BIA REPORT

African Wilderness Restoration

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Biodiversity Impact Assessment for the Proposed Husab Mine Heap Leach Facility

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Biodiversity provides the framework that supports life; without it we won’t survive. Rational custodianship of nature is therefore a non-negotiable obligation.

Project: Biodiversity Impact Assessment for the Proposed Husab Mine Heap Leach Facility

Acceptance[1] of report by client:

Signature..

Signed by	
On date	
On behalf of	
Of address	

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[1] Acceptance means that AWR has fulfilled the Terms of Reference for the project to the client's satisfaction.

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Abbreviations

HLF: Heap Leach Facility
HLWF: Heap Leach Waste Facility
TSF: Tailings Storage Facility
WRD: Waste Rock Dump

1 Introduction

African Wilderness Restoration was requested to evaluate potential biodiversity issues related to the development of a Heap Leach Facility by Swakop Uranium. Three optional locations and layouts for the HLF were proposed by Swakop Uranium. This report summarises the findings of site visit, literature review and impact assessment.

2 Description of the approach followed and assumptions & limitations

2.1 Terms of Reference

In February 2021, SLR Environmental Consulting (Pty) Ltd appointed African Wilderness Restoration to undertake a biodiversity impact assessment for the Heap Leach Project to be developed at Swakop Uranium's (SU) Husab Mine in Namibia's Erongo Region and make recommendations to avoid, minimise or restore potential impacts. This included an update to the baseline biodiversity/ecology using information from Husab Mine's monitoring programmes as well as other sources where available and relevant.

3 Legal background

3.1 Acts and policies relevant to the management of impacts on biodiversity

There are numerous Acts and policies that guide the estimation of the significance of potential impacts to biodiversity. The most critical ones, with their overarching objectives, are listed in Table 1. The location of the Husab Mine in a nationally gazetted protected area where the conservation of biodiversity is the main land use and all other land uses have to follow clear sustainable utilisation principles is a critical fact to consider for any BIA of a development here. I therefore discuss two of the items – the Draft Wildlife and Protected Areas Management Bill and the Strategic Environmental Assessment (and its Plan) for the Uranium Rush – in more detail below. Others, such as the Nature Conservation Ordinance of 1974 and its various amendments over the years, are clearly also of direct importance, but their scope might be a bit too narrow to have a major influence on the gauging of impacts and risk to biodiversity features.

Table 1. List of relevant acts and policies.

	Act, policy or convention	Aims and requirements
1	The Constitution of the Republic of Namibia	Any activities must comply with Section 95(l), which provides for "the maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilisation of living natural resources on a sustainable basis ..."
2	Draft Pollution Control and Waste Management Bill of 1999	Provides for the control and management of several types of pollution, inter alia to reduce their effects on species.

	Act, policy or convention	Aims and requirements
3	The Draft Wildlife and Protected Areas Management Bill (2020)	This draft Bill governs the declaration and management of national protected areas, of which the Namib-Naukluft National Park forms a part. It further contains provisions for conditions and expected actions for mining in a protected area. It defines the use of the mitigation hierarchy to manage the environmental impacts of mines in protected areas, and explicitly allows for the definition of biodiversity offsets.
4	Environmental Management and Assessment Act of 2007	This act provides a set of principles for environmental management, and lists those activities (which includes all types of mining and exploration activities) that require an EIA process.
5	Minerals (Prospecting and Mining) Act 33 of 1992	Provides for EIAs in mining activities, and includes requirements for rehabilitation of prospecting and mining areas and for minimising or preventing pollution.
6	Nature Conservation Ordinance 4 of 1975, with amendments in 1990 and 1996	Provides for the declaration of protected areas and for the specific protection of scheduled species where they occur.
7	Convention on Biological Diversity	Aims to pursue the conservation of biological diversity and the sustainable use of its components. Participating countries are expected to introduce appropriate procedures requiring environmental impact assessment of projects that are likely to have significant adverse effects on biological diversity, with a view to avoiding or minimizing such effects. Also explicitly provides an opportunity for a more positive approach to be taken in impact assessments, to identify opportunities for enhancing biodiversity.
8	Uranium Rush SEA (U-SEA) The U-SEA is elaborated on below.	Overall objectives are to 1) Provide recommendations on accepted overall strategic approaches for sustainable mining development in the Erongo Region, 2) develop and assess viable scenarios of mining development as a basis for subsequent decision-making and formal planning, 3) guide solutions on crucial (cumulative) impacts and challenges stemming from mining, and 4) outline a Strategic Environmental Management Plan (SEMP).
9	Namib-Naukluft Park Management and Tourism Development Plan (2004)*	Defines a constitution for the Namib-Naukluft Park, and provides a set of policies and guiding principles related to a number of themes, amongst which biodiversity features prominently. A key topic in this regard is restoration of degraded ecosystems. Amongst other requirements, it states that no development should result in a decline of more than 10% in the population of a species of special interest (*Welwitschia mirabilis* is listed as one such species). Monitoring is required to ensure that this condition is met, and if necessary special support measures must be put in place.

**This is an old document, and will soon be superseded by the management plans for all coastal parks, which is currently in progress, being developed under the auspices of the Namparks V project of the MEFT. These new plans will be guided by a landscape vision, which emphasises process-orientated aspects of biodiversity such as habitat connectivity and patch dynamics on a range of scales. This is relevant for the proposed HL project because it could affect some insular habitats.*

3.2 The Draft Wildlife and Protected Areas Management Bill[2]

This Act, although not yet tabled in Parliament and as such still under discussion, gives a good idea of the direction that the law will take once it is promulgated. Some detailed changes to the draft version can still be expected, but the main issues are unlikely to change. I therefore highlight some of the most relevant aspects that are addressed in the current draft.

In defining the powers of the minister to refuse approval to mine in specific areas, it lists several areas that will be considered as ecologically highly sensitive. Some of these occur in the proposed Heap Leach project area and will be affected by either one or more of the optional layouts:

(a) migratory corridors and unique habitats;
(b) an area with unique or high biodiversity;
(c) a known breeding area of any marine species, or terrestrial bird, mammal or reptile species;
….
(i) an area inhabited by threatened or endangered species, including specially protected species and protected species;
(j) an area known as essential habitat for specially protected wildlife species, including habitat that is important for species that are migratory even if the animals are only utilizing the habitat for part of the year.

The Bill lists species that are specially protected or protected.

3.3 Strategic Environmental Assessment for the central Namib Uranium Rush

The U-SEA was commissioned by the Government of the Republic of Namibia with overall objectives as summarised in Table 1. Although it depends on voluntary commitment by all parties and as such has relatively little legal standing, by virtue of its topic it stands central to the identification and assessment of impacts, and to devising ways to manage these. Relevant guidelines and principles from the U-SEA are:

- Protection of key habitats is a core recommendation,
- The most important (i.e. 'sensitive') habitats are i) the ridges, inselbergs and valley flanks, ii) large ephemeral rivers, iii) coastal wetlands, iv) springs and ephemeral pans, v) caves, and vi) isolated sand patches.
- Every part of the central Namib is unique and can potentially harbour extremely range-restricted endemic invertebrates. The possibility of mining causing the extinction of certain species is real, but information on precisely where these species occur or how many other undescribed species are also threatened, is not available.
- Maintenance of not only species but primarily ecological processes. Important processes such as surface hydrology and groundwater movement should not be compromised.
- Usage of 'infrastructure corridors', preferably along existing routes. Careful placement of infrastructure corridors to avoid important biodiversity areas, particularly 'no-go' areas, including consideration of alternatives and optimisation of service provision.
- Professional monitoring of key indicators and disclosure of their findings.

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[2] Version of 4 March 2020

- Avoidance of impacts wherever possible, and rehabilitation/restoration after mining/development where avoidance is not possible. Restoration of biodiversity is a core strategy in the management of impacts, and, because so little is known about how to do this, much research is required. Closure and rehabilitation guidelines are:
    - All structural elements (site and external) will be removed from site, access roads ripped and graded over.
    - Alaskite mines: the open pit, waste rock dumps, and tailings dam or heap leach residue facility will remain.
    - Backfilling of shallow carnotite mine pits.
    - Closure planning starts many years ahead of the closure date to ensure that it is implemented in a logical, cost-effective and equitable manner. This includes ongoing rehabilitation of disturbed areas.
- The population of Welwitschia plants adjacent to the mine is considered to be of high biodiversity value.
- Specific mention is further made that funding should be provided for long-term scientific research on specific threatened species.

4 Methods

4.1 Data and information sources

The principal data sources were the same as those used for the original BIA of Husab Mine (Wassenaar & Mannheimer, 2010), updated where relevant. Where required, unpublished studies conducted under the auspices of the Gobabeb Namib Research Institute for Swakop Uranium were referred to.

4.2 Site visit

The sites for both the proposed optional locations, the so-called "base case" and the alternative location east and north of the TSF were visited on 16 and 17 April 2021. This was done to confirm the presence of species, the locality, extent and condition of habitats, and to make observations of ecological features and the possible presence of important ecological functional processes.

5 Description of the receiving environment

5.1 Physical environment

The Husab Mine is located south of the Khan River about 20 km north-east of its confluence with the Swakop River in the central Namib (Figure 1). The whole mining area is located within the Namib-Naukluft National Park, with the result that the end land-use is the conservation of biodiversity, with conservation principles aligned to the Convention on Biodiversity to which Namibia is a signatory.

For the purposes of the BIA for Husab Mine (Wassenaar & Mannheimer, 2010) and although the current impact is limited to only a part of the whole area, the study area was defined as the broadly triangular area of ~20 000 ha bordered in the north-west by the Khan River, in the north-east by the boundary of the Namib-Naukluft Park, and in the south by an east-west line following a local park road (Figure 1).

The region is hyper-arid, with a long-term average of less than 50mm rain pa (Mendelsohn et al. 2002). Spatial and temporal variability in rainfall is high (Mendelsohn et al. 2002). Rainfall mainly occurs as convective summer storms (Lindesay & Tyson 1990), with the total annual average sometimes falling in one event.

Summers are moderately hot (average maximum temperature during the hottest month is about 30°C), but the climate is tempered by cool coastal conditions brought inland by prevailing westerlies, south-westerlies and southerlies (Lindesay & Tyson 1990; Mendelsohn et al. 2002). Winters are cool (average minimum temperature in coldest month is between 10 and 12°C), but hot easterly bergwind conditions can result in unseasonal warm conditions. Frost is rare and cloudy conditions are common, with approximately 125 days of fog per year at Swakopmund (Mendelsohn et al. 2002). The number of fog days decreases sharply with distance from the coast (Lancaster et al. 1984). Fog probably occurs in the study area between 50 and 90 days per year.

The dominant geomorphologic features are large, gentle south-sloping gravelly plains, weathered marble ridges and deeply incised river valleys. To the southeast of the project area lies the Husab Mountain, a prominent large marble ridge. Geologically the area is characterised by granites, gneisses, meta-sediments, marble ridges, and unconsolidated gravels and sands. Soils are shallow and, as is generally the case in the central Namib, organic components are poorly developed (Abrams et al. 1997). The northeast-southwest flowing Khan River and the east-west flowing Swakop River form the main drainages (both being ephemeral), but numerous washes drain the gravel plain, predominantly in a south-westerly direction.

An earlier study on the vulnerability of the Welwitschia plants to upstream surface hydrology has shown the importance of all westerly-flowing ephemeral drainages for the species' local population health (Wassenaar, 2018).

5.2 Biological environment

The description of the biological environment should be read with reference to species lists presented in Wassenaar & Mannheimer (2010). Here I present only those biodiversity features that are relevant to the proposed development and indicate from the start how these relate to the location and layout of the two proposed options (see Figure 16).

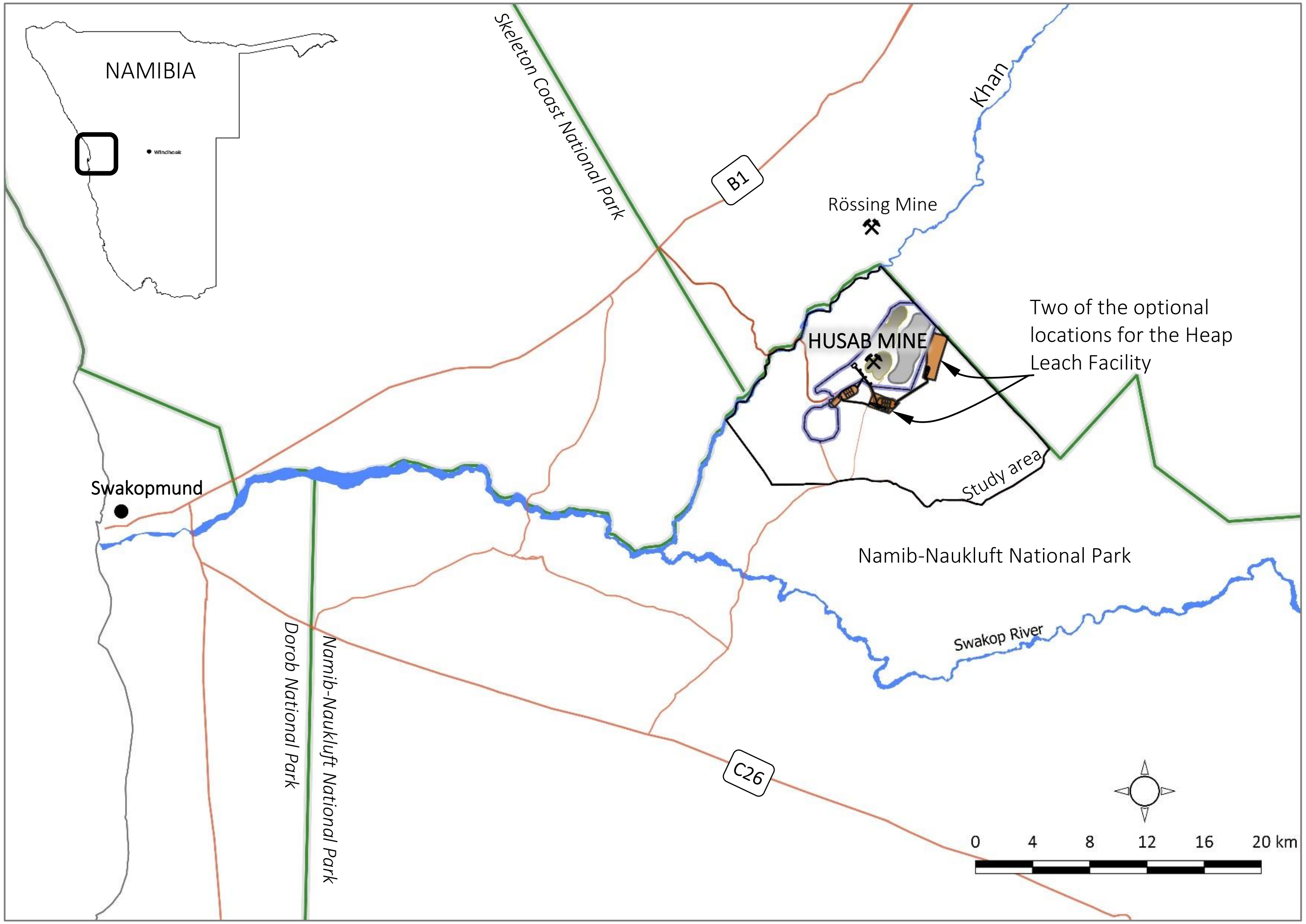

Figure 1. The location of the mine relative to the main features of the central Namib coastal region.

The study area used in Wassenaar & Mannheimer (2010, also used in the current report) is outline in thick black line and two optional locations for the Heap Leach facility and its associated infrastructure and services are shown in orange. The third option is similar enough to one of the others that the differences won't show up at this scale; it is thefore not presented here, but is presented in detail below.

The study area falls in the "Namib" **biome** (Irish 1994). The central Namib is known for high levels of endemism in plants, reptiles, invertebrates, and mammals (Barnard 1998). Vegetation cover is sparse, mostly concentrated in washes and ravines and on rocky marble ridges, as well as on distributed patches of mostly perennial grasses on the gravel plains that form an important part of the available fodder for large grazers such as Hartmann's mountain zebra. These patches are probably formed by surface water flows, a well-known phenomenon in arid and hyper-arid areas, but are maintained by gerbils (Shaanika, 2020).

Fog-dependent species such as *Zygophyllum stapffii* and *Stipagrostis* spp. are generally dominant, but plant communities are set apart by numerous **endemic and near-endemic taxa**, including *Commiphora oblanceolata*, *Euphorbia giessii*, *Ruellia diversifolia*, *Aloe asperifolia* and others (Table 2).

Immediately to the south of the mine is a population of ***Welwitschia mirabilis*** (Figure 6). This is the largest population of this charismatic and iconic desert plant in the central Namib and includes many of the largest specimens known from Namibia, such as the 'Giant Welwitschia" (Kers 1967). The sensitivities map produced in 2010 for the original EIA has been updated with information gathered over the past 10 years through monitoring and research. The sensitivities of the limestone ridge, and drainage channels has been increased (Figure 4).

The linear infrastructure of Option H will cross the Welwitschia population in the No-go area (see below) (Figure 6). The proposed waste facility for option 1 will also overlap with the approximate route of the channel bypass (Figure 6) proposed as a mitigation measure should the extension of the current WRD go ahead.

Wassenaar & Mannheimer (2010) defined **twelve habitats** across the whole study area based on their physical and ecological characteristics (see Table 9 in Wassenaar & Mannheimer, 2010). Of these, three will be impacted by the two proposed alternative project footprints, namely the plains drainage channels, koppies and ridges on plains and grassy plain (Figure 2). The sensitivity ratings for the habitats were comprehensively described in Wassenaar & Mannheimer (2010). The footprints of the three proposed HLF alternatives will affect areas that have been rated least sensitive (parts of the grassy plains habitat), sensitive (plains drainage channels), very sensitive (koppies and ridges on plains) and no-go (the area covered by the Welwitschia plants) (Figure 4).

A relatively small number of desert-adapted **mammal species** occur here. The Vulnerable (IUCN, 2008) Hartmann's mountain zebra (*Equus zebra hartmannae*) is perhaps the most important of the large mammal fauna, but gemsbok (*Oryx gazella*) and springbok (*Antidorcas marsupialis*) also occur. Important small mammals are endemic species such as the dassie rat (*Petromus typicus*), the pygmy rock mouse (*Petromyscus collinus*) and **Setzer's hairy-footed gerbil (*Gerbillurus setzeri*)**. The latter has been shown to play an ecological engineering role, creating habitat for plants (particularly grasses) and thus food for a range of large mammal herbivores (Shaanika, 2020). They are estimated to improve plant productivity through their burrowing activities more than three times over the background processes that normally affect it.

A recent study has shown how widespread the effect of gerbils is on the productivity of the gravel plains outside the Husab fence line (Shaanika, 2020). The gravel plains, consisting of mostly unconsolidated loamy sandy gravel mix, support only sparsely distributed vegetation. Some of these are perennial shrubs such as the pencil bush (*Arthraerua leubnitziae*) or dollar bush (*Zygophyllum stapffii*), but most of the biomass consists of ephemeral grasses such as *Stipagrostis* sp. Only in the numerous unremarkable vegetation patches do these grass species receive enough moisture to become perennial and only in those patches where gerbils dig their burrows does the total biomass become significant. These patches reach their highest density with the highest number of burrows per patch on the grassy plains habitat (Figure 10 and Figure 12). When including a data set from 2012, which was done before the construction of the mine, it becomes clear that the mine's construction has already led to a relative loss of this functionally important ecological feature (Figure 13).

Table 2. An overview of restricted-range endemic plant species, protected plant species and near-endemic plant species of conservation concern found or expected to occur in the Husab study site (reproduced from Wassenaar & Mannheimer, 2010). Species that could occupy habitats that are affected by the three optional layouts for the HLF are indicated in bold.

Listing is in alphabetical order within four categories of endemism. Categories were similar to Burke (2007) and Burke et al. (2008), with the only difference being that Mendelsohn et al.'s (2002) vegetation zones were used instead of regional boundaries. Distribution of endemics is based on records from the National Herbarium database (SPMNDB). Red Data Categories: LC = least concern; NT = near threatened; VU = vulnerable; NA = not assessed (Loots 2002, 2005).

Species	Longevity	Habitat in central Namib	Conservation status	Recorded / Expected	Notes
Species that are only known from the central Namib or have only occasionally been recorded elsewhere					
Aizoanthemum galenioides	annual	Plains, drainage lines, hills, rocky outcrops, inselbergs	LC	R	Most commonly recorded along the central Namib coast, however reasonably common on sandy plains at Husab, possibly due to fog carried inland by river courses.
Cleome carnosa	annual	Sandy drainage lines, shallow depressions on plains, hills, rocky outcrops and inselbergs	LC	R	Usually only found in drainage lines, occasionally on plains.
Helichrysum marlothianum	annual	Sandy watercourses		E	Known from only a few collections in four quarter-degree squares centred on the general Rössing area.
Species known from the central Namib and one other vegetation zone					
Aloe namibensis	Perennial, long-lived	Prefers sandy pockets on rocky slopes and ridges, also occurs on sides of gneiss/granite gullies.	Protected LC Cites II	R	Occurs as far east as the escarpment zone. Potentially impacted by several uranium developments.
Crotalaria colorata subsp. colorata	perennial	Drainage lines, gullies, rivers		E	Previously recorded from southern Namib also, but that record an incorrect determination.
Lithops ruschiorum	Perennial, long-lived	Reasonably restricted habitat preferences, usually occurring on rocky slopes on hills and ridges composed of quartz, pegmatite, calcrete, calcite and marble substrates.	Protected LC	E	Has been reliably reported from Husab in the vicinity of the Giant Welwitschia site (G. Erb pers. comm.) as well as elsewhere in the EPL. Recent work (Loots In prep) has confirmed its presence as far north as the Khumib River. It was not recorded during three field visits by us but is a cryptic species with typically widely scattered sub-populations. Although it has been assessed as 'least concern (LC)' by the Red Data list it is a formally protected species that has been impacted by the Rössing mine in the past; this should be factored in when the sensitivity of habitats is being considered.

Species	Longevity	Habitat in central Namib	Conservation status	Recorded / Expected	Notes
Species known from the central Namib and more than one other vegetation zone					
Aloe asperifolia	perennial, long-lived	Depressions, drainage lines, gullies, plains, hills, rocky outcrops and inselbergs	Protected LC	R	Slow-growing.
Arthraerua leubnitziae	perennial, long-lived	Depressions, drainage lines, gullies, plains, hills, rocky outcrops and inselbergs	LC	R	Fog-dependent, potentially impacted by several uranium developments.
Commiphora saxicola	perennial, long-lived	Depressions, drainage lines, gullies, hills, rocky outcrops and inselbergs	LC	R	Potentially impacted by several uranium developments but reasonably widespread.
Commiphora virgata	perennial, long-lived	Hills, rocky outcrops and inselbergs	LC	R	Potentially impacted by several uranium developments but very few were recorded during fieldwork for current project. This is the far western edge of its distribution range; it is more common on the escarpment.
Dauresia alliariifolia	perennial	Hills, rocky outcrops and inselbergs	LC	R	Reasonably widespread.
Euphorbia giessii	perennial	Only occurs on rocky ridges, commonly seen on marble ridges in study area	LC	R	Possibly fog-dependent, virtually restricted to the desert biome. Only known from rocky ridges, which form a relatively small proportion of the central Namib.
Petalidium canescens	perennial	Depressions, drainage lines, gullies, plains, hills, rocky outcrops and inselbergs	LC	R	Reasonably widespread.
Petalidium pilosi-bracteolatum	perennial	Drainage lines, marble ridges	LC	R	Fragmented population across its range. Common in large washes and on marble ridges at Husab, which may represent its western-most limit in the central Namib. Not recorded in recent work at Langer Heinrich, Rössing or Goanikontes.
Zygophyllum cylindrifolium	perennial	Depressions, drainage lines, gullies, plains, hills, rocky outcrops and inselbergs	LC	R	At Husab most common on marble ridges.

Species	Longevity	Habitat in central Namib	Conservation status	Recorded / Expected	Notes
Zygophyllum stapffii	perennial, long-lived	Drainage lines, rivers, rocky slopes, shallow depressions on plains	LC	R	Fog-dependent, potentially impacted by several uranium developments.

Near-endemic and protected species not mentioned above					
Acacia erioloba	perennial, long-lived	Drainage lines, rivers, hills, inselbergs	Protected	R	Increasing threats countrywide.
Commiphora oblanceolata	perennial, long-lived	Marble ridges, hills, rocky outcrops, inselbergs, gullies.	NT	R	Disjunct distribution, central Namib population appears to be centred on Husab EPL. Not found at Langer Heinrich, very few at Rössing, low numbers at Goanikontes. Of concern because thought to possibly be a distinct taxon from the Northern Namib and Angolan populations.
Euclea pseudebenus	perennial, long-lived	Drainage lines and rivers	Protected	R	Widespread in Namibia.
Faidherbia albida	perennial, long-lived	Rivers	Protected	R	Widespread in Namibia.
Hoodia currorii	perennial	Marble and other rocky ridges and slopes, plains	LC	R	Illegal collecting a threat.
Hoodia pedicellata	perennial	Marble and other rocky ridges and slopes	VU	R	Main threat thought to be illegal collection.
Maerua schinzii	Perennial, long-lived	Riverbanks, rocky slopes	Protected	R	Widespread in Namibia.
Sterculia africana	Perennial, long-lived	Rocky slopes	Protected	R	Reasonably widespread in Namibia.
Tamarix usneoides	Perennial	Riverbeds and large drainages	Protected	R	Widespread in Namibia.
Welwitschia mirabilis	Perennial, long-lived	Depressions, drainage lines, plains, rocky slopes	Protected LC	R	Large proportion of central Namib population appears to be concentrated on this EPL (Kers 1967, Cooper-Driver 1994)
Ziziphus mucronata	Perennial, long-lived	Riverbanks and large drainage lines	Protected	R	Widespread in Namibia.

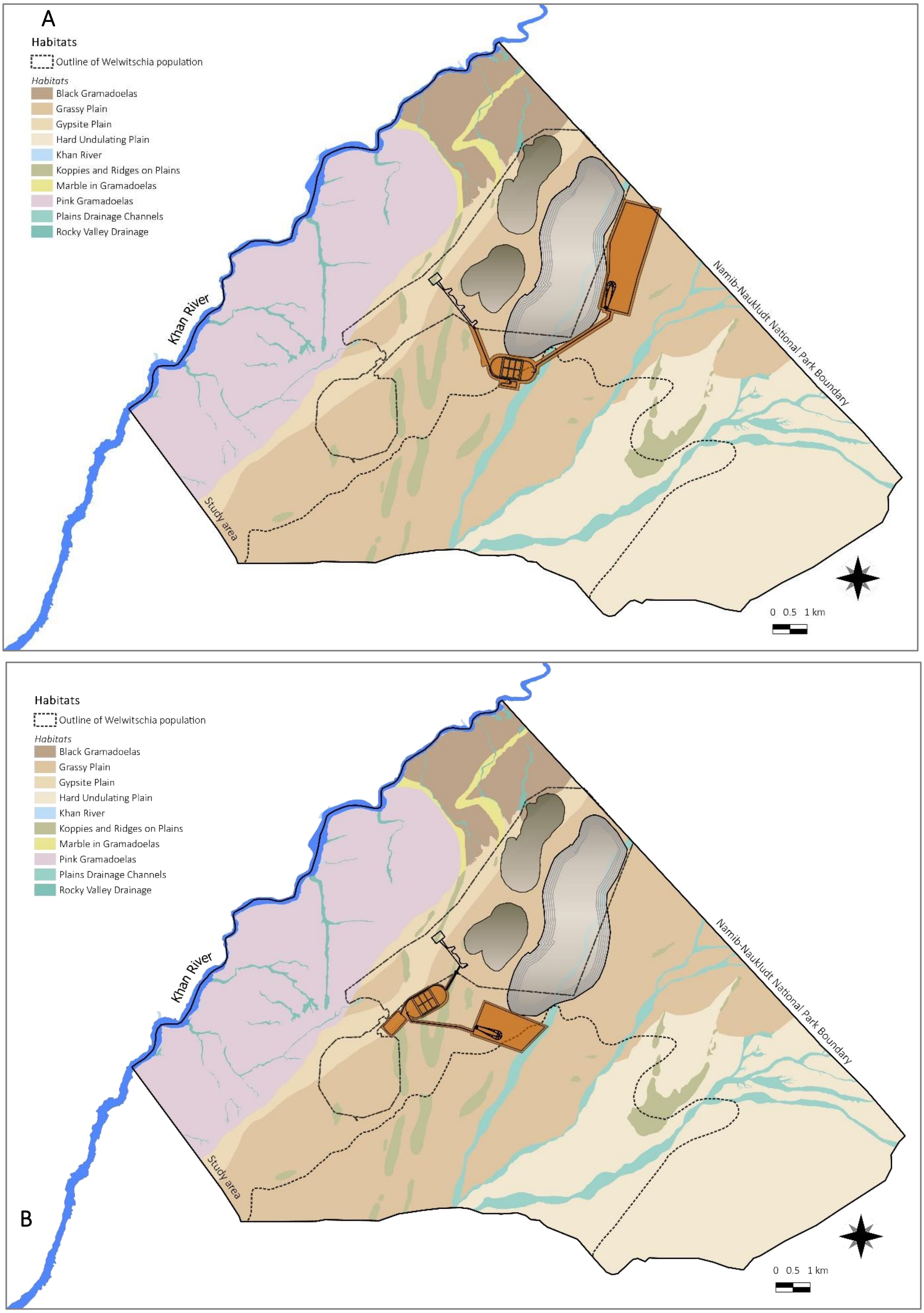

Figure 2. Two of the optional locations and layouts for the Heap Leach facility and its associated infrastructure (A: Option G; B: Option H) superimposed on the habitats of the study area (Wassenaar & Mannheimer, 2010).

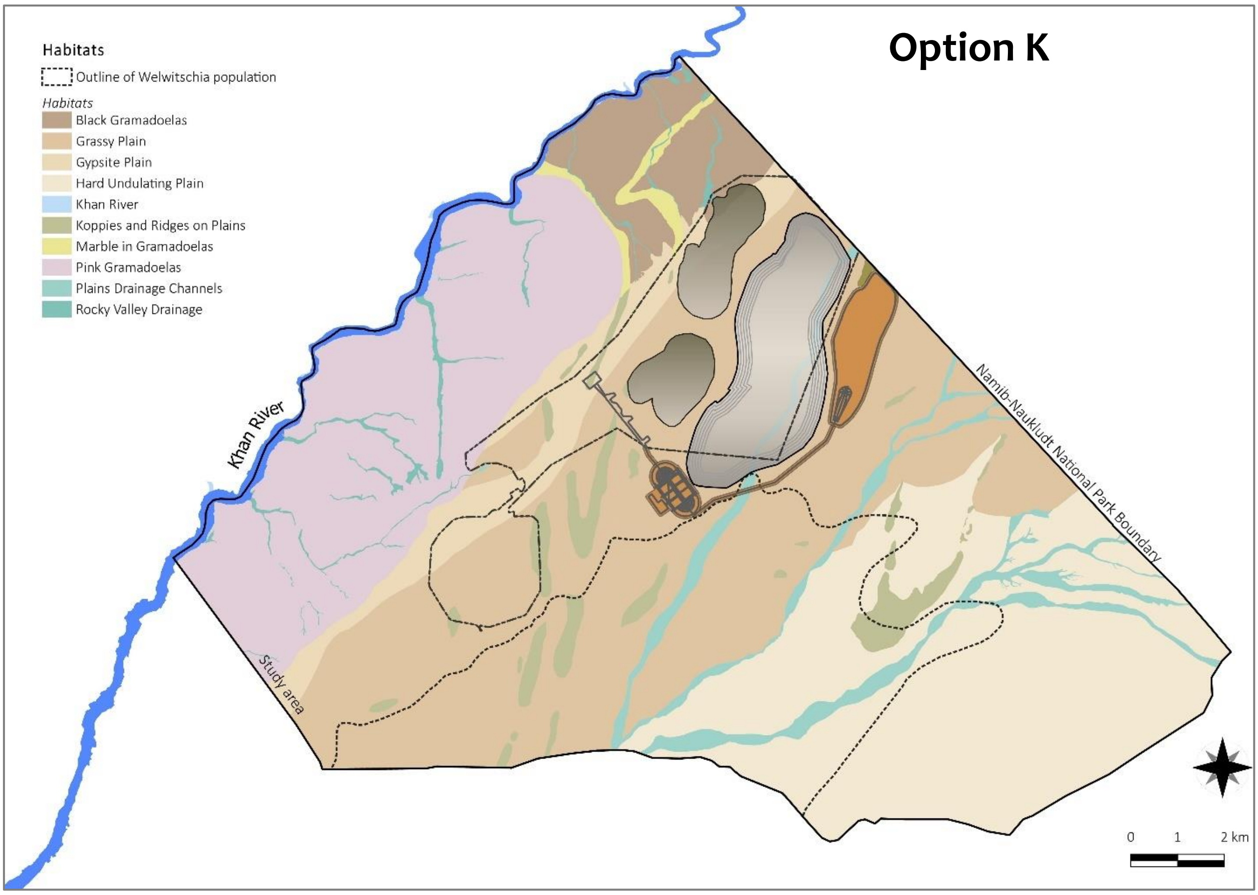

Figure 3. The third optional location and layout for the Heap Leach facility and its associated infrastructure (Option K) superimposed on the habitats of the study area (Wassenaar & Mannheimer, 2010).

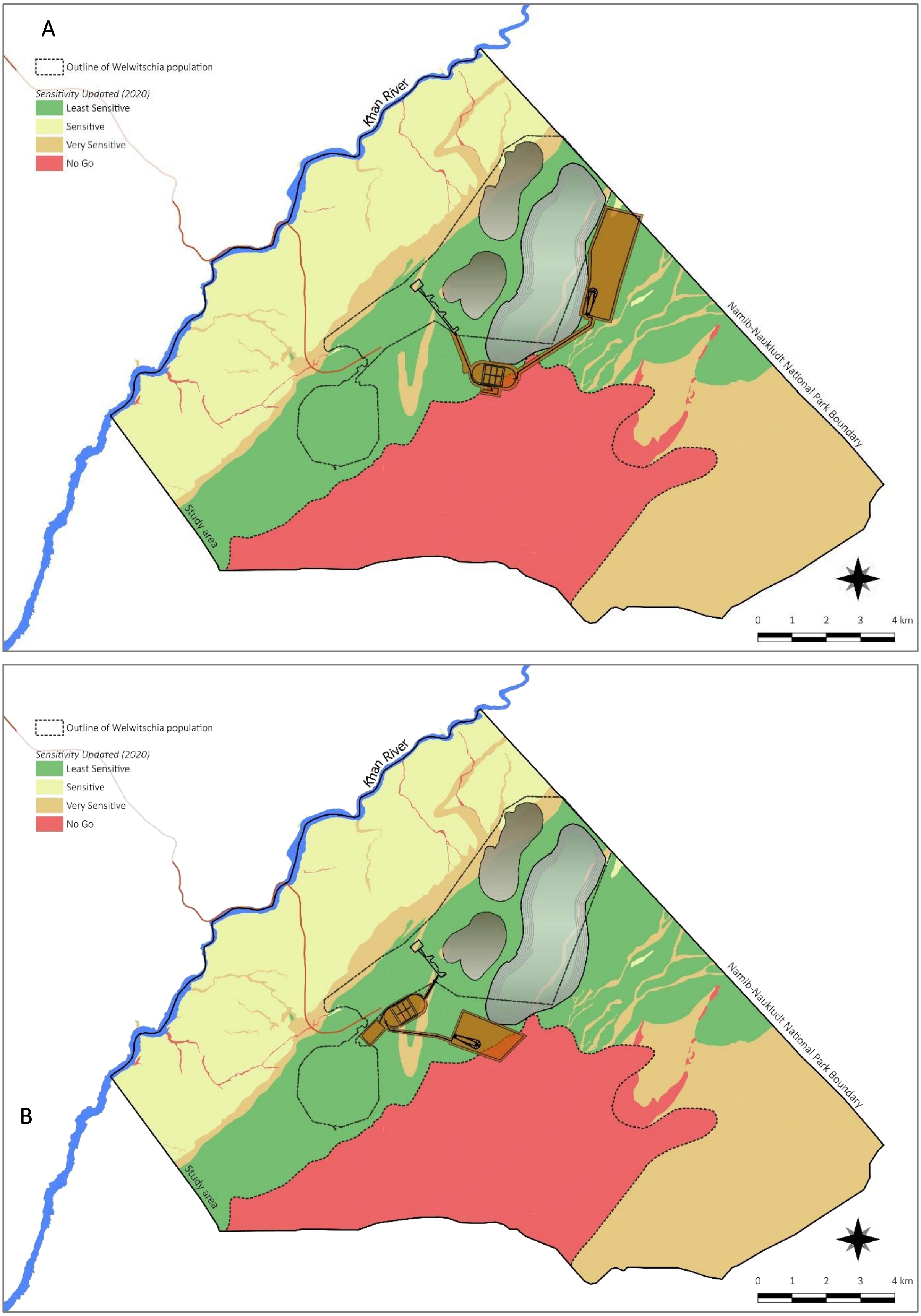

Figure 4. The two optional locations and layouts for the Heap Leach facility and its associated infrastructure (A: Option G; B: Option H) superimposed on the sensitivity of the different habitats for various disturbances (Wassenaar & Mannheimer, 2010).

Note the changes in the sensitivity ratings for some habitat units, based on new data and information.

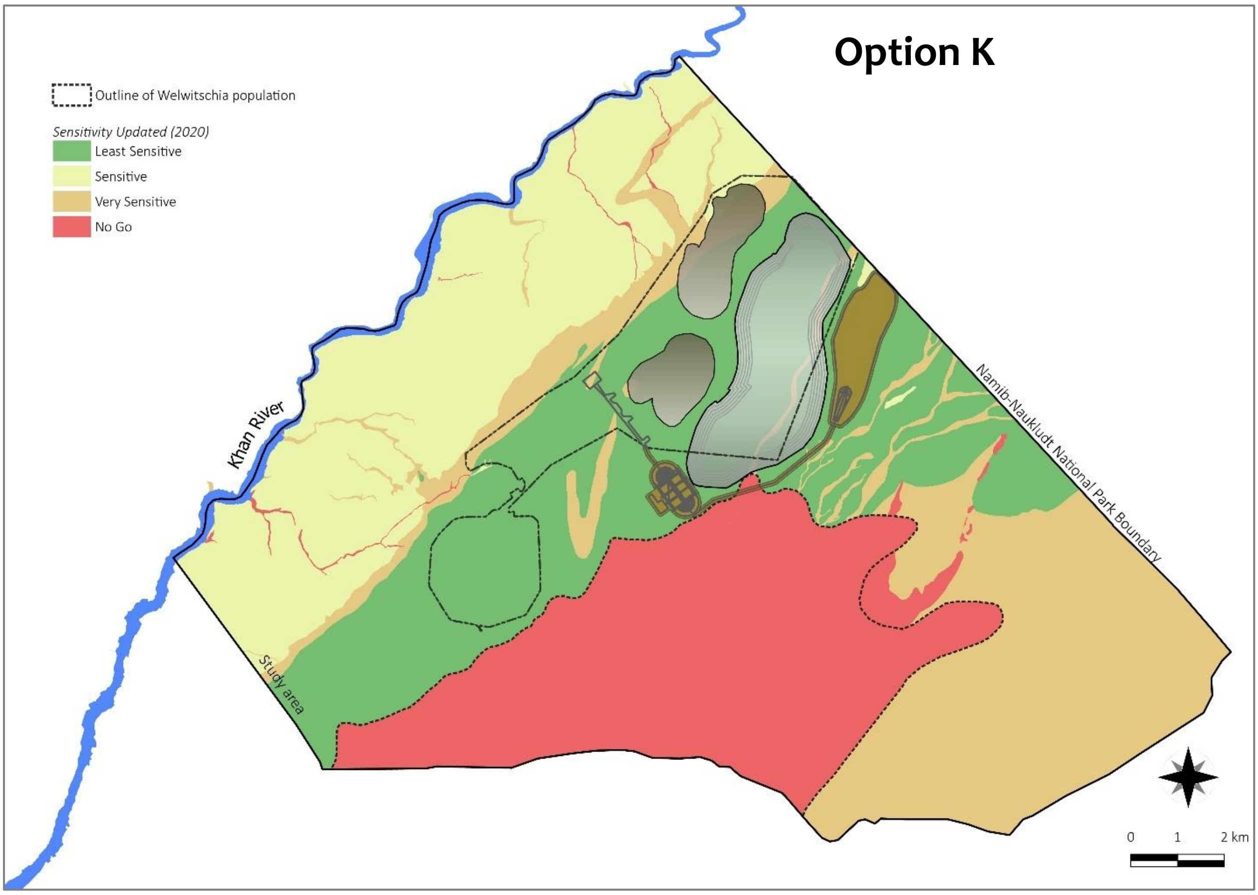

Figure 5. The third optional location and layout for the Heap Leach facility and its associated infrastructure (Option K) superimposed on the sensitivity ratings of the habitats of the study area (Wassenaar & Mannheimer, 2010).

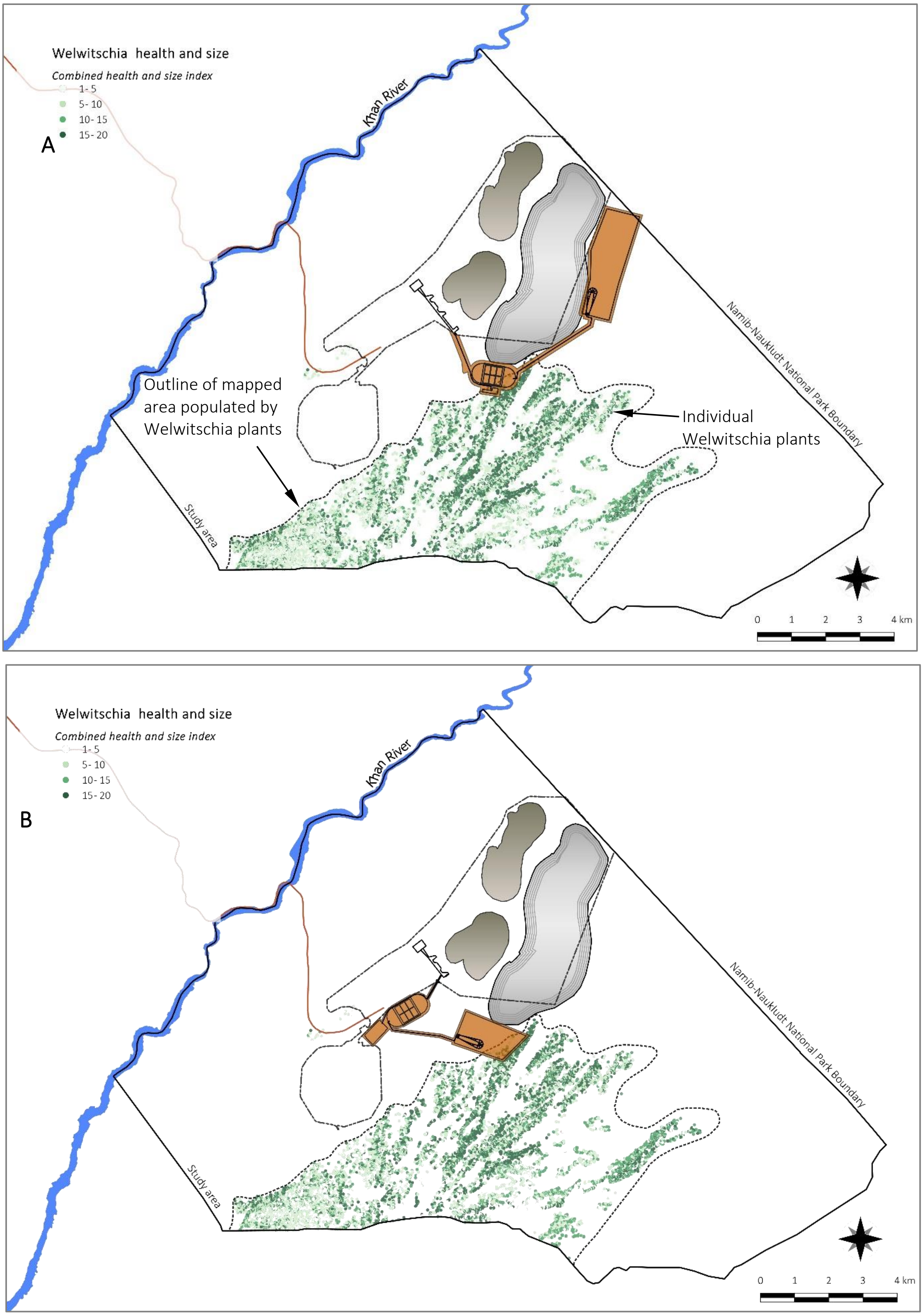

Figure 6. The two optional locations and layouts for the Heap Leach facility and its associated infrastructure (A: Option G; B: Option H) superimposed on a map depicting the extent of the area populated by Welwitschia plants in the study area.

The individual plants are each represented by a single dot; the colour of the dot denotes the relative health-size index with light green indicating small, less healthy plants and darker green indicating successively larger and/or healthier plants (adapted from Wassenaar, 2018).

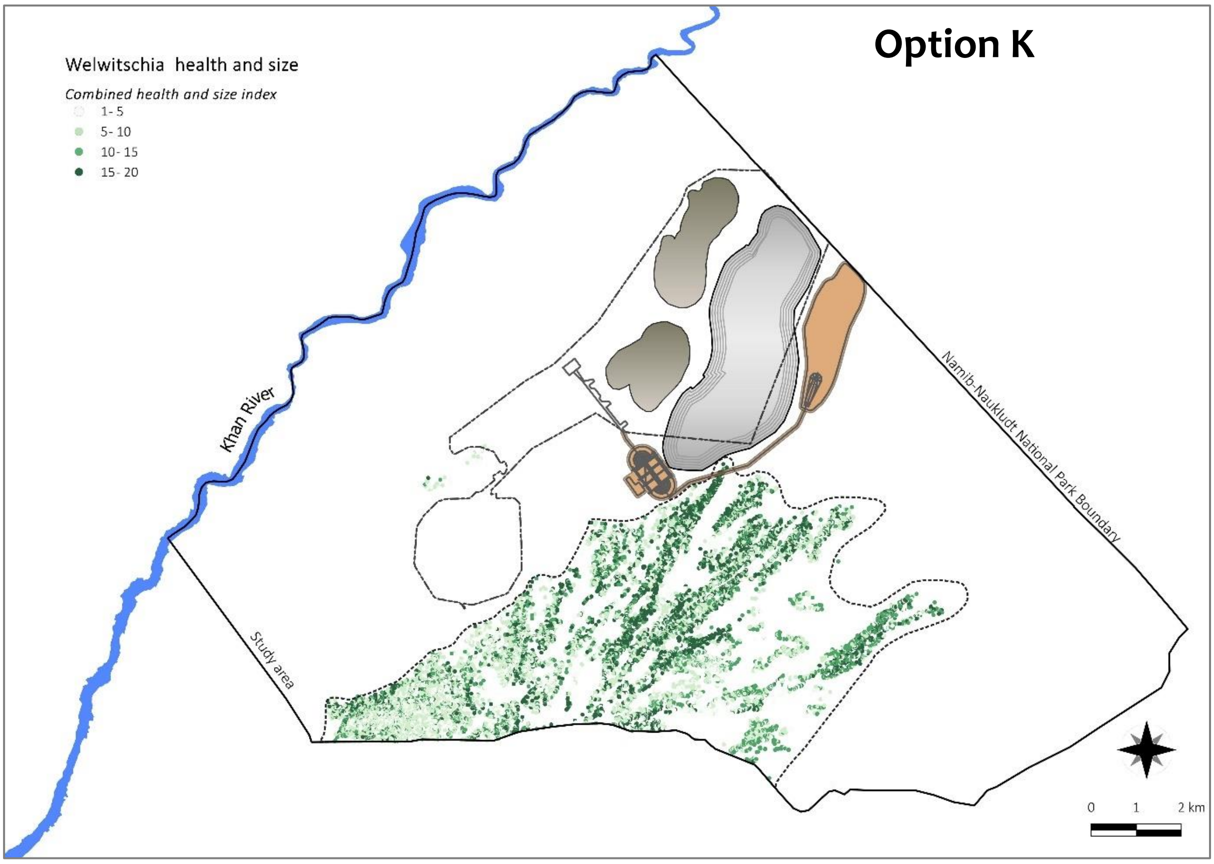

Figure 7. The third optional location and layout for the Heap Leach facility and its associated infrastructure (Option K) superimposed on a map depicting the extent of the area populated by Welwitschia plants in the study area.

The individual plants are each represented by a single dot; the colour of the dot denotes the relative health-size index with light green indicating small, less healthy plants and darker green indicating successively larger and/or healthier plants (adapted from Wassenaar, 2018).

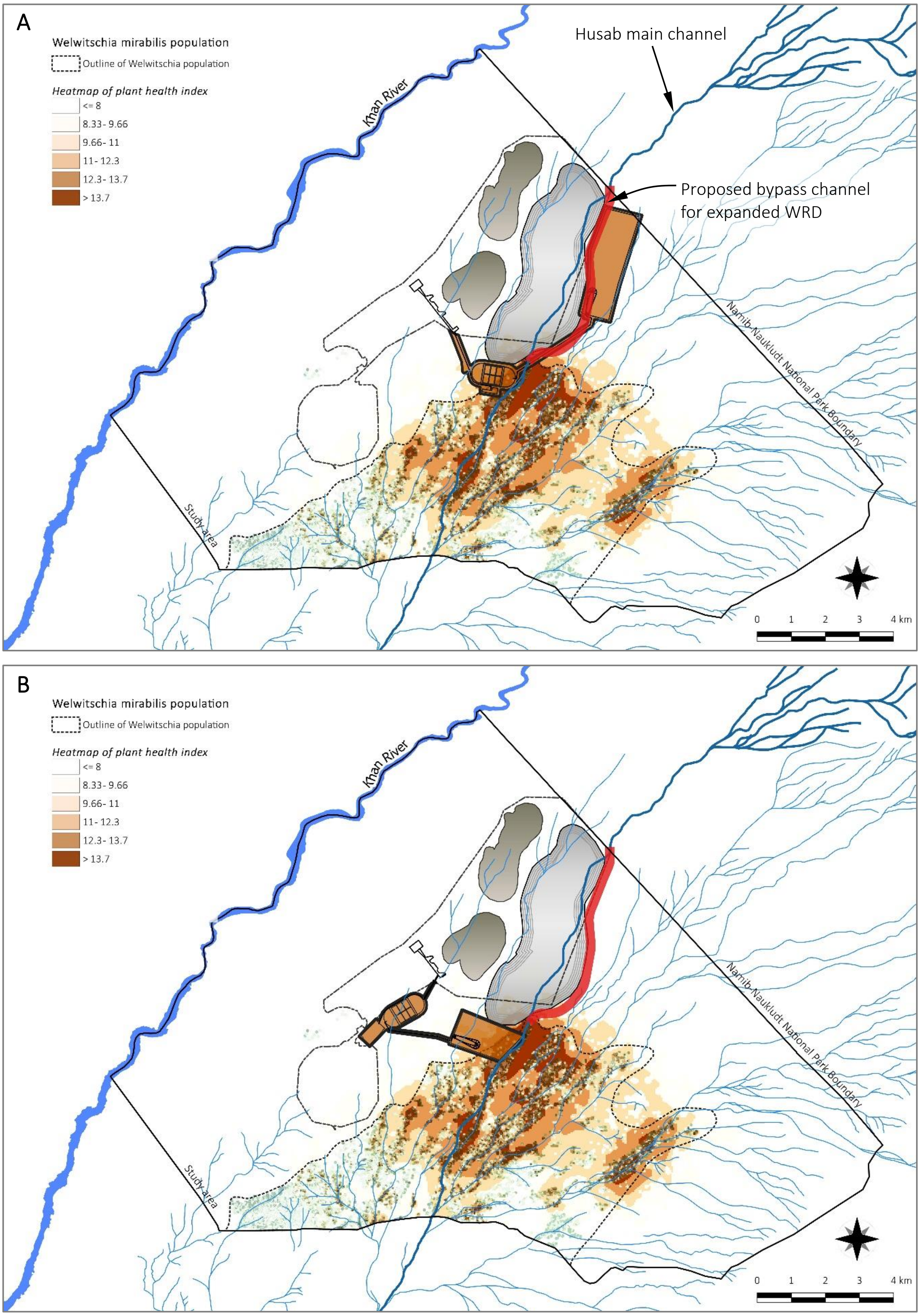

Figure 8. A heatmap of the combined index of plant size and health (see Figure 6) relative to the location of the main drainage lines, specifically the critical Husab Main Channel.

Darker brown colours indicate an area where plants with a higher index tend to cluster, representing higher value habitat for the species. Option G is shown in A and Option H in B. Note the position of the bypass channel, a mitigation proposed for the BIA of the expanded WRD.

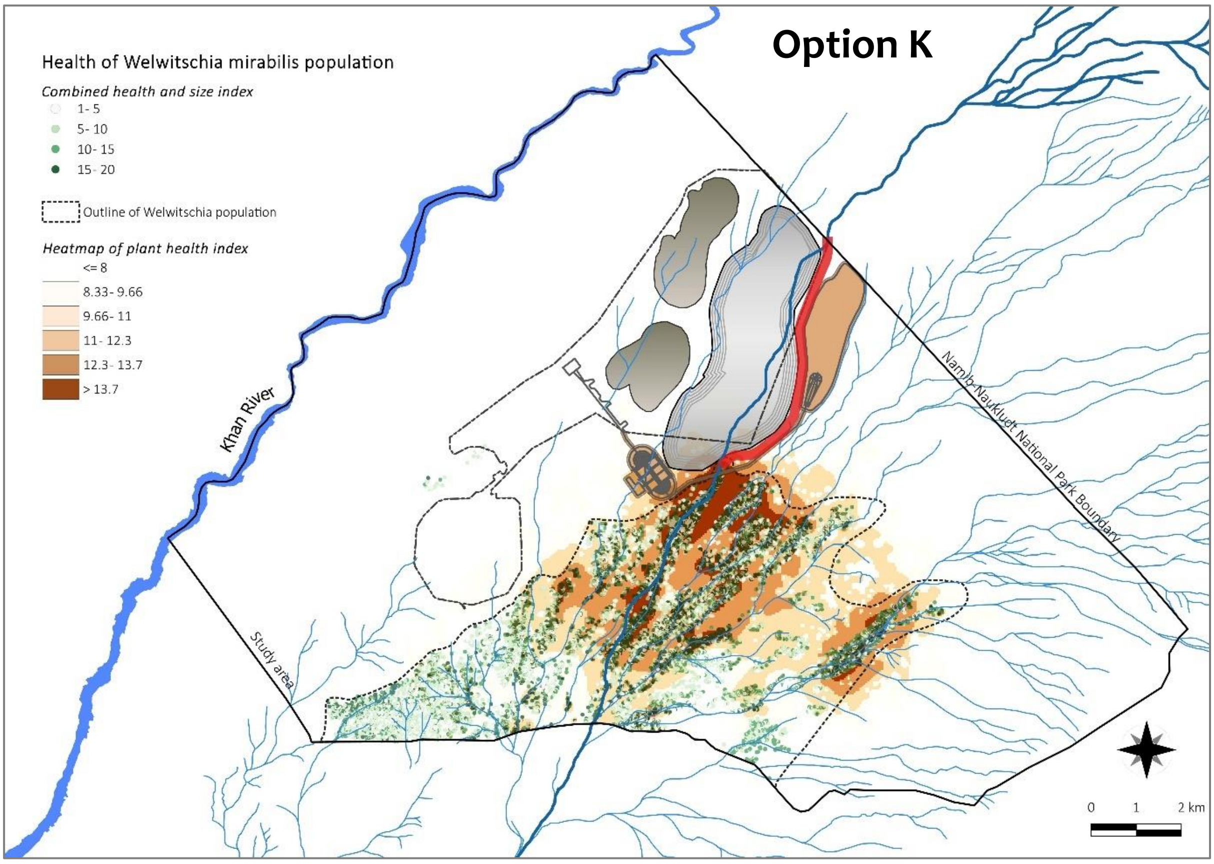

Figure 9. A heatmap of the combined index of plant size and health (see Figure 4) relative to the location of the main drainage lines, specifically the critical Husab Main Channel, for Option K.

Darker brown colours indicate an area where plants with a higher index tend to cluster, representing higher value habitat for the species. Note the position of the bypass channel, a mitigation proposed for the BIA of the expanded WRD.

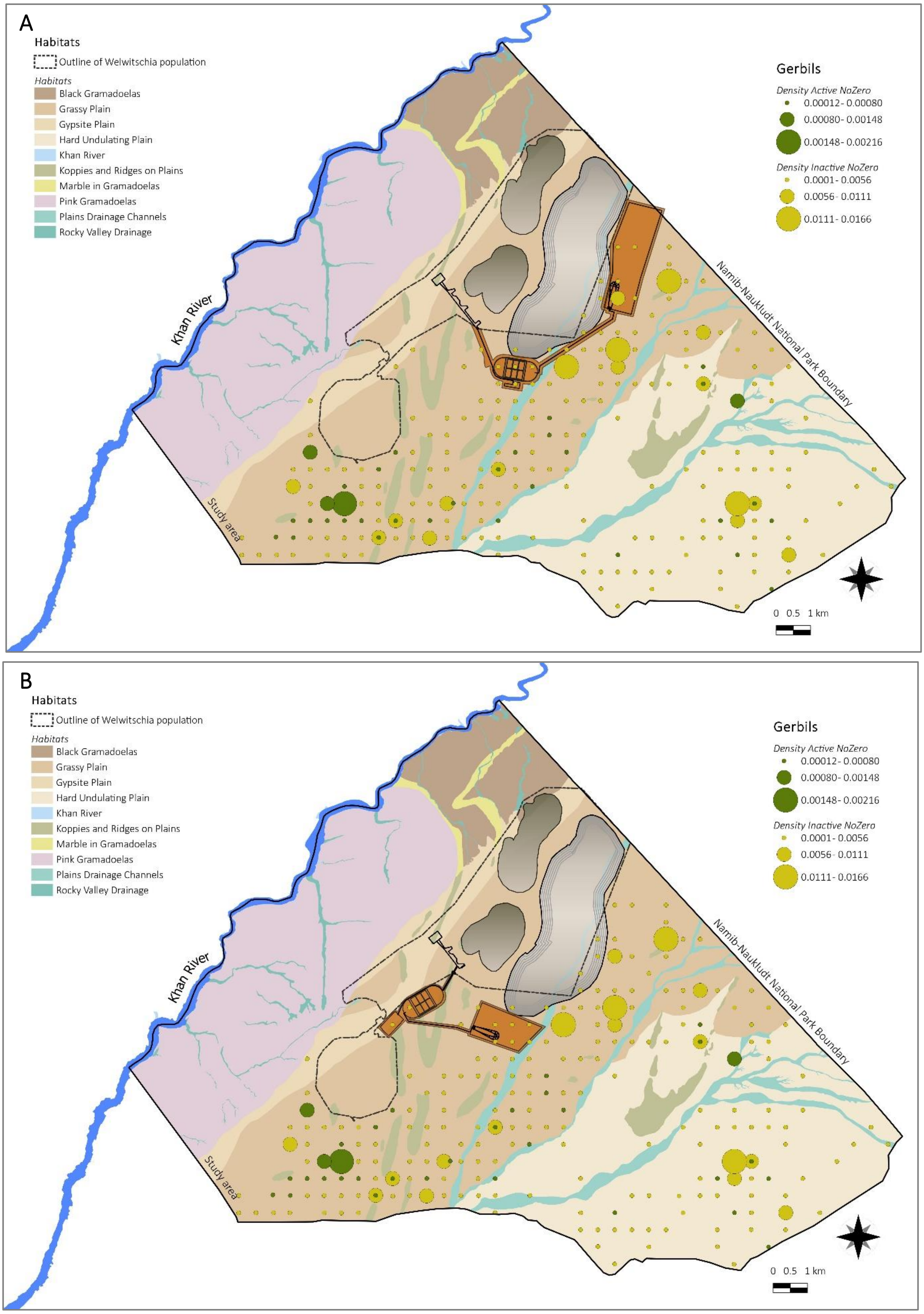

Figure 10. The distribution outside of the mine fence of vegetation patches with gerbil burrows superimposed onto the habitats of the study area, relative to the location of Option G (A) and H (B).

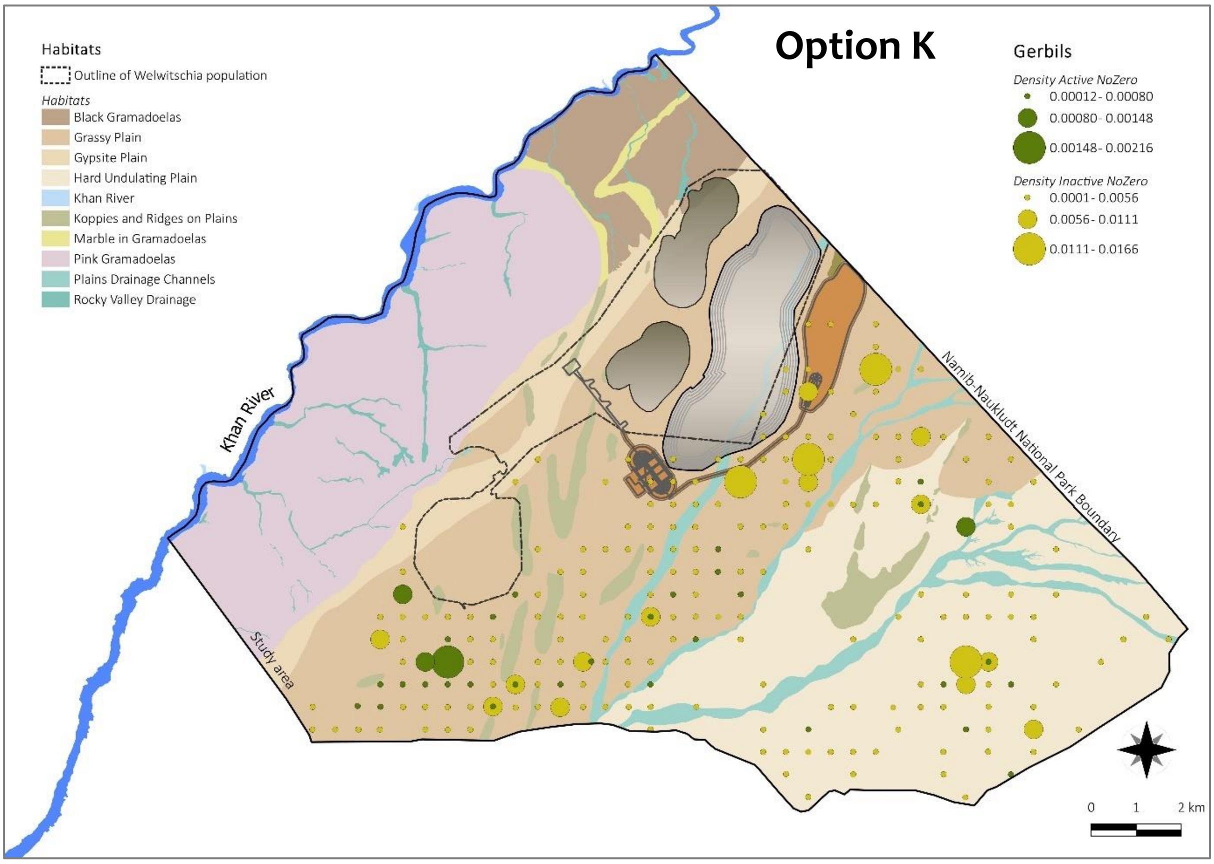

Figure 11. The distribution outside of the mine fence of vegetation patches with gerbil burrows superimposed onto the habitats of the study area, relative to the location of Option K.

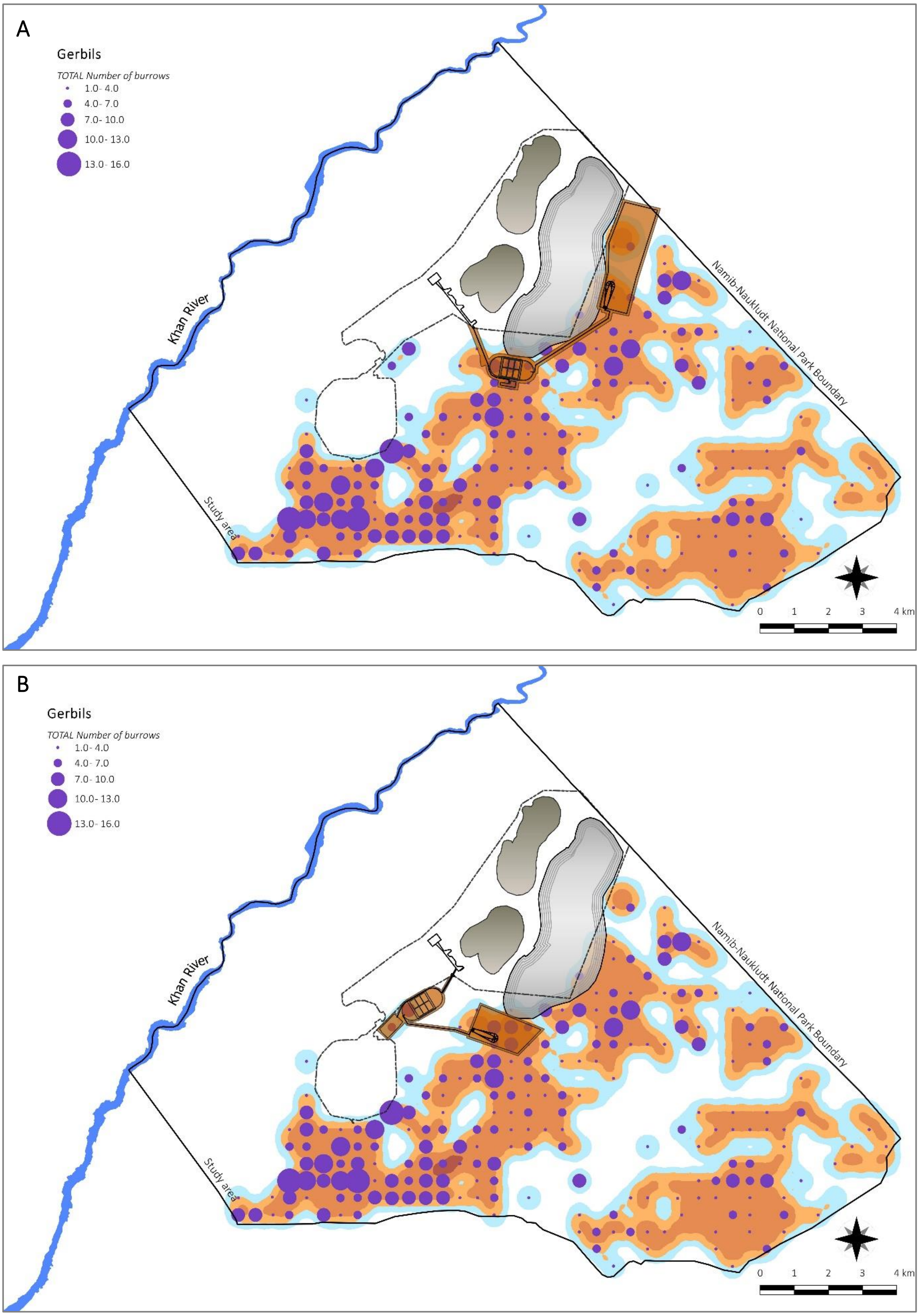

Figure 12. The distribution outside the mine fence of vegetation patch density, relative to the distribution of number of burrows per patch.

The colours represent a "heatmap" gradient from light blue to orange with blue signifying the lowest density values and darker orange the highest. Adapted from Shaanika (2020). Superimposed on that is the location and layout of Options G (A) and H (B).

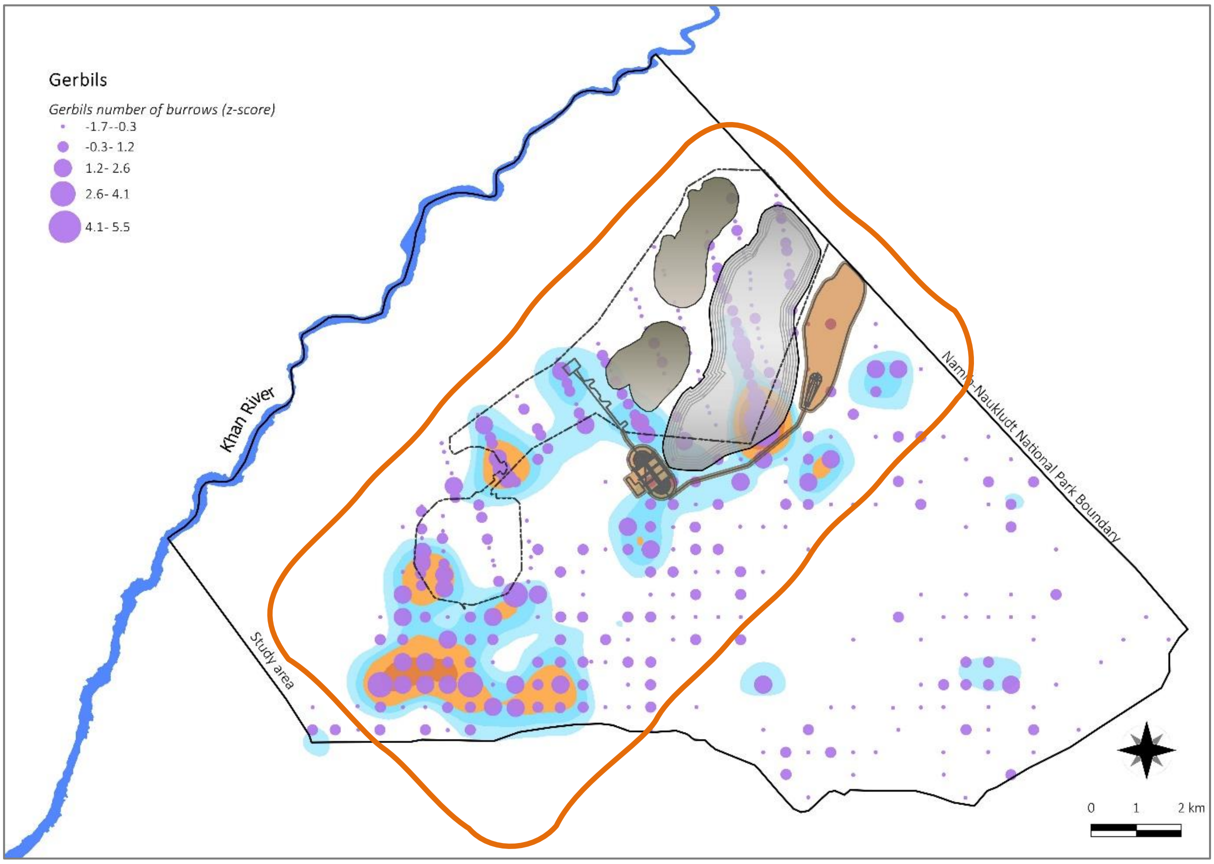

Figure 13. The distribution of the number of burrows per patch, overlain on a heatmap showing the spatial tendency for higher z-scores of number of burrows per patch. Superimposed on that is the location and layout of Option K.

Different fromFigure 12, the colour gradient from light blue to orange here represent a "heatmap" of z-scores of number of burrows per patch. The dataset on which it is based was combined from two surveys, the first conducted in 2012 and the second in 2020 (see Shaanika, 2020). Because these two surveys used different survey methods, I standardized the data by calculating a z-score (value minus mean divided by standard deviation). The inclusion of the 2012 data (before mining), shows the relative loss of numbers of burrows that has already occurred when the mine was constructed. The orange rectangle indicates the general area where the highest numbers of burrows seem to be concentrated. This area includes the mine and the proposed HL infrastructure.

Although they do generally prefer rocky hillsides, **Hartmann's mountain zebra** is a common sight on all the plain habitats in the study area. It is suspected that the gerbil-engineered grass productivity is a major reason for their continued presence in this hyper-arid zone with its regular droughts (Shaanika, 2020). Based on number and age of tracks, they tend to prefer the south-eastern area near the Husab Mountain, but they are also regularly found near the mine itself, with at least one of the HLF options showing a significant overlap with higher numbers.

However, subsequent surveys done in the Husab Monitoring Programme (data not available in the same format yet) show that although numbers in the south-eastern area remain relatively stable, their presence in other parts of the study area is variable and probably depends as much on seasonal rains as it does on disturbance by human activity. Note, the zebra are not monitored in the largely inaccessible rocky sections north of the mine, but do occur there.

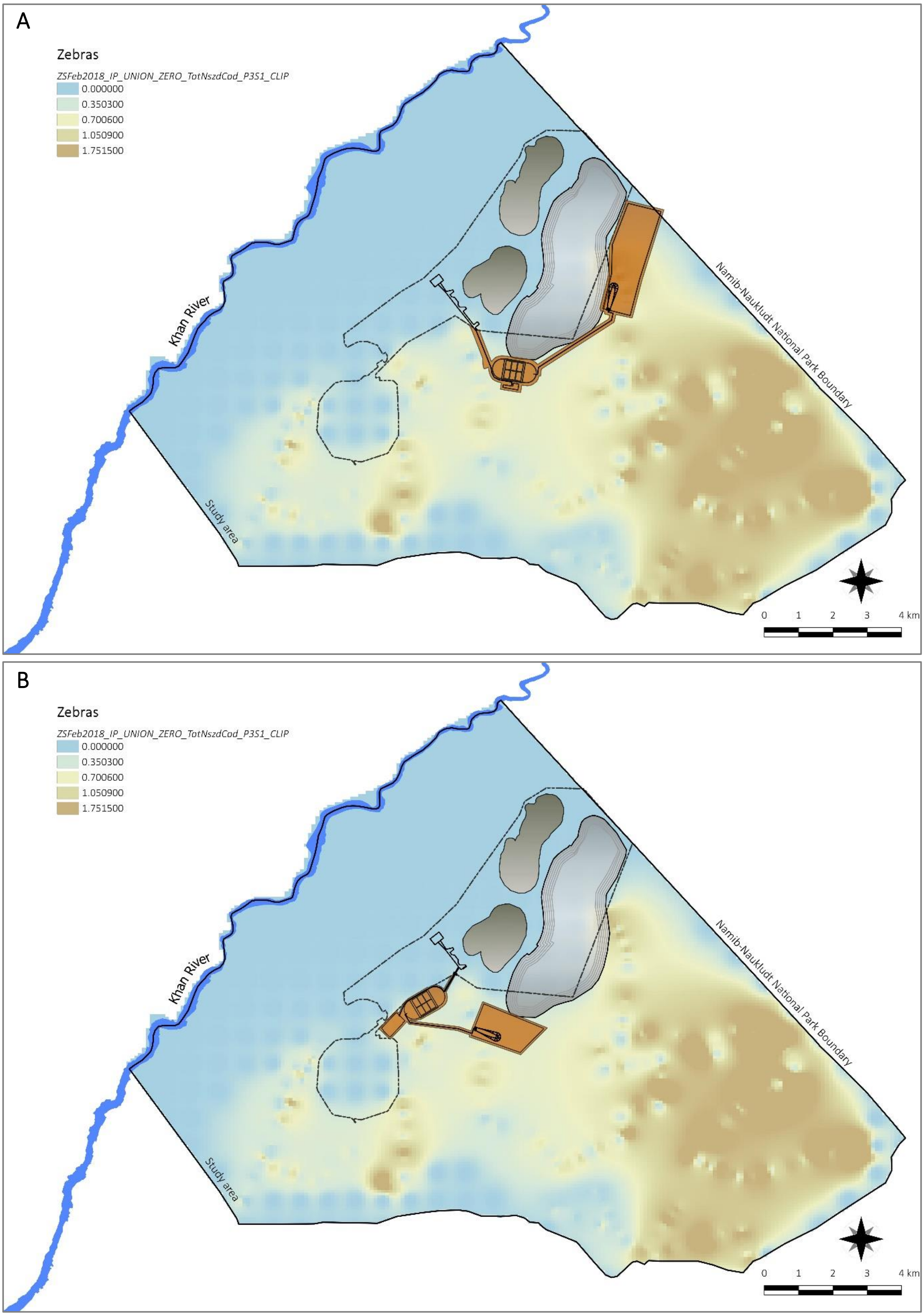

Figure 14. The layout and location of options G (A) and H (B) superimposed on the distribution of zebras across the study area, as determined in 2018.

The colour gradient represents the value of an index of activity based on number of tracks encountered, with blue being the lowest and gold the highest. Note, zebra are not monitored in the inaccessible rocky sections north of the mine, but do occur there.

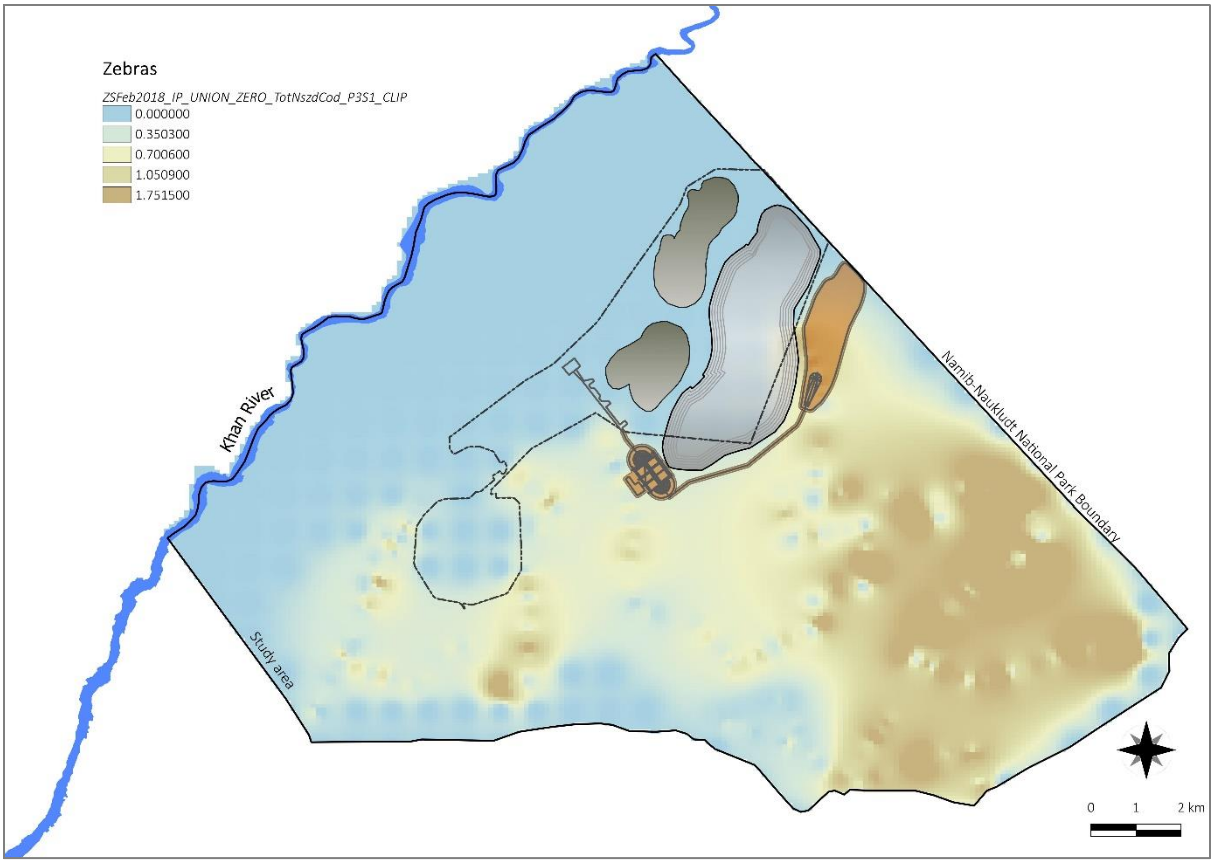

Figure 15. The layout and location of option K superimposed on the distribution of zebras across the study area, as determined in 2018.

6 Identification of environmental aspects and potential impacts

6.1 Impact assessment method

Environmental issues (i.e. potential impacts) were identified based on experience of the receiving environment and specifically its biodiversity. Biodiversity aspects were based on Slootweg & Kolhoff (2003). The assessment of the scale of environmental impacts were based on experience and existing baseline information from current activities in and around the Husab Mine and related project sites, following the assessment methodology in Table 3.

Table 3. Impact Assessment Methodology. Note: Part A provides the definition for determining impact consequence (combining intensity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		Significance = consequence x probability
Definition of CONSEQUENCE		Consequence is a function of severity, spatial extent and duration
Criteria for ranking of the SEVERITY of environmental impacts	H	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	L	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	L	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
SEVERITY = L					
DURATION	Long term	H	Medium	Medium	Medium
	Medium term	M	Low	Low	Medium
	Short term	L	Low	Low	Medium
SEVERITY = M					
DURATION	Long term	H	Medium	High	High
	Medium term	M	Medium	Medium	High
	Short term	L	Low	Medium	Medium
SEVERITY = H					
DURATION	Long term	H	High	High	High
	Medium term	M	Medium	Medium	High
	Short term	L	Medium	Medium	High
SPATIAL SCALE			L: Site	M: Local	H: Regional/ national

PART C: DETERMINING SIGNIFICANCE							**PART D: INTERPRETATION OF SIGNIFICANCE**	
PROBABILITY (of exposure to impacts)	Definite/ Continuous	H	Medium	Medium	High		High	It would influence the decision regardless of any possible mitigation.
	Possible/ frequent	M	Medium	Medium	High		Medium	It should have an influence on the decision unless it is mitigated.
	Unlikely/ seldom	L	Low	Low	Medium		Low	It will not have an influence on the decision.
			L	M	H			
			CONSEQUENCE					

*H = high, M= medium and L= low and + denotes a positive impact.

The sources of risk, modifiers of the level of risk and the impact mechanisms followed those defined by Wassenaar& Mannheimer (2010). In addition, the overall and individual impact assessments were made in the context of the mine's location in a protected area (where the end land use is biodiversity conservation) and of two main regulatory aspects, namely the importance that the draft Wildlife and Protected Areas Management Bill assign to specific ecological and biodiversity properties, and the various principles defined by the SEA for the Uranium Rush (SAIEA, 2010).

6.2 Project description

Swakop Uranium intends to develop a Heap Leach Facility (HLF) to utilise their low-grade run-of-mine (ROM) material in order to further extract available uranium. Three alternative locations and layouts have been proposed[3]. These are as follows:

A. In **Option G** , the HLF itself, together with the ponds, are located immediately to the SW of the existing expanded WRD, and the HL waste facility (HLWF) is located to the WRD's SE, adjacent to the planned bypass channel for the expanded WRD (Figure 16A).
B. In contrast, in **Option H,** the ponds and HL Facility are located along the Plant's existing southern fence and the HLWF is placed in the area to the SW of the current expanded WRD "toe" (Figure 16B).
C. Option K, proposed after the first draft of the current report, tucks the HL Facility into the leeward side (for east winds) of the main expanded WRD, and spreads the HLWF onto the least sensitive grassy plain habitat to the SE of the main WRD, in a geomorphic shape and avoiding all drainage lines including the proposed bypass channel.

The following section was copied verbatim from Liebenberg-Enslin (2021, p4):

Available uranium (U) in the Low-grade run-of-mine (ROM) material, that was to be treated through the through the newly constructed Tank Leach Facility (TLF) at the end of the LOM, will be extracted through a heap leaching process. The Low-grade ROM will undergo primary crushing and thereafter

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[3] As per email from Mr E. Louw, SLR, dated 3 May 2021, wherein two of the layouts were provided with the instruction to "*Note [that] these are the final options to consider*". Subsequently, after the first draft of the current report was reviewed, a third layout option was proposed, again considered to be the final one. The latter is provided here as Option K.

secondary crushing and screening, from where it will temporarily stored on a stockpile. The material will then go to the final High-Pressure Grind Rolls (HPGR) crushing process (SGS Bateman, 2021). From where it is conveyed to an agglomeration drum at the Heap Leach Pad where additional leach agents (flocculant, hydrogen peroxide, and sulphuric acid) are added. The agglomerated product is then placed on the HL pad.

The HL pad will be designed to ensure optimal size for full leaching and reclamation cycle of the material. According to the SGS Bateman study (2021), the HL pad will consist of six cells for the stacking, leaching, drain down, rinse, and reclamation operations, as well as a dormant cell to allow flexibility in the operation. The HL pad will have a capacity of 7.5 million tonnes per annum (tpa), the pads covering an area of 261 000 m² (450 m by 580 m) and a height of 9 m. One HL cycle will take 100 days resulting in 6.21 cycles per year – each cycle will include 17 days for stacking, 3 days for curing; surface piping and pipe laying, the leaching process will take 50 days whereafter 2 days for washing, 8 days for draining, 3 days for piping and network removal, and 17 days for reclamation.

The post leach residue will be collected with a bucket onto a conveyor system which will transport it to a dedicated waste storage facility where it will be deposited by means of a grass-hopper stacker. The waste storage facility will be 70 m high, with benches every 15 m accommodating 375 000 tpa of leach residue (SGS Bateman, 2021). According to the Golder [Associates] report (2017), the chemical composition of the waste material includes solids with low leachability and comprise of silica (34-35%), aluminium (5.8-6.2%), iron (2.2%), sodium (1.6-1.7%) and potassium (4.1-5.4%). These chemical elements, including in its current form (solids, low leachability), do not constitute a human health risk, but the pH of the waste material will be between 4.5 and 5.2, classifying as a skin corrosive and eye irritant.

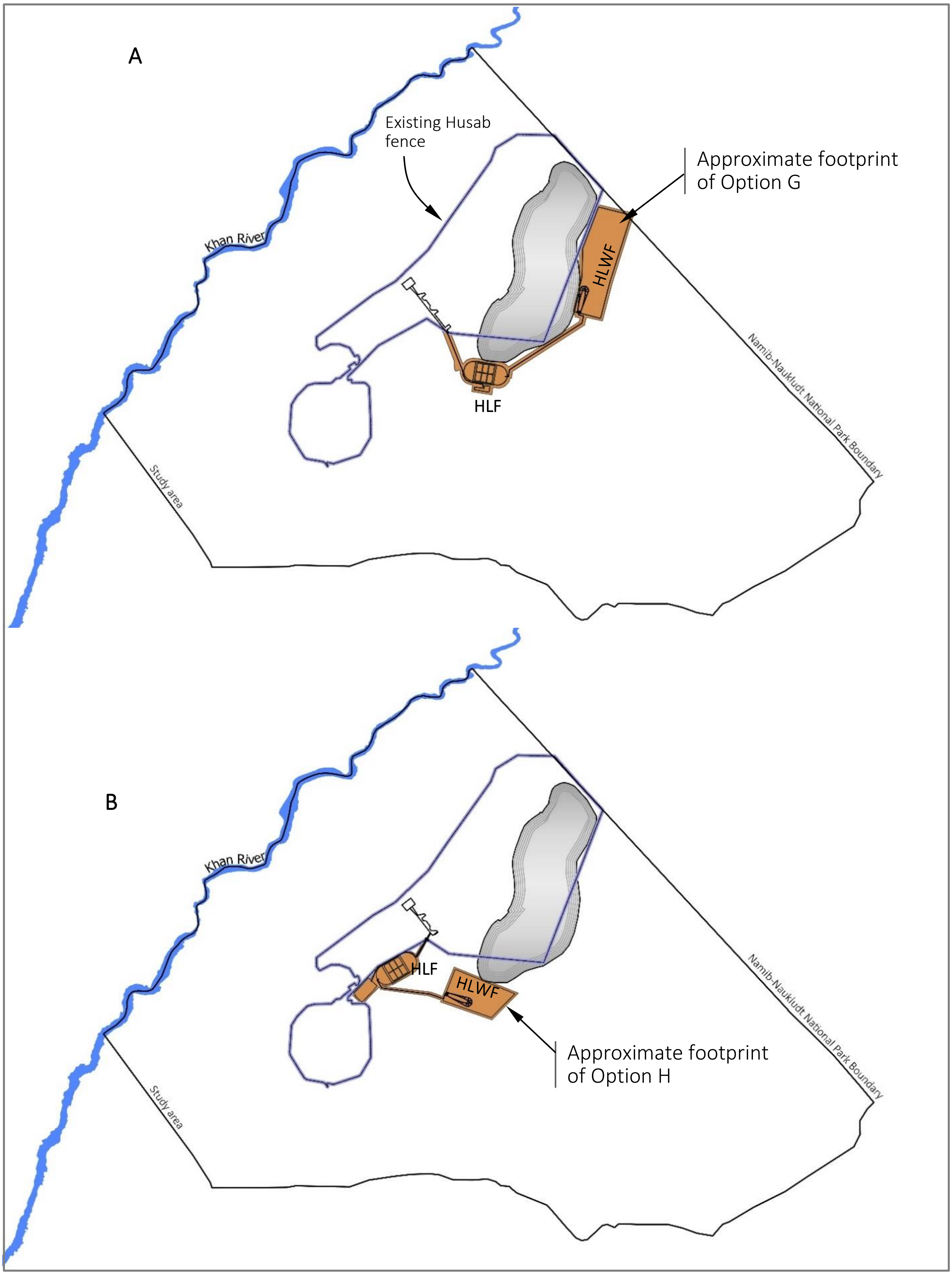


Figure 16. Options G (A) and H (B) for the location and layout of the proposed Heap Leach project, including the Heap Leach Facility itself (HLF), its associated linear infrastructure and its waste facility (HLWF).

Outlines of the footprints for both options were digitised as a ~50 m buffer around the outer lines on supplied technical drawings on plan. Refer to Figure 1 for a description of the study area and other features and to other figures for the location of the two options relative to biodiversity features.

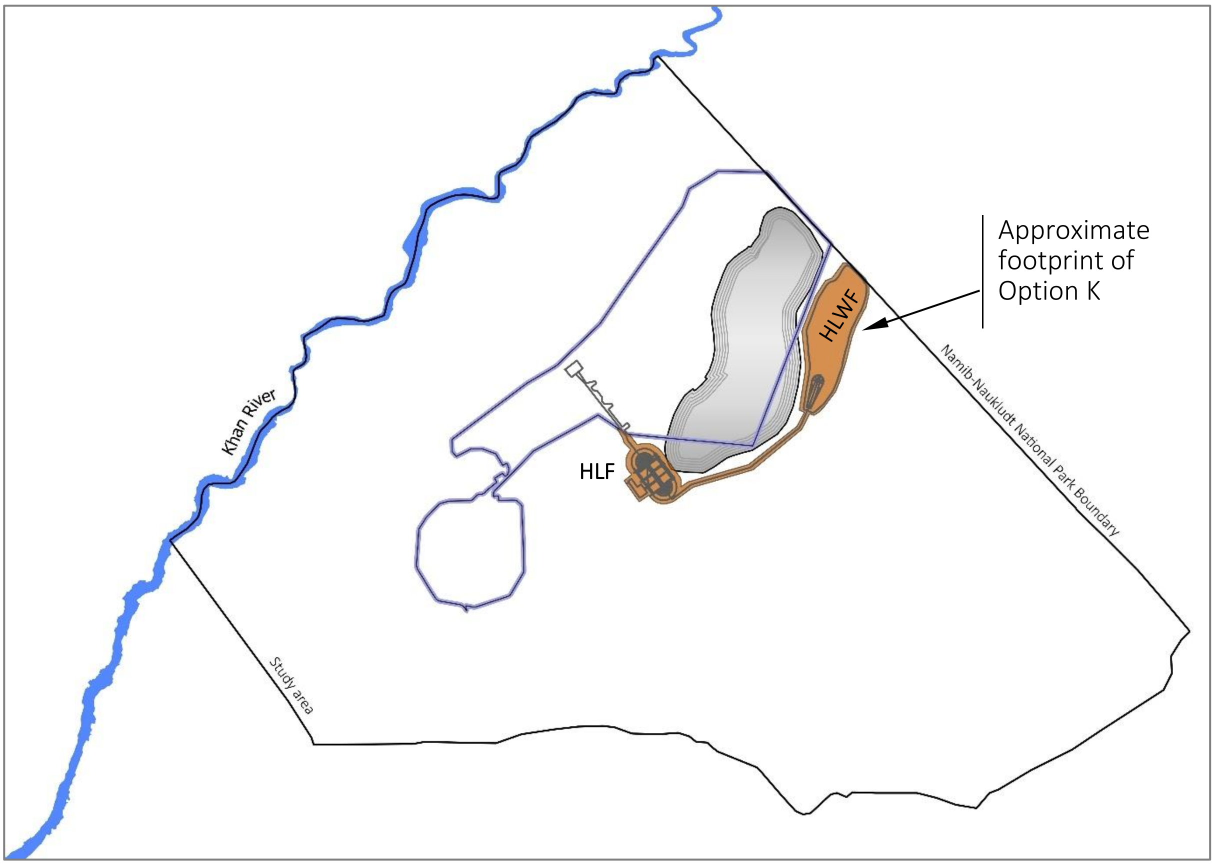


Figure 17. Layout and location of proposed Option K for the HL Facility, the HLWF and the connecting infrastructure, the final one.

The outlines of the footprint was digitised as a ~50 m buffer around the outer lines on supplied technical drawings on plan. Refer to Figure 1 for a description of the study area and other features and to other figures for the location of this optional layout relative to biodiversity features

6.3 Potential key impact factors

Here I discuss some of the potential impact factors involved in the proposed HL project. These are particularly pertinent and are the most important aspects that might sway a decision on proceeding, altering or cancelling any project here.

6.3.1 Dust as a plant stressor

Dust consists of particulate matter that is small enough to be raised and carried by wind. Many industries, and especially mining, are associated with particulate emissions ranging from carbon soot to mineral dust (Farmer, 1993). Dust is mostly viewed from the perspective of its effects on human health, but it has been shown to affect plants' physiological processes – and thus presumably also their 'health' – through a number of pathways (Grantz et al., 2003).

The effect of dust on plants differs firstly according to the particles' size distribution and shape and their chemical characteristics (Farmer, 1993; Grantz et al., 2003). Secondly, the effects will differ depending on whether it clogs stomata, causes physical damage, or decreases the amount of photosynthetically active radiation (PAR) reaching the photosynthesis apparatus (Van Heerden et al., 2007), or increases leaf temperature because of a net absorption of infrared radiation (Grantz et al., 2003), or all of these together.

Clogging of stomata results in a decrease in the amount of CO_2 that can be assimilated during photosynthesis. This aspect, together with the blocking of PAR, is the best studied mechanism. During mining, dust is mostly produced and subsequently dispersed after an event that disturbs the soil surface, like blasting, moving soil with front-end loaders or trucks driving on loose material (Petavratzi et al., 2005).

It is therefore not always a continuous phenomenon, being associated with events that occur at certain times of day. In this regard, the timing of dust dispersion matters for plants: if it is deposited when the stomata are closed (at night for C3 and C4 plants, in the day for CAM plants), it interferes less with the photosynthesis process than if it is deposited when the stomata are open (Hirano et al., 1995).

Size is the second factor that modulates the clogging effect – smaller particles tend to be more effective at blocking the stomatal opening than larger particles do (Hirano et al., 1995). The size of a typical stoma on a Welwitschia plant is 10 µm, about the same as the largest dust particles that fall in the PM10 class. Hence, if the dust source contains a relatively large fraction of PM10 class particles, this effect of clogging is likely to be greater. Clogging further depends on the distribution of stomata on leaves. For example, Welwitschia leaves have equal numbers of stomata on the upper and lower surfaces (Krüger et al., 2017). Dust deposition on these leaves will thus affect principally the stomata on the upper leaf surface, leaving the lower stomata open to allow gas exchange, but presumably at least partially affecting water use efficiency and gas exchange. The stomatal distribution of other desert plants of the area has not yet been studied in detail.

The decreased amount of PAR reaching the cells and photosynthesis apparatus results in a decreased amount of electron transport along the photochemical pathway, thus decreasing the amount of carbon that can be assimilated (Sharifi et al., 1997; Van Heerden et al., 2007). Physical damage can be caused through abrasion as a result of high windspeeds during east wind conditions – this is quite common in the Namib and especially Welwitschia leaves can be damaged in this way (pers. obs.).

Photograph 1. An example of a Welwitschia leaf that has been abraded by dust that is carried by the strong east winds.

Naturally occurring desert dust is probably rounded due to constant abrasion, whereas dust created by blasting and crushing is more angular, and the sharper/rough edges can cause physical damage to the plant leaves (and stems) (Van Heerden et al., 2007).

The various effects described above have all been documented to lesser or greater degree, but there is still confusion about the extent of damage that will result in either decreased productivity, or decreased reproduction or in plant death.

Monitoring at the Husab Mine has only shown an indication of a relationship between dust load and plant health where some mortalities of plants close to the pits where dust loads are truly excessive (> ~500mg/m^2/day). The physiological effects and secondary losses of plant material through abscission of leaves can be reversible if the stressor is removed (Van Heerden et al., 2007; Bao et al., 2016), with some indication that growth rates can be affected depending on the type of dust (Bao et al., 2016). However, continued stress cause by abrasion on desert plants will affect plant health and perhaps hamper the plants growth or survival.

However, although the pH of any material being deposited on another could be considered an important modulator of its ultimate effects, there is surprisingly little known about the role of dust pH in damaging plant tissues. Some research has shown that alkaline or acidic particulate matter can cause cell death through focal plasmolysis (Farmer, 1993; Grantz et al., 2003). Most documented general toxic effects of dust particles on vegetation are linked to their acidity, trace metal content, nutrient content, surfactant properties, or salinity (Grantz et al., 2003), but the levels at which significant plant damage occurs are still a bit of a mystery, particularly for pH. The implication of this uncertainty is that the potential for impacts as a result of highly alkaline (caustic) or acidic (corrosive) dust should be assessed with the precautionary principle until more is known about potential impacts.

Photograph 2. Deposition of windblown dust on the lee side of Welwitschia plants resulting from strong east wind conditions. An accumulation of acidic dust such as this may have impacts on soil conditions, and on the near surface roots of the plants.

An additional pathway for an impact to occur to plants is the caking of the surface of the soil by fine particles that forms a physical crust when receiving low moisture additions (such as would happen in a fog or light rainfall event). This pathway has received scant attention in the literature. Heavy rainfall and hoof action of grazing animals can break such a crust quickly, but it is possible that it might have enough effect to decrease the amount of water infiltration from local rainfall. Additionally, the pH of the dust may further affect soil nutrient availability (Grantz et al., 2003).

6.3.2 Water stress

This subject has been dealt with in detail for the BIA of the proposed expansion of the main WRD (Wassenaar, 2018; the relevant section from that report is reproduced in Appendix 1). Several lines of evidence suggest that variable, irregular surface flows in the ephemeral drainage lines on the gravel plains are most likely critical for the survival of at least the Welwitschia plants and most likely for all the other local perennial shrub species. All of these, and especially the Welwitschia plants, occur near such drainage lines at the bottom end of long ephemeral catchments. The details of the surface and sub-surface hydrology could be interesting, but the report by Wassenaar (2018) suggests that the persistence of these plant species depend on these drainages simply being kept patent. Any interference with surface flows is thus likely to lead to downstream impacts on plant vitality and ultimately on population health.

6.3.3 Koppies and ridges as inselbergs

Inselbergs are isolated hill structures that represent distinctly different habitats from their surroundings (Burke, 2002; 2003). Although the arid zone of Namibia is notoriously difficult to classify into distinct plant communities that are characterised by distinguishing species, inselberg communities are however mostly quite distinct from their surroundings. (Burke, 2002). As a result, they often harbour species that are adapted to the microhabitat conditions there, especially soil moisture profiles.

Although inselbergs are normally considered on a large scale, in the regional landscape of the central Namib with its vast gravel plains, all isolated rocky ridges could function as inselbergs. In the study area especially, the rocky ridges are significantly more diverse, not only in plants, but also small mammals and reptiles, than the surrounding plains (Wassenaar & Mannheimer, 2010). The ridges do differ in terms of their diversity and distinctness of species composition though, principally because of their geology. In this regard the marble ridges and granite koppies provide more nooks and crannies (i.e habitat) for plants to grow, and cracks and fractures for water to infiltrate than the ridges formed by schist outcroppings.

The value of the marble outcrops as refugia for species, such as the range-restricted Husab sand lizard (*Pedioplanis husabensis*), and thus as a key factor in explaining a region's diversity should be assessed at a landscape scale. Species are usually distributed over larger regions, wherever suitable habitat occurs within dispersal distance. A break in the distribution of ridges across a larger landscape will increase the effective dispersal distance for a ridge-specialist species and decrease the chances that it will find the next available suitable habitat when dispersing. It is impossible to tell how many of these inselberg-like ridges may be lost before it affects the regional distribution of a species, but because distance and location will influence dispersal and colonisation rates, it will happen sooner than the total area of suitable habitat suggests. As such, the marble ridges are usually considered as special habitats that are sensitive to disturbance, not only for each ridge separately, but as a collection of suitable habitat islands in the larger landscape.

6.4 Potential impacts for Option G

6.4.1 Interference with water supply to the Welwitschias

This impact refers to biodiversity features and processes described in Figure 8.

Nature of impact: Negative. A previous study (Wassenaar, 2018) has shown that the viability of the population of Welwitschia plants to the south of the mine is in all likelihood critically dependent on uninterrupted surface flows in the numerous catchments that feed into the main drainage of the plain south of the mine. One drainage line in particular, the so-called Husab Channel (see Figure 6) is probably key to the survival of the majority of the plants, but all E-W flowing drainage lines contribute to the overall health of the plants (Figure 6).

The currently proposed HLWF infrastructure for Option G of the HLF will mostly miss the important drainage lines to its SE, but will block the bypass channel which was approved as a mitigation for the expanded main WRD (Figure 18; see also Figure 8). The aim of this bypass is to maintain flow in the so-called Husab channel, which is one of the most important drainages for the Welwitschia field. **Any blockage of this channel would result in a fatal flaw not only for the current project but for the expansion of the main WRD as well**. The fact that the currently proposed layout of the HLWF will block the bypass channel results in a highly significantly negative rating for this impact before mitigation.

Mitigation: Place the infrastructure in such a position that it will not interfere with any E-W flowing surface drainages. Be sure to avoid interfering with water flow in the drainage line running along the SE of the HLWF (see Figure 18) by allowing a buffer of at least 30m between the edge of the HLWF and the edge of the drainage channel. Most importantly, the bypass channel has to be avoided entirely by allowing a buffer of at least 30m between the edge of the HLWF and the edge of the bypass channel along its entire length. See **Error! Reference source not found.** for proposed locations and shape of t hese two features to minimise the impact of blocking of surface flows.

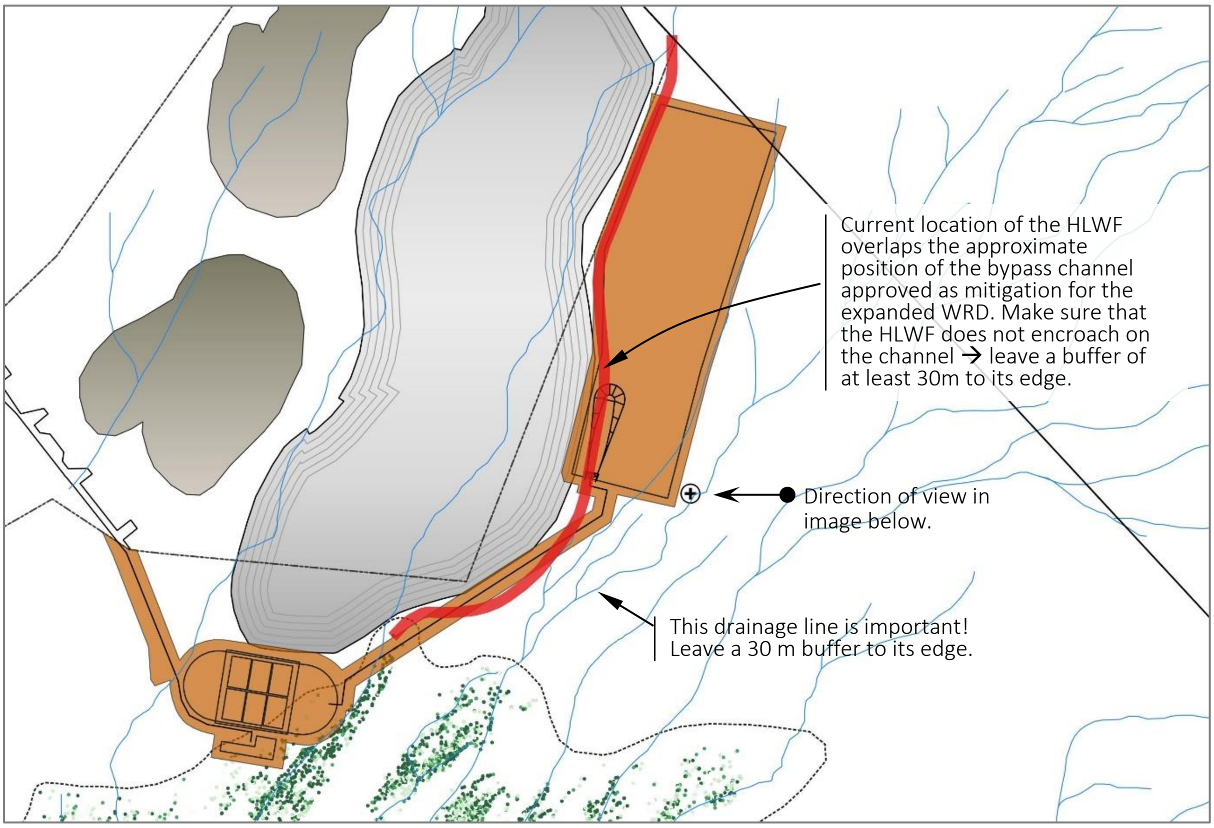
Impact after mitigation: Should the blockage of the bypass channel be entirely avoided, the rating of the impact would decline to Low.

Summary: Interference with water supply to the Welwitschias

	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High	Low	CONSEQUENCE	High	Low
DURATION	High	Low	PROBABILITY	High	Low
SPATIAL SCALE	Medium	Low	SIGNIFICANCE	**High**	HIGH*

*IMPORTANT NOTE:

It is quite clear that the main condition for the approval of the expansion of the current main WRD, namely the construction of a bypass for the Husab Channel, has not yet reached the ears or eyes of the planners of the Heap Leach project. This might simply be an oversight and could be easily corrected. But there is some precedent here that is cause for great concern: At the time of the main Husab EIA, a similar kind of mitigation was approved for the original layout of the main WRD. Even existing technical drawings of the current WRD includes this “clean water channel and pond”, with dispersion channels to the starved drainage lines closer to the large marble ridge E of the TSF. This mitigation was designed to replace water for the catchments that were effectively halved by the mine plant, but it was simply never constructed. That particular issue was not critical, so it could be overlooked to some extent, but the current issue is of a much greater importance. Hence, **I recommend that the mitigated impact be rated as high**, in spite of its theoretically possible low rating, until the project planners have included the bypass channel as a technically acceptable plan.



Current location of the HLWF overlaps the approximate position of the bypass channel approved as mitigation for the expanded WRD. Make sure that the HLWF does not encroach on the channel → leave a buffer of at least 30m to its edge.

Direction of view in image below.

This drainage line is important! Leave a 30 m buffer to its edge.

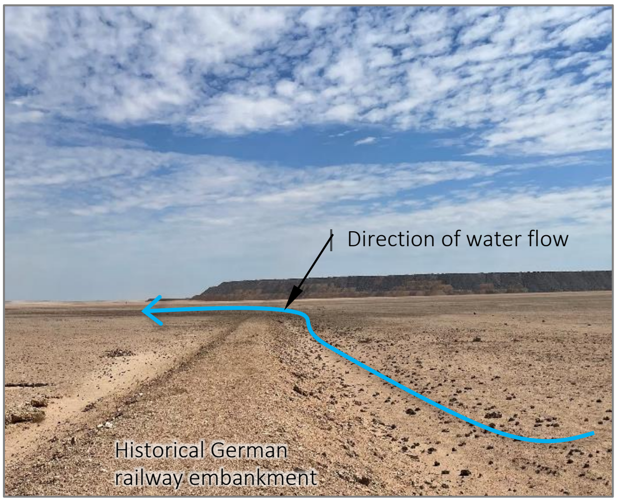


Figure 18. The location of a critical point close to the boundary of the proposed HLWF for option G (black cross in circle). The inset photograph was taken while standing on the old railway embankment near the black cross, on the map looking twards the current WRD. Drainage is from the R to the L on the picture. Where the water meets the embankment, it flows away from the viewer for about 30 m before cutting through the embankment and continuing further SW (to the L), following the dark patch in the background. This shows that the drainage line would at times carry enough water to contribute to soil moisture for the Welwitschias further downstream. It is thus important for this drainage line to be kept patent. Additionally, the thick red line shows the approximate path and location of the bypass channel that was approved as a mitigation for the expansion of the main WRD. The currently proposed location of the HLWF would clearly block this channel.

6.4.2 Dust deposition on the plants growing on the marble ridges downwind of the HLF and on the Welwitschia plants downwind of the HLWF and HLF.

This impact is relevant to all biodiversity features, but in particular it relates to two sites of special biodiversity interest, namely the protected plant species on the main marble ridge and the Welwitschia plants in the large population to the SW of the project (Figure 2A, Figure 4A, Figure 6A and Figure 19; also refer to Section 6.3.1 above). In particular, a large source of dust emissions is the processes that occur on the HLF itself, and in Option G this is located virtually on top of the NE edge of the Welwitschia field (Figure 19).

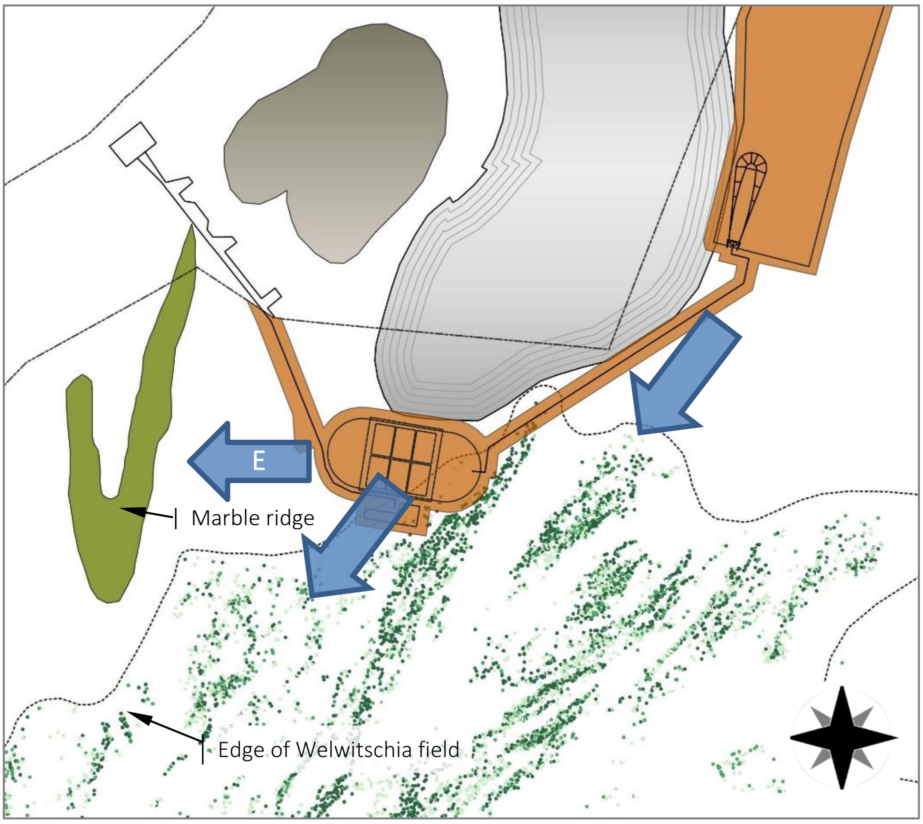


Figure 19. The location of the HLWF and HLF for Option G relative to the two main biodiversity features, the Welwitschia field and the marble ridge. Blue arrows indicate the north-easterly and easterly wind directions referred to in the text.

Nature of impact: Negative. The overall risk that dust will affect plant (or other organisms) health is a function of 1) the total dust load of the various particulate sizes per day and per year, 2) the distribution of wind directions and velocities at different times of the year, 3) the likely fallout pattern (plus the location of the dust sources relative to the biodiversity features of interest), and 4) the chemical nature and physical shape (including angularity) of the dust.

<u>Likely sources and loads of dust emissions</u>: With heavy dust loads[4], plants can be physiologically compromised or die. Several mechanisms are involved in dust impacts, including clogging of stomata, interference with photosynthetically active radiation, and increases in leaf temperatures. All these mechanisms can result in compromised photosynthesis and water conservation.

At the proposed HLF, particulate matter emissions will derive from crushing (located near the low-grade ore stockpile) and screening operations, conveyor transport and transfer of low-grade ore, stacking of the HL pad, reclamation of leach waste, road transport and wind erosion from the stockpiles, HL pad and HLWF (Liebenberg-Enslin, 2021). Predictions, based on design criteria and production rates for the so-called base case option (not evaluated in the current BIA) and using emission factors linking the quantity of a pollutant with the releasing activity suggest that crushing and screening are the main contributing sources to unmitigated emissions, followed by materials handling (Liebenberg-Enslin, 2021).

Overall, without dust mitigations in place, the HL project will contribute 10%, 4% and 2% of overall emissions of TSP, PM10 and PM2.5 respectively, but this reduces to 5%, 3% and 1% respectively with

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[4] There is not good data to define what I mean by "heavy" dust loads. Plants inside the unmitigated dispersion zone of the current dust dispersion model for Husab Mine typically receive more than 150 and up to 1,700 mg/m^2/day (Wassenaar, 2018), with the plants near the pits receiving the highest loads. These plants are all physiologically compromised, and those that received the highest loads have died. However, the relationship between plant health and dust load remains poorly clarified, and particularly the potential multiplier effect of high or low pH of dust.

mitigation (Liebenberg-Enslin, 2021). However, it is important to note that there are no mitigations foreseen for the HLWF and the HLF Pads (Liebenberg-Enslin, 2021). Overall, the dust fallout impact from the base case HL project was rated as low significance, but both options G and H were expected to exceed health standards over the short term with higher ground level concentrations measured at the Giant Welwitschia, the Welwitschia flats and the Husab Campsite (Liebenberg-Enslin, 2021).

Total dust emissions are expected to be relatively low, especially with mitigation, at least as a fractional contribution by the HL project to the overall dust emissions, but the area close to the HLF will experience dust loads exceeding national safety standards. Observations of the situation of plants growing in close vicinity to the pits, it is likely that the plants immediately adjacent to the HLF will experience dust loads high enough to cause permanent damage and death.

Distribution of wind directions and velocities: In the context of producing an impact on biodiversity, the northeasterly winds are the most relevant because these are most likely to disperse wind-eroded dust from the HLWF and the HLF itself towards the Welwitschia population. A small but significant component of the annual wind portfolio is similarly high velocity easterlies, which would also affect plants on the marble ridge, although this is admittedly a smaller issue than the risks to the Welwitschia population. The northeasterlies typically start in the period March to May but reach their highest velocities (~4% > 10 $m.s^{-1}$ and a further ~5% between 7 and 10 $m.s^{-1}$) in the period from June to August (Liebenberg-Enslin, 2021). During this latter period, for a total of approximately 15% of the time, NE winds exceed the minimum threshold for lifting and transporting dust particles (Liebenberg-Enslin, 2021). Although the expected dust loads may thus be low on average, there is a chance that dust can be transported towards the biodiversity features during a significant part of the year. This risk is currently unknown, but the dispersion model's fallout pattern (Liebenberg-Enslin, 2021) suggests that it is indeed present (see photograph 2).

The likely fallout pattern: Liebenberg-Enslin (2021) simulated the dispersion of dust from the base case option (Figure 20). In this scenario, the main infrastructure is located to the SE of the main WRD, with the HLWF between the HLF and the park boundary (Figure 20). She considered the primary source of dust to be the crusher, which is located in the plant area near the pit (and thus for all practical purposes not important in terms of biodiversity impacts), followed by the HLF with almost no contribution from the HLWF.

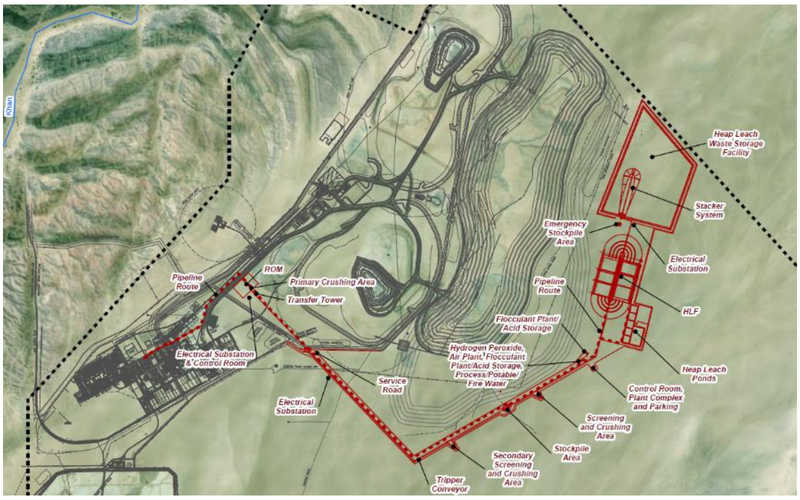

Figure 20. The discarded Option A, also referred to as the "base case".

The dispersion model, clearly following this scenario (see Figures 17 to 31 in Liebenberg-Enslin, 2021) predicts for almost all unmitigated scenarios and for many of the mitigated scenarios, that especially PM10 fallout will reach a significant number of plants in the Welwitschia field.

It is very difficult to compare this scenario to Option G, where the only source of dust emissions from the base case area would be the HLWF, which would however be located closer to the Welwitschia field than in the base case. Additionally, the HLF will be located virtually on top of the NE edge of the Welwitschia field (Figure 19). Considering all the above, and using the precautionary principle, in summary I consider the likelihood that dust from the HLWF will reach the plants for more than 30 days in the year to be at least moderately high (for HLWF) and high (for HLF), even though the total amounts might be relatively small, especially for the fraction larger than PM10.

The issue of acid dust: The pH of the waste material in the HLWF, and thus also the pH of any dust emitted from there, will be between 4.5 and 5.2, enough to be considered a skin corrosive and eye irritant (Golder Associates, 2017). A pH lower than neutral is likely to have corrosive effects on plant tissues, which will be multiplied over time and with fog precipitation, thus exacerbating any existing damage as a result of natural dust scour. There is however surprisingly little information available on this aspect (see Section 6.3.1 above), with the result that it is difficult to gauge the risk to the plants. In the case of Option G, this would be principally the plants in the Welwitschia field to the SW of the HLF and HLWF.

Rating: The overall incremental dust load as a result of the HL Project is apparently low. However, with the currently proposed location of the HLF being so close to the Welwitschia field, the likelihood will increase significantly, and will quite possibly lead to the death of some plants.

In addition, the fact that the dust will be corrosive, coupled with an at least marginal overlap of north-easterly winds and fog, it is highly likely that mortalities will be even higher.

Although plants can theoretically be cultivated and their populations restored after mining, the plant species involved in this impact are not subjects for easy cultivation. Welwitschia is also a long lived species, purportedly reaching ages of up to ~ 1 000 years.

Death of Welwitschia and most of the rocky ridge specialists will be non-mitigatable and cannot be restored. As such the unmitigated impact will be medium, with uncertainty in almost all categories forcing this up to high. After mitigation, the impact could theoretically decrease to low, but the remaining uncertainty about the chances that acid dust may contribute significantly to mortality, dictates that the rating should remain at least medium.

Mitigation: Locate the HLWF as far away from the Welwitschia field as possible. Locate the HLF as far away from the marble ridge and Welwitschia field as possible. See **Error! Reference source not found.** f or proposed locations and shape of these two features to minimise the impact of dust. Apply all mitigations proposed by Liebenberg-Enslin (2021).

Summary: Dust deposition					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High (?)	Low (?)	CONSEQUENCE	Medium (?)	Low (?)
DURATION	Medium (?)	Medium (?)	PROBABILITY	Medium (?)	Low (?)
SPATIAL SCALE	Medium	Low	SIGNIFICANCE	**High (?)**	**Medium (?)**

Management/research: With the significant uncertainty around the effect of acidic dust on plant leaves (Welwitschia and other species), it is proposed that a research project should be done to determine the effect of dust of various pH levels on plant leaves and plant health overall prior to the development of the Heap Leach project.

Additionally, monitoring points with dust buckets should be located at various critical points at increasing distances from the dust sources and close to plants in order to be able to link dust loads to individual receiving plants with greater certainty.

6.4.3 Encroachment of HLF into the no-go area and consequent loss of individual Welwitschia.

This impact refers to biodiversity features and processes described in Figure 6 and Figure 19.

Nature of impact: Negative. The proposed location for the HLF encroaches into the no-go area defined by the Welwitschia field. Since translocation of Welwitschias is fraught with risk and has proved to date to be unsuccessful on an individual basis, the construction of the currently designed waste facility here will most likely lead to the death of most of the plants.

This unique, iconic, and protected plant is well-known amongst cognoscenti and professional and amateur botanists and is an important tourist attraction. Any impacts on it will thus carry the additional multiplying effect of damage to company reputation. In addition, this will affect biodiversity features that are in an area that was defined to be No Go on the basis of its biodiversity features. By definition this means that there are no mitigations other than avoidance possible, and it is thus a **fatal flaw** that should prevent this option.

However, the current location of the HLF is likely an oversight because of the use of an older version of the sensitivity map. The map was recently updated to reflect data and information that have been added from studies and monitoring since the drafting of the original sensitivity map by Wassenaar & Mannheimer (2010). The impact of the loss of individual plants will be exacerbated by, and cumulative to, the potential effect of high loads of acidic dust close to the HLF on plants in the immediate vicinity of the HLF.

Rating: Without mitigation this encroachment will result in a highly significantly negative impact, and possibly a fatal flaw. With mitigation it will be non-existent.

Mitigation: Avoid the impact by shifting the HLF away from the no-go area. See **Error! Reference source not found.** for two possible locations that would both avoid this impact.

Summary: Encroachment of HLF into the no-go area and consequent loss of individual Welwitschia					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High	Low	CONSEQUENCE	High	Low
DURATION	High	Low	PROBABILITY	High	Low
SPATIAL SCALE	Low	Low	SIGNIFICANCE	High	Low (zero)

6.4.4 Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils that excavate their burrows here, with consequent knock-on effects on plant productivity and large herbivore presence.

This impact refers to biodiversity features and processes described in Figure 10 and Figure 12.

Nature of impact: Negative. Clearing and levelling of land for construction of the HLWF and its associated linear infrastructure will destroy a proportion of the vegetation patches, some of which are occupied by and enhanced by the presence of gerbils, that provide food for large mammals, in particular Hartmann's mountain zebra.

A Master's level study conducted on the role of gerbils as ecological engineers has conclusively shown that these small mammals are critical for the maintenance of vegetation productivity on the gravel plains. The enhanced productivity of the naturally occurring vegetation patches is quite likely the reason why zebras are resident in this hyper-arid zone. A study conducted for Swakop Uranium's biodiversity monitoring programme has shown that the zebras do indeed utilise the area in question. The destruction of these vegetation patches and the removal of the gerbils will thus lead to an unknown reduction in the number of zebras that can be supported in this area, as well as to a reduction in the time that they can spend here.

Although the likelihood of the impact is high, the total proportion of patches that are affected compared to the patches across the whole area is probably still fairly small. Nevertheless, there are remaining uncertainties with regard to the spatial and temporal dynamics of this feature and process (only further studies on plant productivity in relation to the use of the plains by large mammals will tell whether both dimensions may be more or less significant than currently thought), hence the significance rating of medium is correct.

Mitigation: Avoidance is only possible if another location option is chosen for the HLF. There are possibly only a few options to minimise the area of the footprint involved, and it is unlikely that this will lead to a significant reduction in the extent of the impact. As such, there are no real mitigations possible, and the mitigated and unmitigated ratings are thus the same.

Summary: Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	Low	Low	CONSEQUENCE	Low	Low
DURATION	Medium	Medium	PROBABILITY	Low	Low
SPATIAL SCALE	Low	Low	SIGNIFICANCE	Low	Low

6.5 Potential impacts for Option H

6.5.1 Destruction of gravel plain vegetation patches and the ecological engineering effect of gerbils that excavate their burrows here, with consequent knock-on effects on plant productivity and large herbivore presence

This impact refers to biodiversity features and processes described in Figure 10 and Figure 12.

Nature of impact: For mechanism, see Impact 6.4.4 above. The location of the infrastructure for Option H is however such that the density of vegetation patches and the number of burrows per patch under the infrastructure footprint is relatively low. The sheer size of this impact is therefore likely to be small from the outset.

Mitigation: Avoidance is only possible if another location option is chosen for the HLF. There are possibly only a few options to minimise the area of the footprint involved, and it is unlikely that this will lead to a significant reduction in the extent of the impact. As such, there are no real mitigations possible, and the mitigated and unmitigated ratings are thus the same.

Summary: Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	Low	Low	CONSEQUENCE	Low	Low
DURATION	Medium	Medium	PROBABILITY	Low	Low
SPATIAL SCALE	Low	Low	SIGNIFICANCE	**Low**	**Low**

6.5.2 Dust deposition on the plants growing on the marble ridges downwind of the HLF and on the Welwitschia plants downwind of the HLWF and HLF.

This impact is relevant to all biodiversity features, but in particular it relates to two sites of special biodiversity interest, namely the protected plant species on the main marble ridge and the Welwitschia plants in the large population to the SW of the project (Figure 2B, Figure 4B, Figure 6B and Figure 21; also refer to Section 6.3.1 above). For Option H, the main dust sources that could contribute to dust loads on plants are the processes that occur on the HLF itself, and the location of the HLWF near the Welwitschia field (Figure 19).

Nature of impact: Negative. Refer to Impact 6.4.2 for a detailed description of the contribution of the total dust load of the various particulate sizes per day and per year, the distribution of wind directions and velocities at different times of the year, the likely fallout pattern (plus the location of the dust sources relative to the biodiversity features of interest), and the chemical nature of the dust to the overall impact.

The same issue of the location of the biodiversity features to the SW of the HL Project (thus being open to high velocity north-easterlies that dominate in the winter) that was identified in Option G exists in the case of Option H, with one important difference: in Option H the HLF is located to the west of the marble ridge, thus protecting the marble ridge from the north-easterlies. However, as explained in Liebenberg-Enslin (2021), the predominant winds in the summer months are westerlies. The close proximity of the HLF to the west of the marble ridge thus exposes the ridge to acidic dust from that direction. Importantly, all the biodiversity features of special interest will be within the high-level fallout zones for both the HLF and HLWF. As a result, the location and layout of infrastructure for Option H represents a sum total of risks to species in both the marble ridge and the Welwitschia field that would be unavoidable, even with mitigation.

Rating: The large amount of uncertainty makes it extremely difficult to rate this impact with any confidence. Overall, the fact that the risk is unavoidable even with mitigation suggests that the significance should be considered high, and the unmitigated effect is indeed rated as high here. However, it is also quite possible that the mitigations will significantly decrease this risk, hence the post-mitigation rating of medium is warranted. ***It must be noted though that the assessment is made with a large caveat emptor – there are a number of unknowns that may affect the rating in the end, starting with the poor knowledge of the effect of acid dust on plants***.

Mitigation: Locate the HLWF as far away from the Welwitschia field as possible. Locate the HLF as far away from the marble ridge and Welwitschia field as possible. See **Error! Reference source not found.** for proposed locations and shape of these two features to minimise the impact of dust. Apply all mitigations proposed by Liebenberg-Enslin (2021).

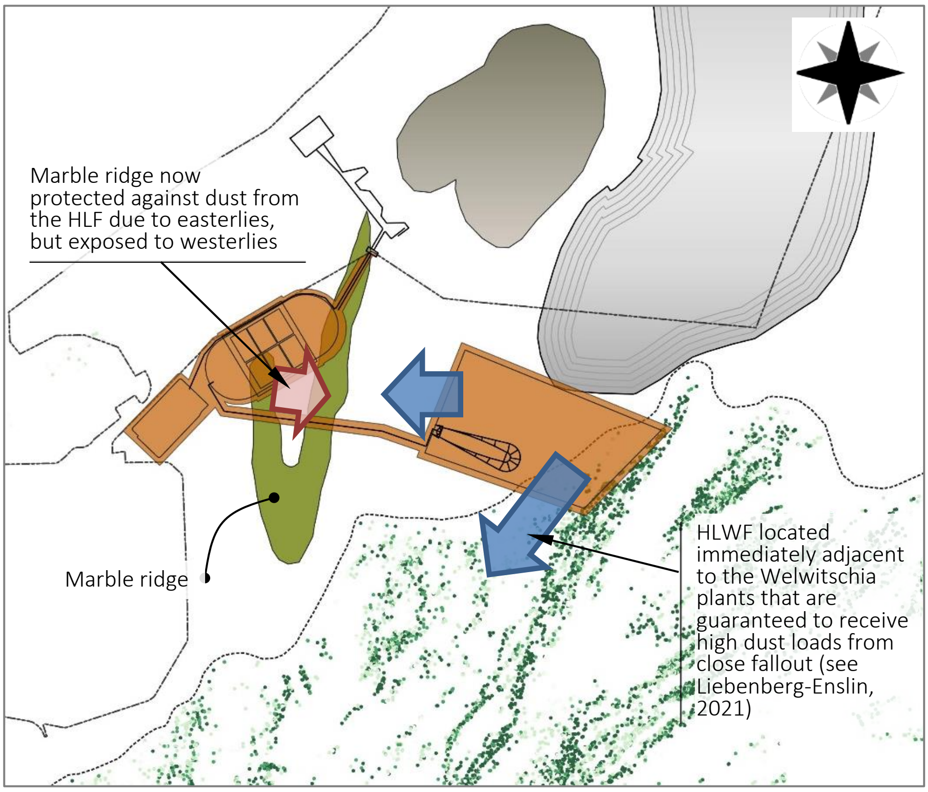

Figure 21. The location of the HLWF and HLF relative to the two main biodiversity features, the Welwitschia field and the marble ridge.

Blue arrows indicate the main wind direction in the winter and the pink arrow indicates (broadly) the main direction in summer.

Summary: Dust deposition					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High (?)	Medium (?)	CONSEQUENCE	Medium (?)	Medium (?)
DURATION	Medium (?)	Medium (?)	PROBABILITY	Medium (?)	High (?)
SPATIAL SCALE	Medium	Low	SIGNIFICANCE	**High (?)**	**Medium (?)**

6.5.3 Encroachment of HLF into the no-go area and consequent loss of individual Welwitschia.

This impact relates to biodiversity features and processes described in Figure 4 and Figure 6.

Nature of impact: Refer to Impact 6.4.3. The same mechanism and probable cause apply here.

Rating: Without mitigation this encroachment will result in a highly significantly negative impact, and possibly a fatal flaw. With mitigation it will be non-existent.

Mitigation: Avoid the impact by shifting the HLF away from the no-go area. See **Error! Reference source not found.** for two possible locations that would both avoid this impact.

Summary: Encroachment of HLF into the no-go area and consequent loss of individual Welwitschia					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High	Low	CONSEQUENCE	High	Low
DURATION	High	Low	PROBABILITY	High	Low
SPATIAL SCALE	Low	Low	SIGNIFICANCE	High	Low (zero)

6.5.4 Destruction of habitat-specialist and other plant, vertebrate and invertebrate species of conservation significance

This impact refers to biodiversity features described in Figure 4 and Table 2, as well as a number of detailed tables and figures in the original BIA by Wassenaar & Mannheimer (2010).

Nature of impact: The marble ridge, part of the Koppies and Ridges on Plains habitat, was rated as Very Sensitive because it supports a relatively high number of protected and small-range species of conservation concern. See Figure 22 for some of the species that are found on the marble ridge habitat. Some of the most important are *Euphorbia giessii*, a Namib endemic, and *Lithops ruschiorum*, a protected species that occurs mostly on rocky hillsides, but several others have been recorded here or are known to occur in similar habitats close by. This V-shaped ridge, with the two arms of the “V” pointing northwards, is not uniform across its length. The western northwards-projecting arm is noticeably less diverse towards its tip (Figure 22 D) than over the rest of the ridge (compare Figure 22A).

The highest diversity, both structurally and in terms of species richness, is on the bottom corner of the “V”, stretching for some distance northwards along its eastern arm. It is also in this area along the arm that a population of *Lithops ruschiorum* was recorded during the main BIA for Husab Mine (Wassenaar & Mannheimer, 2010). In addition, rescued lithops rescued from other areas impacted by the development of the mine were relocated here.

Option H will have a footprint onto this marble ridge in two places: 1) more towards the north-eastern tip, where diversity is relatively low and 2) onto the higher diversity eastern arm (see Figure 21 and Figure 23, also compare Figure 22A and D). All organisms under the footprint and for some distance around it will be destroyed during construction, causing the direct loss of individuals and habitat. With a buffer of about 50 m around the outer edges of the technical drawings, this footprint effect would become quite significant and would affect a large number of protected species of conservation concern. From the technical drawings it does not appear as if avoidance is possible. Translocation of individual plants might be possible, but its value would be questionable since it will not replace lost habitat.

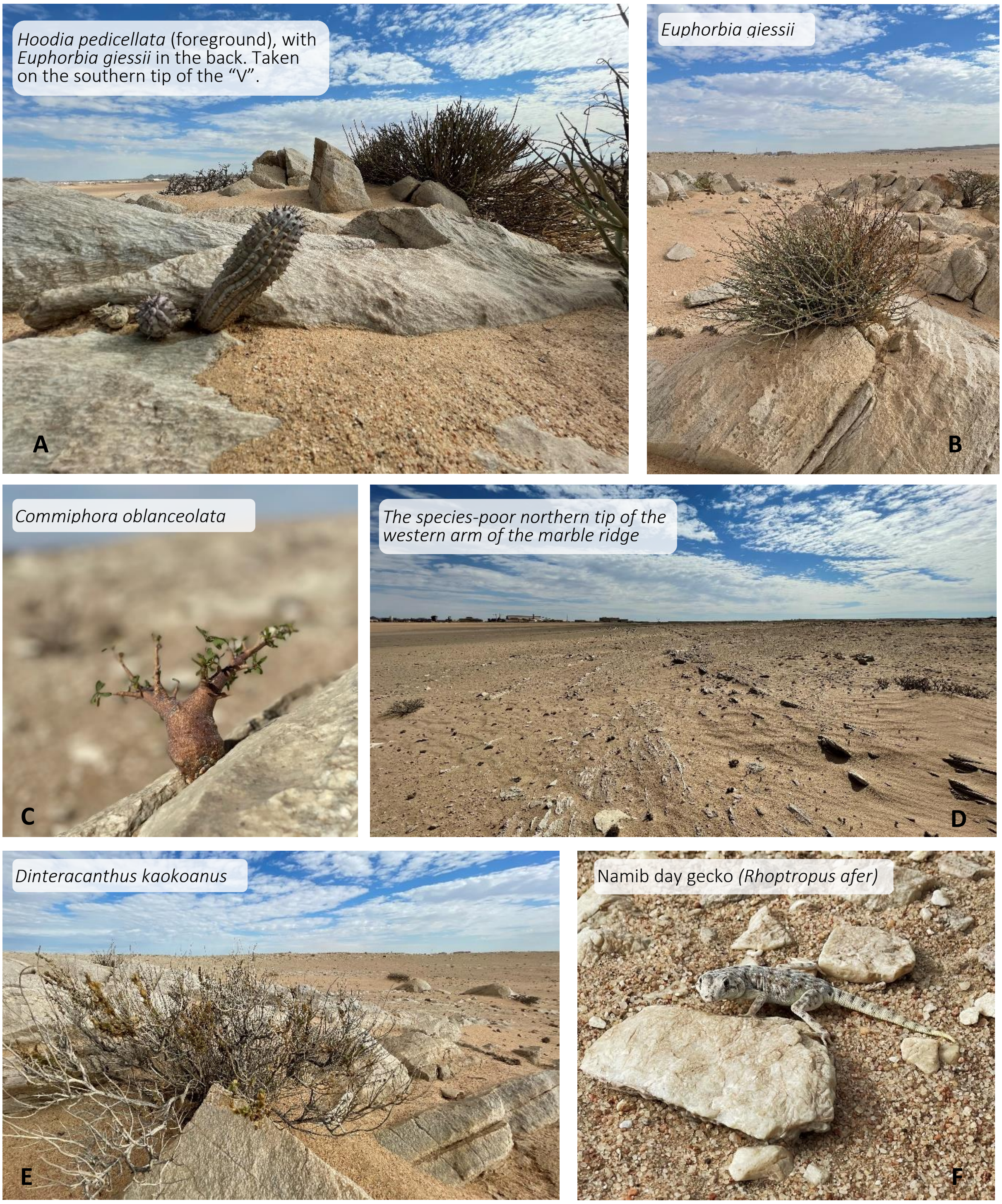

Figure 22. Some of the species that occur on the marble ridge.

Rating: There are few or no options for avoidance, the mitigation option of translocation is inferior and will decrease the extent of the impact only partially, and the habitat cannot be restored. This impact is therefore rated as high before mitigation and medium after mitigation, but this is increased to high on the grounds of the precautionary principle*.

Mitigation: Site inspection with definition of vertebrate and invertebrate habitat and – where possible – species, as well as identification of all affected plant species. Translocation of individual plants to suitable alternative locations where this is a possibility. Adaptation of detailed design to avoid the location of those that cannot be moved and to generally minimise the infrastructure footprint as far as possible.

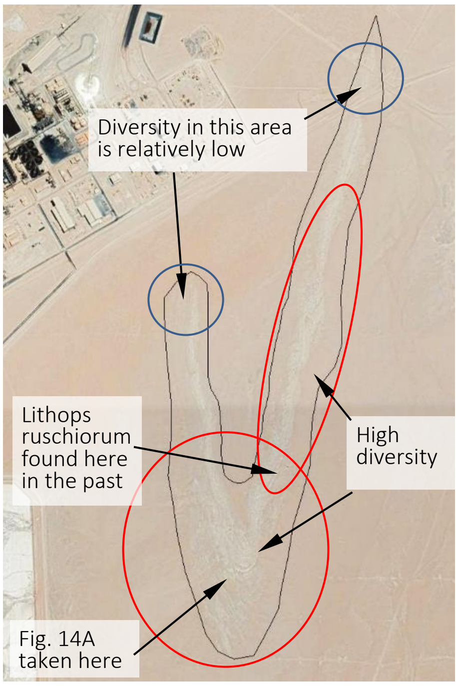

Figure 23. An aerial view of the V-shaped marble ridge near the TFS and plant.

Diversity is not uniform across the whole area, with most diversity clustered on its more structurally diverse bottom end and on the eastern arm.

Summary: Destruction of marble ridge plants and habitat					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High	High	CONSEQUENCE	High	Medium
DURATION	High	Medium	PROBABILITY	High	High
SPATIAL SCALE	Low	Low	SIGNIFICANCE	**High**	HIGH**

*NOTE: this type of habitat is relatively common across the Namib, but a small part of this particular ridge has already been lost to the development of the mine and the mine has caused disturbance to the even more important northwards extension (near the low grade ore stockpile) of the same formation into the Khan gramadoelas. This means that any further disturbances or destruction of this habitat would lead to a significant increase in the cumulative impact.

**NOTE: The rating keys out as Medium, but the uncertainty and possible poor outcome of translocation as a mitigation option increases this rating to a High under the precautionary principle.

6.6 Potential impacts for Option K

6.6.1 Interference with water supply to the Welwitschias (Option K)

This impact refers to biodiversity features and processes described in Figure 8.

Nature of impact: Negative. The viability of the population of Welwitschia plants to the south of the mine critically depends on uninterrupted surface flows in the numerous catchments that feed into the main drainage of the plain south of the mine (Wassenaar, 2018). Although the HLWF for Option K misses the drainage lines as well as the proposed bypass channel for the expanded main WRD (Figure 24, arrows 2 and 3), it is still at this stage a concept outline. There is therefore a chance that the final drawings will not entirely avoid these critical drainages. Should this occur, the water that could have been transported downstream to the Welwitschias after a large upstream rain event, will be prevented from doing so, thus raising the risks to the plants.

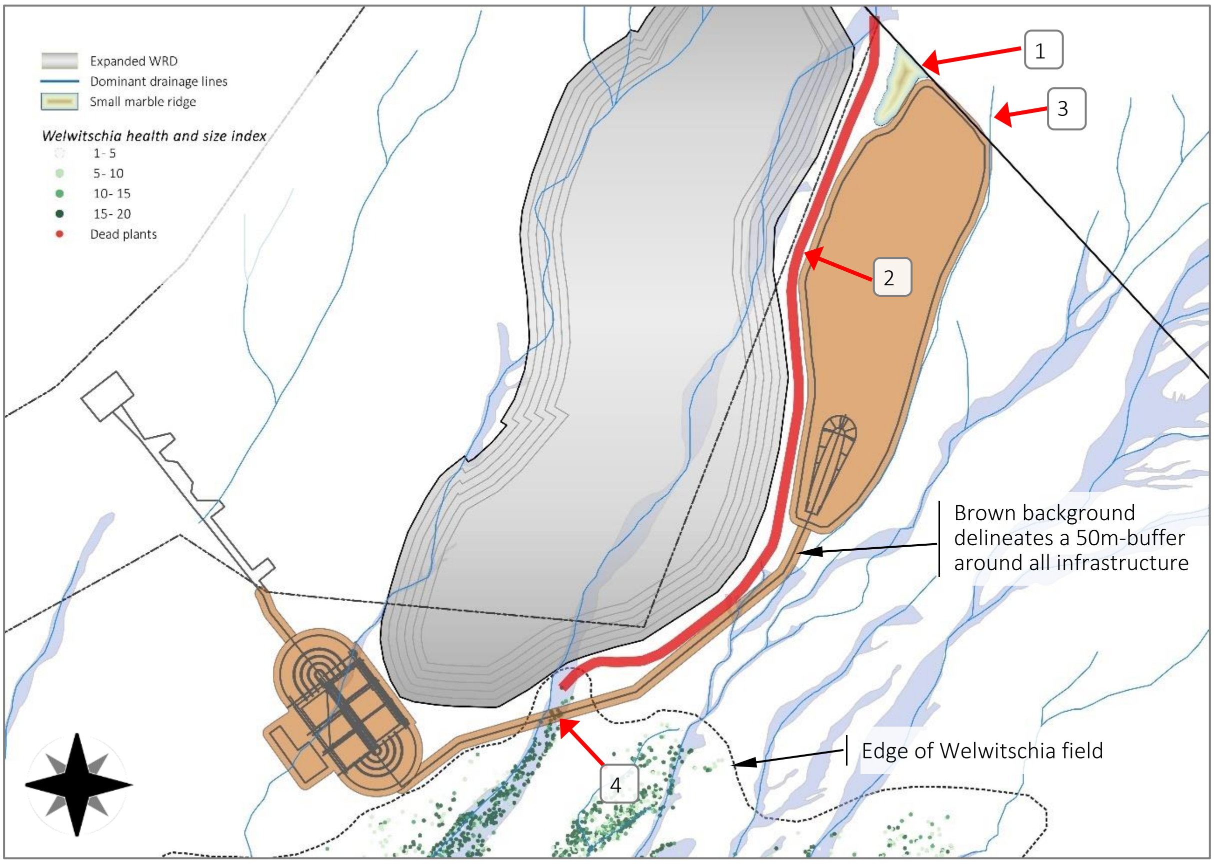

Figure 24. Layout and location of Option K (HLWF has idealised shape).

Note that the shape and location of the HLWF in this case is approximate, as it was digitised by eye from a supplied image. Key issues to avoid in the final design of the HLWF are indicated with red arrows:

1. *Arrow 1 points to the location of a small marble ridge, considered to be sensitive to disturbance on biodiversity grounds – this should be avoided.*
2. *Arrow 2 points to the approximate position of the proposed bypass channel for the expanded WRD.*
3. *Arrow 3 points to the location of a minor drainage line that should be avoided.*
4. *Arrow 4 indicates the point where the conveyor belt will cross the main Husab Channel as well as some Welwitschia plants. Construction here requires a specific Standard Operating Procedure to ensure avoidance of plants and avoidance of obstruction of water flow.*

Additionally, at the point where the conveyor belt crosses the Husab Channel (Figure 24, arrow 4), the siting of support structures for the belt could interfere with water flow.

Rating: The severity would measurable, thus medium; duration almost permanent for those plants affected; spatial scale is beyond the site boundary, giving a high consequence. It is possible that the designers will fail to keep these instructions in mind, thus the total significance becomes High before mitigation.

Mitigation: Ensure that design specifications for the HLWF includes explicit instructions to keep all infrastructure edges at least 50 m away from the closest edge of recognisable drainage channels as well as from the bypass channel (see Figure 24). Construct a bridge to support the conveyor belt where it crosses the Husab Channel (Figure 24, arrow 4). No support structures should be built inside the channel itself.

Impact after mitigation: Should the blockage of the bypass channel and all other visible drainage lines be entirely avoided, the rating of the impact would decline to Low.

Summary: Interference with water supply to the Welwitschias					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	Medium	Low	CONSEQUENCE	High	Low
DURATION	High	Low	PROBABILITY	Medium	Low
SPATIAL SCALE	Medium	Low	SIGNIFICANCE	**High**	**Low**

6.6.2 Destruction of or damage to Welwitschia plants underneath or in the vicinity of the conveyor belt (Option K).

This impact refers to biodiversity features and processes described in Figure 24.

Nature of impact: Negative. Individual plants may be damaged or destroyed during the construction of the conveyor belt, its support structures and any service roads along the infrastructure. The loss of any single plant represents a loss of reproductive potential and therefore an increased risk to the population. However, the total number of plants at risk is a very small percentage of the total population, hence the significance of this impact is already not large. It is rated as Medium.

Mitigation: Ensure that design specifications for the conveyor belt clearly specifies that no structure may be erected closer than 30 m from any individual Welwitschia plant. Similarly, the design specifications for any service roads should make it clear that the edge of the road should not come closer than 30 m from the nearest individual Welwitschia plants.

Draft a Standard Operating Procedure for locating, marking and avoiding individual plants during construction of the conveyor belt and any service road.

Impact after mitigation: By keeping a distance of at least 30 m between individual plants and any physical structures and roads, it should be possible to avoid damage to plants, thus the impact should decrease from Medium to Low.

Summary: Destruction of or damage to Welwitschia plants underneath or in the vicinity of the conveyor belt					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	Medium	Low	CONSEQUENCE	Medium	Low
DURATION	High	Low	PROBABILITY	Medium	Low
SPATIAL SCALE	Low	Low	SIGNIFICANCE	**Medium**	**Low**

6.6.3 Dust deposition on the plants growing on the marble ridges downwind of the HLF and on the Welwitschia plants downwind of the HLWF and HLF (Option K).

This impact is relevant to all biodiversity features, but in particular it relates to two sites of special biodiversity interest, namely the protected plant species on the main marble ridge and the Welwitschia plants in the large population to the SW of the project (Figure 3, Figure 5, and Figure 7; also refer to Section 6.3.1 above). In particular, a large source of dust emissions is the processes that occur on the HLF itself, and in Option K the HLF is located only about 1 km from the high-diversity areas of the main marble ridge (blue arrow 1 in Figure 25) and from the edge of the Welwitschia field in a south-westerly direction (blue arrow 2 in Figure 25).

Nature of impact: Negative. Refer to Impact 6.4.2 for a detailed description of the contribution of the total dust load of the various particulate sizes per day and per year, the distribution of wind directions and velocities at different times of the year, the likely fallout pattern (plus the location of the dust sources relative to the biodiversity features of interest), and the chemical nature of the dust to the overall impact.

The same issue of the location of the biodiversity features to the SW of the HL Project (thus being open to high velocity north-easterlies that dominate in the winter) that was identified in Option G exists in the case of Option K. The only difference is that in Option K the HLF has been moved off the Welwitschia field and tucked into the wind-shielded corner behind the main WRD. This location, while still posing an unknown risk to both the main marble ridge habitat and the downwind Welwitschia plants, is probably the best one of the available options, but for all intents and purposes, the risks to the biodiversity due to dust remain about the same as for Option G.

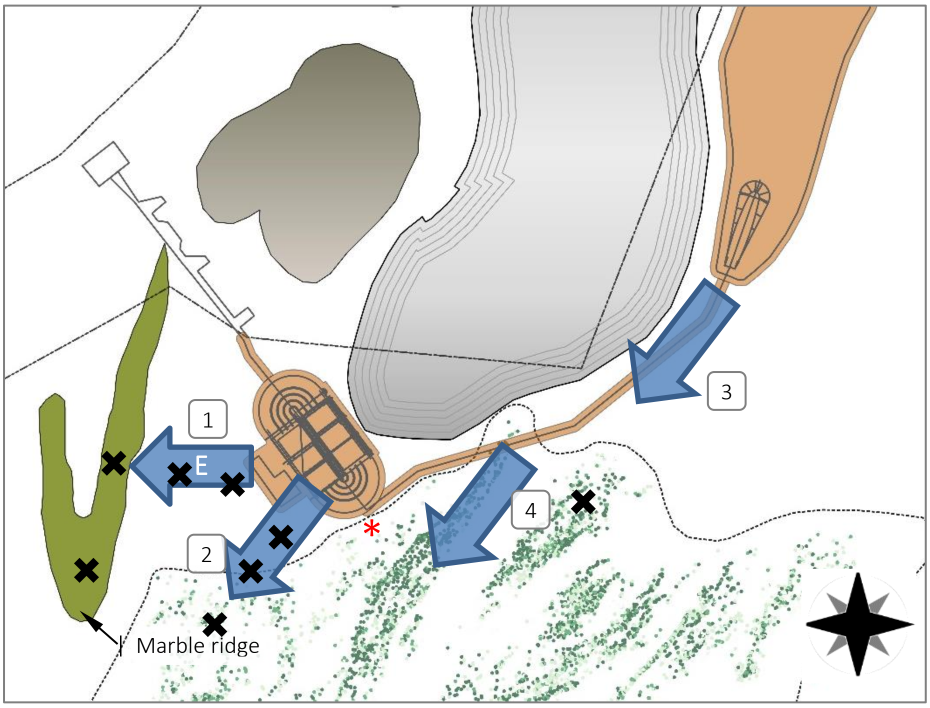

Figure 25. The location of the HLWF and HLF for Option K relative to the two main biodiversity features, the Welwitschia field and the marble ridge. Blue arrows indicate the north-easterly and easterly wind directions referred to in the text.

The blue arrows indicate risks of dust deposition from specific sources in specific directions. Arrows 1 to 3 are similar as indicated for Option G. Arrow 4 indicates the potential additional risk of dust from the conveyor belt and service road.

The red asterisk indicates the point where the HLF is immediately adjacent to the Welwitschia field.

Black "X"s indicate the proposed location of additional dust buckets (see Management/research below.

<u>Likely sources and loads of dust emissions</u>: Also refer to Impact 6.4.2 and 6.5.2 and Liebenberg-Enslin (2021) for more detail on the predicted dust fallout pattern and the possible mechanism through which dust can affect plants. The sources of dust for Option K are likely to be the same as for Option G, while the dust loads may be slightly lower or the same. Differently from Option G, the HLWF is likely to pose a smaller risk for the downwind (for NE-winds) Welwitschia plants by virtue of being located slightly further away from the Welwitschia field, with the bulk of its mass even further away (compare Figure

19 and Figure 25). An additional source of dust in Option K is the use of a service road along the conveyor belt route, but this will be a small contribution to the total load. Despite the location of the HLF to the north of the Welwitschia field (thus only vulnerable when wind is blowing directly from the north), its closeness to plants (see the red asterisk in Figure 25) additionally increases the chances that dust will reach some of the closer plants.

Distribution of wind directions and velocities: Similar to Option G, in the context of producing an impact on biodiversity, the northeasterly and easterly winds are the most relevant because these are most likely to disperse wind-eroded dust from the HLWF and the HLF itself towards the Welwitschia population and the marble ridge. In general the risks caused by the HLF remain the same as for Option G, or potentially somewhat smaller because it is possible that the main WRD could shield the HLF from the north-easterlies.

The likely fallout pattern: This is similar or slightly different to the case for Option G. Again using the precautionary principle, I consider the likelihood that dust from the HLWF will reach the plants for more than 30 days in the year to be at least moderate for the HLWF and moderately high for the HLF, even though the total amounts might be relatively small, especially for the fraction larger than PM10.

The issue of acid dust: The pH of the waste material in the HLWF, and thus also the pH of any dust emitted from there, will be between 4.5 and 5.2, enough to be considered a skin corrosive and eye irritant (Golder Associates, 2017). A pH lower than neutral is likely to have corrosive effects on plant tissues, which will be multiplied over time and with fog precipitation, thus exacerbating any existing damage as a result of natural dust scour. There is however surprisingly little information available on this aspect (see Section 6.3.1 above), with the result that it is difficult to gauge the risk to the plants. In the case of Option K, this would be principally the plants in the Welwitschia field to the SW of the HLF and less so the HLWF.

Rating: The overall incremental dust load as a result of the HL Project is apparently low. However, with the proposed location of the HLF in Option K still being so close to the Welwitschia field, the likelihood of multi-day dust coating occurring will be high for at least the plants in the immediate vicinity (within the high-concentration fallout zone) and could theoretically lead to the death of some plants.

In addition, the fact that the dust might be corrosive adds an unknown amount of risk of mortality.

Although plants can theoretically be cultivated and their populations restored after mining, the plant species involved in this impact are not easy to cultivate. Welwitschia is also a long-lived species, purportedly reaching ages of > 1 000 years.

Welwitschia and many of the marble ridge specialists, including *Lithops ruschiorum* (which is directly downwind and thus specifically threatened), are endemic and protected. Death of individual Welwitschia plants and most of the other rocky ridge species will be non-mitigatable and cannot be restored. As such the unmitigated impact will remain medium, with uncertainty in almost all categories forcing this up to high.

Mitigation: Apply all mitigations proposed by Liebenberg-Enslin (2021). Ensure that the leached material remains moist until the point where it is loaded onto the conveyor belt for transport to the HLWF. Ensure that material being transported on the conveyor belt remains moist enough to decrease the production of dust to almost zero. Ensure that the pH of material being transported to the HLWF is as close to neutral as is possible (in the range of 6 to 7)

Impact after mitigation: After mitigation, the impact could theoretically decrease to low, but the remaining uncertainty about the chances that acid dust may contribute significantly to mortality, dictates that the rating should remain at least medium and that an intensive monitoring programme should be instituted.

.Summary: Dust deposition (Option K)					
	UNMITIGATED	MITIGATED		UNMITIGATED	MITIGATED
SEVERITY	High (?)	Low (?)	CONSEQUENCE	Medium (?)	Low (?)
DURATION	Medium (?)	Medium (?)	PROBABILITY	Medium (?)	Low (?)
SPATIAL SCALE	Medium	Low	SIGNIFICANCE	High (?)	Medium (?)

Management/research: With the significant uncertainty around the effect of acidic dust on plant leaves (Welwitschia and other species), I recommend that additional dust buckets should be placed in a number of locations around the main dust sources to monitor both dust loads and pH of dust (see Figure 25). Simultaneously, the health of plants near the dust buckets should be estimated using a number of indicators and correlated with dust levels and pH, while comparing with control plants that are definitely outside the zone of potential risk. Should there be any indication of damage to the relative health of these plants, further systematically controlled investigation may be necessary to determine the probable cause, and mitigations should be reviewed and improved.

6.6.4 Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils that excavate their burrows here, with consequent knock-on effects on plant productivity and large herbivore presence.

This impact refers to biodiversity features and processes described in Figure 10 and Figure 12.

Nature of impact: Negative. Clearing and levelling of land for construction of the HLWF and its associated linear infrastructure will destroy a proportion of the vegetation patches, some of which are occupied by and enhanced by the presence of gerbils, that provide food for large mammals, in particular Hartmann's mountain zebra.

A Master's level study conducted on the role of gerbils as ecological engineers has conclusively shown that these small mammals are critical for the maintenance of vegetation productivity on the gravel plains. The enhanced productivity of the naturally occurring vegetation patches is quite likely the reason why zebras are resident in this hyper-arid zone. A study conducted for Swakop Uranium's biodiversity monitoring programme has shown that the zebras do indeed utilise the area in question. The destruction of these vegetation patches and the removal of the gerbils will thus lead to an unknown reduction in the number of zebras that can be supported in this area, as well as to a reduction in the time that they can spend here.

*IMPORTANT NOTE:

The real issue here is that **this impact is cumulative**. Viewed in isolation, the destruction of the unknown number of vegetation patches and associated enhanced productivity as a result of the presence of gerbil burrows is still relatively minor. However, the mine, and the expanded WRD have already caused the loss of a large number of burrows, in a zone of the grassy and gypsite plains that appear to be important habitat for the gerbils (Figure 13). As with many processes where the key factor causes a multiplied effect (gerbils enhance productivity three times), the loss of the factor could lead to an exponential decline in herbivore biomass. It is however at this stage impossible to estimate the severity of this cumulative impact, since the role of gerbils in enhancing productivity has only recently been quantified (Shaanika, 2020).

Rating: Although the likelihood of the impact is high, the total proportion of patches that are affected compared to the patches across the whole area is probably still fairly small. There are remaining uncertainties with regard to the spatial and temporal dynamics of this feature and process (only further studies on plant productivity in relation to the use of the plains by large mammals will tell whether both dimensions may be more or less significant than currently thought). However, the impact itself is relatively minor, hence the significance rating of Low is correct.

Mitigation: Avoidance is only possible if another location option is chosen for the HLF. There are possibly only a few options to minimise the area of the footprint involved, and it is unlikely that this will lead to a significant reduction in the extent of the impact.

Impact after mitigation: As there is no option to avoid or minimise this impact the mitigated and unmitigated ratings are thus the same. There is also no mitigation possible for the cumulative impact.

<table>
<tr><th colspan="6">Summary: Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils</th></tr>
<tr><th></th><th>UNMITIGATED</th><th>MITIGATED</th><th></th><th>UNMITIGATED</th><th>MITIGATED</th></tr>
<tr><td>SEVERITY</td><td>Low</td><td>Low</td><td>CONSEQUENCE</td><td>Low</td><td>Low</td></tr>
<tr><td>DURATION</td><td>Medium</td><td>Medium</td><td>PROBABILITY</td><td>Low</td><td>Low</td></tr>
<tr><td>SPATIAL SCALE</td><td>Low</td><td>Low</td><td>SIGNIFICANCE</td><td>Low</td><td>Low</td></tr>
<tr><td colspan="6">CUMULATIVE IMPACT</td></tr>
<tr><td colspan="4">The most important issue in relation to the destruction of vegetation patches and the associated ecological engineering effect of gerbils is that this is cumulative. Because the magnitude of the effect of the gerbils on herbivore biomass is currently only based on the measured effect of gerbils on productivity and is as such highly uncertain, I recommend that the cumulative impact be rated as high because of the uncertainty.</td><td colspan="2">SIGNIFICANCE:
HIGH</td></tr>
</table>

6.7 Potential impacts as a result of the temporary water pipeline

This infrastructure was installed at least seven years ago and was in operation for an unknown duration during this period. It consists of a relatively small diameter (~250 mm) pipe laid on the ground surface along the Khan Mine valley, across the Khan River and up the valley that carries the permanent access road for Husab Mine. Its potential impacts to biodiversity were fully assessed during the BIA of the linear infrastructure for Husab Mine. At the time it was not considered to contribute significantly to any of the identified impacts. As such, it is considered that the rating for the impact at this stage is low with and without mitigation.

7 Conclusions

7.1 Weighing up the options

The impact assessment delivered a range of overall ratings (Table 4). Two of these impacts (interference with Welwitschia water supply[5] and encroachment into the no-go area) are likely the result of simple errors caused by the use of an old version of the sensitivity map. Theoretically these could be easily corrected (although any further movement of the HLF in Option G and the HLWF in Option H will exacerbate the impact of dust on biodiversity), and for the purposes of deciding on the best option will for now be ignored here.

Before the addition of Option K, Option G was the preferred one having only one uncertain medium and one low rating. Option H has the same uncertain medium and one low rating for the same impacts, but has an additional impact that is rated high before mitigation and will probably remain high after mitigation (see Impact 6.5.4 above for the reasoning behind this rating).

Option K results in less interference with water flow, and the chance that the impact could decrease to almost negligible if mitigations are applied. It also entirely avoids any direct footprint impact to the marble ridge. However, being located directly east of the marble ridge and immediately adjacent to the Welwitschia field, the potential issue of dust deposition remains a worrying uncertainty, especially in view of the potential acidic nature of the dust (Golder Associates, 2017).

Table 4. Summary of impact ratings for the two options.

	Impact	**Option G**		**Option H**		**Option K**	
		Bef. mit.	**Aft. mit.**	**Bef. mit.**	**Aft. mit.**	**Bef. mit.**	**Aft. mit.**
6.4.1, 6.6.1	Interference with water supply to the Welwitschia field	H	H*	-	-	H	L
6.6.2	Destruction of or damage to Welwitschia plants underneath or in the vicinity of the conveyor belt (Option K).	-	-	-	-	M	L
6.4.2, 6.5.2	Dust deposition	H (?)	M (?)	H (?)	M (?)	H (?)	M (?)
6.4.3, 6.5.3	Encroachment of HLF into the no-go area	H	L	H	L	-	-
6.4.4, 6.5.1, 6.6.4	Destruction of the gravel plain vegetation patches and the ecological engineering effect of gerbils	L	L	L	L	L	L
6.5.4	Destruction of habitat-specialist and other plant, vertebrate and invertebrate species of conservation significance	-	-	H	H	-	-

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[5] The current plans for Option G suggest that there is no recognition by the mine planners of the bypass channel for the expansion of the main WRD, as it is placed on top of the area where this channel should run (see Figure 18). I am here assuming that this very important and critical error will be corrected before long and will therefore not discuss the potential impact of blockage of surface water flow to the Welwitschia field further here. **However, my overall assessment is conditional upon Swakop Uranium showing us technical drawings that include this bypass channe**l. Without such firm evidence of commitment to a critical mitigation (which can only be assumed for the HL Project), the current project's Biodiversity Impact Assessment will overall be rated as a fatal flaw.

Option K is thus the preferred one of the three that I formally assessed. There are however a few caveats and conditions to this evaluation. With regard to the potential corrosive nature of the dust. the actual corrosivity is entirely unknown. It may turn out to have a minor effect at the pH levels of the waste material (4.5-5.2), or it may not. Second, the corrosive effect is unlikely to be significant unless the dust is wetted by fog (rain would more likely just wash the dust off). Hence, the overlap of fog days with strong wind days will be a major determinant of the severity of the effect. Fog peaks in the summer, so high dust loads in the winter, as occurs with NE and E winds, will theoretically mean a significantly lower risk. However, none of this is yet known. The overall argument here is therefore more in favour of moving forward than of halting the project, but the uncertainty increases the risk assessment enough to strongly recommend an intensive monitoring of dust loads and their potential effects on the plants around the HLF.

In addition, the cumulative impacts on the ecological engineering function adds an unmitigatable effect that would represent a residual impact for the whole Husab project. As such it would be a candidate for calculating biodiversity offsets[6], but magnitude is still unknown. This should be quantified before an offset is determined.

7.2 Note of displeasure, final recommendation

Husab Mine is located in a national park, where the protection of biodiversity and the enjoyment of nature are the primary land uses. Its presence inside the park sits uncomfortably with the main land uses, but its impacts on biodiversity features as such were fairly well contained. The heap leach project, coming soon after an expansion of the main WRD, which followed on the addition of a large tailings storage facility (that was not part of the original EIA), represents what has now become an unacceptable pattern of footprint creep. Each of the individual additional developments do not on their own cause enough significant harm to organisms or ecological processes to become a fatal flaw, but the cumulative impact has certainly grown significantly. The problem from the perspective of biodiversity protection in the face of a development like this is that much of the loss, especially in cumulative terms, is intangible. Even where we can measure it in some way (e.g. we know that the ecological engineering function is equal to at least three times normal plant productivity), its relative significance is unknown because the magnitude and importance of these issues in maintaining the arid and hyper-arid desert ecosystems here have never been properly measured. I recommend that the Environmental Clearance Certificate for the HL Project, should it be issued, should come with an additional condition: Swakop Uranium must show some tangible evidence that they acknowledge that they are located in a National Park, that they support the protection and restoration of biodiversity to a high standard (to the level of re-instating lost biodiversity, not just the planting of some plants), and that this will be done through the support of studies of ecosystem structure, function (including properties such as food web structure) and composition with the aim of understanding the target for future restoration.

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[6] The current policy environment in Namibia does not allow a feasible route to biodiversity offsets, but there are encouraging signs that this will change in the near future.

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APPENDIX 1

Reviewing the ecophysiology and ecohydrology of Welwitschia

Geographic distribution

Welwitschia occurs only in the Namib Desert, with populations established in areas that receive between ~40 mm and ~250 mm rain per year on average (Figure 28). The plants occur both within and outside the fog zone (Figure 28). The study population at Husab Plains occurs on the hyper-arid part of the scale, where the very low ratio of mean annual precipitation (MAP) to mean annual potential evapotranspiration (PET) of ≤ 0.05 (UNEP, 1992) means that all soils are generally dry, that soils will dry out quickly after a rain event (Figure 29), that plant-available moisture (PAM) will consequently be unpredictable in time and space and that plants will, on average, experience a large water deficit (Figure 29). In addition, although the Namib is a relatively temperate place on average (Figure 28), daytime temperatures can be high, affecting leaf temperature and thus photosynthesis efficiency (Herppich et al., 1997; Krüger et al., 2017). The hot, extremely dry air that is typical of east wind conditions not only causes physical damage to leaves (Eller et al., 1983), but also a large vapour pressure deficit (and thus a strong drying effect) at the time the plant has to open its stomata to take up CO_2. It is additionally associated with high dust deposition.

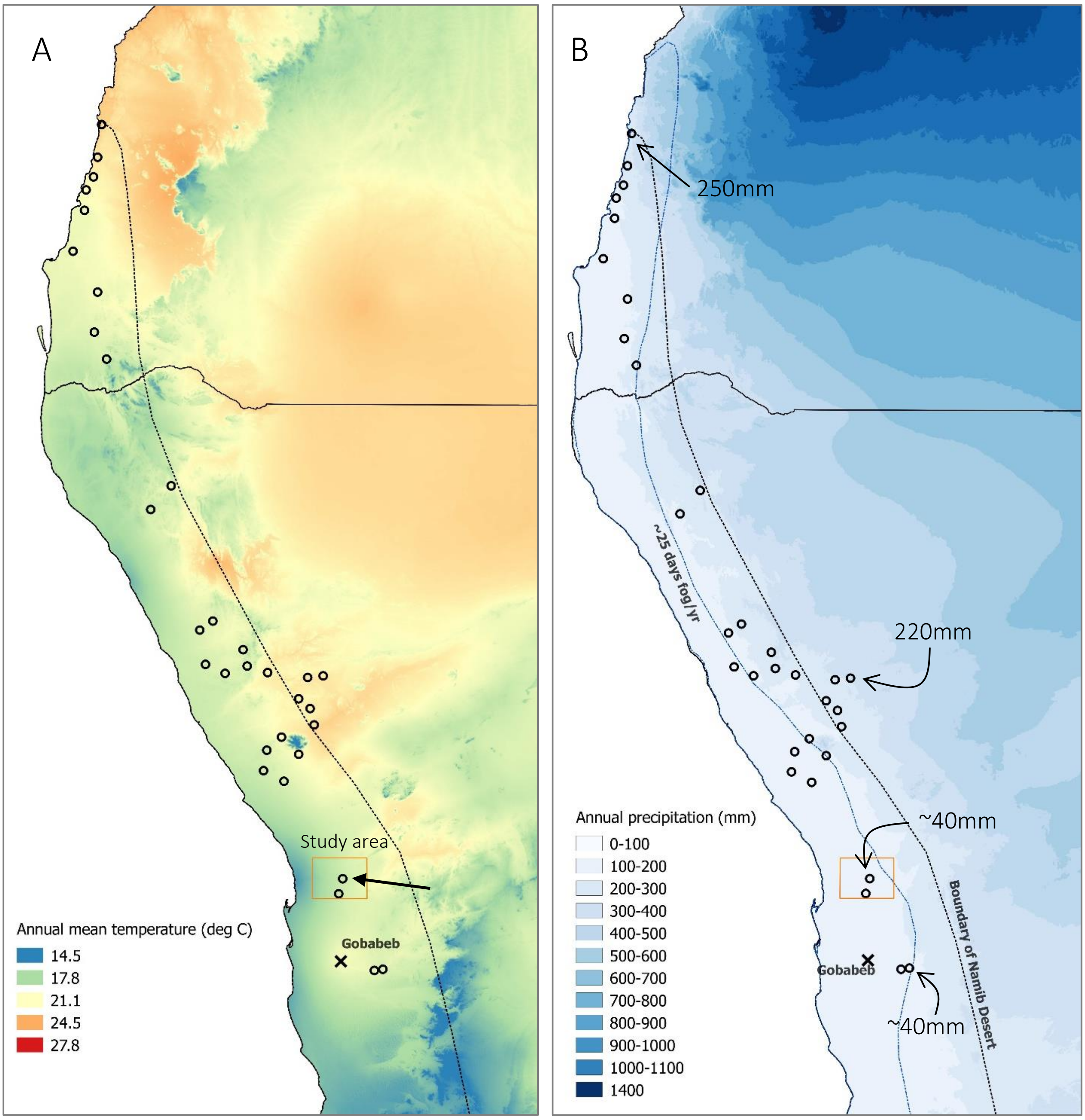

Figure 26. The location of the main Welwitschia populations (o) across its entire geographic range, relative to the annual mean temperature (A) and annual total rainfall (B).

The dotted black line shows the approximate eastern extent of the Namib Desert. The stippled blue line is the approximate position of the eastern edge of the zone receiving 25 days or less fog per year (extracted from Mendelsohn et al., 2002). The study population is the upper of the two circles inside the orange rectangle (indicated with a black arrow on (a)). The numbers on (b) indicate approximate long-term annual precipitation at the specific populations. Welwitschia populations were reproduced from Kers (1967). Annual mean temperature and precipitation were extracted from the WorldClim database version 2 (Fick & Hijmans, 2017; http://www.worldclim.org/).

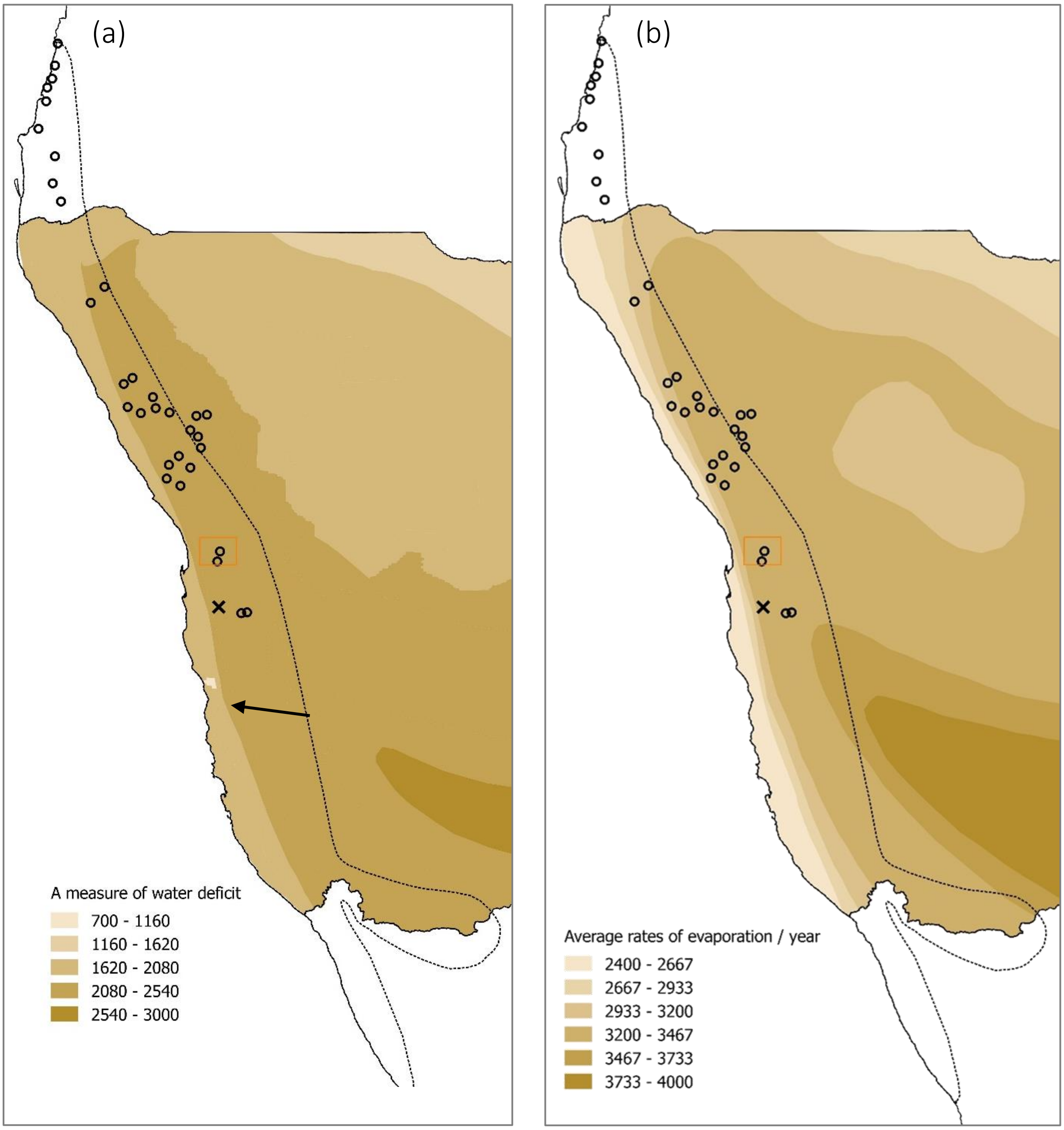

Figure 27. The location of the main Welwitschia populations (o) across its entire geographic range, relative to soil water deficits.

In (a), the deficit is represented by the difference between precipitation and potential evapotranspiration, and in (b) it is the average evaporation rate. The dotted line shows the approximate eastern extent of the Namib Desert. The study population is the upper of the two circles inside the orange rectangle (indicated with a black arrow on the left-hand map). Welwitschia populations were reproduced from Kers (1967). Both water deficit and evaporation data are from Mendelsohn et al. (2002), downloaded from www.the-eis.com.

Adaptation to aridity

How does Welwitschia overcome this basic set of challenges, and do it well enough that some individuals may exceed 1,000 years of life? A plant that has reached such an advanced age will have encountered a number of good years with an excess of water, but it is just as likely to have encountered some extended droughts. Whatever its strategy, it seems to be successful, given both the longevity of some individuals and the apparently low mortality rate[7].

Some of the basic and more obvious adaptations to aridity are anatomical in nature. Welwitschia is clearly not a succulent, and it is not certain whether it uses its stem to store water (measurements of transpiration – see below – suggests that this is not an important tactic). However, similar to xerophytes in general, the leaves do have a thick cuticular layer and epi-cuticular wax to protect against high irradiation and temperatures (Herppich et al., 1997; Krüger et al., 2017) and presumably at least partially against water loss through parenchymal cell walls. The waxy layer additionally provides a smooth surface for condensation and encourages water droplets to run off, dropping onto the soil. A higher density of feeder roots in the region where its leaves touch the ground (Henschel et al., In Prep) suggests that this leaf-harvesting and channelling of water to the soil surface might be a specific adaptation, but it could also be a by-product of a strategy to avoid high leaf temperatures.

Other adaptations to frequent drought and an unreliable water supply, which are not macroscopic or anatomical, are possible. Perhaps the most important of these is the basic chemical pathway that a plant uses to assimilate carbon during photosynthesis. This can be one of three alternative but not mutually exclusive pathways: C3, C4 and CAM (see Box 1 for an explanation of these terms).

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[7] Although it is not possible to determine true mortality because many dead stems will have been washed away in floods or have slowly decayed, of all the plants recorded in the 2014 Welwitschia census by SU, only 7% were dead. Even with due consideration to all uncertainties, this is a remarkably low number.

Smith & Epstein (1971) were the first to suggest that Welwitschia is not an ordinary C3 plant, based on a relatively high level of $\delta^{13}C$[8]. This kind of value is typical for C4 plants but also close to the typical value for CAM plants. These findings and subsequent work on greenhouse plants that showed incorporation of C into malic acid at night (see studies cited by von Willert et al., 2005) led to the suggestion that Welwitschia employs the CAM pathway, at least at times. The obvious conclusion was that this was one of the main reasons that the species is able to survive in these hyper-arid conditions.

However, Von Willert et al. (1982) failed to find evidence of net CO_2 uptake at night in controlled temperature and humidity conditions.

Box 1. C3, C4 and CAM refer to different chemical pathways through which carbon is assimilated during photosynthesis. In the C3 pathway, two molecules of a 3-carbon acid is formed in the reduction of CO_2, while in the C4 pathway, a 4-carbon acid molecule is formed. Both C3 and C4 plants open their stomata during the day to take up CO_2 (and release water and O_2). Of the two, C4 (often found in warm environments) is a lot more efficient, transpiring about 2.5 times less water than C3 plants (which are often found in cooler environments). CAM stands for Crassulacean Acid Metabolism. This pathway involves the opening of stomata and uptake of CO_2 during the night, when cool temperatures and higher relative humidity prevent a high loss of water. The CO_2 is stored in the form of Malic acid, which is then metabolised during photosynthesis in the daytime. This water-sparing pathway is often found in succulents and other arid-adapted plants. If a plant shows a net uptake of CO2 and forms malic acid at night, it is likely to utilise the CAM pathway.

The pathway that a plant employs to assimilate C during photosynthesis is therefore central to any questions about its ecohydrology. The strategies are not mutually exclusive – many intermediate forms exist and some plants are able to switch between modes depending on moisture availability (amongst others).

Eller et al. (1983) investigated the gas exchange pattern of the species more comprehensively in situ on plants growing in the current study population near Husab Mine and showed that it is typical of a C3 plant in arid conditions. They also found that malic acid (and other acids), although unusually high, varied with leaf age and spatially across the leaf, implying that a low number of replicate measurements as were made in the past will not capture the full range of values. Additionally, they did not find evidence for a nocturnal increase in malic acids, as would occur in CAM plants (see Box 1). In their opinion the high $\delta^{13}C$ and malate levels did not constitute enough evidence for a CAM pathway. They pointed out that the presence of some C4-like anatomy (as was showed by previous workers) suggested that the species may be somewhere intermediate between C3 and C4 and that the high $\delta^{13}C$ values could be a function of both high levels of organic acids and variation in habitat. They could however not explain the relatively high levels of organic acids.

Subsequent workers have not disputed Eller et al.'s (1983) conclusion that Welwitschia utilises C3 pathway, and is perhaps intermediate between C3 and C4 in some respects. However, there remained a lingering doubt about whether it can optionally utilise the CAM pathway. Isotopic signals of plants that obtain one-third or less of their carbon in the dark (thus through processes associated with CAM) may be confused with C3 plants when identified on the basis of carbon isotope content alone (Winter & Holtum, 2002). Winter & Schramm (1986) investigated the environmental control of CO_2 exchange on well-watered plants in a greenhouse and found a "low potential for CAM", expressed only in a reduced rate of net CO_2 loss at night when plants normally lose CO_2 during respiration. von Willert &

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[8] Carbon has 12 protons, but the number of neutrons vary. $\delta^{13}C$ is an isotope of carbon with 13 neutrons (i.e. it is "heavier") instead of 12. The ratio of $^{13}C : {}^{12}C$ (measured as parts per 1,000 against a high standard value, thus always negative) in a plant is a function of physicochemical processes such as photosynthesis, which discriminates against heavier isotopes to varying degrees. The measured ratio therefore indicates what photosynthetic pathway it uses. C3 plants typically have values of -44 to -33‰, C4 between -16 to -10‰ and CAM between -20 to -10‰. Welwitschia, with values ranging from -23 to -17‰ depending on the study, is thus higher than C3 plants and closer but still lower than C4, but very similar to CAM plants.

Wagner-Douglas (1994) could also not find evidence for nocturnal uptake of CO_2 at three contrasting habitats under extremely different environmental conditions. In contrast, the results of Von Willert et al. (2005) suggest that the species is indeed a facultative CAM plant, switching to this mode in December and January when the nights are shortest. CO_2 uptake at night was however never more than 4% of the total uptake, a remarkably low figure. They could not explain why, if this was available to the plant, Welwitschia makes so little use of a facultative shift to CAM when the conditions suggest it should. This is even more surprising as it seems to be a typical strategy for Namib Desert shrubs (von Willert et al., 1983).

Although its metabolism is not water-efficient, it contains water loss by opening its stomata only in the morning from sunrise for a few hours (Herppich et al., 1996; 1997; Krüger et al., 2017). Although some plants do show two peaks of CO_2 exchange, the second peak appears to be independent of stomatal movement (Eller et al., 1983; Von Willert et al., 2005). The rapid opening and closing of stomata is probably facilitated by thin sections of the wall of the stomatal guard cells that play the role of specialised hinges (Krüger et al., 2017). With such a short period of open stomata, the plant also has to maximise CO_2 uptake. A high density of stomata on both leaf surfaces allows high rates of gas exchange during the irregular and infrequent periods when moisture is favourable (Krüger et al., 2017). Thick-walled support structures inside the leaf parenchyma and sunken stomata (which decreases the CO_2 diffusion pathway) further enables efficient gas exchange during brief periods when photosynthesis can be done economically (Krüger et al. 2017).

Although there are still uncertainties, particularly in terms of the spatial and temporal variability across its range, the overall picture that is emerging is of a species that is essentially a C3 plant with a poorly developed ability to optionally switch to CAM depending on the season and perhaps the habitat, and a limited ability to reduce water loss during transpiration by opening its stomata for only part of the day. The most important implication of this is that Welwitschia, being typical of a C3 plant, is not an efficient user of water. Transpiring throughout the day, it will have lost between 25-35% of its actual leaf water content around noon, with a total loss of ~0.96L of water per m^2 leaf surface per day on average (von Willert et al., 1982; Eller et al., 1983). Not surprisingly, leaf water potential also drops steadily throughout the day and at a faster rate where the soil was moist (von Willert et al., 1982; Herppich et al., 1997). Although not measured directly, its high rates of leaf growth (Henschel & Seely, 2000; Wassenaar & Shuuya, 2017), which correlates with both rainfall and humidity but is consistently above zero and ranges from < 0.1mm/day to 1.8mm/day, has to be a large consumer of water (and carbon – von Willert & Wagner-Douglas, 1994) simply to maintain leaf turgor and chemical integrity in the cells.

Transpiration loss may be a necessary way to counter rising leaf temperature as a result of heat gain over the large leaf area (Eller et al., 1983), but the total loss seems to be high for a plant growing in a region with < 30 to ~100 mm rain pa. For comparison, the leaf succulent Zygophyllum stapffii, growing in the same habitat, loses only 0.7% of its leaf water in the same period (this was reported in Eller et al., 1983; but it is not clear where they obtained that value). The photosynthetic efficiency Welwitschia plants (Herppich et al., 1996; Krüger et al., 2017) and long-term growth (Henschel & Seely, 2000), as well as the spatial distribution of plant health parameters (Shuuya, 2016) suggest that Welwitschia experiences stress from drought-related water deficits. Living in the desert is therefore not an easy problem to solve. Still, the obvious conclusion from the species' poor adaptation to aridity is that Welwitschia must either be very efficient at finding enough water to maintain such high rates of loss, or there is a lot of water available.

Consequently, its water sources have long been debated (Pearson, 1929; Henschel and Seely, 2000) and the question of how it is able to balance its water budget in the short and long-term has not yet been answered adequately. However, since Henschel & Seely's 2005 paper that defined some of the key uncertainties, more studies have been done, with the result that certain aspects are now better known including its root architecture, isotopic studies of the origin of moisture sources and soil structure.

Roots, stable isotopes and origin of moisture

A recent study of the root architecture of seven Welwitschia plants that had to be removed for the construction of a road and pipeline showed that the species is not a phreatophyte (i.e., it does not tap its moisture from a deep groundwater resource), but most likely relies on pockets of moisture trapped in the soil and within the calcretised layers of the vadose zone (Henschel et al. In Prep). The same study also suggested the intriguing possibility that Welwitschia might be able to utilise crystalline water from gypsum crystals that are common below ground surface. This must however still be confirmed and is unlikely to be a major source of moisture.

Vadose water in the Husab Plains can only come from rainfall, and this is supported by isotope studies showing a clear signature of continental moisture (i.e. rainfall arriving from the east across the sub-continent) and less from an Atlantic source (Soderberg 2010, Henschel et al., In Prep). The latter would indicate a reliance on fog, which is relatively common in the area (Lancaster et al. 1987) or winter rainfall, which is exceedingly rare. A recent unpublished report by Külls et al. (2015), based on analysis of stable isotope ratios of oxygen and hydrogen in soils adjacent to five of the excavated plants near the Husab Mine, suggested that soil moisture mostly (3 out of 5 samples) derives from episodic major rain events. Isotope ratios in the other two samples suggested their moisture derived from light local rainfall or fog.

Landscape, soils and sub-surface structure

Soil properties affect the surface hydrology, infiltration rates and the depth to which rainwater penetrates into the gravel plains (Mills et al., 2006; Li et al., 2016). Calcrete layers (such layers are known as "petrocalcic horizons") can block rainwater infiltration at one metre or deeper, resulting in the formation of a thin horizon of moisture perched above the deeper unconsolidated gravels and overlain by gypsum (Wilkinson, 1990; Heine & Walter, 1996). These petrocalcic horizons, which are common across the Husab Plains (and in the central Namib in general; Eckardt et al., 2001), therefore probably represent a keystone structure that retains and can subsequently release infiltrated rain water (Duniway et al., 2007; 2010). This would result in a more resilient moisture environment for arid-adapted plant species (Duniway et al., 2010), although the scope, dynamics and sustainability of this source for the central Namib and Welwitschia specifically has not yet been established.

Van der Waals (2017) analysed 19 soil profiles dug along the length of the Husab Channel from the northern lease boundary to just inside the Welwitschia field (Figure 30). Samples were selected to capture the variability perpendicular to the linear drainage depressions, which is an idealised catena (van der Waals, 2017). He also analysed the soil chemistry at the same sites and assessed the landscape position of Welwitschia plants from satellite images. Based on his findings he presented a landscape (catena) model of drainage channels with thick, permeable sediments at the bottom of a shallow catena, surrounded by gravels with a hardened crust and dense subsoil (Figure 31). He found that old and mature plants preferentially grow in fluvial areas where sedimentation dominates and where there is little evidence of erosion. He concluded that the hydrological functioning of this landscape is dominated by runoff from the adjacent consolidated and gypsum-crusted gravels, and that "the contribution of upland flow to the overall water regime is low".

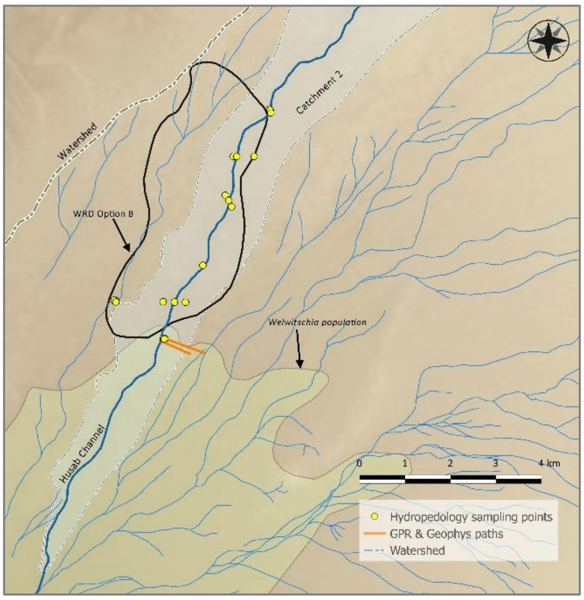

Figure 28. Location of hydropedology sampling points, as well as the paths for the GPR/HLEM (Knupp, 2011) and resistivity (Symons, 2011) surveys.

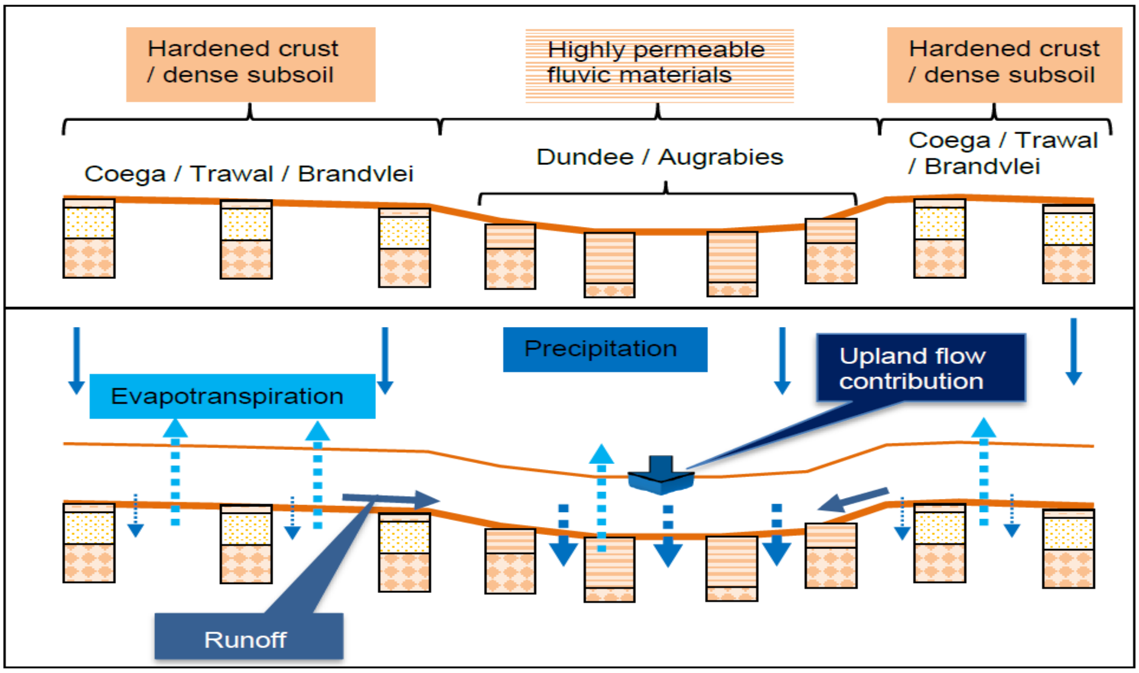

Figure 29. Schematic representation of the soils in the Husab Mine landscape as well as their hydrological functioning (reproduced from van der Waals, 2017).

The upper schematic shows the idealised distribution of soil types along the catena and the lower one shows the deduced hydrological functioning. It predicts that water from local precipitation will mostly run off (thick solid arrows; thin dotted arrows indicating low infiltration) towards the channel where it will infiltrate the deeper, crust-free sediments (thicker dotted arrows indicate high infiltration rates). Evapotranspiration (thick, light blue dotted arrows), occurring principally on the run-off areas, is the main driver of the crusting process. In this model, the upland flow contribution is low.

Van der Waals' study penetrated the soil to a maximum depth of 1.5 m (Pit 6; van der Waals, 2017). Geophysical studies conducted by Symons (2011; using a resistivity meter) and Knupp (2011; using both a Horizontal Loop Electromagnetic [HLEM] and Ground Penetrating Radar [GPR]) determined underground structure, to a depth of about 40 m, along transects crossing over the Husab Channel and onto the adjacent gravel plain at about the same point as van der Waals' southernmost pits at the northern edge of the Welwitschia field (Figure 30).

The two geophysical studies agreed on the presence of an anomaly between ~5 and ~25 m below ground surface (Figure 32). Knupp interpreted this anomaly as the presence of a perched saline aquifer, but it is more likely to have been the calcrete layer that Symons found. Both studies also showed that this calcrete layer is disrupted for the full width of the active drainage channel, and again near the eastern edge of their transects for a shorter distance (Figure 32).

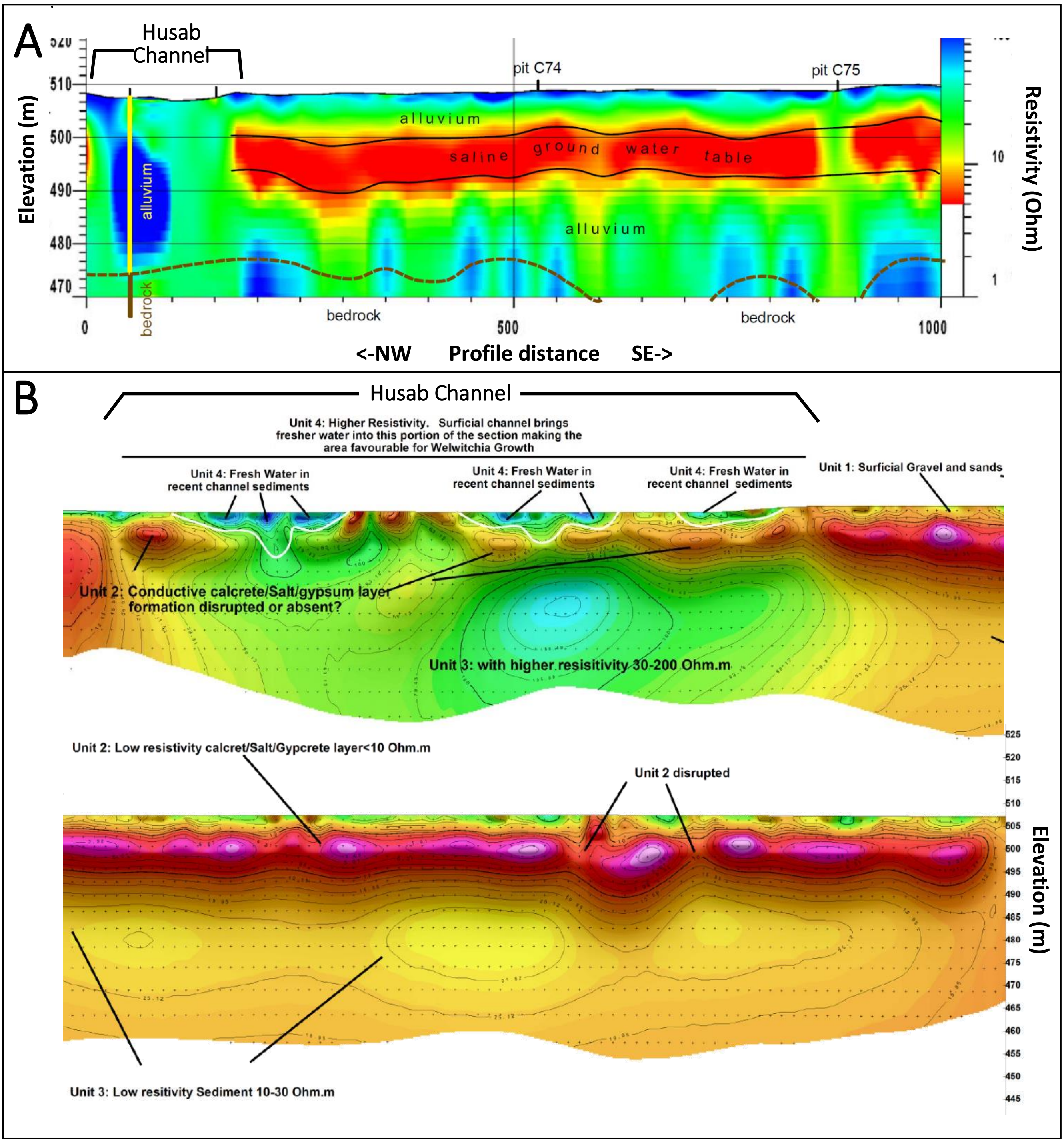

Figure 30. The results of an HLEM (A) and resistivity (B) survey along two transects crossing the Husab Channel at the northern edge of the Welwitschia field.

See Figure 28 *for more detail on the locations. The upper diagram in B represents the first ~210 m of the transect and the lower diagram the last ~200 m. Reproduced from Knupp, 2011 (A) and Symons, 2011 (B).*

Rain and the catchment

Evidence from a number of sources now suggests that the primary moisture source for Welwitschia plants in the Husab Plains population is rainfall and not fog or groundwater. The question is whether plant-available moisture is only derived from showers that fall on top of the plants (or in the immediate vicinity), or whether it can also flow from upstream with rain showers falling elsewhere in the catchment. It is important to note here that the plants' leaf growth only responds when more than about 11 mm rain had fallen in one day (Henschel & Seely, 2000).

Rainfall in the central Namib varies not only over time, but also across space. From grass productivity data, Henschel et al. (2005) deduced that the scale of rainfall-induced variability in productivity has a radius of 5 km or less, which is approximately the width of a cumulus cloud. This confirmed the finding of Sharon (1981). From long-term rainfall data recorded at Rössing Mine, it can be deduced that it will rain at least once a year, on average (Metago, Undated). The vast majority of these events will however be small. Between July 2014 and April 2017 (1,035 days), Husab Mine received the equivalent of 44.3 mm average rain per year[9], falling on the equivalent of about 23 days per year. Almost 82% of the precipitation events totalled < 2mm/day and only four were more than 10 mm/day. Three of the latter events were >20 mm/day with the highest being just over 27 mm. At the Tinkas weather station of the Department of Water Affairs near Langer Heinrich Mine, a mean annual precipitation of 29.7 mm was measured between 1983 and 2007, with a maximum daily rainfall of 33.3 mm and an average of 11.4 rainfall days per year (quoted by Church & Smit, 2017). From the same Tinkas data it can be predicted that a day on which >11 mm rain will fall can be expected to occur every two years on average.

The spatial and temporal variability in rainfall decreases in concert with an increase in average annual precipitation as one moves further inland (Figure 33; Figure 34; Mendelsohn et al., 2002). The above values can therefore be expected to change as one moves east from the location of the Welwitschia field to the headwaters of the Husab Channel – average annual rainfall will increase more than three times and variation will decrease by about 25%.

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[9] Based on data received from Swakop Uranium, as collected by their Automatic Weather Station at Husab Mine. This represents a relatively short time series, so conclusions based on analyses of these data should be taken with due caution.

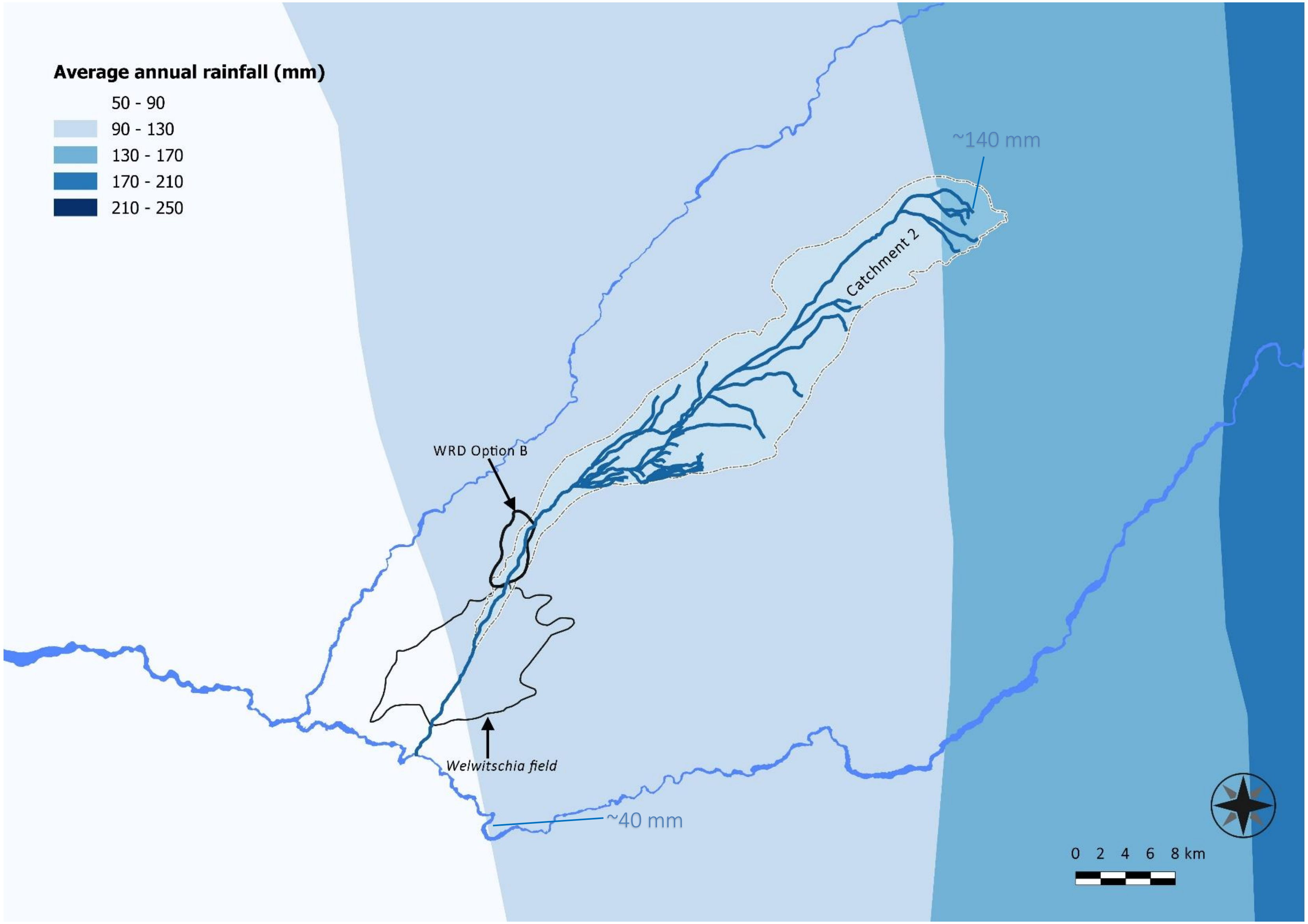

Figure 31. The Husab Channel and Welwitschia field relative to estimated average precipitation (source: Mendelsohn et al., 2002). Catchment 2 is the catchment of the Husab Channel.

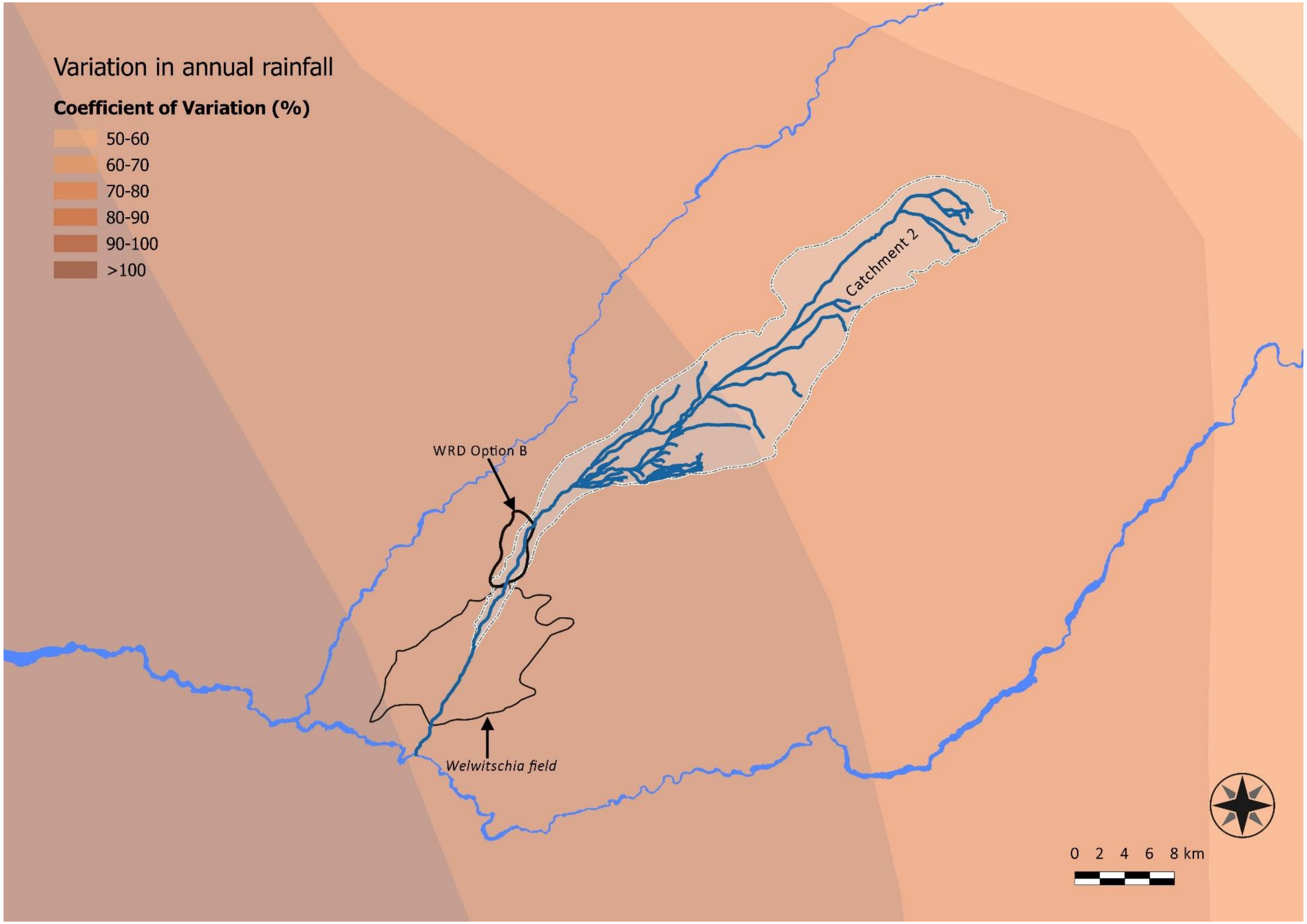

Figure 32. The variation across years in rainfall decreases from west to east.

Here rainfall variation is an integrated modelled estimate of the coefficient of variation total annual precipitation (from Mendelsohn et al., 2002). This model predicts that the Husab Mine is located in a zone where variation is between 90 and 100% of the mean. The variation at the Husab Channel's headwaters is between 80 and 90%.

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