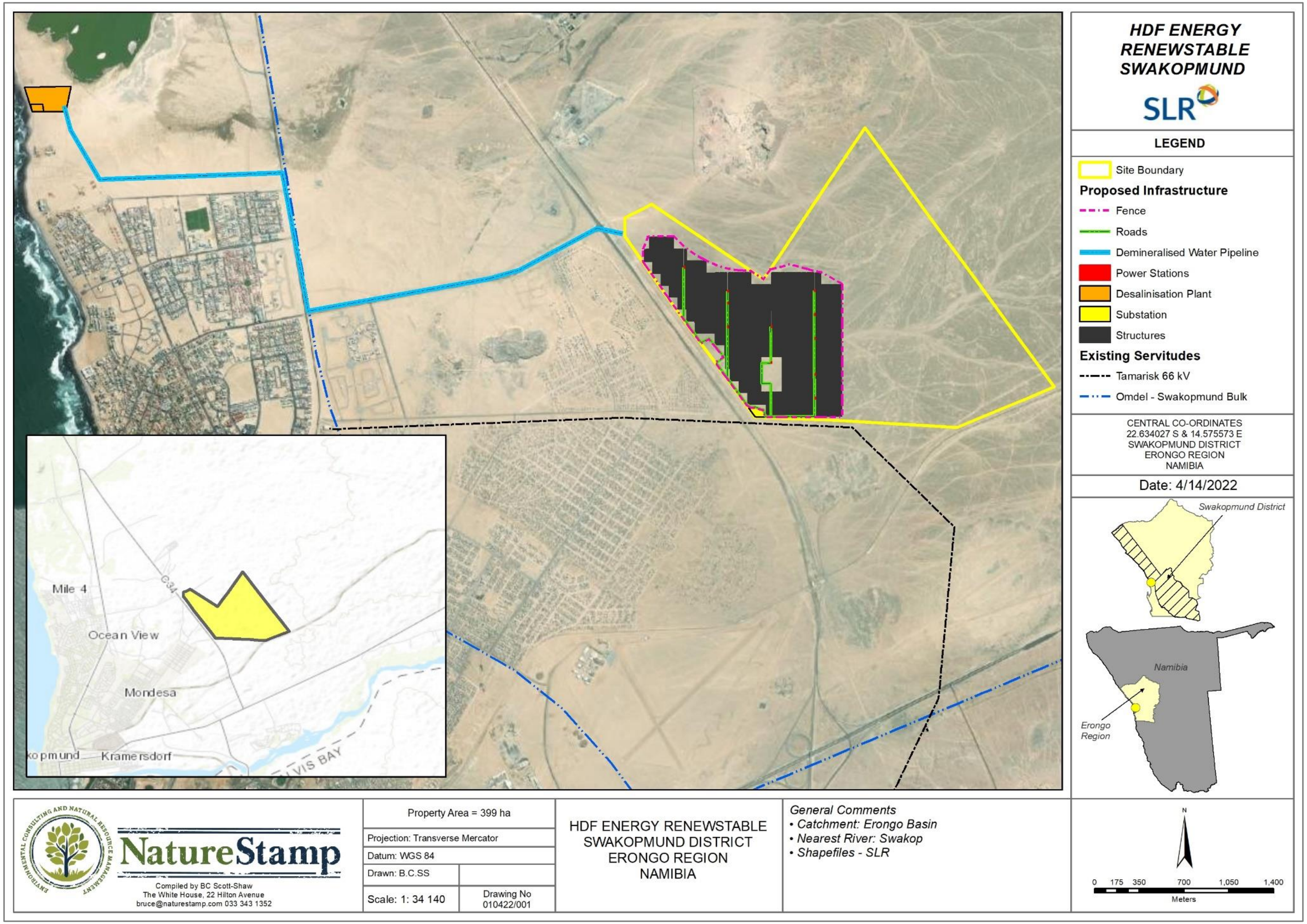

Figure 2 Locality map of the proposed HDF Energy Renewstable Facility

1.2 Terms of reference

i. **Geo-hydrological Investigation**

a. Background & Data Collection:

- Current status of groundwater quality on site;
- Possible impact on down-gradient resources;
- Geological Investigation
- Requesting and gathering data from the local Municipality, Namibia Water and possibly private consultants and drilling and pump-testing companies;
- Collation of gathered data and existing database data for the compilation of a groundwater database; and

b. Geo-hydrological assessment of the water use activity/impact in terms of:

- Groundwater pollution potential;
- Possible impact on down-gradient resources;
- Hydrocencus (5 km radius);
- Surrounding groundwater users potentially impacted; and
- Impacts and mitigation measures.

c. Groundwater Monitoring Programme & Management Plan:

- Compile a Groundwater Monitoring programme -Monitor boreholes available to assess groundwater flow regimes upstream, downstream and at the site.
- Management plan submitted in terms of groundwater quality and quantities

2. RELEVANT LEGISLATION

Since independence, there have been a number of changes to policies relevant to water in Namibia. Surface and groundwater in Namibia is governed by the Water Resources Management Act (2004; 2013). This Act provides for the management and conservation of all water resources of Namibia, including inland waters, the sea and meteoric water, i.e. water that occurs in or is delivered from the atmosphere. The Act regulates the abstraction, use and supply of water, lays down rules relative to water pollution, defines water rights and sets up an administrative framework to implement the purposes of the Act. The timeline of policies in Namibia is as follows:

- The Water Act No. 54 of 1956
- The Namibia Water Corporation Act No. 12 of 1997
- The National Water Policy White Paper 2000
- The Water Resource Management Act No. 24 of 2004
- The Water Supply and Sanitation Policy 2008
- The Integrated Water Resource Management Plan 2010
- The Water Resources Management Act No. 11 of 2013

The following is of particular relevance to groundwater and the proposed development:

- Act No. 11: Water Resources Management Act, 2013. Provides for the management, protection, development, use and conservation of water resources; to provide for the regulation and monitoring of water services and to provide for incidental matters.
  - Part 12 control and protection of groundwater, Section 66 – promoting the sustainable use and protection of aquifers.

3. STUDY SITE

The proposed HDF Energy Facility is located adjacent to the town of Swakopmund and falls within the Erongo basin. The site is located on a minor low gradient footslope coastal catchment between the Omaruru and the Swakop greater catchment areas. This catchment is 2 522 ha (25 km^2) and consists of ephemeral poorly defined drainage lines.

The Swakopmund area is underlain by rocks of the Damara Sequence, intruded by dolerite dykes of Karoo age. The complex stratigraphic relationships within the Damara Sequence have not as yet been clearly defined and formation names attributed to the different rock types must be regarded as provisional.

Cenozoic superficial deposits, comprising thin colluvial soils, alluvium and luvio-marine deposits overlie the bedrock to varying depths.

The mean annual rainfall (MAP) of this area is 51 mm, which mostly occurs between January to April. The highest daily rainfall recorded over the last two decades was 72.6 mm. Temperatures are moderate in this area with little variation throughout the year. 37.6 °C is the highest daily maximum temperature, with -3 °C the lowest daily temperature over the last two decades.

Table 2 Mean monthly rainfall and temperature observed near Swakopmund (derived from historical data)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Rainfall (mm)	5.3	11.7	10.1	14.1	1.8	1.5	0.0	0.1	0.9	1.6	3.1	1.6	51.9
Maximum Temperature (°C)	22.82	22.96	23.27	22.60	23.02	22.65	20.74	18.94	20.03	20.76	21.88	22.50	21.85
Minimum Temperature (°C)	16.00	16.46	16.17	15.29	14.01	12.40	10.46	10.16	11.59	13.00	13.97	15.27	13.73

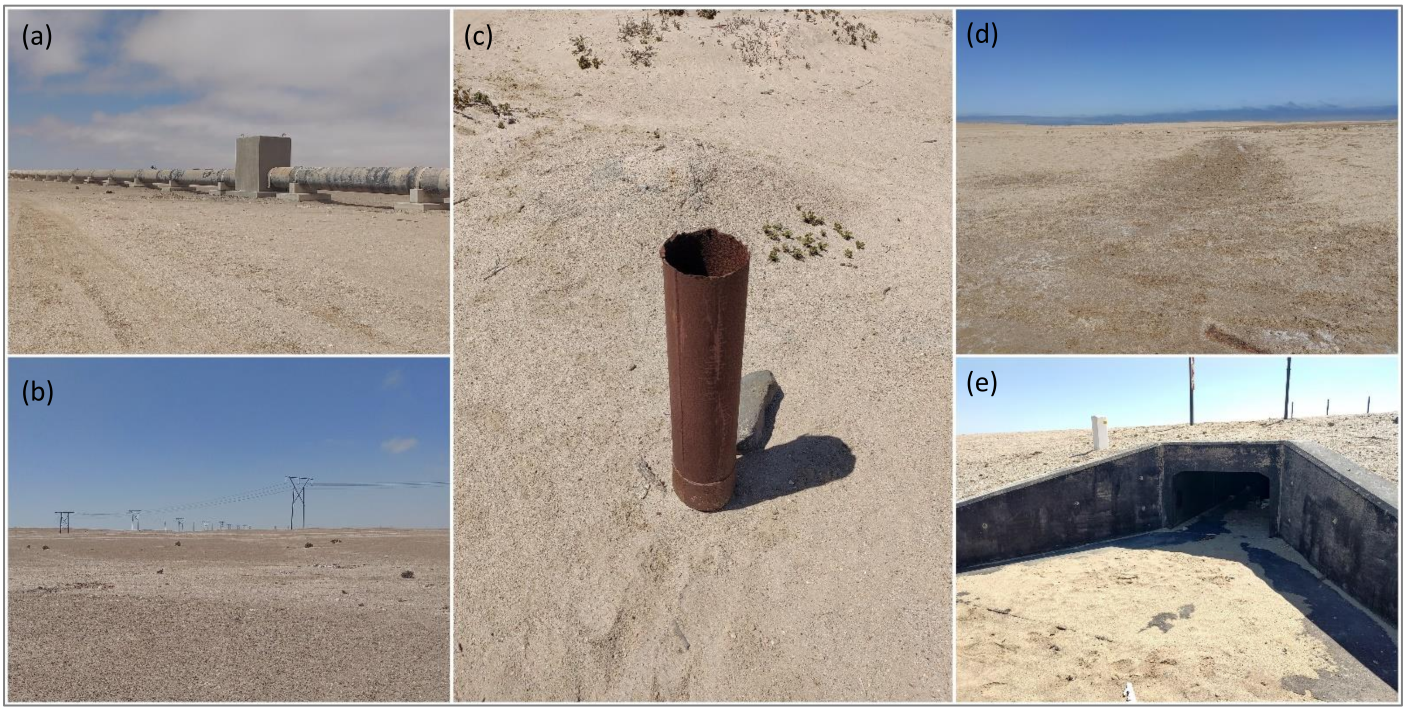

Figure 3 Typical setting of the surrounding site with the Omdel bulk water pipeline (a), the Tamarisk 66 kV OHL (b), an inactive borehole adjacent to Rossmund Golf Club (c), an ephemeral drainage line within the project area (d) and a portal culvert under the C28 road (e)

4. METHODOLOGY

A detailed description of the methods has been provided. The regional context and desktop analysis were used as the point of departure. Subsequently, a site visit was undertaken to assess groundwater infrastructure (if present). A site visit during the week of the 7th to the 11th of February 2022 was conducted to provide necessary in-field procedures including: soil sampling, the recording of dominant vegetation and topography/ terrain analysis, assessments of existing hydrological infrastructure and water sampling. This assessment was undertaken during a dry period. Additional groundwater databases are provided in Annexures A, B and C.

The assessment of these systems considered the following databases where relevant:

Table 3 Data type and source for the geohydrological assessment

Data Type	Year	Source/Reference
Aerial/Satellite Imagery	2016, 2019, 2021	Surveyor General/Landsat 8
Topographical	2015	Google Maps
Elevation	2011	Alos Palsar
River Shapefile	2002	Ministry of Agriculture, Water & Forestry
Geology Shapefile	2009	Ministry of Agriculture, Water & Forestry
Groundwater Data	Ongoing	Ministry of Agriculture, Water & Forestry, Personal Communication & Literature
Land Cover	2021	Africa Geoportal
Water (various)	N/A	Ministry of Agriculture, Water & Forestry

*Data will be provided on request

Table 4 Equipment used during the site visit

Equipment Used	Description
Bailer	Used to abstract water from a borehole. 10 abstractions are undertaken before a sample is taken to ensure that the water abstracted is recharged water representative of the site.
Dip Meter	Used to measure the depth of the water table in a borehole.
GPS (GPSMAP 64)	Used to mark points of interest such as boreholes and auger points.
Auger (Bucket)	Used to take soils samples as well as identifying soil form and family.
Munsell Colour Chart	Used to determine soil value, hue and chroma.

4.1 Background Data/Regional Context

It is extremely important that, when a development occurs or operates near water resources or using water resources, downstream/down gradient or nearby users are considered. The extent of downstream/down gradient users dependent on the delivery of sufficient amounts of water and of a sufficient quality will determine if the development has a negative impact. A desktop study was undertaken to determine the climatic conditions and geological formations. An analysis of nearby users was undertaken.

4.2 Site Visit

A site visit was conducted by Bruce Scott-Shaw of NatureStamp (Pty) Ltd between the 7th to the 11th of February 2022. Previous site visits have been undertaken by other specialists and are referenced where necessary. The current condition was assessed as follows -

- The vegetation characteristics of the full project area was assessed for the determination of cover characteristics, changes in geology and soils that drive the vegetation growth;
- The presence and dimensions of any hydrological infrastructure such as dams, boreholes and irrigation schemes were documented and recorded;
- The overall state of drainage channels, streams and rivers was assessed;
- The slope of the study site as well as proximity to water resources were noted;
- The state of existing gauging stations (nearby) was assessed to determine if the structure is accurately recording streamflow (e.g. evidence of under cutting or damaged features); and
- The identification of any obvious faults or outcrops that may influence the geohydrology was recorded.

4.2.1 Groundwater Infrastructure

An assessment of any existing groundwater infrastructure was undertaken. The assessment determined the current state of each site and the potential in relation to the underlying geology and annual rainfall. Sites were assessed as:

- Is the pump/borehole currently working?
- If not, when did it stop working?
- If not why did it stop working?
- What are the operational boreholes being used for?
- For operational boreholes the following information was obtained where available:
  - pump installation depth,
  - borehole depth;
  - depth of water level;
  - yield of the borehole;
  - depth of water strike(s); and
  - volume abstracted.

4.2.2 Soil assessment

Terrain Units: The terrain units were derived through a combination of contour lines and the site assessment. This allowed for the identification of drainage lines and each hillslope position. This further assisted the sampling design. Numerous auger points were selected and drilled with samples being taken from selected points.

Effective Depth: The effective depth is the profile depth of the soil (from surface to below) to which plant roots can penetrate to obtain water and nutrients. Certain layers (such as hard rock) would limit the roots and prevent them from growing further down the profile. This value can be useful to land managers to determine the likeliness of erosion.

Soil Structure & Texture: A detailed texture and structure analyses were undertaken in the lab (Figure 4). This allowed for the soils condition to be understood. Furthermore, these findings allowed for inputs to be derived for the models used. For each sample, coarse material (> 2 mm) was excluded. This was important as there were disturbances from the road throughout the site. The following sieve sizes were used to determine the soil texture:

- Sand – 2.0 – 0.005 mm
- Silt – 50 – 2 µm
- Clay - < 2 µm

Soil Classification: A Munsell soil colour chart was used to determine the hue, value and chroma of soil samples. This assisted in determining if signs of wetness were present, if the colour characteristics matched the short list of likely horizons and assisted in determining the angular structure as well as the level of mottling. For example, the chart was used to determine if the B-horizon was red or yellow-brown in colour or the difference between a paler E-horizon and a neocutanic B-horizon.

Soil Bulk Density & Porosity: Soil bulk density and porosity were measured by taking a known volume core sample. The following calculations were used:

1. *Bulk density (g/cm^3) = Dry soil weight (g) / Soil volume (cm^3)*
2. *Porosity = Volume (air) + Volume (water)/Total Volume*

Figure 4 Texture analysis of soil samples

4.3 Groundwater (Hydrogeological) Assessment

4.3.1 Hydrocensus

In order to analyse the potential for groundwater options, a hydro-census of all boreholes within 5 km was undertaken. A borehole bailer and a dip meter were used where boreholes were accessible and still active. Borehole sites were obtained through the desktop investigation and 'ground-truthed' on site.

The Namibian Monitoring Information System & Hydrogeological Map was utilized to collate historical groundwater depths, recharge rates, water quality and site details (Figure 5). Notable boreholes were marked using a GPS. Access was considered for these boreholes and potential borehole sites. Historical boreholes that were observed on or near sites were marked and investigated. The final yield data was compiled into a GIS database for the production of groundwater maps.

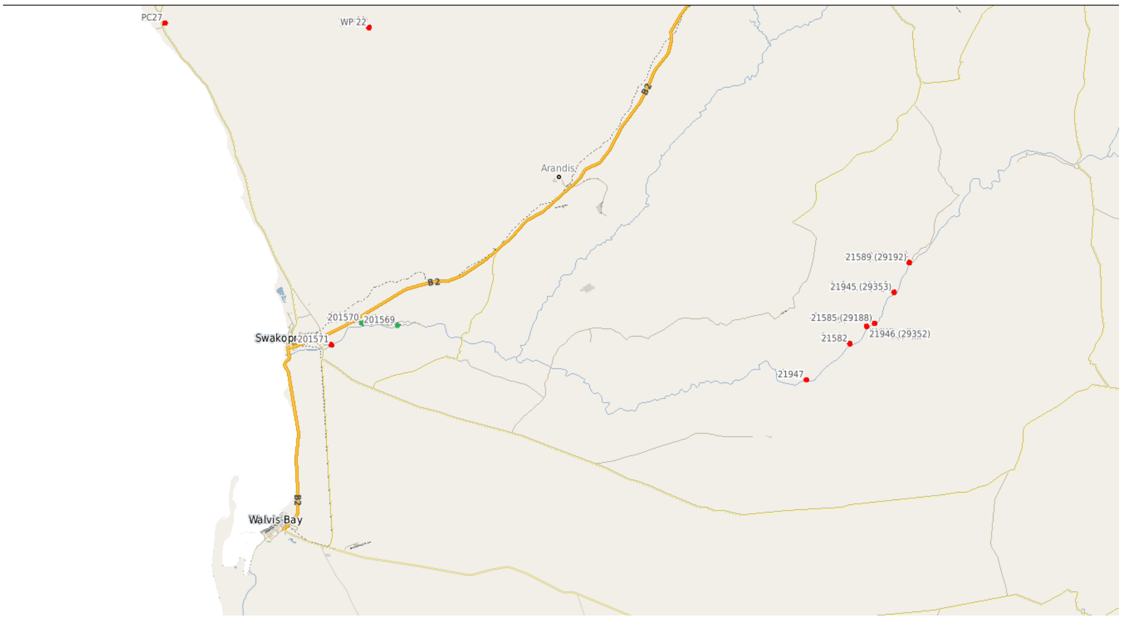

Figure 5 NA-MIS database interface

This process not only assisted in determining the general state, condition and productivity, but allowed for the identification of key boreholes for sampling, yield assessments and potential operational and construction use. Additionally, any groundwater users that may be impacted upon were identified.

4.3.2 Hydrogeological Modelling

Numerous models developed for a variety of uses are available. As such a predicament exists as to which model or sub-model is best suited for the intended use. Some models are designed and developed for specific purposes, while others are more general and integrated in their applicability (Schulze, 2007). Model complexity is a major determinant as to which model is selected, as the input data available, time constraints and budget significantly influence model selection. The level of detail on processes, on spatial disaggregation and temporal disaggregation should also be considered in models (Schulze et al., 1995). The following limitations were identified at the site:

- Very little data on groundwater is available for the area;
- Most boreholes have been inactive for many years;
- Data that is available does not have an assured reliability.

As a surface water assessment is also being undertaken for the site, a surface water model (Soil and Water Assessment Tool, SWAT) and a groundwater driven model (MODFLOW) were considered. There is also a possibility of these two models being coupled at a later stage. This is important as the groundwater catchment may be different from the topographical catchment in this area.

4.3.2.1 Soil Water Assessment Tool (SWAT)

The input required for ArcSWAT is spatially explicit soils data, landcover/management information, and elevation data to drive flows and direct sub-basin routing (Arnold, 2005). ArcSWAT lumps the parameters into hydrologic response units (HRU), effectively over-riding the underlying spatial distribution. These HRUs are grouped according to the topography, soils (type/structure/depth/chemical properties), landcover and slope. One of the most important drivers is the meteorological data, which has been vastly improved in this model over recent years. ArcSWAT has options to use measured solar radiation, wind speed, relative humidity and evaporation data. Daily rainfall and temperature data may be generated if unavailable or missing for the simulation period and there are no limitations to the number of rainfall and temperature gauges that can be used in the simulation (Neitsch et al., 1999).

The SWAT model uses the water balance equation (Equation 1) in its simulation of the hydrological cycle (Arnold et al., 2009).

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad \text{Eq. 1}$$

Where SW_t is the final soil water content (mm); SW_0 the initial soil water content on day i (mm); R_{day}: being the precipitation on day i (mm); Q_{surf} the surface runoff on day i (mm); E_a the total evaporation on day i (mm); W_{seep} the water entering the vadose zone on day i (mm) and Q_{gw} the return flow on day i (mm).

Although not a groundwater model, the daily groundwater interactions simulated in the model provide a suitable approach to identify and quantify potential impacts on groundwater users.

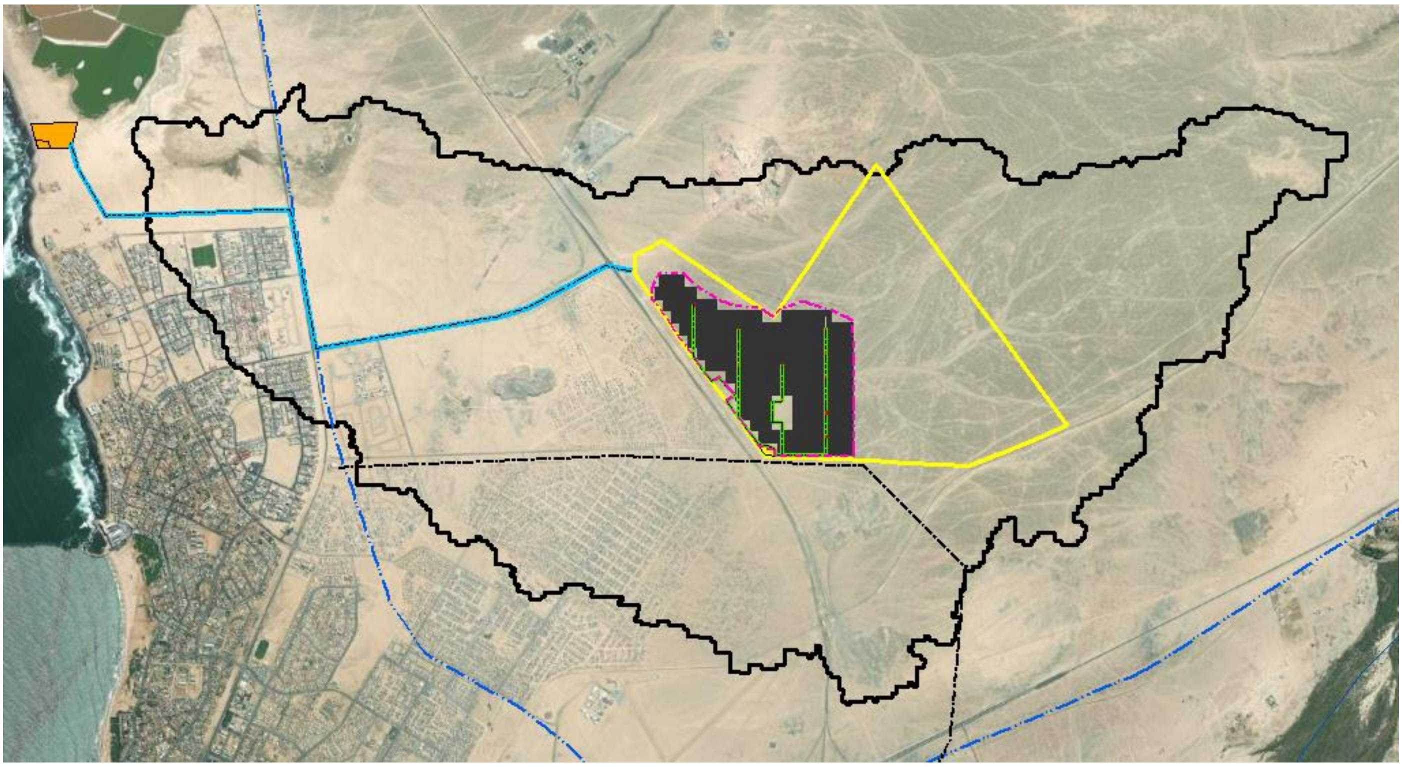

Figure 6 Catchment area delineated through the ArcSWAT model for the proposed study area

4.3.2.2 MODFLOW

The spatially-distributed groundwater model (MODFLOW) uses the following inputs to drive the model:

- Rainfall and A-Pan.
- Borehole data (water level).
- Land use data.
- Geological data used for the initial estimates of the spatial distribution of the hydraulic properties.

MODFLOW-NWT inputs to the aquifer with either 1-dimensional unsaturated subsurface recharge, using the Unsaturated Zone Flow (UZF1) package (Niswonger *et al*., 2006). MODFLOW 6 was used for the development of the simple groundwater state of the study area.

4.4 Impact Assessment

An assessment of the potential impacts of the Swakopmund site was guided by the SLR Impact Table Guidelines. A pre- and post-mitigation assessment was undertaken.

Table 5 SLR impact table interpretation of significance

PART D: INTERPRETATION OF SIGNIFICANCE		
Very High -	Very High +	Represents a key factor in decision-making. In the case of adverse effects, the impact would be considered a fatal flaw unless mitigated to lower significance.
High -	High +	These beneficial or adverse effects are considered to be very important considerations and are likely to be material for the decision-making process. In the case of negative impacts, substantial mitigation will be required.
Medium -	Medium +	These beneficial or adverse effects may be important but are not likely to be key decision-making factors. The cumulative effects of such issues may become a decision-making issue if leading to an increase in the overall adverse effect on a particular resource or receptor. In the case of negative impacts, mitigation will be required.
Low -	Low +	These beneficial or adverse effects may be raised as localised issues. They are unlikely to be critical in the decision-making process but could be important in the subsequent design of the project. In the case of negative impacts, some mitigation is likely to be required.
Very Low -	Very Low +	These beneficial or adverse effects will not have an influence on the decision, neither will they need to be taken into account in the design of the project. In the case of negative impacts, mitigation is not necessarily required.
Insignificant		Any effects are beneath the levels of perception and inconsequential, therefore not requiring any consideration.

4.5 Groundwater Recommendations

Results from the hydrogeological assessment and impact assessment were used to provide recommendations on impacts of the proposed development and feasibility of groundwater resources.

5. LIMITATIONS AND ASSUMPTIONS

In order to apply generalized and often rigid scientific methods or techniques to natural, dynamic environments, a number of assumptions are made. Furthermore, a number of limitations exist when assessing such complex ecological systems. The following constraints may have affected this assessment –

- A Garmin GPSMAP 64 was used in the mapping of waypoints on-site. The accuracy of the GPS is affected by the availability of corresponding satellites and accuracy ranges from 1 to 3 m after post-processing corrections have been applied.
- A Munsell Soil Colour Chart was used to assess soil morphology. This tool requires that a dry sample of soil be assessed. However, due to in-field time constraints, slightly wet soil samples were assessed. Wet samples would have consistently lower values than dry soils; and this is taken into consideration.
- Limited data was available at times (particularly on groundwater infrastructure). As such, some assumptions were made in the absence of data. These assumptions used data from nearby areas. Reliance was placed the landowner's recollection and on the models used in the absence of suitable data.

6. RESULTS AND DISCUSSION

Results detailing the desktop assessment done as well as findings from this updated study with the site visit are provided in this Section.

6.1 Background Data/Regional Context

6.1.1 Terrain & Vegetation

The catchment is very flat with its highest point at 125 masl to the east and 6 masl to the west. Throughout the catchment these are small undulating dune like features. Water flows between these features after a rainfall event through the path of least resistance.

The study area is classified as a central desert vegetation type with less than 0.1 % vegetative cover. Dominant species that occur on site are lichens and Psilicaulon salicornioides. The topography is gentle with an elevation of 4 meters at the desalinization plant and 133 meters at the highest point in the catchment. The project footprint has a low point of 50 meters and a high point of 76 meters.

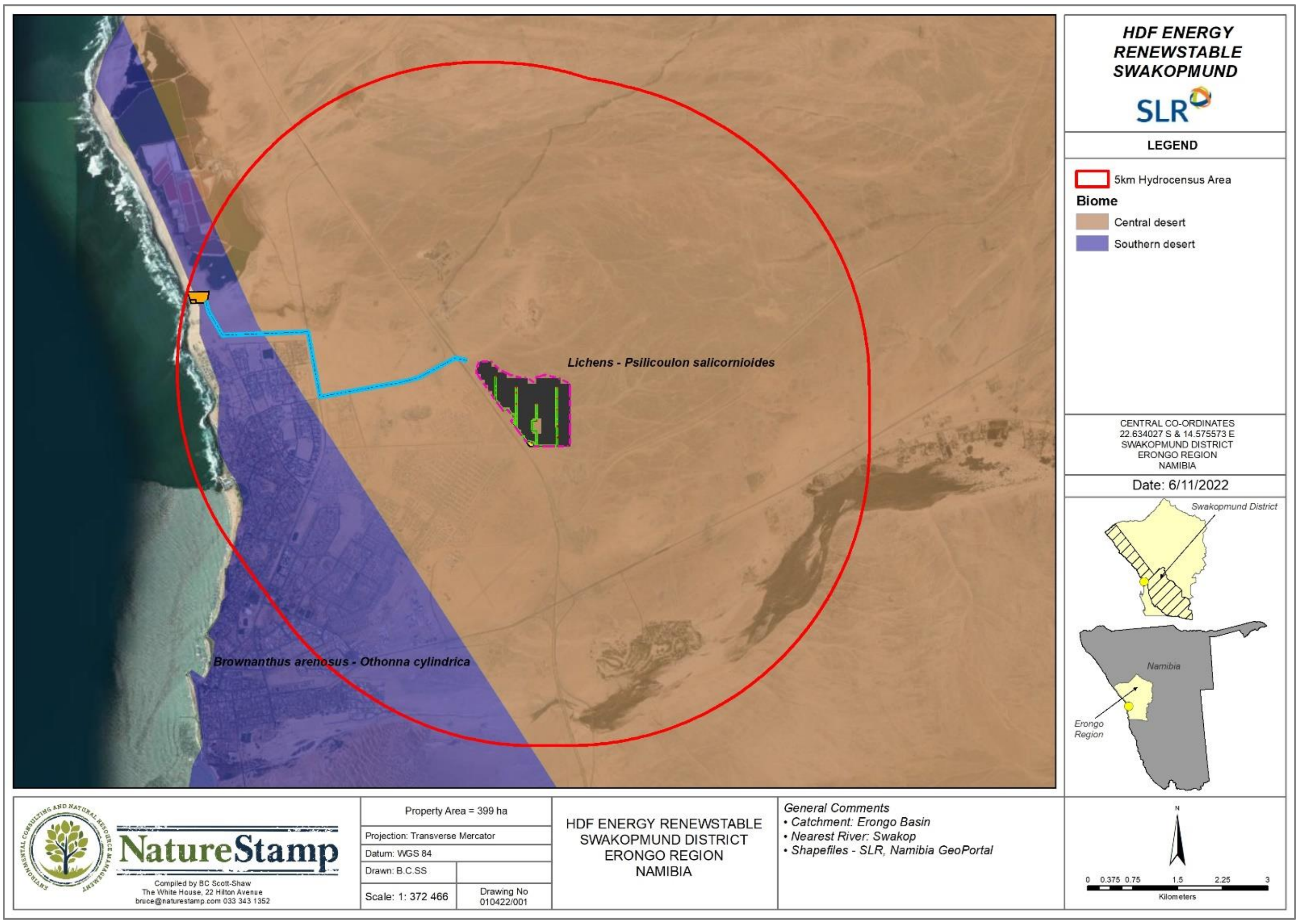

Figure 7 Current land use within the study area

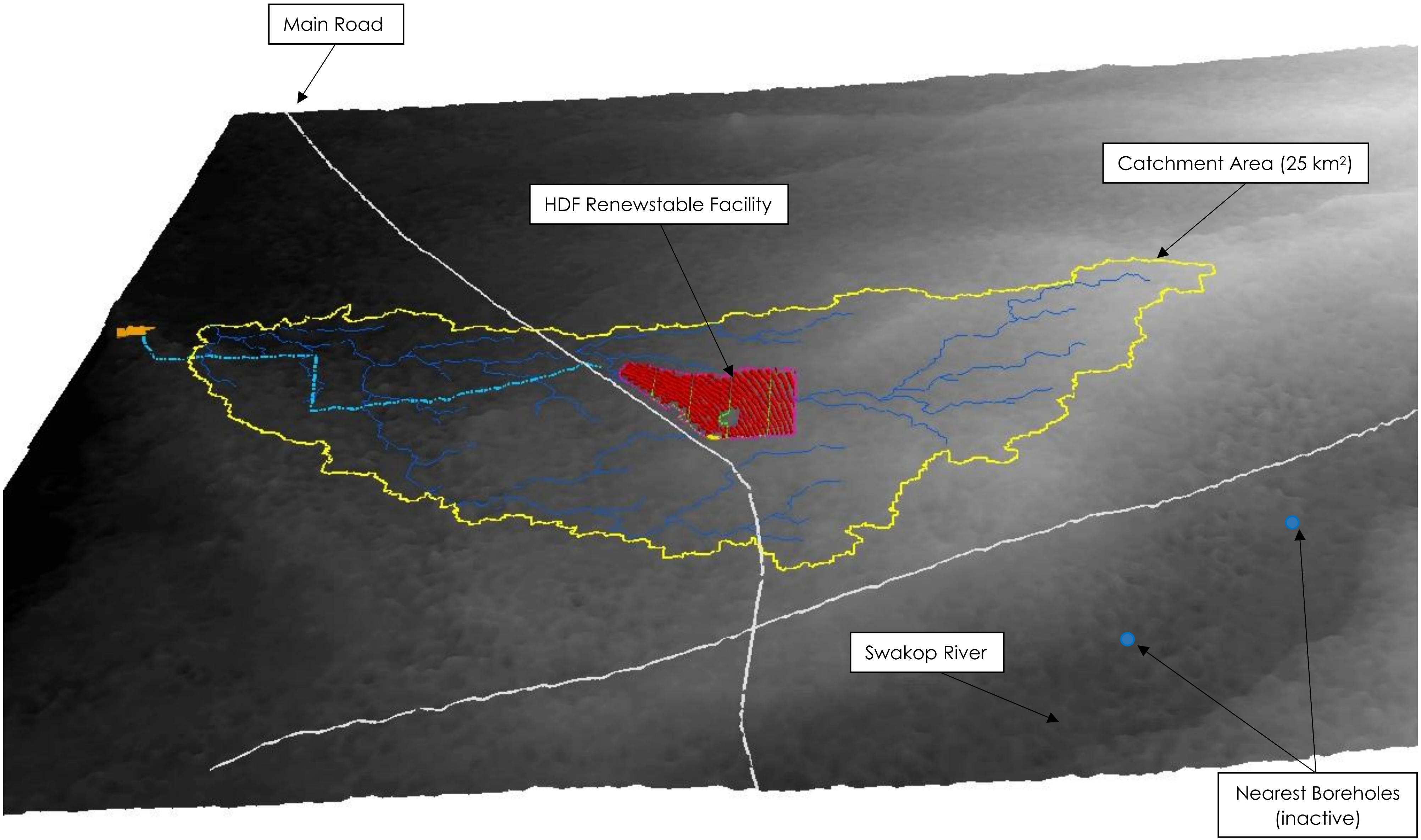

Figure 8 Exaggerated terrain model for the surrounding area of the proposed HDF Energy Renewstable Facility

6.1.2 Climate Data

The mean annual rainfall (MAP) of this area is 51 mm, which mostly occurs between January to April. The highest daily rainfall recorded over the last two decades was 72.6 mm. Temperatures are moderate in this area with little variation throughout the year. 37.6 °C is the highest daily maximum temperature, with -3 °C the lowest daily temperature over the last two decades.

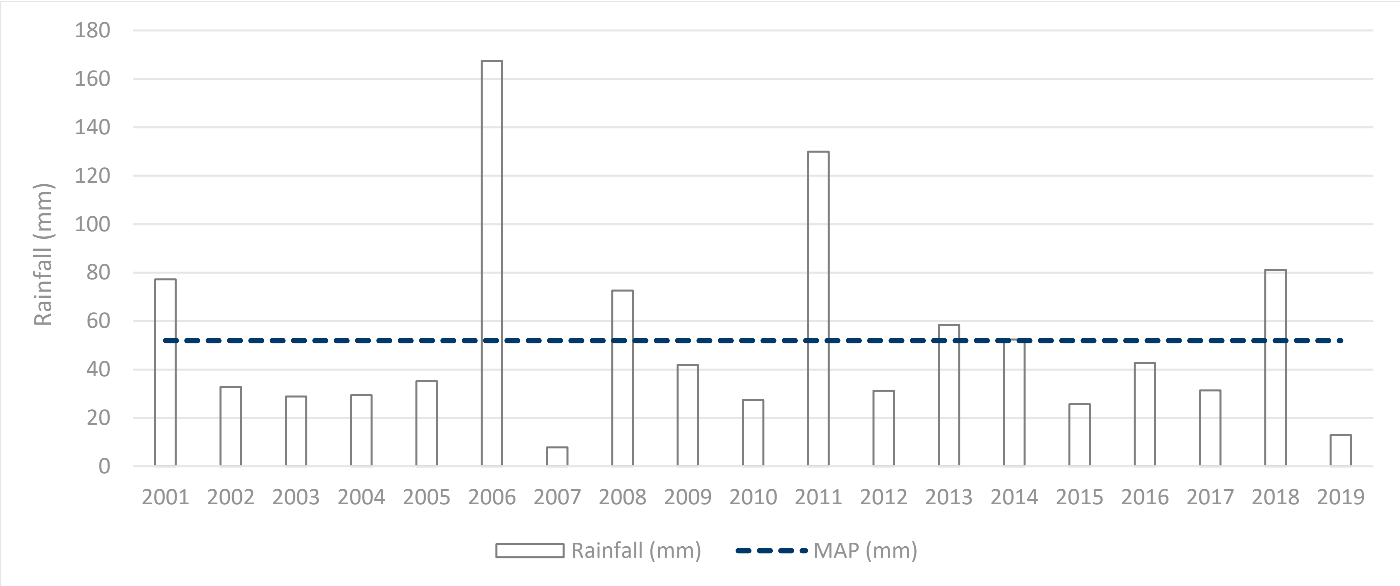

Figure 9 Annual rainfall observed since 2001 in Swakopmund

6.1.3 Prevailing Soils

Soils observed throughout the study area are characteristed as unconsolidated colluvial soils, primarily petric gypsisols. Gypsic yermosol, haplic yermosol and takyric solonchak occur throughout this area. Rock types are metamorphic sedimentary rocks (schist, quartzite or marble) with granitic intrusions. Swakopmund is located next to the dune belt of the Namib Desert (Mendelsohn et al., 2003), with Cenozoic luvio-marine and alluvial deposits that overlie Precambrian Damara Sequence (young sequence) rocks and Karoo age dolerites. The project area is dominated by fluvio-marine deposits that can be defined as (Bulley, 1986):

- Light grey to brown, loose to medium dense but locally strong cemented by gypsum, gravelly fine to medium sand with localized development of moderately hard gypcrete layers.
- Zones of brown, firm, micaceous, fine sandy silt occur in some parts of Vineta.

Table 6 Mean Stratigraphic column for the Swakopmund area (Bulley, 1986)

<table>
<tr><th colspan="2">GEOLOGICAL UNIT</th><th>THICKNESS</th></tr>
<tr><td colspan="2">Colluvial soils</td><td>< O,5m</td></tr>
<tr><td colspan="2">Swakop River alluvium</td><td>Generally < 10m, but up to 30m in deep channels</td></tr>
<tr><td colspan="2">Fluvio-marine deposits</td><td>1 - 5m</td></tr>
<tr><td colspan="2"></td><td>ROCK TYPE</td></tr>
<tr><td rowspan="4">Damara Sequence</td><td>Karibib Formation</td><td>Calc-silicate rock</td></tr>
<tr><td>Karibib Formation</td><td>Marble</td></tr>
<tr><td>Rössing Formation</td><td>Dolomitic marble</td></tr>
<tr><td>-</td><td>Gneissic-granite</td></tr>
</table>

6.1.4 Prevailing geology

The Swakopmund area is underlain by rocks of the Damara Sequence, intruded by dolerite dykes of Karoo age. The complex stratigraphic relationships within the Damara Sequence have not as yet been clearly defined and formation names attributed to the different rock types must be regarded as provisional. Cenozoic superficial deposits, comprising thin colluvial soils, alluvium and luvio-marine deposits overlie the bedrock to varying depths.

The groundwater potential of fractured aquifers in the Swakop Group of the Damara Sequence is generally low (Smith, 1965). However, the carbonates (marbles and limestones) are of moderate potential and at properly selected targets like fracture zones and karstified contact zones, higher yields can be found (Smith, 1965). Significant groundwater catchments in the area include the Otjiwarongo marble aquifer, Kalkfield (granite) and Hochfeld (undifferentiated).

The proposed project site is considered to have a low vulnerability, little to very low groundwater potential and extremely low recharge. The two identified boreholes are adjacent to the Swakop river.

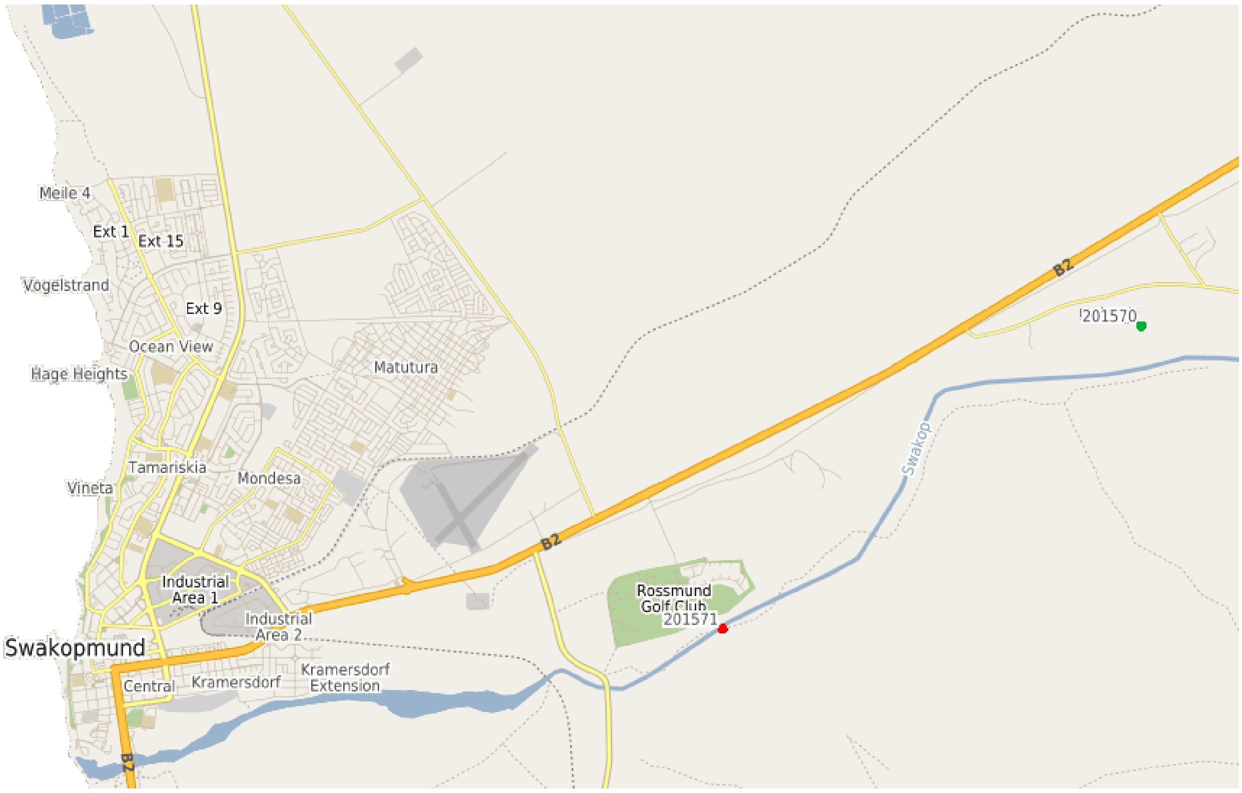

Figure 10 Nearest boreholes to the project site (NA-MIS Namibian Monitoring Information System)

The most significant aquifer presently utilised is the marble aquifer north and north-east of Otjiwarongo. The water supply scheme relies on a fractured and slightly karstified marble band of the Karibib Formation, which allows medium to high pumping rates and supplies.

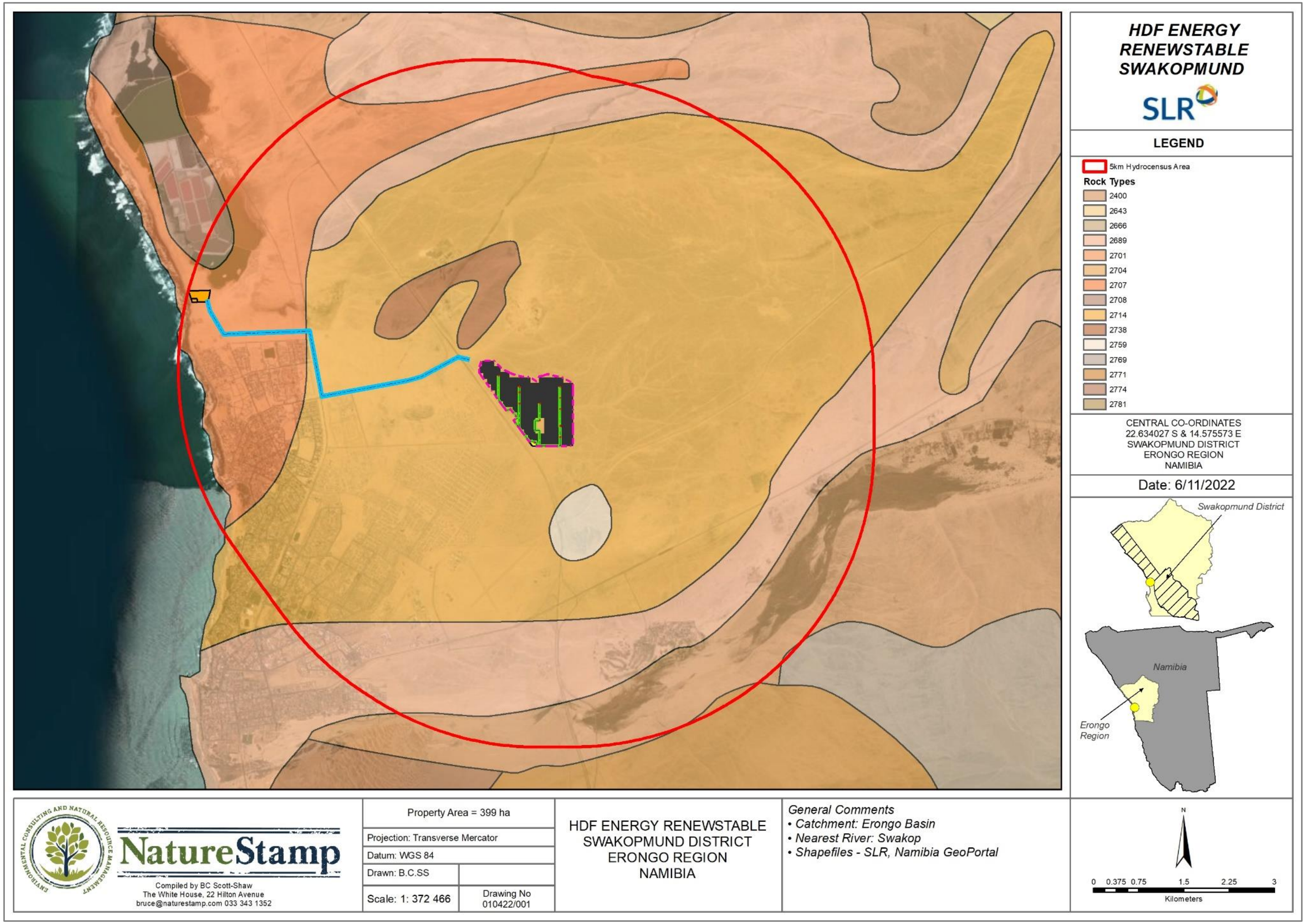

Figure 11 Geological formations and boreholes within 5 km of the study area

6.2 Soil Texture & Structure

There was little difference in the soil structure and texture throughout the site. Almost the entire proposed area had uniform unconsolidated colluvial petric gypsisols. The soils throughout the sites were sandy with scattered marble and limestone deposits. Two sections of dolorite dykes were identified within the site boundary. The soils were consistently light brown with a weak structure. The colour classification was as follows:

- Hue: 2.5 Y
- Value: 8
- Chroma: 3

The soils were slightly luvic as the B-horizon had a higher clay content to the A-horizon. The incremental measurements for the HDF Energy Renewstable Facility site is provided in Table 7.

Table 7 Average soil texture at incremental depths for the petric gypsisols

Sieve Diameter (µm)	Soil Mass per Depth Increment (g & %)					
	0.3m		0.5m		0.75m	
>2mm	157.18	29%	193	41%	191	39%
300	168.02	31%	150	32%	171	35%
180	195.12	36%	80	17%	88	18%
150	10.84	2%	28	6%	24	5%
106	5.42	1%	5	1%	15	3%
90	5.42	1%	9	2%	0	0%
53	0	0%	5	1%	0	0%

Foundation design should be guided from founding solutions recommended by a geotechnical specialist. Cognizance of the weak structure should be taken into consideration during planning and construction. Furthermore, the areas of dolerite will require different founding solutions. The following is a general guide:

- Compaction of founding-subsoils/development of typically 1.5 x least foundation width; reinforced strip footings; lightly reinforced masonry and effective surface drainage precautions.
- Effective stormwater controls are important to ensure that the quickly transported sands do not move leading to undercutting of structures. However, as the rainfall is so low, only simple Stormwater practices are needed.

Figure 12 Nearby quarry site where a full profile could be derived

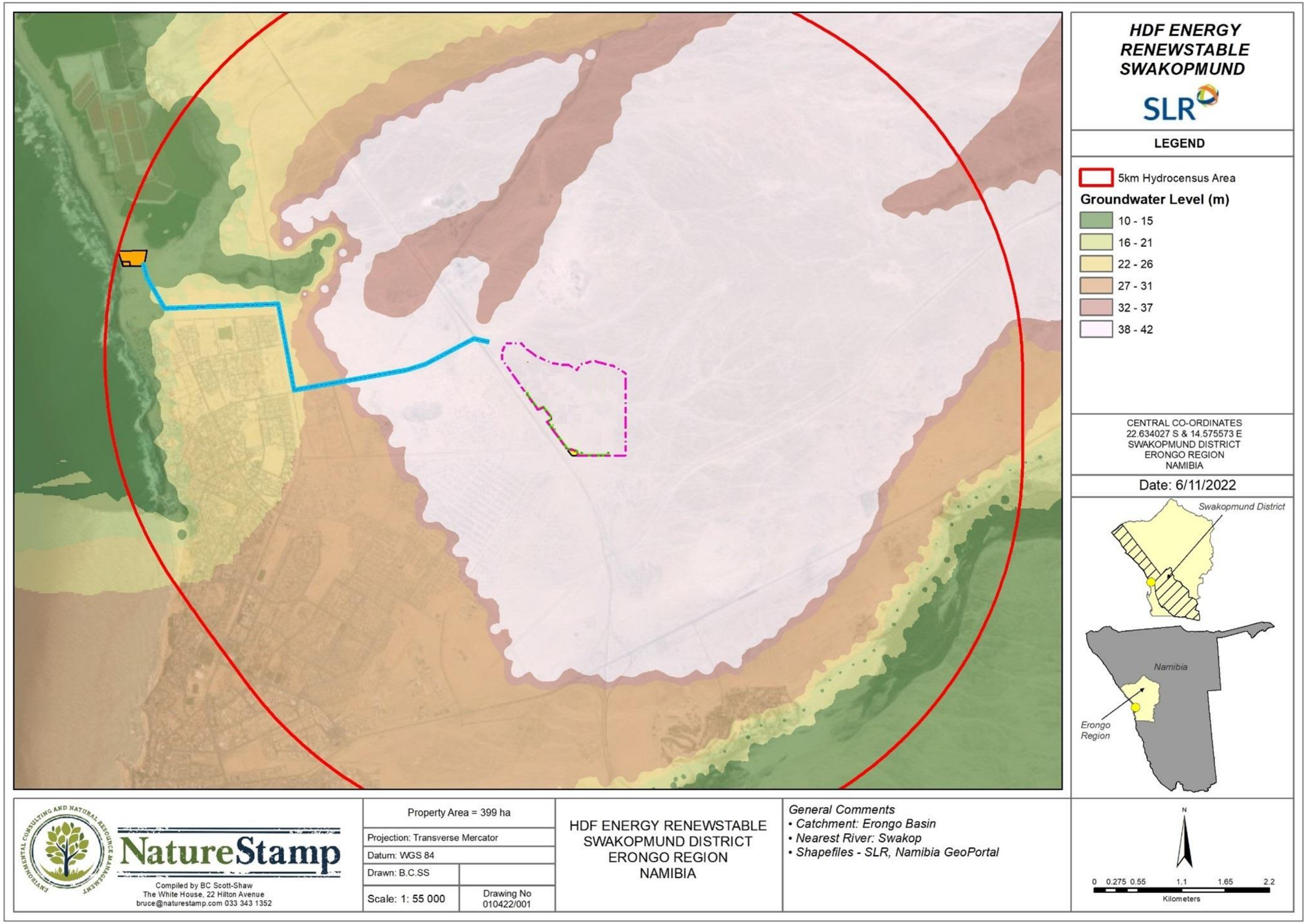

Figure 13 Water table level within 5 km of the proposed HDF Energy Renewstable Facility

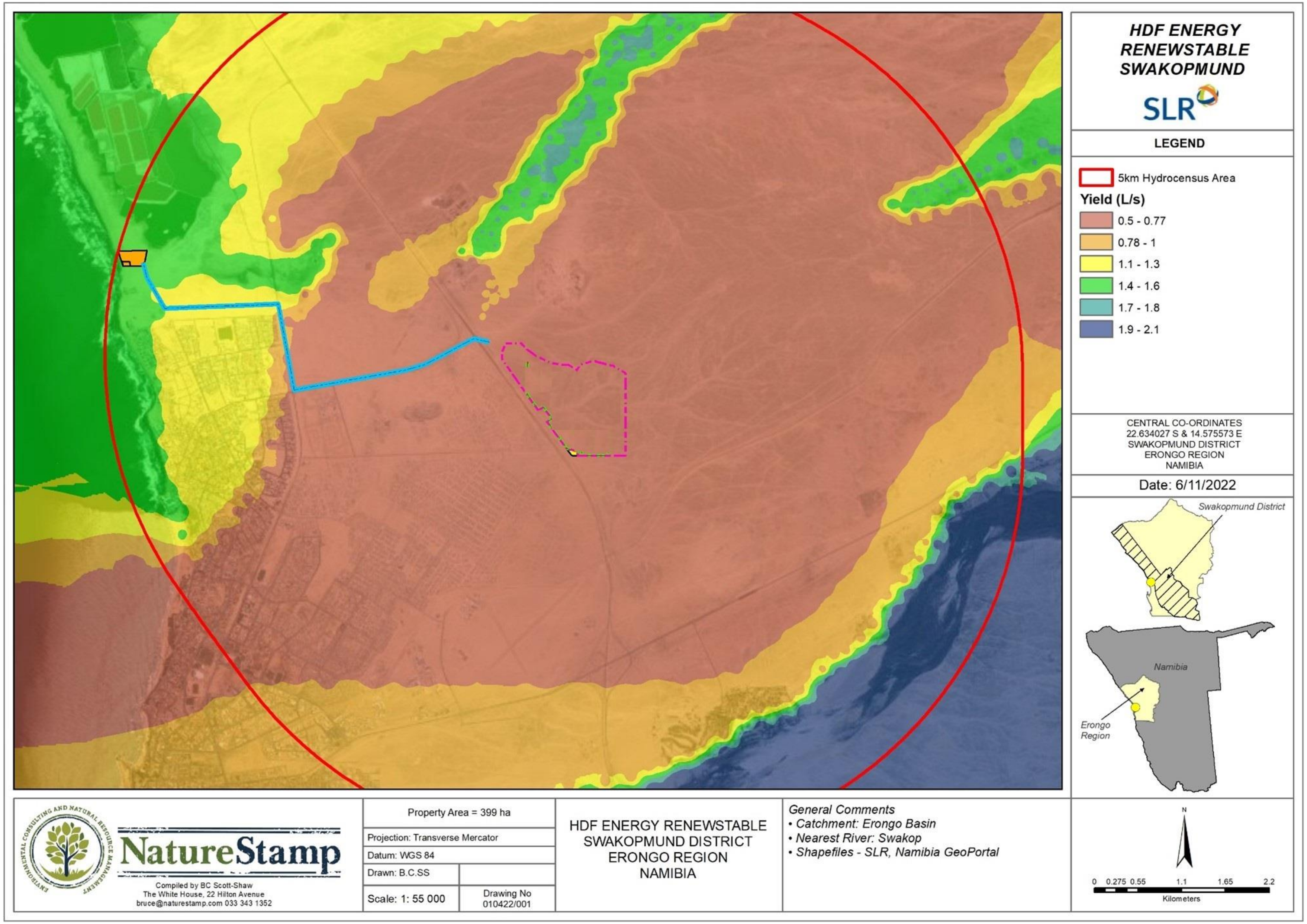

Figure 14 Groundwater yield within 5 km of the proposed HDF Energy Renewstable Facility

Table 8 High yielding boreholes within the greater drainage basin

ID	Type	Latitude	Longitude	WW no	Depth	Level	Yield	Water Quality	Rock
1	Borehole	-17.5001	24.35257	37113	49	6	22	C	Kalahari
2	Borehole	-17.5059	12.7948	33962	39	8	4	A	Quartzite
3	Borehole	-17.5611	16.35397	37070	259	20	18	C	Kalahari (Very Deep Aquifer)
4	Borehole	-17.6097	12.9416	36681	74		0		Gneiss
5	Borehole	-17.6461	24.16922	36622	70	14	19	C	Kalahari
6	Borehole	-17.6816	24.46502	37111	39	4	22	C	Kalahari
7	Borehole	-17.6902	23.42113	36479	68	24	19	A	Kalahari
8	Borehole	-17.7041	12.756	33963	59	17	1	A	Gneiss
9	Borehole	-17.7071	24.03052	36451	69	23	11	B	Kalahari
10	Borehole	-17.7801	16.8444	36867	200	55	13	A	Kalahari
11	Borehole	-17.8222	23.39272	36502	61	31	9	A	Kalahari
12	Borehole	-17.8571	23.71302	36543	73	16	10	B	Kalahari
13	Borehole	-17.8868	15.9562	9124	668		10		Kalahari, Karoo
14	Borehole	-17.8874	24.19542	36575	27	9		B	Kalahari
15	Borehole	-17.893	18.28392	39962	101		1		Kalahari
16	Borehole	-17.9505	23.47782	36529	76	29		B	Kalahari
17	Borehole	-17.9713	13.8561	33969	70	16	3	B	Shale
18	Borehole	-17.973	14.0287	33964	71	40		A	Dolomite
19	Borehole	-17.986	13.8184	33958	104		0		Shale
20	Borehole	-17.996	13.659	33959	108	23	3	A	Shale
21	Borehole	-18.0619	12.7666	33972	103		0		Quartzite, shale
22	Borehole	-18.0856	23.3762	36540	59	7		B	Kalahari
23	Borehole	-18.204	19.48798	39964	72		22		Kalahari
24	Borehole	-18.2492	21.03687	39961	81		13		Kalahari
25	Borehole	-18.2657	19.92525	39966	70		13		Kalahari
26	Borehole	-18.3471	16.5661	8191	101	15	10	D	Kalahari
27	Borehole	-18.3521	13.8957	33966	70	38	7	A	Dolomite
28	Borehole	-18.3697	19.10807	39965	120		4		Kalahari
29	Borehole	-18.4329	13.9395	33967	100	62	1	A	Siltstone
30	Borehole	-18.5208	16.7725	2731	244	Artesian	100	D	Kalahari (Oshivelo Artesian Aquifer)
31	Borehole	-18.5867	14.25833	36680	121	3	4	A	Calcrete, mudstone, sandstone
32	Borehole	-18.7793	12.9451	33975	15	7	26		Gneiss
33	Borehole	-18.9746	14.15555	35489	56	31	7	A	Calcrete, clay
34	Borehole	-18.9746	14.15555	35490	154	32	15	A	Calcrete, clay, shale
35	Borehole	-18.9954	17.60146	39980	398	11	2	B	Shale, mudstone (Karoo sequence)
36	Borehole	-18.9964	16.4046	9581	32	Artesian	8	D	Dolomite (Tsumeb Subgroup)
37	Borehole	-19.0194	14.47157	35827	101	13	150	B	Dolomite (Abenab Subgroup)
38	Borehole	-19.0849	14.04905	35491	183	56	11	A	Calcrete, clay, shale
39	Borehole	-19.1097	15.21255	37229	63	11		B	Kalahari (Limestone of Unconfined Kalahari Aquifer)
40	Borehole	-19.2139	16.05861	3617	46	15		C	Kalahari (Limestone of Unconfined Kalahari Aquifer)
41	Borehole	-19.3025	18.0746	40000	400	66	25	B	Dolomite, limestone (Abenab subgroup)
42	Borehole	-19.3384	17.18271	39984	335	12	12	B	Quartzite, shale (Mulden group)
43	Borehole	-19.3871	14.57475	37180	63	32		B	Khoabendus Formation
44	Borehole	-19.4174	17.61896	39991	140	53	1	B	Quartzite (Nosib formation)
45	Borehole	-19.4184	17.88354	39972	85	37	2	B	Gneiss (Grootfontein basement complex)

46	Borehole	-19.5215	14.36407	4245	49	37	3	D	Gneiss
47	Borehole	-19.991	19.7358	39967	117		23		Kalahari
48	Borehole	-20.0296	18.1947	37741	462	33	33	B	Kalahari
49	Borehole	-20.1326	20.14354	39913	225	138	0		Kalahari
50	Borehole	-20.1529	20.797	39909	201	7	1	B	Dolomite
51	Borehole	-20.159	16.8929	30643	78	5	144	A	Marble
52	Borehole	-20.1632	14.85734	7647	31	5	8	C	Gneiss
53	Borehole	-20.2185	14.07537	20020	58	6	2	B	Basalt
54	Borehole	-20.2504	16.7611	29494	102	36	36	A	Marble
55	Borehole	-20.3467	14.46168	39938	34	23		D	Gneiss
56	Borehole	-20.3696	15.11598	30815	95	11	0	C	Schist
57	Borehole	-20.4619	20.78952	39912	157	120	5	B	Calcrete, dolomite
58	Borehole	-20.5334	17.36987	39910	171		0		Clay, siltsone, mudstone, schist
59	Borehole	-20.5414	14.49924	6393	33	22	5	D	Granite
60	Borehole	-20.6761	20.81943	39907	165	144	1		Kalahari
61	Borehole	-20.8743	19.13697	39979	201		0		Sandstone, marble
62	Borehole	-20.9436	17.43833	34684	120	75	2	A	Sandstone
63	Borehole	-21.7992	18.87472	35206	102	1	100	A	Kalahari, quartzite (Eskadron)
64	Borehole	-21.8202	15.5614	22159	27	7	8	A	Alluvium of Khan River with bedrock of granite, schist
65	Borehole	-21.8302	20.47874	39906	201		0	A	Quartzite
66	Borehole	-21.9141	14.4602	22194	100	28	70	A	Alluvium of Omaruru Delta
67	Borehole	-22.0848	19.8981	39905	177		0	A	Kalahari
68	Borehole	-22.1433	19.07555	35224	120	23	34	A	Kalahari, quartzite
69	Borehole	-22.1536	17.1115	39908	99	6	1	C	Schist
70	Borehole	-22.1914	19.04306	35229	102	24	82	A	Kalahari, quartzite
71	Borehole	-22.2878	19.22778	35203	108	26	68	A	Quartzite
72	Borehole	-22.3681	19.05222	35215	102	22	39	A	Quartzite
73	Borehole	-23.2542	18.98668	39839	256	58	8		Sandstone (Auob member)
74	Borehole	-23.3407	14.7748	20146	33	10	74	A	Alluvium of Kuiseb River
75	Borehole	-23.4005	19.62557	39846	204	59	20	C	Sandstone (Auob member)
76	Borehole	-23.401	19.62489	39845	53	45	0		Basalt (Kalkrand basalt)
77	Borehole	-23.4011	19.62621	39847	356	10	12		Sandstone (Nossob member)
78	Borehole	-23.6475	18.38873	39840	131	17	3	A	Sandstone (Auob member)
79	Borehole	-23.6481	18.38871	39841	209	7	3		Sandstone (Nossob member)
80	Borehole	-23.8878	18.03833	34572	39	13	34	A	Basalt
81	Borehole	-23.9272	18.04667	34534	54	3	6	A	Basalt
82	Borehole	-23.9692	18.03944	34569	44	6	8	A	Basalt
83	Borehole	-24.0019	18.215	39857	141	2	45	A	Sandstone (Auob member)
84	Borehole	-24.0459	18.7934	39842	102	19	2		Calcrete (Rietmond formation)
85	Borehole	-24.0479	18.79312	39843	253	16	20	A	Sandstone (Auob member)
86	Borehole	-24.0486	18.79614	39844	409	Artesian	0	A	Sandstone (Nossob member)
87	Borehole	-24.3284	18.39794	39848	187	Artesian	1		Sandstone (Nossob member)
88	Borehole	-24.7996	19.33457	39851	385	Artesian			Sandstone (Nossob member)
89	Borehole	-24.8001	19.33483	39849	169	102	3		Kalahari
90	Borehole	-24.8006	19.3352	39850	273	104	4	B	Sandstone (Auob member)
91	Borehole	-25.0006	17.85667	33749	50	2	10	D	Carbonaceous shale

92	Borehole	-25.0925	17.50889	34260	90	45	6	A	Sandstone
93	Borehole	-25.1953	17.35	33761	154	130	1	B	Sandstone
94	Borehole	-25.2912	18.4165	39853	250	22	0		Sandstone (Nossob member)
95	Borehole	-25.2916	18.41678	39852	55	10	7		Kalahari
96	Borehole	-25.3494	17.6897	33784	86	12	4	A	Sandstone
97	Borehole	-25.4517	19.43373	39855	250	172		D	Sandstone (Auob member)
98	Borehole	-25.4603	19.42444	39854	129	60	0	C	Kalahari
99	Borehole	-25.4615	19.43324	39856	346	20		D	Sandstone (Nossob member)
100	Borehole	-25.48	17.48972	34692	50	16		A	Sandstone
101	Borehole	-25.5172	17.53556	34695	93	37	1	B	Sandstone
102	Borehole	-25.7342	17.39611	33739	250	192	1	B	Sandstone
103	Borehole	-26.2189	18.8125	34682	44	9	9	A	Sandstone
104	Borehole	-26.3342	17.4467	33742	250	209	1	B	Sandstone

Table 9 Groundwater schemes within the greater drainage basin

No	Scheme name	Lat	Long	Geology	Production	Depth	Quality
1	Aasvoelnes	-19,44000	20,11000	Kalahari	18	145	A
2	Ai-Ais	-27,90000	17,50000	Alluvium (Fish River)	58	15	A-B
3	Aminuis	-23,64000	19,37000	Sandstone, shale (Karoo)	86	186	B
4	Andara	-17,97200	21,26600	Kalahari (calcrete, sand)	10	55	D
5	Anichab	-20,95000	14,84000	Alluvium (Ugab River)	25	10-15	B
6	Anker	-19,77000	14,55000	Quartzite, granite (Huab Complex)	31	57-66	C
7	Aranos	-24,14700	19,11800	Sandstone (Karoo)	300	204-387	A
8	Ariamsvlei	-28,12000	19,84000	Meta-sediments (Nama Group)	40	100-120	B-C
9	Aroab	-26,80000	19,63000	Sandstone (Nama Group)	60	77-124	A
10	Aus	-26,66000	16,27400	Granite-gneiss (Namaqualand)	24	42-142	A-C
11	Bagani	-18,10900	21,65000	Kalahari	1	114	C-D
12	Berg Aukas	-19,50300	18,23600	Dolomite (Otavi Group, Damara)	700	92-98	B
13	Bergsig	-20,21000	14,06000	Basalt	2	12	A-B
14	Berseba	-25,99000	17,76000	Sandstone (Nama Group)	40	34-42	A
15	Bethanien	-26,50000	17,13000	Shale, limestone (Nama Group)	120	75	B-D
16	Brandwag	-19,68000	17,98000	Dolomite (Otavi Group, Damara)	0	15-60	B
17	Buinja	-17,86000	19,36000	Kalahari	6	57-79	A
18	Buitepos	-22,28000	19,99000	Tsumis Quartzite (Damara)	9	40-60	B
19	Bukalo	-17,72000	24,53000	Kalahari	70	40-54	B
20	Chinchimane	-17,98500	24,12400	Kalahari	30	50	B-C
21	Daan Viljoen	-22,54000	16,95000	Mica schist (Khomas, Damara)	60	76-125	B
22	Dordabis	-22,95000	17,66000	Quartzite (Rehoboth Sequence)	20	42-76	A-B
23	Epukiro Post 3	-21,58000	19,45000	Marble, quartzite, schist (Damara)	60	50-180	B-D
24	Epukiro Post 10	-21,52000	19,47000	Marble, quartzite, schist (Damara)	20	126-182	A-B
25	Ernst Meyer	-22,37000	19,40000	Kalahari & quartzite (Damara)	18	55-60	A
26	Erwee	-19,69000	14,30000	Quartzite, granite (Huab Complex)	30	58-65	B-C
27	Fransfontein	-20,21000	15,05000	Shale, dolomite, sandstone, limestone (Damara)	140	61-151	B
28	Gabis	-28,10000	18,61000	Namaqualand gneiss	19	56-86	C-D
29	Gainachas	-25,76000	17,71000	Sandstone (Nama Group)	3	32-39	A
30	Gibeon	-24,74000	17,89000	Sandstone (Dwyka, Karoo)	340	30-43	A

31	Gobabeb	-23,56000	15,04000	Alluvium (Kuiseb River)	2	30-40	B-D
32	Gobabis NE	-22,24000	19,11000	Damara Sequence	80		
	Black Nossob	-22,32000	18,92000	Damara Sequence	0	30	
	Grunental	-22,37200	18,39400	Damara Sequence	110	60-108	A
	South Station	-22,51000	18,98000	Damara Sequence	30	72-76	A
	Witvlei (> Gobabis)	-22,41000	18,47000	Damara Sequence	16	65	A
33	Goblenz	-20,09900	18,14500	Kalahari	800	100-450	A-B
34	Gochas	-24,75000	18,74000	Sandstone & shale (Karoo)	70	130-235	A
35	Grünau	-27,72000	18,38000	Granite (Namaqualand Complex)	10	58-160	B-D
	Klein Halali	-19,05000	16,49000	Calcrete (Kalahari)	10	20-70	C
	Renosterkom	-19,09800	16,52000	Dolomite (Damara)	80	67-87	B
37	Henties Bay	-22,09000	14,29000	Alluvium (Omaruru Delta)	35	32-35	A
38	Hochfeld	-21,49000	17,85000	Damara Sequence	10	46-66	A
39	Kahenge	-17,68000	18,67000	Kalahari	26	38-40	A
40	Kalkfeld	-20,89000	16,19000	Meta-sediments, granite (Damara)	50	19-183	A-B
41	Kalkrand	-24,25000	17,26000	Basalt (Karoo)	100	65-77	B
	Town & Airport	-19,62000	14,84000	Intrusives, metased. (Huab Complex)	34	60-100	B-D
	Kalkrand	-19,64000	14,98000	Huab covered 10 m calcrete (Tertiary)	29	100-120	B
43	Karasburg	-28,00000	18,68000	Shale, dolerite (Karoo)	300	27-78	B
	Hä Ibichsbrunn	-21,96000	15,90000	Marble (Damara)	130	80-120	B-C
	Spes Bona	-21,78000	15,94000	Alluvium (Khan), limestone, shale (Damara)	0	31-76	
46	Kayengona	-17,89000	19,88000	Kalahari	140	50-60	A
47	Khorixas	-20,38000	14,96000	Calcrete, dolomite (Damara)	700-1.6	31-150	B
48	Koes	-25,93000	19,12000	Sandstone (Ecca Group, Karoo)	70	43-70	B
49	Koichab	-26,20000	15,87000	Sand, gravel, clay (Tertiary)	600-1.0	59-107	A
50	Kosis	-26,71000	17,32000	Sandstone, shale, limestone (Nama Gr.)	45	60-70	A-B
51	Kriess	-25,00000	18,16000	Sandstone (Karoo)	10	80-90	A
52	Kuiseb	-23,19000	14,66000	Alluvium (Kuiseb River)	5.500	15-50	A-B
53	Kwakwas	-23,21000	16,90000	Quartzite, schist (Rehoboth Sequence)	No info	79-104	A-B
54	Leonardville	-23,50300	18,79000	Sandstone, shale (Karoo)	60	188-280	A-B
55	Maltahöhe	-24,81000	16,99000	Quartzite (Nama Group)	200	31-46	C
56	Mangetti Duin	-19,52000	19,73000	Kalahari	40	180-197	A
57	Maroelaboom	-19,25000	18,80000	Kalahari	4	147	B
58	M'Kata	-19,50000	19,63000	Kalahari	9	170	A
59	Mpunguvlei	-17,67000	18,23000	Kalahari	20	86-90	D
60	Mupini	-17,86000	19,63000	Kalahari	5	50-57	C
61	Namutoni	-18,80000	17,04000	Kalahari	150	39-43	B
62	Nei Neis	-21,47000	15,04000	Alluvium (Omaruru River)	330	12-28	A-C
63	Nkurenkuru	-17,63000	18,62000	Kalahari	20	40-60	
64	Nyangana	-18,02000	20,68000	Kalahari	80		
65	Oamites	-22,98000	17,07000	Marble (Damara)	250	100-150	No info
66	Okaukuejo	-19,18000	15,92000	Kalahari (calcrete)	250	10-80	B
67	Okombahe	-21,35000	15,40000	Alluvium (Omaruru River)	380	25-26	A
68	Okondjatu	-20,98000	18,23000	Damara under Kalahari	70	98-100	B
69	Omatako	-19,44000	19,22000	Kalahari	20	161-184	B
70	Omatako Dam	-21,14000	17,17000	Sandstone, shale (Karoo)	4	55-90	B-D

71	Ombika	-19,33000	15,94000	Dolomite, limestone (Otavi, Damara)	12	20-130	B
72	Omdel	-22,09000	14,29000	Alluvium (Omaruru Delta)	5.500	50-100	B
73	Omega	-17,89000	22,15000	Kalahari	115	70-90	B
74	Ondekaremba	-22,48000	17,42000	Khomas schist (Damara)	4	96-125	B
75	Onderombapa	-23,15000	19,56000	Sandstone, shale (Karoo)	4	93-96	A
76	Opuwo	-18,06000	13,85000				
	SE wellfield	-18,15000	13,95000	Otavi Group, Damara	25	90-120	B
	NW wellfield	-18,04000	13,82000	Karoo (Dwyka) / calcrete	780	56-110	C-D
77	Oshivelo	-18,62000	17,17000	Kalahari (sand, shale)	300	68-74	B
78	Osire	-21,08000	17,37000	Omingonde Fm (Karoo)	55	57-77	A-B
79	Otavi	-19,64000	17,35000	Limestone, dolomite (Otavi, Damara)	500	60-61	A-B
80	Otjimbingwe	-22,35200	16,13600	Alluvium (Swakop River)	280	12	A-C
81	Otjinene	-21,14000	18,79000	Damara under Kalahari	150	63-125	A-C
82	Otjiwarongo	-20,46000	16,64000	Marble (Damara)	1.800	66-185	B
	Otjituuo	-19,44800	18,21000	Dolimite (Berg Aukas formasie)	900	85-100	A
83	Otjovasandu	-19,25000	14,51000	Metamorphosed lava (Khoabendus)	10	61	B-C
84	Ovitoto	-21,91000	17,10000	Damara Sequence	40	32-38	B
85	Plessisplaas	-21,71000	19,04000	Kalahari, Gamsberg granite	10	56-82	A
86	Rietfontein	-21,90400	20,91800	Kamtsas Fm (Damara)	140	48-109	C
87	Rooidaghek	-19,25000	19,27000	Kalahari	10	180	
88	Runduhek	-18,78700	18,94200	Kalahari	30	250	
89	Rupara	-17,84000	19,08000	Kalahari	10	77-82	A
90	Sambiu	-17,91000	20,03000	Kalahari	30	60-70	A
91	Schlip	-24,04300	17,13100	Limestone, dolomite, shale (Nama)	230	43-104	B
92	Seeis	-22,45000	17,62000	Alluvium (Seeis River)	30	12-15	No info
93	Sesfontein	-19,12000	13,61000	Dolomite, phyllite (Damara)	20	36-51	A-B
94	Spitzkoppe	-21,85000	15,20000	Granite, schist (Damara)	13	60-92	C-D
95	Stampriet	-24,34200	18,40900	Sandstone, shale (Karoo)	60	84-101	A
96	Terrace Bay	-20,18900	13,20100	Alluvium (Uniab River)	17	10-20	A-D
97	Tondoro	-17,77000	18,79000	Kalahari	70	65-68	A
	Old schem e	-25,89000	18,11000	Shale (Dwyka, Nama Group)	30	47-109	A-C
	New boreholes	-25,92000	17,94000	Shale (Dwyka, Nama Group)	0	57-100	B-C
99	Tsintsabis	-18,78000	17,96000	Kalahari	30	31-93	B
100	Tsumkwe	-19,59000	20,50000	Kalahari	55	20-35	A-C
101	Tubussis	-21,54800	15,46200	Schist, quartzite (Damara)	20	13-110	B-C
102	Usakos	-21,99200	15,60100		285	15-100	A-B
103	Warmbad	-28,44100	18,74200	Namaqualand granite-gneiss complex	25	107-110	C-D
104	Witvlei	-22,41000	18,50000	Quartzite, limestone (Damara)	140	31-38	B-D
105	Windhoek	-22,59000	17,08000	Auas quartzites	2.000	77-305	A
106	Omaruru	-21,41000	15,95000	Alluvium (Omaruru River)	1.000	12-16	A
107	Tsumeb	-19,25000	17,71000	Dolomite	2.000	130-200	A
108	Outjo	-20,11000	16,16000	Dolomite	800	90-100	A
109	Grootfontein	-19,56000	18,11000	Dolomite	2.000	50-70	A

6.3 Groundwater Recharge

The results from the modelling exercise showed the difference between the pre- and post-development scenario. Groundwater recharge is highly dependent on the soils throughout the catchment and the overlying landcover. Contributions to groundwater are often ignored in hydrological studies and can form a significant loss or gain in a catchment. Areas of low recharge can correspond to soils with higher clay contents and vegetation with a high biomass and deep rooting depths. However, due to the very low rainfall of 51 mm and dry soils, the groundwater recharge during an average year is zero mm. This means that no water will contribute to groundwater except during extreme events.

The annual water balance is the most summarized output from SWAT. It provides a good visual representation as to how rainfall is partitioned through the hydrological cycle, allowing for quick comparisons between scenarios. A visual output for each scenario has been provided in Figure 15. The results show that the only change between scenarios is the increase in surface runoff and a slight subsequent loss in ET. This increase is however still of a very low volume and would be easy to manage on site. There would be a net gain of water to the system due to the discharge of up to 41 m^3 per day from the desalinisation plant.

The results from the MODFLOW model were insignificant and were not displayed.

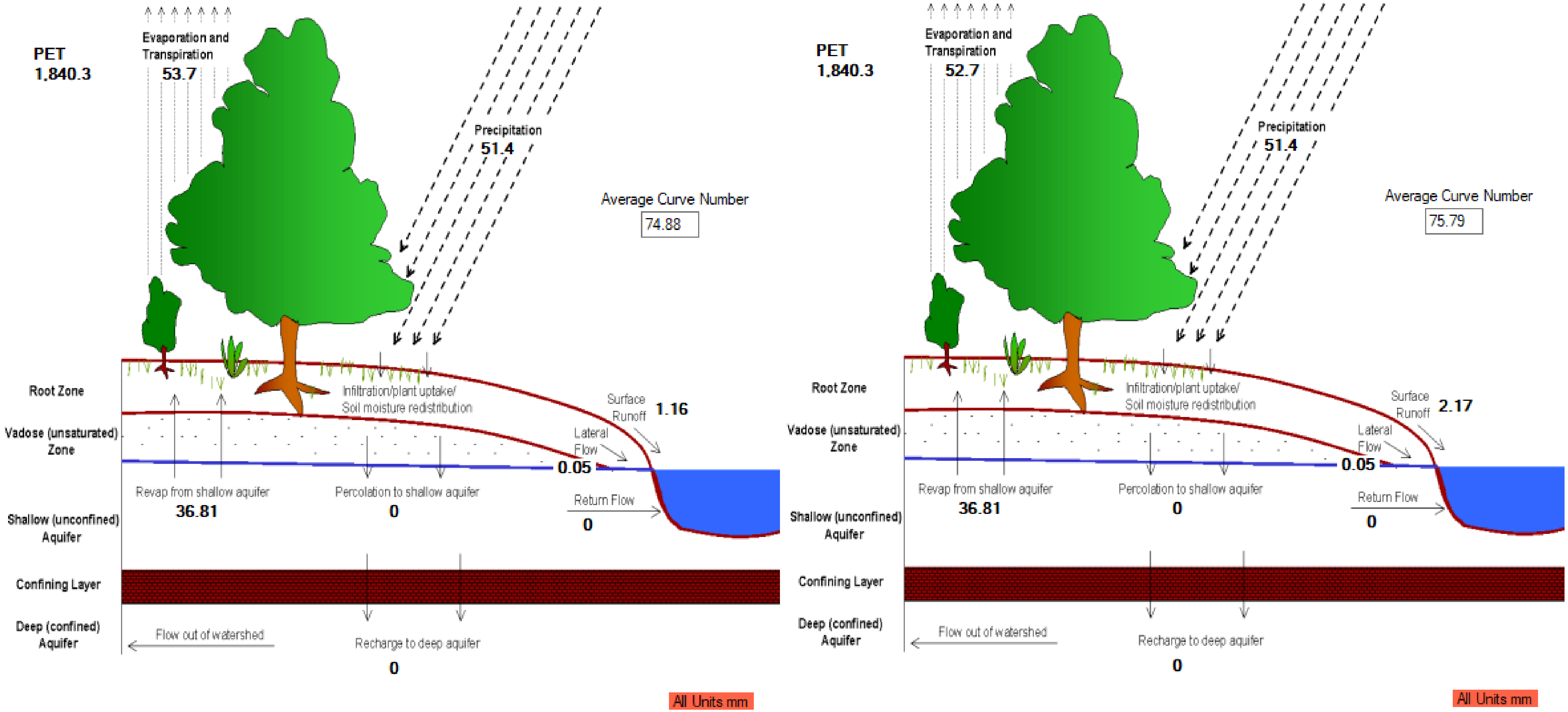

Figure 15 Annual water balance of the pre- and post-development scenarios for the HDF Energy Renewstable Facility

7. POTENTIAL GROUNDWATER IMPACTS & MITIGATION

The site for the proposed Renewstable® Swakopmund Project is near completely bare (desert). The primary surrounding impacts are settlements, a recycling facility which has led to visible pollution on the site, asphalt and dirt roads, which cross watercourse areas leading to a loss/disturbance of wetland area and potential pollution of the watercourses. The geomorphology is in a generally good state although there are slight areas of erosion around the site. Most of the site is not vegetated due to the dry climate.

7.1 Present Impacts

Within and around the Renewstable® footprint, the potentially existing impacts on the groundwater and respective catchment areas include -

- The clearance of natural habitat for settlements and associated roads;
- Hardened surfaces resulting in a reduction in infiltration;
- Point source pollution from settlements & industry;
- Concentrated flow paths from drain outlets/dongas along the roads;
- Historical modification of watercourse systems for agriculture and infrastructure construction; and
- Various servitudes.

In the broader catchment, similar impacts are present as noted for the site proposed Renewstable® project. Additional existing impacts on the groundwater resources and respective catchment areas include -

- Infrastructure development within wetland systems (wetland encroachment) or river banks – leading to a direct loss of wetland systems and decrease in groundwater recharge;
- Agricultural activities such as crop production and farms - increased nutrients applied to lands potentially contaminating groundwater;
- Expansion of town areas resulting in an increased water demand and an increase in water pollution;
- Unregulated boreholes that may put strain on the limited groundwater resources;
- Litter and solid waste disposal – direct water pollution; and
- Poor or absent sanitation – direct water pollution.

7.2 Potential Impacts During Construction

The identified construction impacts have been classified in the form of impact tables (Tables 10 and 11).

Impacts likely to occur during construction are described in Section 7.2.1 to 7.2.3. These impacts are further assessed in Tables 10 and 11.

7.2.1 Decreased Infiltration and Groundwater Recharge

The construction activities associated with the roads, compounds and PV areas result in disturbances in the soils (earth moving equipment, spoil areas, excavation etc.) which lead to concentrated flow paths (erosion), increased runoff and subsequent reduced infiltration that would contribute towards groundwater recharge.

The **significance** of this impact is low without mitigation and very low with mitigation. This is largely due to the very low rainfall in this area and prevailing very low groundwater recharge.

The following **mitigation measures** are recommended and should be included in the EMPr (Section 7):

- Manage storm water on site (the post development discharge should equal the pre-development discharge). Attenuation structures should allow for infiltration of clean water that would promote groundwater recharge;
- Preserve topsoil for use in rehabilitation during and after construction completion. This would assist in restoring the natural flow regimes, particularly infiltration; and
- Revegetate disturbed areas during and after construction completion to the pre-development state. This will allow for increased infiltration.

Monitoring is important to ensure that the implemented mitigation measures are successful. The following monitoring is required:

- Ensure all clean water is dissipated towards the natural flow area and all dirty water is directed towards a control structure where infiltration can occur.
- All attenuation structures need to be monitored to ensure drainage is functional and sediments are not being transported off the site.
- Ensure no sediments are allowed to enter the natural system.

Table 10 Loss of groundwater recharge and general change in hydrology

Issue	**Impact on Local Hydrology (Groundwater recharge)**	
Description of Impact		
o Increase in surface runoff due to hardened surfaces. o Increase in the erosion potential due to concentrated flow paths. o Reduction in infiltration reducing groundwater recharge.		
Type of Impact	Direct	
Nature of Impact	Negative	
Phases	Construction	
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Medium	Medium
Duration	Short-term	Short-term
Extent	Local	Local
Consequence	Medium	Low
Probability	Probable	Possible / frequent
Significance	Low -	Very Low -
Degree to which impact can be reversed	The impact is partially reversible if adequate storm water structures are put in place. Additionally, the construction footprint could be minimised with spoil areas being placed on already disturbed areas and concentration points being allowed to infiltrate appropriately.	
Degree to which impact may cause irreplaceable loss of resources	Without mitigation there would be a net loss groundwater recharge. Additionally, there would be an increase in open soil leading to erosion and loss of soil stability.	
Degree to which impact can be mitigated	There is a reasonable scope for mitigation measures to be effective. A storm water management plan would encourage infiltration and reduce this impact.	
Mitigation actions		
The following measures are recommended:	An adequate storm water management plan to be designed by an appropriate engineer. Here, the engineer should account for both natural run-off (that which can be released into the natural landscape with no detrimental effect) and excess artificial run-off generated by the proposed development structures. Other structures that may be considered are semi-permeable surfaces that can absorb artificial run-off but releases a certain amount into the landscape. Energy dissipating structures can also be used.	
Monitoring		

The following monitoring is recommended:	o All impervious surfaces to be monitored to ensure drains etc. are functional. o Ensure all clean water is dissipated towards the natural flow area and all dirty water is directed towards a control structure. o Ensure no sediments are allowed to enter the system.	
Cumulative impacts		
Nature of cumulative impacts	The cumulative impact considers the combined impact of the surrounding linked developments. The site for the project is natural. The cumulative impact would be low due to the significant distances for the type of development, extremely low rainfall and the low impact on groundwater resources in the given area. Groundwater recharge in this area only occurs after very high rainfall events.	
Rating of cumulative impacts	**Without Mitigation**	**With Mitigation**
	Low -	Very Low -

7.2.2 Potential Spills Contaminating Groundwater

Construction activities associated machinery/vehicles (spills), handling of fuels, cement mixing areas etc. lead to a decrease in water quality due to contamination of groundwater. This could be at the time of the spill where a contaminated volume infiltrates or at a later period after a rainfall event. Additionally, spills may alter the movement of water through the soils (water repellent substances).

The **significance** of this impact is medium/moderate without mitigation and low with mitigation. This is largely due to the difficulty of managing spills, particularly spills that have entered subsurface systems.

The following **mitigation measures** are recommended and should be included in the EMPr (Section 7):

- Provide suitable ablution facilities for construction workers with waste removed from the site and disposed of at a suitable location;
- Prevent and manage spills;
- Manage and remove construction waste from the site before it accumulates to a hazardous level (potential point source pollution areas). This includes all soil that may be contaminated;
- Ensure a spill management plan is in place and appropriate spill management materials are available on site;
- Ensure drip trays are used under machinery/equipment and any storage of hazardous chemicals is on a bunded area; and
- Environmentally friendly alternatives to chemicals commonly used should be considered.

Monitoring is important to ensure that the implemented mitigation measures are successful. The following monitoring is required:

- The site should be continually checked to ensure vehicles and equipment are not leaking (prevention).
- Construction areas should be continually checked to identify spill areas. Should a spill be identified, the spill management procedure should be implemented.
- In the event of a severe spill with hazardous substances, groundwater users within a 5km radius (although very limited) must be notified and assurance made that the groundwater aquifer is not contaminated.

Table 11 Potential spills from construction areas, storage areas and machinery

Issue	Potential Spills Contaminating Groundwater	
Description of Impact		
o Spills from machinery. o Spills from vehicles. o Spills from cement mixing areas. o Litter from staff. o Increase risk of pollutants being washed into the groundwater system.		
Type of Impact	Direct	
Nature of Impact	Negative	
Phases	Construction	
Criteria	Without Mitigation	With Mitigation
Intensity	Medium	Low
Duration	Short-term	Short-term
Extent	Local	Local
Consequence	High	Medium
Probability	Probable	Possible / frequent
Significance	Medium -	Low -
Degree to which impact can be reversed	The impact is partially reversible if spill management plans (including spill kits) are put in place. Staff should be trained on preventing spills. Maintenance must occur in designated areas. Hazardous chemicals need to be bunded.	
Degree to which impact may cause irreplaceable loss of resources	Should hazardous chemicals enter watercourses, long-term damage may occur. This is likely without mitigation.	
Degree to which impact can be mitigated	There is a good scope for mitigation measures to be effective.	
Mitigation actions		
The following measures are recommended:	o Spill prevention kits must be available on site. Eco-friendly alternatives are recommended. o Activities to stop during heavy rainfall periods. o Drip trays to be present and maintenance only to occur in designated lined areas.	
Monitoring		
The following monitoring is recommended:	o The ECO must confirm all designated maintenance areas. o Basic water quality to be checked in the event of a spill and monitored. o The ECO must audit any likely pollution areas regularly.	
Cumulative impacts		
Nature of cumulative impacts	The cumulative impact would be low due to the depth of the water table, the poor infiltration and the lack of groundwater users in the greater area. Cumulative impacts could occur without mitigation.	
Rating of cumulative impacts	Without Mitigation	With Mitigation
	Medium -	Very Low -

7.3 Potential Impacts During Operation

The operational impacts are similar to the construction phase impacts. The key impacts include the reduction in groundwater recharge (due to increased impervious areas) and a decrease in water quality (potential spills/contaminants from maintenance vehicles, infrastructure and equipment). The significance of the identified operation impacts has been classified in the form of impact tables (Tables 12 and 13) which addresses both water quality and quantity. Although infrequent, rainfall events exceeding 70 mm in a day have occurred here. As such, these events need to be accommodated to match the pre-development state and ensure the continued hydrological patterns and prevent hazardous substances entering the groundwater.

7.3.1 Reduction in Infiltration and Groundwater Recharge

The operation activities associated with the access road, power facilities and PV areas result in significant impervious areas that were previously sparsely vegetated natural land. This results in a reduction of infiltration (alteration of flow pattern).

The **significance** of this impact is low without mitigation and very low with mitigation. This is largely due to the very low rainfall in this area, of which a small percentage contributes to groundwater recharge.

The following **mitigation measures** are recommended and should be included in the EMPr (Section 7):

- Storm water should allow for clean water to be released and allowed to infiltrate;
- Attenuation structures should be maintained to promote infiltration of clean water that would increase groundwater recharge;
- Gutters and drains should be monitored to ensure blockages are not present and sediments/contaminants are not present; and
- Revegetation must be maintained below the drip line of the PV areas to promote infiltration;

Monitoring is important to ensure that the implemented mitigation measures are successful. The following monitoring is required:

- Ensure storm water structures are clean and operational.
- Inspect and ensure that no contamination of attenuation structures occurs and the structure is infiltrating effectively.
- Inspect success of revegetated areas such as below the PV drip line.

Table 12 Impact on local hydrology during operation

Issue	Impact on Local Hydrology (Groundwater Recharge)	
Description of Impact		
o Increase in surface runoff due to impervious surfaces. o Increase in the erosion potential due to concentrated flow paths. o Reduction in infiltration. o Increase risk of pollutants being washed into the system.		
Type of Impact	Direct	
Nature of Impact	Negative	
Phases	Operation	
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Medium	Low
Duration	Short-term	Short-term
Extent	Local	Local
Consequence	Medium	Low
Probability	Probable	Possible / frequent
Significance	Low -	Very Low -

Degree to which impact can be reversed	The impact is partially reversible if adequate long-term storm water structures are put in place. Discharge should match pre-development state.	
Degree to which impact may cause irreplaceable loss of resources	Without mitigation there would be an increase in erosion which would cause irreplaceable damage to the ecosystem and future loss in infiltration.	
Degree to which impact can be mitigated	There is a reasonable scope for mitigation measures to be effective. A storm water management plan must be followed.	
Mitigation actions		
The following measures are recommended:	An adequate storm water management plan to be designed by an appropriate engineer. Here, the engineer is to account for both natural run-off (that which can be released into the natural landscape with no detrimental effect) and excess artificial run-off generated by the proposed operation structures. Other structures that may be considered are semi-permeable surfaces that can absorb artificial run-off but releases a certain amount into the landscape. Energy dissipating structures can also be used. Clean and dirty water must be separated.	
Monitoring		
The following monitoring is recommended:	o All impervious surfaces to be monitored to ensure drains etc. are functional. o Ensure all clean water is dissipated towards the natural flow area and all dirty water is directed towards a control structure. o Ensure no sediments are allowed to enter the system.	
Cumulative impacts		
Nature of cumulative impacts	The cumulative impact would be low due the very limited rainfall. The structures have a relatively low impact on groundwater in a given area.	
Rating of cumulative impacts	**Without Mitigation**	**With Mitigation**
	Low -	Very Low -

7.3.2 Potential Spills Contaminating Surface Water

Operation activities associated service vehicles (spills), storage of chemicals (Potassium Hydroxide and Glycol) and detergents from panel cleaning may lead to a decrease in water quality due to contamination of surface water. This could be at the time of the spill due to a volume of contaminated substances entering the subsurface or at a later period after a rainfall event. Additionally, spills may alter the movement of water through the soils (water repellent substances).

The **significance** of this impact is low without mitigation and very low with mitigation. This is largely due to limited activity during operation on site and limited storage of chemicals.

The following **mitigation measures** are recommended and should be included in the EMPr (Section 7):

- Prevent and manage spills (Potassium Hydroxide and Glycol);
- Remove any waste from the site at a suitable disposal facility;
- Ensure a spill management plan is in place and appropriate spill management materials are available on site;
- Ensure PV cleaning materials do not get discharged into the soil;
- Ensure fire suppression systems are in place that may lead to explosions/further spills;
- Ensure hazardous chemicals are on a bunded area (120 % of the storage volume); and
- Environmentally friendly alternatives to chemicals commonly used should be considered.

Monitoring is important to ensure that the implemented mitigation measures are successful. The following monitoring is required:

- The site should be intermittently checked to ensure service vehicles and storage areas are not leaking (prevention).
- Should a spill be identified, the spill management procedure should be implemented.

- An ECO should identify, record and report chemicals, spills and disposal of any chemicals on site.
- Should a serious/hazardous spill occur, groundwater users need to be notified (within a 5km radius).

Table 13 Impact on groundwater water quality during operation

Issue	**Potential Spills**	
Description of Impact		
o Spills from maintenance equipment. o Spills from maintenance vehicles. o Litter from staff. o Spills from the hydrogen plant/refueling plant.		
Type of Impact	Direct	
Nature of Impact	Negative	
Phases	Operation	
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Medium	Low
Duration	Short-term	Short-term
Extent	Local	Local
Consequence	Medium	Low
Probability	Probable	Possible / frequent
Significance	Low -	Very Low -
Degree to which impact can be reversed	The impact is partially reversible if spill management plans (including spill kits) are put in place. Staff must be trained on preventing spills. Maintenance must occur in designated areas. Hazardous chemicals need to be bunded. Spills must be prevented from entering the sub-surface.	
Degree to which impact may cause irreplaceable loss of resources	Should hazardous chemicals enter the unsaturated zone, long-term damage may occur. This is likely without mitigation.	
Degree to which impact can be mitigated	There is a good scope for mitigation measures to be effective.	
Mitigation actions		
The following measures are recommended:	o Spill prevention kits must be available on site. Eco-friendly alternatives are recommended. o Activities/maintenance to stop during heavy rainfall periods. o Drip trays to be present and maintenance must only occur in designated lined areas.	
Monitoring		
The following monitoring is recommended:	o The ECO must confirm all designated maintenance areas. o Basic water quality to be checked in the event of s spill. o The ECO must audit any likely pollution areas regularly.	
Cumulative impacts		
Nature of cumulative impacts	The cumulative impact would be low due to the significant distances away from groundwater users and the overall low impact. Cumulative impacts could occur without mitigation.	
Rating of cumulative impacts	**Without Mitigation**	**With Mitigation**
	Low -	Very Low -

Table 14 Impact of the 'No-Go' alternative

Issue	No Go Alternative	
Description of Impact		
o Impact accrued due to the development not proceeding. o The natural environment would subsequently not change. o Pre-existing impacts would continue with a slight projected increase in impacts. o Due to water and financial constraints, landowners are likely to construct more water pipelines to increase availability and distribution.		
Type of Impact	Direct	
Nature of Impact	Negative	
Phases	Planning	
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Low	N/A
Duration	Long-term	
Extent	Local	
Consequence	Low	
Probability	Probable	
Significance	Low -	
Degree to which impact can be reversed	The impact is reversible if future activities follow best practice guidelines.	
Degree to which impact may cause irreplaceable loss of resources	Not applicable.	
Degree to which impact can be mitigated	Not applicable.	
Mitigation actions		
The following measures are recommended:	Not applicable.	
Monitoring		
The following monitoring is recommended:	Not applicable.	
Cumulative impacts		
Nature of cumulative impacts	The cumulative impact would be low/negligible.	
Rating of cumulative impacts	**Without Mitigation**	**With Mitigation**
	Very Low -	N/A

7.4 Proposed Mitigation

Although there is a low risk of groundwater contamination and a very low risk of groundwater quantity impacts, it is still important to apply mitigation measures to ensure that even slight risks are addressed. The following measured are proposed by the specialist for operation:

- Construction should stop during heavy rains as this would minimise the risk of contamination and erosion/sediment loss during these periods. Movement of vehicles during these periods can cause severe erosion.
- Although limited, vegetation clearing should be limited as much as possible and plants rescued for rehabilitation.
- Directing clean stormwater towards natural drainage lines, contours and dispersing over semi-vegetated, flat areas (preferably the existing ephemeral drainage lines).
- Vehicles and equipment must be kept clean and serviced off site.
- Staff/workers on-site must be educated on identifying potential erosion areas and best practice guidelines.
- Energy dissipating measures with regards to stormwater management should be installed where necessary to prevent soil erosion and promote infiltration.

- The engineer or contactor must ensure that only clean stormwater runoff enters the environment.
- Drainage should be controlled to ensure that runoff from the project area does not culminate in off-site pollution.
- Infrastructure must have the following:
    - Completely lined infrastructure (concrete bunded area), with the capacity to contain 120% of the total amount of petrochemicals or other chemicals stored within a specific tank. This excludes partially pervious areas that do not store chemicals;
    - Spills must be completely removed from the site unless an oil separator is installed;
    - Valves / taps to contain or release any spillage collected from storage tanks; and
    - Fire extinguisher equipment installed within each facility.

Furthermore, the following soil erosion measures would be put into place –

- Erosion control measures should be put in place to minimize erosion along the construction areas. Extra precautions must be taken in areas where the soils are deemed to be highly erodible.
- Soil erosion onsite should be prevented at all times, i.e. post- construction activities.
- Erosion measures should be implemented in areas prone to erosion such as near water supply points, edges of slopes etc. These measures could include the use of sand bags, hessian sheets, retention or replacement of vegetation if applicable and in accordance with the EMPR and the biodiversity impact assessment.
- Where the land has been disturbed during construction, it must be rehabilitated and re-vegetated back to its original state after construction.
- Stockpiling of soil or any other material used during the construction phase must not be allowed on or near slopes, near a watercourse or water body. This is to prevent pollution of the impediment of surface runoff.

7.5 Impacts associated with Climate Change Projections

The following potential impacts may arise as a result of climatic changes in the future, which would possibly affect the HDF Energy Renewstable Facility drainage areas and surrounding environment:

- Increase in extreme weather events such as powerful rain/thunderstorms, strong winds, intense heat waves, severe coldness and increased lightning strikes.
- This would likely cause flooding within the watercourses, which could damage the surrounding environment.
- The risk of contamination of watercourses would increase due to significantly greater volumes of runoff, which may lead to disease outbreaks and human health problems.
- Alien vegetation uses more water than indigenous vegetation, therefore reducing natural water supplies / choking natural watercourses. Alien plants have the ability to overpower indigenous vegetation and becoming overgrown within rivers and streams.

8. ENVIRONMENTAL MANAGEMENT PROGRAMME (EMPr) INPUT

The objectives of the EMPr is to ensure that any impacts remain at a low risk/sensitivity.

Table 15 Rehabilitation actions for inclusion into the EMPr

Objective	Action	Timing
Manage water Water Usage	1. Ensure the 41 m^3/day discharge is managed. This water should be checked for high mineral levels and slowly discharged. There is potential to create a pan wetland with this excess water.	With immediate effect (Construction & Operation)
	2. Ensure storm water structures promote infiltration	With immediate effect (Construction)
Ensure surface and groundwater quality is not impacted upon	3. In the event of a spill, implement a spill contingency plan and monitor surface and/or groundwater for 6 months if spill is not contained.	Construction and Operation
Manage stormwater from the roads and construction areas	4. Ensure drip trays are used under vehicles/machinery and that impervious floor surfaces are constructed to ensure chemicals and waste do not enter the sub-surface.	With immediate effect throughout construction.
Manage spills during construction	5. Ensure drip trays are used under vehicles/machinery and erosion control measures are implemented. 6. Ensure a spill contingency plan is put into place.	With immediate effect ECO to check every 2 months
Manage watercourse areas	7. Ensure watercourse/wetland buffers are marked so that activities do not occur near them. 8. Remove alien species and manage indigenous species as per the vegetation component.	With immediate effect and ongoing
Manage spills during operation	9. Completely lined infrastructure (concrete bunded area), with the capacity to contain 120% of the total amount of chemicals stored within any construction area. 10. Spills must be completely removed from the site. 11. Fire extinguisher equipment installed within permanent structures. 12. Ensure air circulation to prevent the build up of chemicals. 13. Implement the storm-water management plan and ensure appropriate water diversion systems are put in place. 14. Compile (and adhere to) a procedure for the safe handling of chemicals. 15. Compile an emergency response plan and implement should an emergency occur. 16. Ensure that spill kits (if appropriate) are available on site for clean-up of spills and leaks. 17. Drip-trays or containment measures must be placed under equipment that poses a risk when not in use. 18. Immediately clean up spills and dispose of contaminated soil at a licensed waste disposal facility. 19. Dispose of waste appropriately to prevent pollution of soil and groundwater. 20. On-site maintenance to be done over appropriate drip trays/containment measures and any hazardous substances must be disposed of appropriately. 21. Record and report all fuel, oil, hydraulic fluid or electrolyte spills to the PM / Engineer / ERP so that appropriate clean-up measures can be implemented.	With immediate effect/Ongoing

9. CONCLUSION & COMPLIANCE STATEMENT

The landowner and developer of the proposed HDF Energy Renewstable Facility must be committed to the conservation of water. The findings from this assessment show a very low risk on groundwater resources. This is due to an extremely low rainfall and negligible groundwater recharge. However, the operation of the facility may discharge up to 41 m^3 of mineralised water per day. Although these levels will not be excessive, there is a strong likelihood that groundwater recharge will occur at the discharge points. This may lead to a point source pollution where spills from the facility could contaminate the discharge point/s. This component should be carefully manged.

Through this investigation, the following was identified:

- Numerous ephemeral drainage lines were identified during the site visit.
- These systems are ephemeral due to very low rainfall in the areas.
- These systems are sparsely vegetated and have no aquatic life present.
- No active boreholes were identified within 5km of the proposed site.
- Groundwater recharge does not occur except during extremely high infrequent rainfall events.
- The **overall impact of the proposed HDF Energy Renewstable Facility is low,** assuming that mitigation measures are adopted and overseen by an ECO.
- The cumulative impacts, when considering nearby existing and proposed developments, was considered to have a low negative impact in the context of groundwater vulnerability.
- Impacts have been identified with proposed mitigation measures. Should these measures be adhered to, the development area would be of low sensitivity.
- A list of conditions has been provided that should be included in the EMPr or similar programme.

NatureStamp is of the opinion that the impacts of the proposed HDF Energy Renewstable Facility on groundwater resources would be low and acceptable, and hence authorization should be given for the project. No fatal flaws existing with the proposed layouts.

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