Site Characterisation for Kuiseb Riparian Ecosystems

Prepared for the

WADE Project

Work Package 2

July 2006

by

Mark Gardiner

Anna Matros-Goreses

Carole Roberts

Mary Seely

of the

Desert Research Foundation of Namibia

and

Gobabeb Training and Research Centre

Acknowledgments

The authors would like to acknowledge the work of four in-service trainees from the Polytechnic of Namibia – Diaso Kaaronda, Michaella Phemelo, Patience Mamili and Jonas Nghishidi – for gathering data in the river, as well as the research assistance provided by a number of Gobabeb interns: Daniel Shapi, Kristin Wouters (for the granulometric surveying), Florian Mayer, Anna-Sophia Stamm and Johannes Rentsch. Joh Henschel provided invaluable guidance and editorial advice. Many of the maps in this report were generated or adapted from data produced from the *Atlas of Namibia* (Mendelsohn *et al.* 2002) made available by the Ministry of Environment and Tourism.

Table of contents

Geographical position

The Kuiseb River is one of twelve ephemeral rivers that flow through western Namibia (Figure 1). It flows some 440 km from its catchment area in the Khomas Hochland just west of Windhoek down to the ocean near Walvis Bay (Jacobson *et al.* 1995). The river serves as a ―linear oasis”, allowing many plants and animals to survive and even to thrive (Seely *et al*. 1981; Theron *et al*. 1980) in an otherwise dry environment. People, too, depend on the Kuiseb: the commercial farmers of the river's upper reaches, Topnaar pastoralists in the lower Kuiseb, and the people of Walvis Bay, Namibia's second-most-populous city. Industrial projects, the port and various uranium and granite mines in the area, also draw on the Kuiseb.

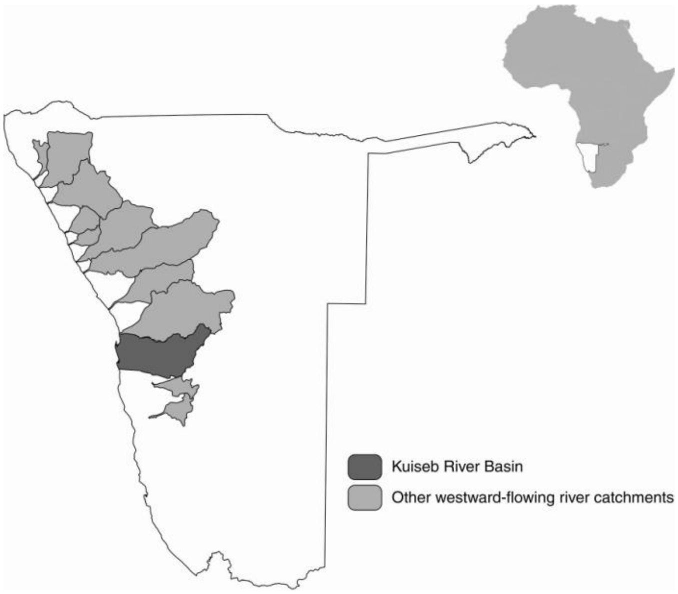


Figure 1: There are 12 westward-flowing, ephemeral rivers in Namibia.

The Kuiseb River Basin can be divided into three sub-basins (Figure 2). In the upper basin, the river drains the Khomas Hochland in a south-westerly direction following the well-developed joint-pattern drainage lines that dissect this elevated area of rolling hills. The river then cuts through the escarpment to the desert plains (and the middle basin) below, where it carves a deep canyon and is joined by its major tributary, the Gaub. The river continues along its south-westerly course across the plains until it reaches the Namib Sand Sea where it turns initially westwards and then, just past Gobabeb, north-westwards. The river course forms a distinct border between the dunes to the south and the gravel plains to the north – two of the driest environments on the planet (Huntley 1985b). As it moves closer to the coast and into the lower basin, the river widens over its bed of unconsolidated sands before petering out in the delta just south and some kilometres inland of Walvis Bay.

The river rarely reaches the Atlantic Ocean. Although the Kuiseb Basin covers an area of almost 22,000 km^2, most of the area has such low rainfall that it produces little to no runoff. The flow of the river is largely dependent on rain falling east of the escarpment and only completes its journey to the Atlantic Ocean at Walvis Bay following exceptional rains in these upper reaches.

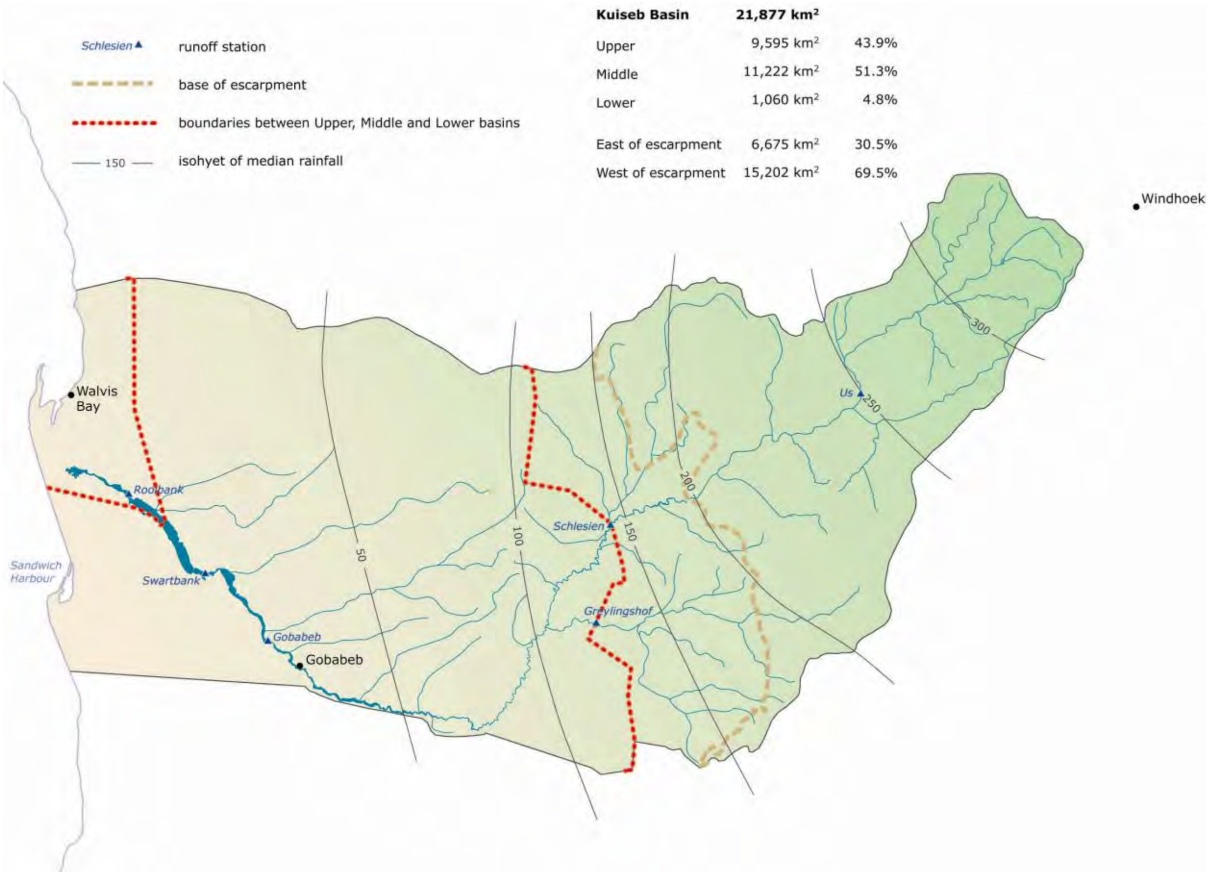


Figure 2: The Kuiseb River Basin

The Kuiseb River Basin not only includes the catchment area of the river, but its wider sphere of influence. The Basin extends down to Sandwich Harbour, where the mouth of the Kuiseb River used to be, and where freshwater springs fed by old channels under the dunes still exist. Walvis Bay, which is supplied with fresh water from the alluvial aquifers in the river's lower reaches, also falls within the Basin, as does the Tumas River. Although it is not linked to the Kuiseb, the Tumas, rising west of the escarpment is considered part of the basin even if it rarely, if ever, flows.

The Gobabeb WADE research site (23°33' S, 15°02' E) is located in the middle course of Namibia's Kuiseb River at about 400 m above sea-level (Henschel *et al*. 2000). The following sections of this report provide an overview of the Kuiseb River Basin and its characteristics and focuses on the WADE research site and its vegetation.

Landscapes and topography

The Kuiseb River Basin is flanked by the Swakop River Basin to the north, where the Khomas Hochland forms the watershed. The Tsondab, Fish and Oanob rivers flow to the south of the Kuiseb Basin, and the Nossob and Olifants rivers to the east. These southerly and easterly drainage basins are divided from the Kuiseb by the Rantberge, Auas Mountains and other small mountain ranges. As the Kuiseb makes its way from the Khomas Hochland to the Atlantic coast, its geomorphology changes considerably, dividing the basin into five broad landscapes (Figure 3).

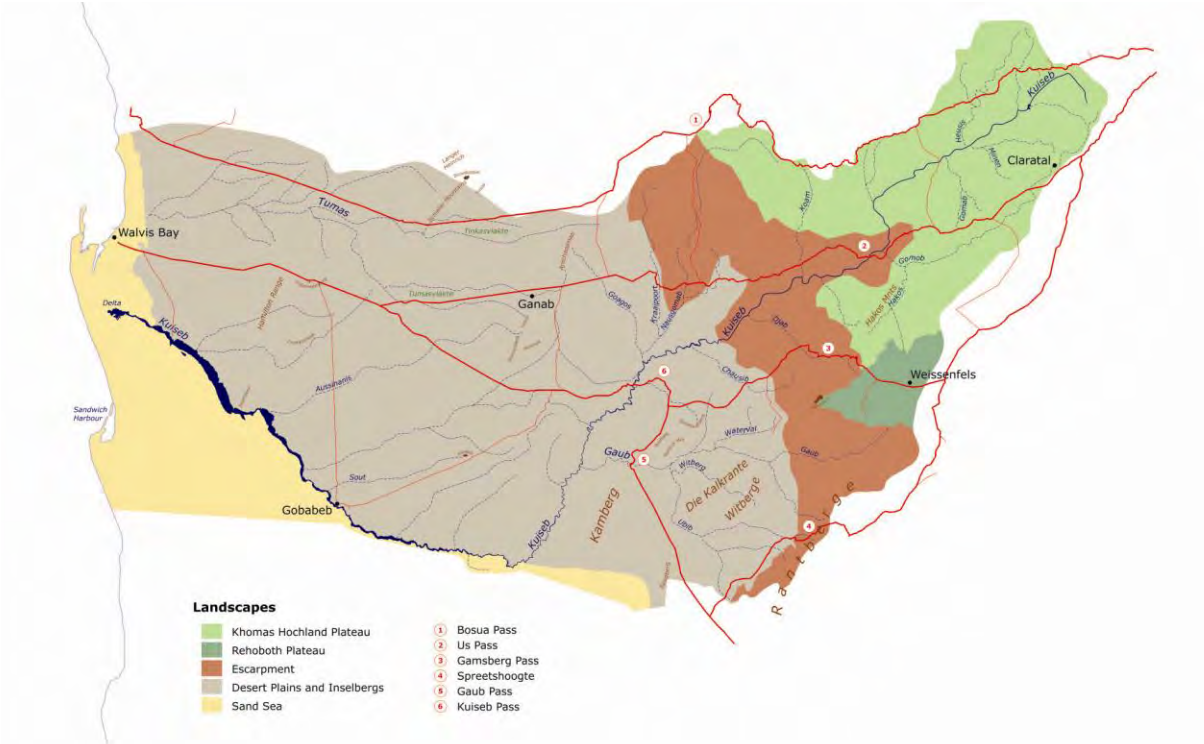


Figure 3: The Kuiseb Basin can be divided into five broad landscapes (adapted from Mendelsohn *et al.* 2002.).

Khomas Hochland Plateau

This area of rolling hills extending west of Windhoek varies in height from about 1,700 m to 2,000 m above sea level. It is a remnant seabed whose geological history dates back approximately 750 million years. The seabed was later folded into a huge mountain range and the pressures and temperatures created during this process transformed the deep-sea sand and clay deposits into the mica-schists that, in spite of many millions of years of erosion, we still see today.

The Kuiseb River rises in the Khomas Hochland and, following the fracture pattern of the mica-schist, it deeply dissects the area. The hills are covered with a thin stony soil that supports an open savanna of low trees and shrubs. The vegetation is dominated by *Acacia hereroensis*, *Combretum apiculatum* and *Ziziphus mucronata*, and a number of perennial and annual grasses in the herb layer. It supports game species such as springbok, kudu, oryx and mountain zebra, and is suitable for extensive livestock farming.

Rehoboth Plateau

The south-western corner of the highland area of the basin extends onto the Rehoboth Plateau. The granites and metamorphic rocks that underlie this high plateau are some of the oldest in Namibia – more than 1000 million years old – and also underlie the Gamsberg, which is covered by a much younger sandstone cap forming the highest point.

This gently rolling landscape with scattered inselbergs, is not deeply incised by the river. The deeper sands characteristic of this area support open grasslands punctuated with low trees and shrubs, while *Acacia erioloba* trees define the meandering/sinuous watercourses.

Great Escarpment

The Great Escarpment, which rims much of southern Africa, divides the central plateau area from the coastal plain, is particularly well developed in the Kuiseb Basin. The land drops dramatically about 1000 m into the Namib Desert below. The Great Escarpment formed about 120 million years ago at the break up of Gondwana, when South America and Africa started to drift apart. It is steepest in the south, as can be viewed from the Spreetshoogte Pass, and is gentlest in the central section of the Basin as experienced along the Us Pass which winds down the escarpment over many kilometres.

The vegetation on the Great Escarpment with its steep slopes, shallow soils and low rainfall reflects the transition to the desert environment below. Trees and shrubs are stunted, and more arid-adapted plants such as *Euphorbia*, *Commiphora*, *Parkinsonia* and *Sterculia*, and *Moringa* and *Myrothamnus* specific to the Escarpment, are found.

Desert Plains and Inselbergs

The extensive gravel plains of the central Namib Desert stretch from the base of the Great Escarpment for over 150 km westwards to the Atlantic Ocean. A handful of rocky outcrops, or inselbergs, which rise out of this very flat landscape afford some relief to the huge plain as it gently slopes to the sea. The granites, quartzites, marbles and schists of these inselbergs expose the underlying hard-rock geology of the area, which is otherwise obscured by a covering of calcareous and gypsum-rich soils and gravel. Swartbank and the Hamilton Range are largely made of limestone, while many of the inselbergs, such as Vogelvederberg, Mirabib and Bloedkoppie, are granite. Farther south-east, the Kamberg comprises layered quartzites and schists whereas Rostock Mountain has a dominantly granitic character.

Along its path, the Kuiseb cuts deeply into the surrounding plains and just beyond the confluence of the Nausgomab River, it has carved a canyon over 200 m deep. The Kuiseb Canyon exposes the history of the area – the schists of the 750-million-year Damara Mountains underlying the much younger Tsondab sandstones (ca. 20 million years old) and layers of conglomerates. The proto-Kuiseb, which preceded the present Kuiseb River, was probably already in existence some 30 million years ago flowing over the schists, and later depositing 15-million-year-old conglomerates – cobbles cemented with calcrete – over the area. These forerunners long preceded the present canyon, which probably only dates back 2–3 million years being formed during a relatively wetter phase in the area.

The floor of the canyon in this area is rocky and holds a few pools of water and only scattered patches of vegetation. The surrounding plains receive very little rainfall (<100 mm), and consequently support very little vegetation most of the time. The inselbergs, however, intercept any rain and fog that there might be and a specialised fauna and flora is found at these islands.

Namib Sand Sea

The Kuiseb River forms the northern border of the Namib Sand Sea. The Sand Sea extends some 400 km north from Lüderitz. It has formed from the accumulation of sand being transported from the coast in a north-easterly direction by onshore winds. These winds form transverse dunes at the coast where they are strongest and blow almost exclusively from one direction, linear dunes further inland, and star dunes at the eastern extent of the dune field. The sands, which are largely quartz grains, ultimately originated from the Orange River through its erosion of the hinterland.

The Namib Sand Sea dates back to the establishment of the Benguela system (9 million years ago) and overlies Tsondab Sandstone which accumulated under desert conditions at intervals between 10 and 20 million years ago.

Although the Sand Sea itself supports almost no vegetation, the Kuiseb forms a linear oasis between the dunes to the south and gravel plains to the north. Alluvial aquifers below the riverbed support dense riparian woodlands of *Faidherbia albida*, *Acacia erioloba*, *Tamarix usneoides*, *Euclea pseudebenus* and *Salavadora persica*.

West of Rooibank, the Kuiseb forms a dry, but extensive, delta. The northern arm of the delta used to open into the sea at Walvis Bay, but was diverted with the construction of a flood-protection wall in 1962. The southern arm is fairly indistinct being a mosaic of river surface, dunes and vegetated sand hummocks. Woody plants include the indigenous *Acanthosicyos horridus*, and shrub forms of *Acacia erioloba* and *Tamarix usneoides*, as well as *Salsola* shrubs and the reed, *Phragmites australis*.

Profile of the river channel

The river begins in a rugged, mountainous area, and once it reaches the escarpment its course runs through a steep-walled canyon (Bate & Walker 1993: 85). The gorge is narrow – sometimes less than 50 m across. By the time the river passes Gobabeb, the walls of the canyon have almost disappeared and the river flows across open desert, allowing its shallow course to broaden. At Gobabeb the river is less than a kilometre across; this broadens to two kilometres and more by the time the river reaches the coast.

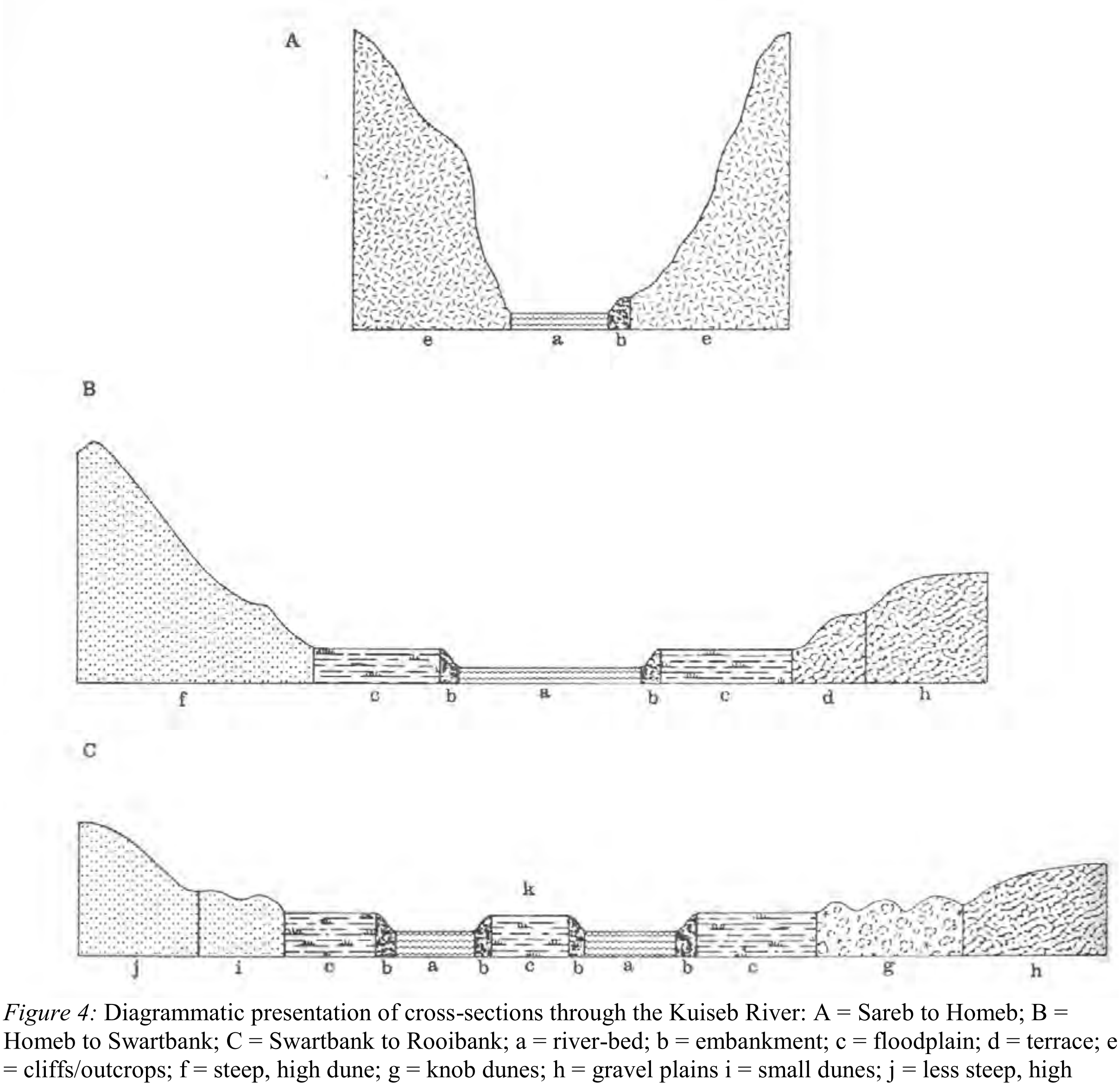


Figure 4: Diagrammatic presentation of cross-sections through the Kuiseb River: A = Sareb to Homeb; B = Homeb to Swartbank; C = Swartbank to Rooibank; a = river-bed; b = embankment; c = floodplain; d = terrace; e = cliffs/outcrops; f = steep, high dune; g = knob dunes; h = gravel plains i = small dunes; j = less steep, high dune; k = island. Adapted from Theron *et al.* 1980.

Figure 4 illustrates the differences in the river channel between the canyon and the delta. Gobabeb's geomorphology falls roughly into the middle class – although, as we will see, transects taken at Gobabeb reveal a somewhat more diverse profile than Figure 3 suggests. As Huntley (1985b) notes, in this lower section of the river, the sandy river bed is divided into compartments separated by intrusions of bedrock, which occur at Narob (some 10 km downstream of Gobabeb), Swartbank, Rooibank and Mile 16. Within these compartments the river is filled with sand and alluvium ―bounded on the northern side by impervious bedrock”. The southern side of the river is generally abutted by dunes, although there are bedrock formations, similar to those to the north, beneath the dunes.

Several studies have recently been undertaken to further detail profiles across the Kuiseb. Figure 5 shows a topographic profile of the Kuiseb in the immediate vicinity of Gobabeb. There is a clearly defined, active river channel (marked as ―present river bed”), as well as a number of fluvial terraces representing remnants of older, broader river channels. In a recent study on landform development in the Kuiseb near Gobabeb, Yamagata and Mizuno (2005) argue that the river valley near Gobabeb has four fluvial terraces, which they classify as ―Lower”, ―Middle 1”, ―Middle 2” and Higher” terraces, although these broadly correspond to the terraces listed in Figure 5. All transects show a relatively flat profile with clearly defined active river channels and several fluvial terraces, although the presence of some features, such as the knob dunes found in Figure 4, is only occasional.

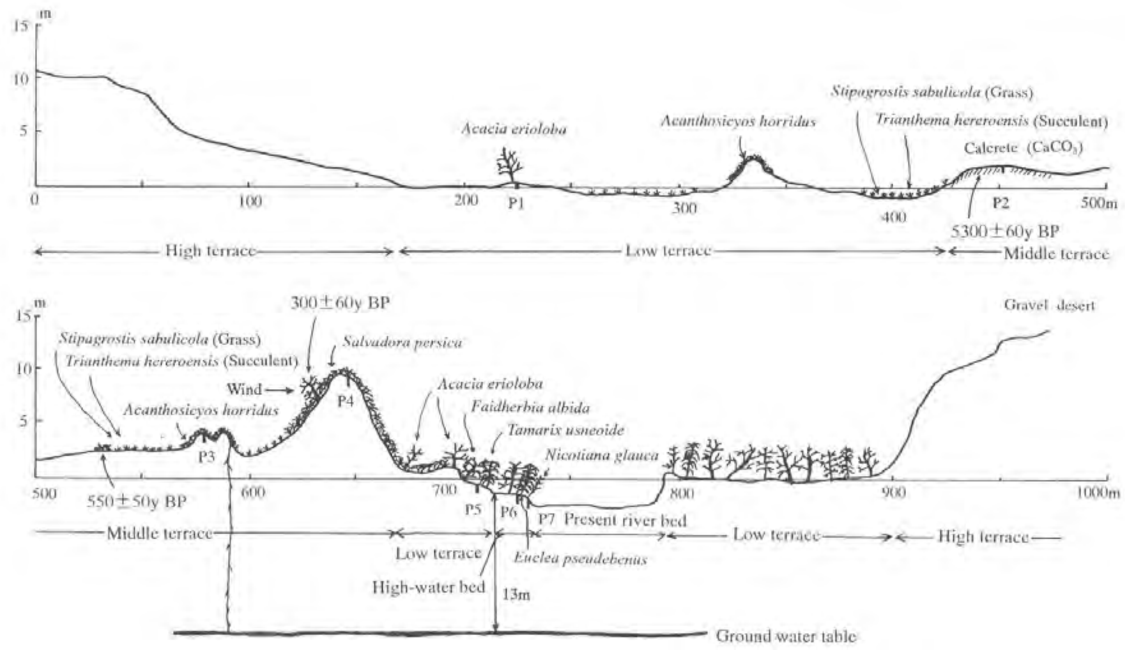


Figure 5: A topographic profile taken near Gobabeb, showing three terraces, as well as accompanying vegetation. Note that inclusion of *T. hereroensis* may be a mistake; this species is normally not found in the river (Robinson 1976). P1–P7 represent points at which soil profiles were taken. From Mizuno & Yamagata 2005.

Figure 6 shows the areas covered by the main channel, islands, secondary channels (where water is only likely to flow in years of unusually high flow, but which are still largely free of vegetation), and principal floodplains in the section of the Kuiseb immediately adjacent to Gobabeb. Within the past 40 years, the channel, channel islands and other land marks were in different locations, more to the north in many instances.

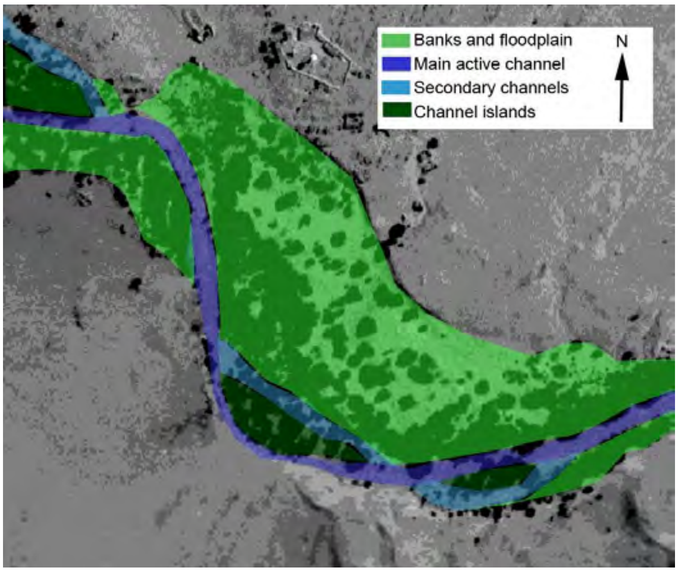


Figure 6: Active river channel, floodplains, islands and secondary channels of the Kuiseb River adjacent to Gobabeb

Soils

Soils throughout the basin are poorly developed – many are very shallow, and derived from the bedrock on which they lie. This, together with low rainfall, makes them unsuitable for crop production. The leptosols that cover the eastern half of the basin are very shallow – especially the lithic leptosols which dominate the Khomas Hochland and Great Escarpment – derived from the underlying rocks, and are coarse textured. Consequently, they are not able to hold much water, and runoff and erosion is high, exacerbated by the hilly landscape. The eutric leptosols covering the Rehoboth Plateau are more fertile, but also shallow. The regosols, although somewhat deeper and finer than the leptosols, are also derived from the rocks they overlie. In essence, the leptosols and regosols are only able to support sparse vegetation cover suitable for low-density stock farming and wildlife.

The petric calcisols that cover the central areas of the desert plains contain accumulations of calcium carbonate, sometimes in the form of a cemented calcrete. Although potentially fertile, the low rainfall of the Namib precludes any substantial plant cover developing on these calcisols.

The gypsisols typical and restricted to the western part of the central Namib Desert are characterised by accumulations of calcium magnesium sulphate ($CaMgSO_4$). The sulphate is derived from sulphur eruptions along the coast which is carried inland by the fog. Reacting with the calcium in the soil, it forms gypsum crusts and in places magnificent ‗desert roses' of gypsum crystals. These gypsum crusts support the unique Namib lichen fields. They are extremely sensitive to disturbance, such as vehicle tracks, which once created, never really disappear.

A detailed description of the sediments in the river channel at Gobabeb is given in Appendix A.

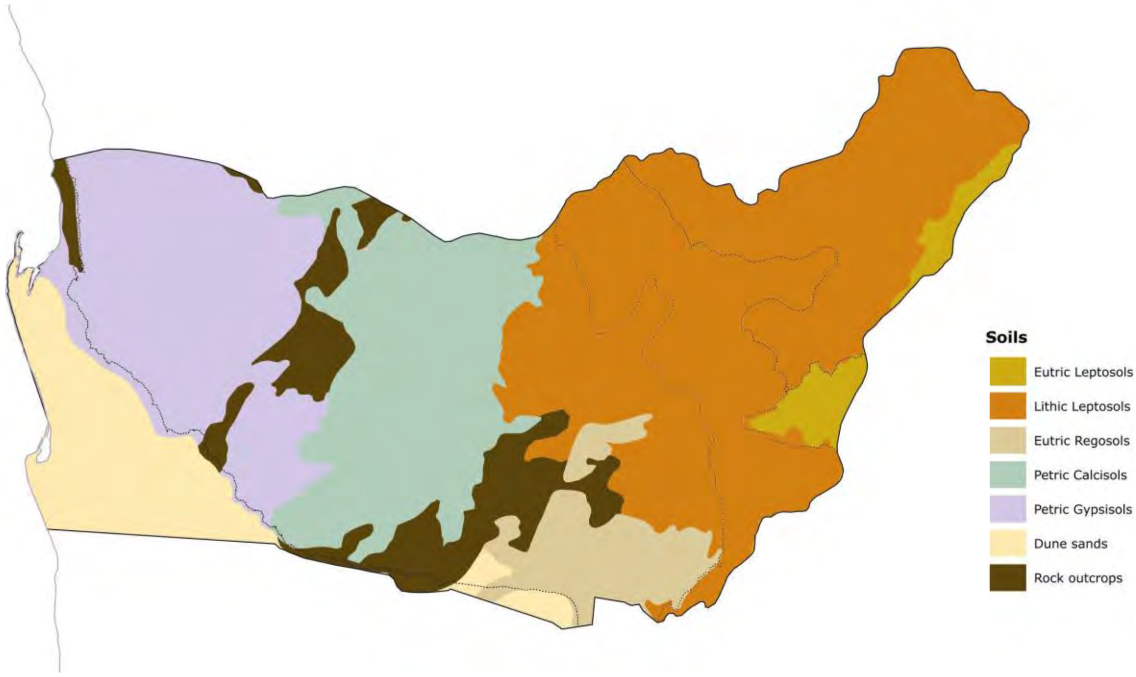


Figure 7: Soils of the Kuiseb Basin (adapted from Mendelsohn *et al.* 2002)

Hydrogeology

It is not so much the age of the rock but the type of rock that influences runoff, and determines whether it stores groundwater and just how easy that water might be to access. Rainwater that infiltrates the ground does so by moving through the cracks in the rock and between the soil particles.

The aquifers in the upper Kuiseb are formed in hard rock, with the water being stored in the cracks, fractures and spaces within the rock. The water table is discontinuous and, generally, the potential of these hard rock aquifers is limited. In the lower Kuiseb, the riverbed consists of unconsolidated grains of sand and gravel, and the water is stored between the particles forming an alluvial aquifer with a continuous water table. These alluvial aquifers in the lower reaches are extensive, relatively high-yielding and have been exploited for over five decades.

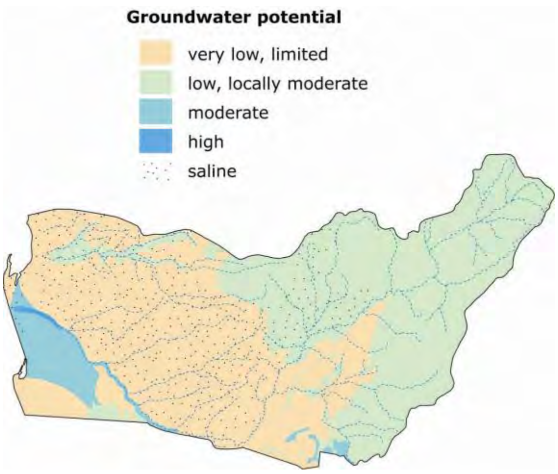


Figure 8: It is only the alluvial aquifers in the lower reaches of the Kuiseb that are relatively high-yielding (using data from Hydrogeological Project, Directorate of Water Affairs).

Climate

Low rainfall coupled with high evaporation rates characterise the Kuiseb Basin, making it an extremely arid area. Conditions, however, do vary from east to west creating a pronounced climatic gradient across the Basin. Above the escarpment, the east receives rain seasonally albeit in variable amounts, whereas the west which lies in the central Namib Desert receives very little rain, but has an alternative source of moisture, fog. Wind, temperature and humidity regimes vary too. These climatic conditions shape the landscape of the Kuiseb Basin, and predetermine the availability of water and consequently the life it supports and, to a large degree, the options for land use and development.

The climatic trends described in the pages that follow are broad and are largely based on trends described for Namibia as a whole (Mendelsohn *et al.* 2002), and adapted using records from the basin where they are available. Local effects of terrain, winds and other factors that can have a significant effect on local conditions are largely masked in these broad trends. There are not many weather stations within the Kuiseb Basin, and even fewer that have been recording conditions continuously over a long period of time; records from the northern half of the Basin are almost non-existent. Windhoek, which lies just outside the Kuiseb Basin, has long-term records that have been used to help illustrate the trends within the area, whereas Gobabeb and Pelican Point and a few other meteorological stations with medium-term records have helped determine these trends. Long-term records from a couple of the farms in the Basin have been invaluable.

Rainfall

Most of Namibia‘s rain falls in summer from moisture-bearing clouds blown in from the north-east as the Inter-Tropical Convergence Zone moves southwards. As the clouds move further and further south and west, they carry less moisture and rainfall decreases. As a result rainfall in the Kuiseb Basin follows a distinct east–west gradient. Rainfall is highest in the eastern area, where over 300 mm can be expected per year, dropping dramatically at the edge of the escarpment, and decreasing to almost nothing in the west. Because so little rain falls in the west, the flow of the Kuiseb River in these parts is almost totally dependent on good rains falling much further inland.

Total annual rainfall figures calculated for a number of stations within and around the Kuiseb Basin are given in Table 1. The figures were calculated from total rainfall values for as many seasons as available between 1960/61 and 2003/04. Although they generally follow the broad trend of decreasing rainfall from north-east to south-west, some do not fit this pattern. For example, Hohenheim has far more rain than expected, while Weissenfels and Isabis have far less, making the median values of these neighbouring farms very different. Nauchas also seems to have relatively high rainfall, especially compared to Weissenfels and Isabis. All four of these sites are on the edge of the escarpment and local topography is probably responsible, at least in part, for these apparent discrepancies. Rainfall can vary substantially within short distances; local elevation due to a mountain peak, such as the Gamsberg, or a koppie, such as those found around Nauchas, at Mirabib or Ganab, and their associated updrafts can have a profound effect on rainfall locally. As clouds are forced upwards, it cools causing condensation and subsequently rain on that side of the mountain from which the rain comes; a rain-shadow will occur on the other side.

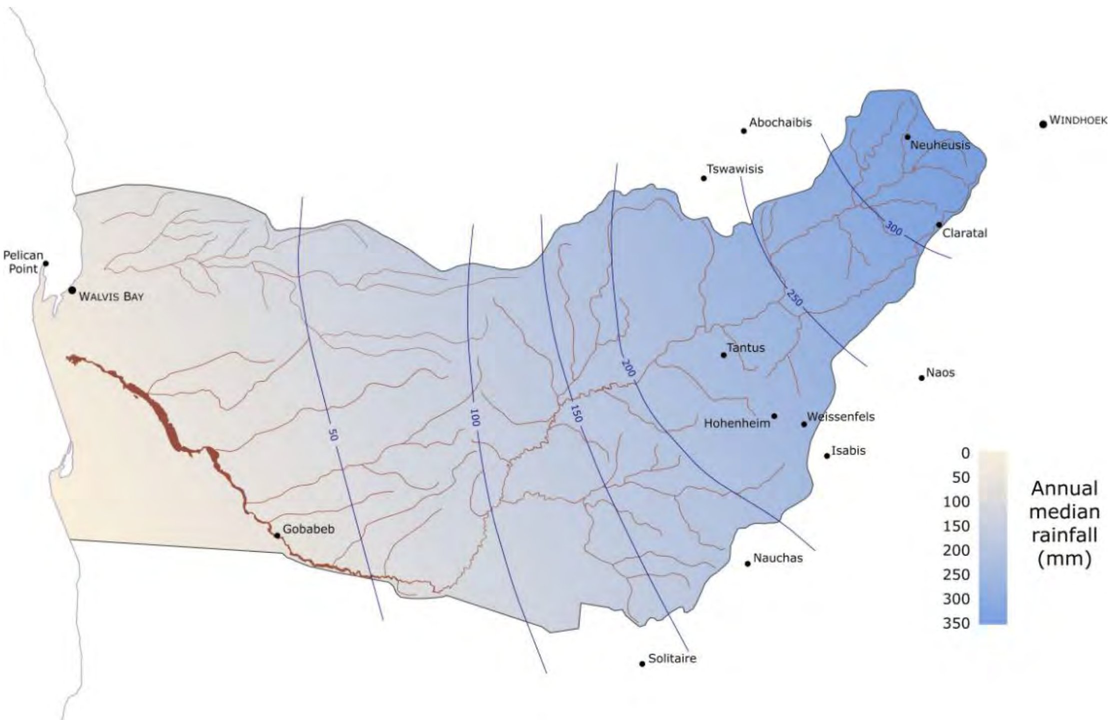


Figure 9: Various rainfall stations in and around the Kuiseb Basin shows a distinct decrease in rainfall from east to west (adapted from Mendelsohn *et al.* (2002) using rainfall data from the Meterological Services, farms Claratal and Weissenfels and the Gobabeb Training and Research Centre).

Table 1: Total annual rainfall

Station	Median (mm)[5]	Minimum (mm)	Maximum (mm)	Range (mm)	Variation (%)[6]	Number of seasons
Windhoek[1]	362.1	126.3	668.6	542.3	33.1	44
Neuheusis[1]	317.9	160.4	739.0	578.6	40.9	29
Claratal[2]	328.6	145.0	702.0	557.0	35.4	44
Abochaibis[1]	269.5	68.0	543.0	475.0	41.3	34
Naos[1]	253.0	70.0	774.7	704.7	53.5	32
Tsawisis[1]	222.3	75.3	598.4	523.1	42.6	31
Tantus[1]	221.8	18.0	470.1	452.1	49.2	29
Hohenheim[1]	261.8	95.0	548.0	453.0	44.1	30
Weissenfels[3]	164.0	67.0	390.0	323.0	45.9	37
Isabis[1]	168.7	62.8	484.5	421.7	51.8	35
Nauchas[1]	195.6	57.9	490.5	432.6	49.3	35
Solitaire[1]	129.6	39.1	349.9	310.8	51.6	29
Gobabeb[4]	14.9	0.4	127.4	127.0	116.6	38
Pelican Point[1]	5.8	0.0	71.4	71.4	145.7	40

The data used to calculate the figures in this table were derived from various sources:

1 Meteorological Services

2 Farm Claratal / Gobabeb Training and Research Centre

3 Farm Weissenfels / Gobabeb Training and Research Centre

4 Gobabeb Training and Research Centre

5 Median rainfall values are given rather than average values, because they give a more reliable indication of how much rain can be expected in a year.

6 Variation in rainfall is the standard deviation of annual rainfall totals expressed as a percentage of the average annual rainfall.

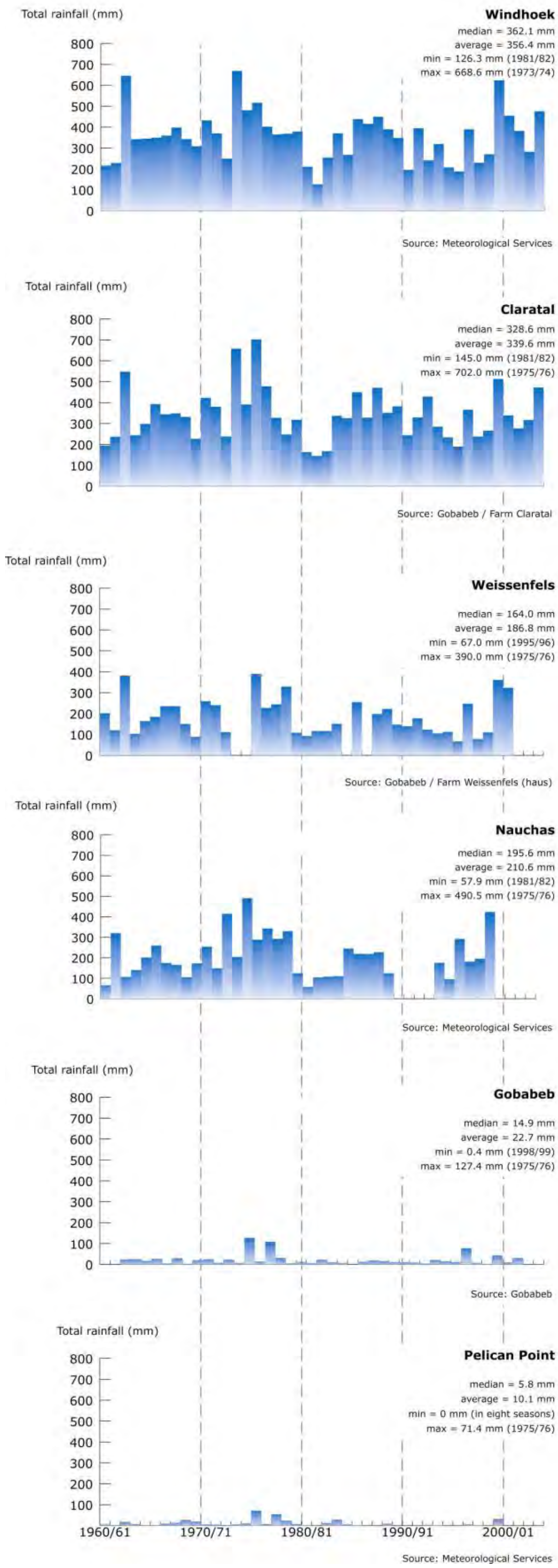


Figure 10: Total annual rainfall (1960/61 to 2003/04) for six stations within or just outside the Kuiseb showing both the east–west and seasonal variations in rainfall

Variation in rainfall

Rainfall in the Kuiseb Basin not only varies geographically, but also varies from year to year, as shown in the medium-term annual total annual rainfalls (Figure 10). Some seasons receive only a fraction of the rain that falls in other seasons – for example, in 1981/82 Windhoek received only 20% of the rain that fell in 1999/2000. It is only in seasons of really high rainfall that we can expect the Kuiseb River to flow all the way to its lower reaches and recharge the aquifers in this area.

The variation in rainfall is expressed statistically as the co-efficient of variation, which simply is the percentage to which rainfall varies from the mean (Table 1). The greater the percentage, the more variable the rainfall from year to year, and less likely it is to approximate the average, median or expected rainfall, making the amount of rainfall in any one year less predictable. The variation in rainfall in the Kuiseb Basin increases from east to west (Figure 11), but even in the eastern areas of the Basin where rainfall is relatively high, rainfall can be expected to vary by more than 30%; in driest areas along the coast, it varies by almost 150%.

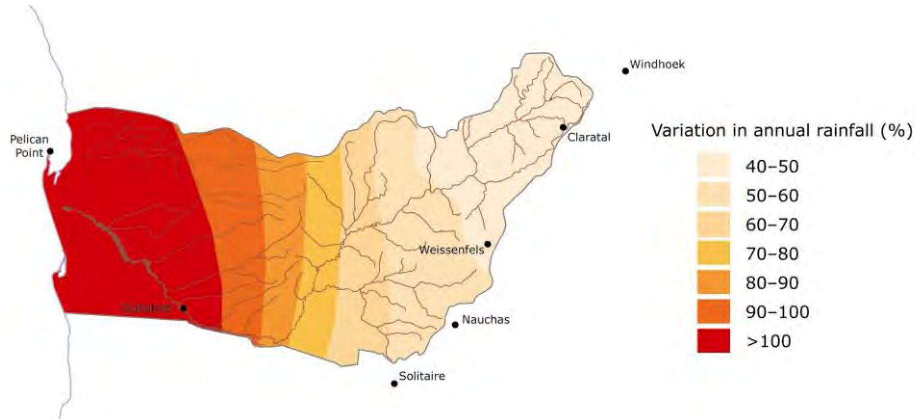


Figure 11: Variation in annual rainfall (adapted from Mendelsohn *et al.* 2002)

Apart from the variation from season to season, long-term records of rainfall also show periods of higher rainfall being followed by periods of lower rainfall, as depicted by the five-year running averages for Windhoek (Figure 12). These periods of wetter or drier seasons are about 15 years long.

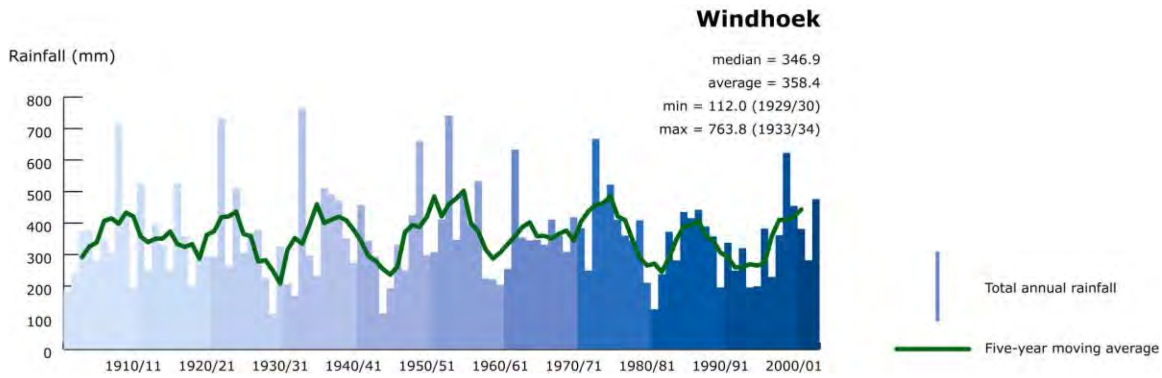


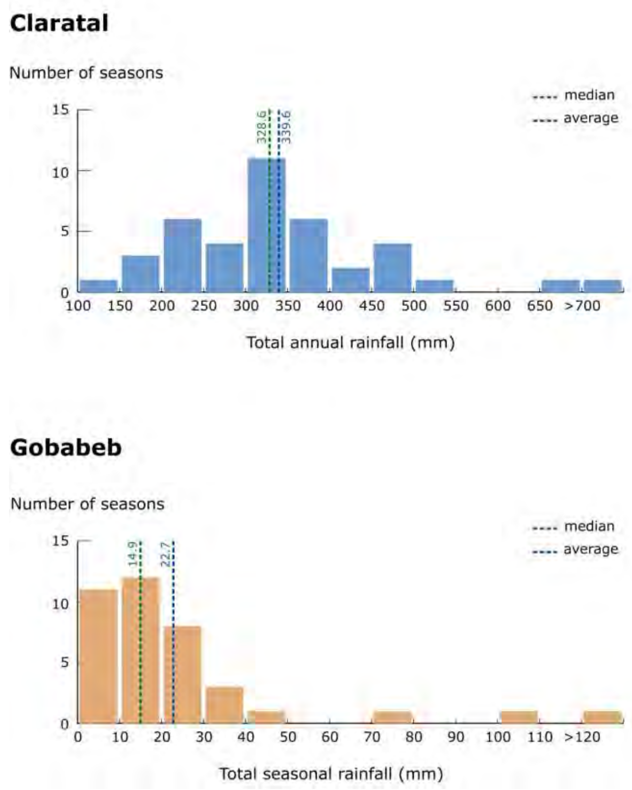
Figure 12: Total annual rainfall figures for Windhoek dating back to the beginning of last century

The value of the median

Rainfall is often expressed as an _average‘ – or _mean‘ – value. Average rainfall is calculated by adding the total amount of rain for a series of years and dividing that value by the number of years. However, in areas of low rainfall, such as the Kuiseb Basin, rainfall is also usually highly variable, and one year of unusually high rainfall pushes up the average considerably, especially if the rainfall records do not extend over many years. This elevated value results in the rainfall often falling _below average‘ in any particular year – misleading us to think that we are having a _bad year‘ or _drought‘, when it is in fact quite normal and should be expected. Usually the drier the climate and more variable the rainfall in an area, the less representative the average value is of the rainfall one can expect.

The median value, however, gives a better idea of how much rain we can expect in any year. It is calculated by ranking the rainfall of each year from lowest to highest. The median is the value in the middle – by definition, half of the years will have more rain than the median value and the other half less.

The average rainfall figure is more than 50% higher than the median for Gobabeb rainfall, whereas for Claratal which receives more rain, a difference of 11 mm between the average and median values only represents a 3% difference in expected rain.



Claratal		Gobabeb
145.0		
163.2		
167.2		
189.6		0.4
195.0		3.5
226.5		4.5
233.4		5.3
237.0		5.5
237.3		6.3
238.0		6.8
243.5		7.0
244.0		7.2
247.4		7.9
265.8		9.2
277.2		10.2
284.4		10.8
298.0		10.8
316.7		10.9
317.5		11.5
325.4		11.8
327.4		12.9
327.9		14.3
328.6	**median**	**14.9**
329.2		15.4
331.5		16.3
337.0		16.8
338.8		19.0
344.0		20.5
348.5		21.4
350.8		22.6
365.8		23.3
380.0		24.0
381.5		24.7
391.0		25.6
393.0		26.6
423.0		30.3
428.5		31.0
450.1		31.2
471.0		42.9
472.7		76.9
477.9		108.6
512.7		127.4
548.0		
658.0		
702.0		
339.6	**average**	**22.7**

Figure 13: The frequencies of total annual rainfalls, and the median and average values (data from Gobabeb and Farm Claratal records)

Seasonality

The Kuiseb River Basin receives most of its rain in the summer months. Although rain might fall from as early as September, it mostly falls between the months of January and April – a characteristic that is typical throughout the Basin. Precipitation does occur in winter following the occasional massive cold front. Although these winter events contribute relatively little water to the system in the east, over the past 44 years they have contributed almost a quarter of the rain that has fallen at Pelican Point. Snow was recorded at Claratal in July 1982 and June 1994.

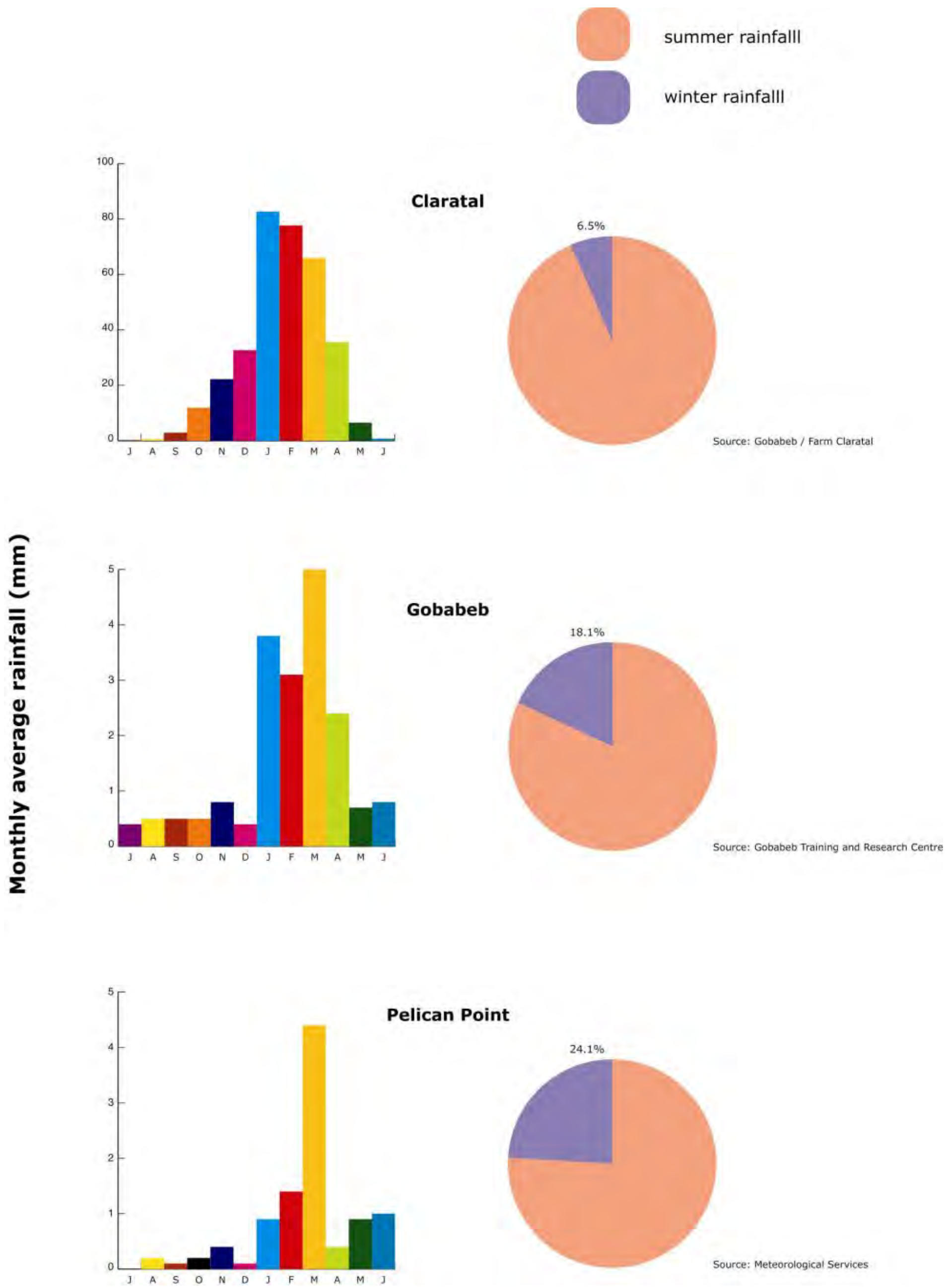


Figure 14: Graphs showing average monthly rain falls at Claratal, Gobabeb and Pelican Point and pie charts of how much rain has been contributed by summer and winter falls for the years for which we there are data.

The rainfall pattern is often described as having a small peak in early summer, followed by a second, large peak bringing the main rains later in the season (see Figure 15, Claratal 1999/00 and 2003/04). This pattern, though, varies from year to year. In some years, such as 2001/02, the rain might all fall late on in the season, in others, such as in 1991/92 and 1945/46, it might be earlier; sometimes, as in 1998/99, it might be more evenly spread throughout the season. Depending on when the rain falls and how it falls (as gentle soaking rain or short, sharp, dramatic storms) determines the amount of runoff and the resultant condition of the veld. Early rains that trigger germination need to be followed up with more rain to enable the grass and seedlings to establish; rains in March usually do not leave enough time for regeneration of the veld before winter sets in.

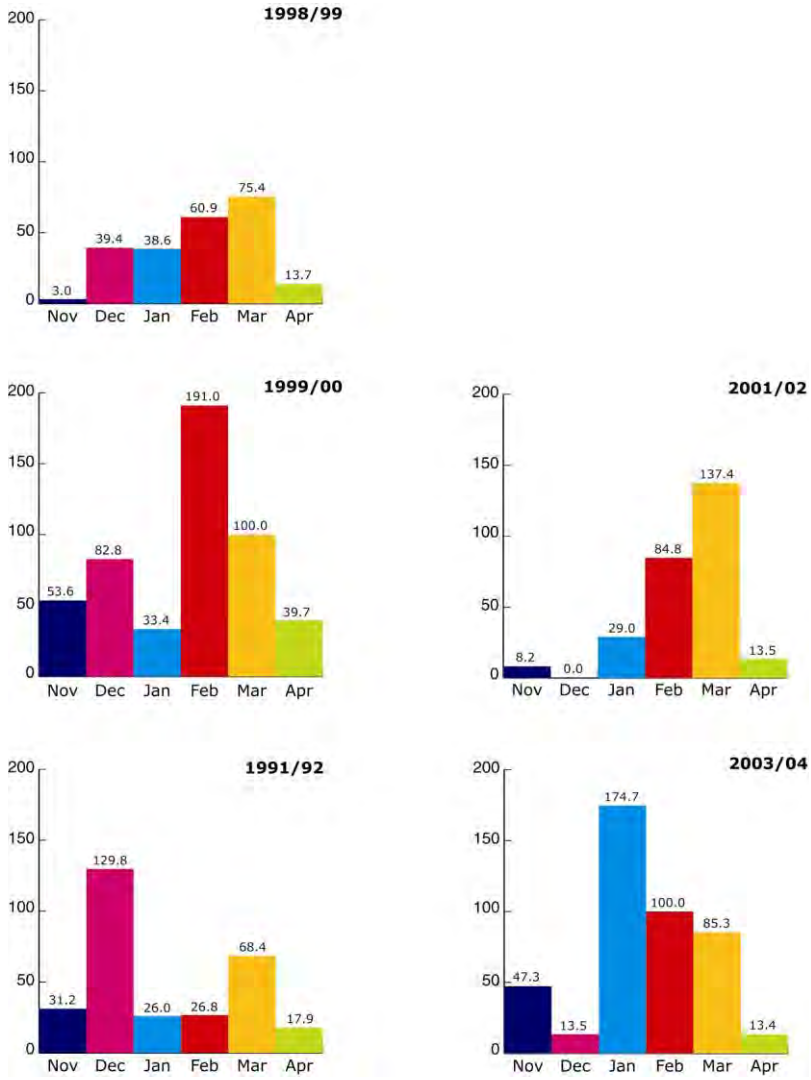


Figure 15: Variation in which months the rain fell at Claratal in five different seasons (from Claratal records)

Fog

In the western reaches of the Kuiseb Basin, fog is an important feature. It brings moisture to an area that otherwise receives little to no precipitation, and acts as an essential source of water for the lichens, plants and animals that live there. At Gobabeb, fog supplements rainfall by almost 40 mm per year. The fog also cools temperatures, increases humidity and reduces radiation, contributing to a lower rate of evaporation where it occurs.

Different types of fog formation are recognised (Henschel *et al.* 1998), but is largely due to humid air being cooled over the Benguela Current at a low altitude. Most commonly fog is brought inland as a low (100–600 amsl) stratus cloud trapped below a strong inversion layer that is intercepted by the land on which it condenses. Depending on the height of the cloud, it is intercepted between 20 and 120 km from the coast, occasionally reaching the escarpment, but most frequently at 20–60 km inland (equivalent to a height of 200–500 amsl).

Although fog and high cloud are a frequent occurrence at the coast, it only precipitates a moderate amount of water. Further inland, where cloud is intercepted by the land, fog contributes significant amounts of water – especially on hills and inselbergs such as Swartbank and Vogelfederberg – that often exceed rainfall (Table 2) and provides a more reliable and regular source of water than rain. This ‗high fog', as it is known, is blown in from a north-north-easterly direction being preceded by a north-westerly wind which is followed by a south-easterly.

Table 2: Fog precipitation in the central Namib Desert

Place	Distance from coast (km)	Altitude (amsl)	Mean precipitating fog events per year	Mean fog precipitation (mm/year)	Mean rainfall (mm/year)
Swakopmund	1	20	65	34	no data
Rooibank	18	63	76	80	17
Swartbank	37	340	87	183	19
Gobabeb	56	407	37	31	27
Vogelfederberg	60	500	77	183	21
Zebra Pan	106	780	16	15	19
Ganab	120	1000	3	3	87

From Lancaster *et al.* (1984), from data collected for varying periods between 1976 and 1981.

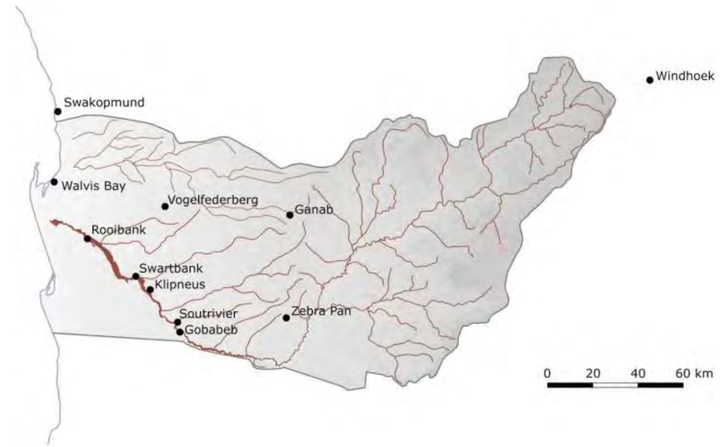


Figure 16: Stations where fog has been measured for various periods of times

At the coast, fog most often occurs between May and September, while inland fog occurs between August and December. Long-term records collected at Gobabeb show us that although the amount of fog precipitation varies considerably from one year to the next, it is less variable than rainfall (co-efficient of variation of fog is 45%, compared to 117% for rain).

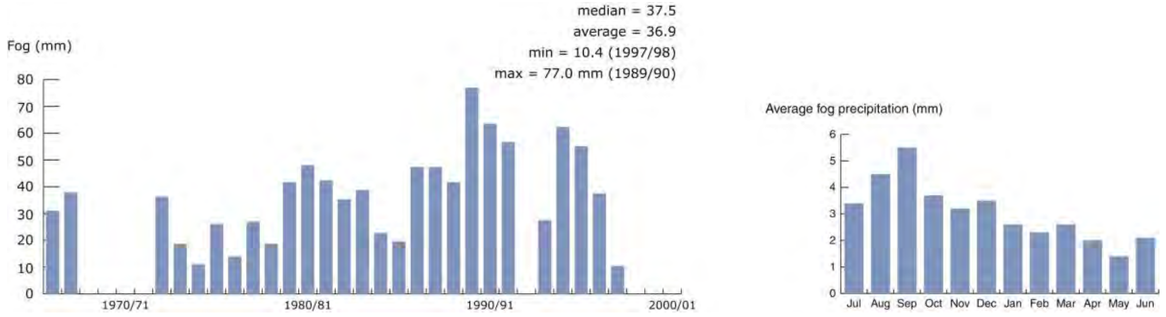


Figure 17: The total annual and average monthly fog precipitation at Gobabeb, 1965/66 to 1997/98 (from records at Gobabeb Training and Research Centre)

The potential of fog water as a source of potable water to supplement the needs of the rural Topnaar communities living along the Kuiseb River, is being investigated (Henschel *et al.* 1998). The amount of precipitation is considerable in some areas (Table 3) and despite problems of seasonal fluctuation and the effects of dry storm winds on fog-collecting equipment, fog harvesting does have potential, not only for human consumption but for growing vegetables and the indigenous !nara plant (*Acanthosicyos horridus*) as well.

Table 3: Fog harvesting at villages along the Kuiseb River

Place	Distance from coast (km)	Altitude (amsl)	Fog events per year	Water collected (ml/m^2)	
				per fog event	per year
Swartbank	37	332	118	2,384	281,312
Klipneus	46	340	118	3,345	394,710
Soutrivier	53	387	75	437	32,775

From Henschel *et al.* (1998), a study on the potential of fog-harvesting carried out between October 1996 and September 1997.

Temperature

Due to different climatic conditions and their influences across the east–west gradient, temperatures show very different characteristics and trends too. Generally, they are hottest in the central Namib Desert, cooler further inland, especially on top of the escarpment, and coolest at the coast (see Figure 18).

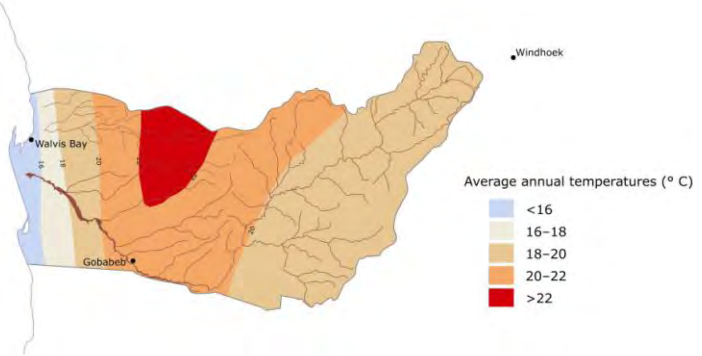


Figure 18: Average annual temperatures in the Kuiseb Basin (adapted from Mendelsohn *et al.* 2002)

Windhoek, being at fairly high altitude has relatively moderate temperatures. Temperatures are typically high in summer peaking from November to January, but seldom reaching the high 30s. Temperatures drop to 0° C on a regular basis in winter and frost conditions are not uncommon in the mornings. The relatively clear skies produce a wide daily range of temperatures throughout the year.

Temperatures at Gobabeb in the central Namib Desert are typically higher than inland. Clear skies and high radiation cause a wide daily range in temperature, although the temperatures are somewhat moderated by warm easterly winds blowing in winter and cooler south-westerlies in summer. The hottest months, on average, are from February to April, but temperatures may reach the high 30s or low 40s any month of the year. The highest temperature in the station‘s 40-year history was recorded in February 2005 – 45° C.

As one moves closer to the coast, the average daily temperature shows less variation from one season to the next, and the daily range becomes smaller. The cold sea temperatures and cooling effects of the fog contribute to a moderate temperatures and frequent cloud cover reduce radiation. The average temperature in Walvis Bay is 20° C throughout the year. The warm winter *berg* (or east) winds warm up winter temperatures, contributing to the lack of seasonal variation, and are responsible for the highest temperatures being recorded in winter. The lowest temperatures are also recorded in winter, but never go below freezing.

Hydrology

The Kuiseb River only flows for short periods of time after good rains in the upper catchment. Surface water at other times is limited to farm dams in the upper basin for varying lengths of time, and a handful of natural pools, seeps and springs mostly in the middle basin. The river does harbour groundwater aquifers along its length and while these aquifers are of relatively low potential for much of river‘s length, they are extensive in the lower reaches.

Flow of the Kuiseb River and the recharge of its underground waters depend entirely on the variable rains in the less-arid eastern reaches of the basin (Figure 11). Although the Kuiseb Basin covers an area of 21,878 km^2, little runoff is produced west of the escarpment and rainfall here does little to help recharge aquifers. Most of the runoff is produced from rain falling over an area that makes up less than a third (30.5%) of the basin (see Figure 2). The rainfall in this small area determines the volume of water that flows down the river, the frequency at which the river flows, the furthest distance to which the water reaches and whether the aquifers in the lower reaches will be recharged. At Gobabeb the river generally flows from a few days to a few weeks a year, although months-long flooding periods have been recorded (Henschel *et al.* 2000; Theron *et al.* 1980: 107), as have periods of years when there was no flow (see Figure 19). The river only completes its journey to the Atlantic Ocean following exceptional falls of rain. Only 16 times since 1837 has the Kuiseb actually reached the sea near Walvis Bay, and for six years the Kuiseb did not flow as far as Gobabeb, some 100+ km away from the Atlantic (Theron *et al.* 1980: 328; van Wyk *et al.* 1985: 107).

Usually as the river flows downstream, all the water evaporates, is captured in dams or filters into the ground long before it reaches the coast. Due to these losses, the average volume of surface water measured at each of the five main flow stations along the Kuiseb River decreases as one moves downstream (Table 4 and Figure 21). At Us in the upper reaches of the basin, the river floods nearly every year. As the water flows downstream, it evaporates

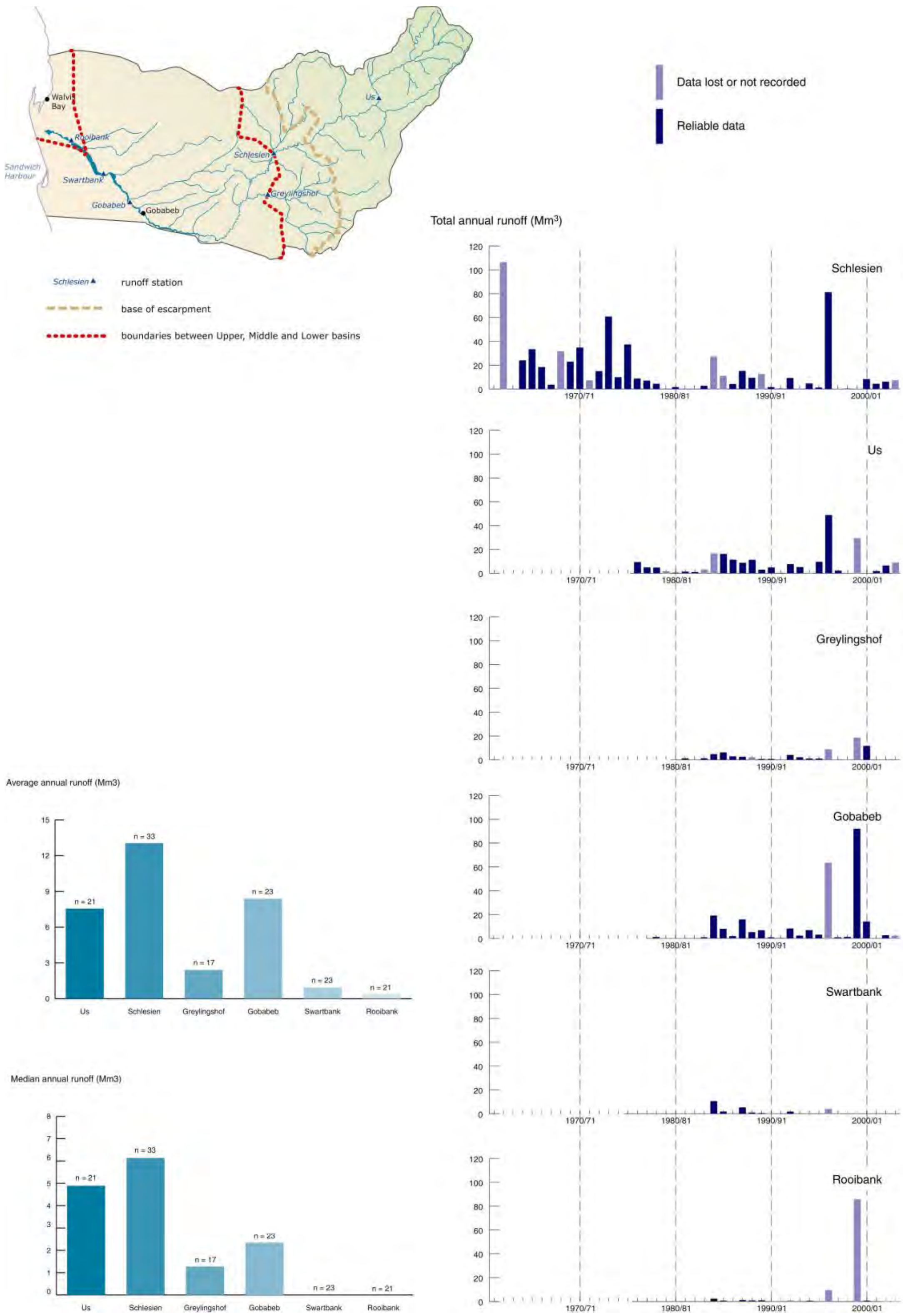


Figure 19: Runoff measured at six flow stations along the Kuiseb and Gaub Rivers over the past 40 years (data from the Directorate of Hydrology, MAWRD). Due to the great variations in total flow along the river each year, the median values of flow present a more accurate reflection of expected flow volumes than the average values.

and soaks into the riverbed while some is held back and stored in dams. Due to lower rainfall in the west, little water is added to the river as it moves further down its course, and the amount of runoff and frequency of floods at the lower reaches of the river is usually much reduced. Only in the floods similar in magnitude to that in 1999/2000, do substantial amounts of water reach Rooibank.

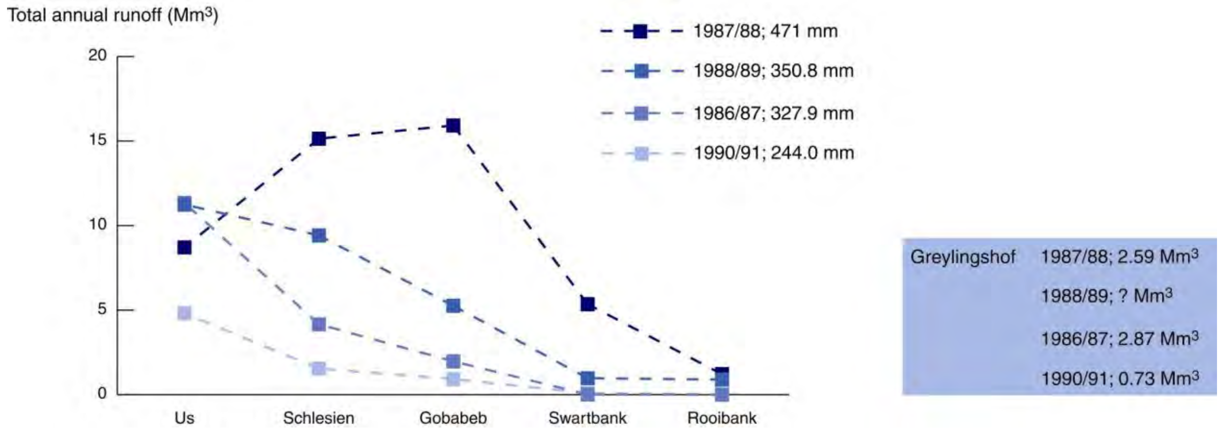


Figure 20: Graph showing the hydrologic decay of total volumes measured at the five stations along the Kuiseb River in four years (Greylingshof is on the Gaub) (runoff data from the Directorate of Hydrology, MAWRD; rainfall figures were measured at Claratal).

Table 4: Floods in the Kuiseb River

	First flood month of wet season	Years with floods	Average runoff (Mm^3)	Median runoff (Mm^3)	Sample size
Us	September	100% (27/27)	7.56	4.89	21
Schlesien	October	95% (40/42)	13.05	6.13	33
Greylingshof	December	90% (18/20)	2.41	1.27	17
Gobabeb	December	85% (22/26)	8.39	2.35	23
Swartbank	January	42% (11/26)	0.93	0.00	23
Rooibank	January	39% (11/28)	0.36	0.00	21

Adapted from Jacobson *et al.* 1995 using data from DWA

People, plants, and animals of the middle and lower Kuiseb depend largely on floodwater seeping into the sand aquifer of the riverbed each year. Over the years this has built up groundwater reserves of about 1500×10^6 m^3 in the lower reaches. The precise extent of recharge is unknown – hence the importance of the WADE project – although sustainable abstraction rates from the lower aquifer to supply the coastal towns have been estimated at 5 x 10^6 m^3 yr^{-1} (Lenz *et al.* 1995).

Holding back the sands of time

Although the Kuiseb River flows, on average, for only a few days a year, this water movement is crucial in keeping the northward migration of the dunes in check (Ward 1984, Ward & von Brunn 1985). The sands of the Namib Sand Sea are continuously pushed in a northerly to north-easterly direction by onshore winds. At the coast, where the southerly winds dominate, the rate of sand movement is greatest – up to 10 m/year. Moving further inland, the effect of the south-westerly winds are tempered by the infrequent, but high velocity, north-easterly berg winds and the northward rate of sand movement is considerably slower – less than 2 m per year (Figure 21).

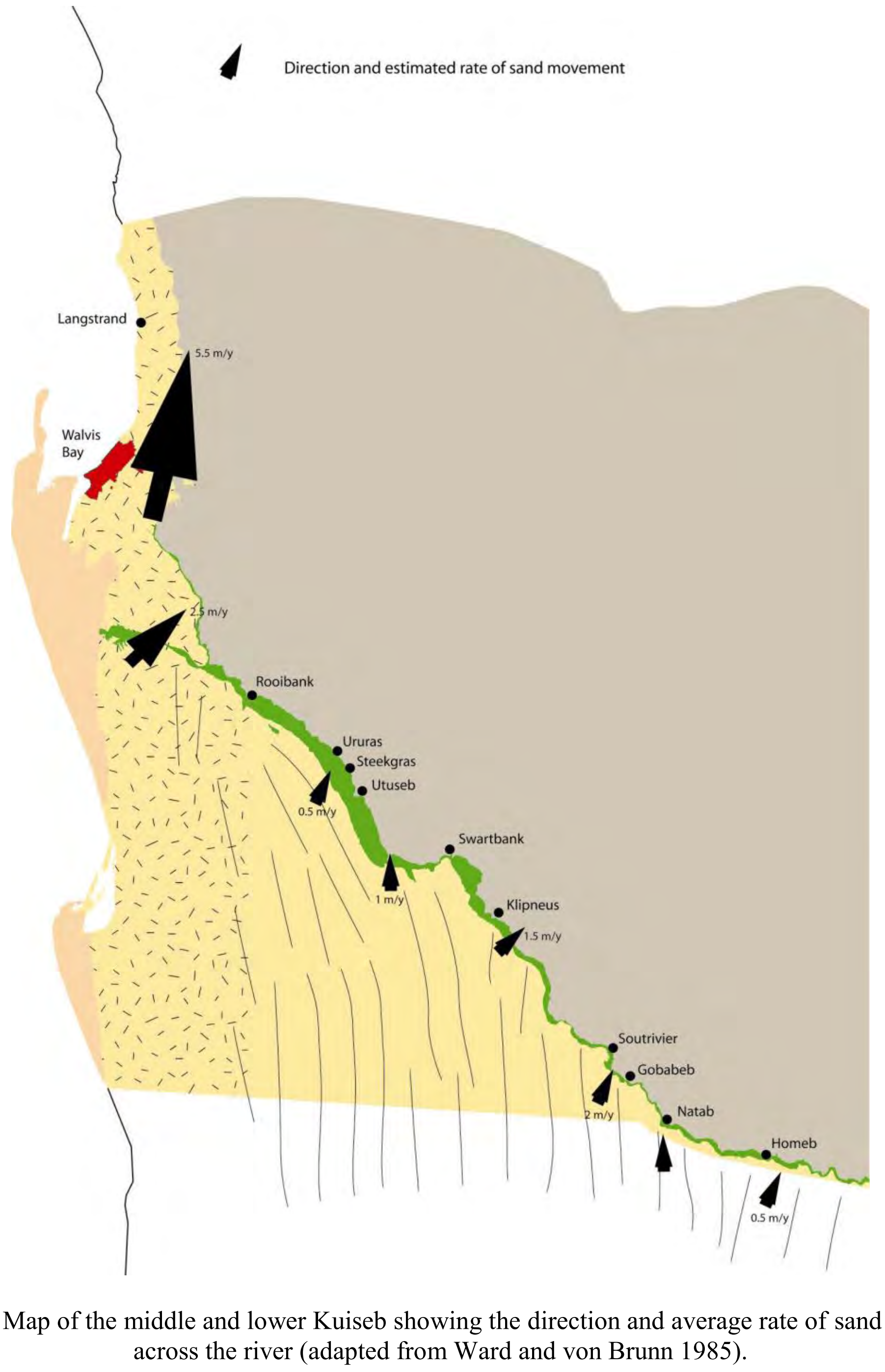


Figure 21: Map of the middle and lower Kuiseb showing the direction and average rate of sand movement across the river (adapted from Ward and von Brunn 1985).

Vegetation cover also slows the movement of sand. Even in the delta, sand piles up around the bases of plants forming semi-stable hummocks. Further upstream, stands of *Stipagrostis* *sabulicola* – the perennial dune grass – have stabilised the bases of the linear dunes to some degree, while the trees in the river affect the wind patterns thereby reducing sand movement.

By measuring the winds, rate and direction of sand movement and assessing the influence of vegetation cover and river flow, Ward & von Brunn (1985) identified flooding of the river as the most important factor in checking the northerly to north-easterly migration of sand. The Kuiseb flow flushes the sands downstream preventing the dunes from migrating across the river, except within the immediate coastal tract where the rate of sand movement is comparatively high and the river rarely flows. The Kuiseb has probably played this role for the last 2 million years, at least since its canyon-like incision.

Dune sand is made up mostly of relatively large, quartz particles, partly rounded by their continuous movement in the wind (Ward 1984). Through the flushing effect of the river, this dune sand is introduced to the otherwise fine-grained silt and clay deposits of the lower reaches of the river, creating pore spaces. It is thought that these pores are a principal factor in facilitating the development of the extensive alluvial aquifers in the lower reaches of the Kuiseb (pers. comm. John Ward).

Three separate multi-year studies of dune movement have placed the speed at which dunes move at between 1.2 m per year and 3–4 m per year, which means that we would expect the dunes to completely block the river were the Kuiseb to experience four or more decades without flooding (Mizuno 2005; Ward & von Brunn 1985; Seely *et al.* 1981).

Before being resolved, there was a major discussion concerning the Homeb silts, a major back-water deposit upstream and downstream of Homeb village. At one time it was thought that sand dunes had blocked the Kuiseb river flow, in a manner similar to Sossus Vlei today e.g. Goudie 1972, Marker and Muller 1978. It is now generally accepted that this was not the case and these sediments represent over-bank flow, e.g. Smith, Mason and Ward 1993. Using fresh-water snail shells found in the deposits Vogel (1982) dated the occurrence of these sediments at 20 000 years before present. More recently, using thermo-luminescence dating techniques, dates ranging from 6300 to 9800 years before present have been established (Bourke *et al.* 2003).

Yet another aspect of sand movement and the dynamics of the Kuiseb‘s course are the fossil watercourses that flow under the sand dunes. These were probably active channels before sand dune or other forces caused the river to move northwards (BGR, Department of Water Affairs, Windhoek).

Lower Kuiseb aquifers

The alluvial aquifers in the Lower Kuiseb are extensive. They run eastwards from Swartbank to the Kuiseb Delta and are compartmentalised into four aquifers. The Swartbank and Rooibank A aquifers really form one continuous aquifer which are separated from Rooibank B and Dorop South aquifers by a hardrock barrier (Figure 22). It is thought that they are all interconnected, but the route and rates of percolation are not well understood. There is a series of palaeochannels running through the underlying Tsondab sandstone south of the river along which groundwater flows towards Sandwich Harbour.

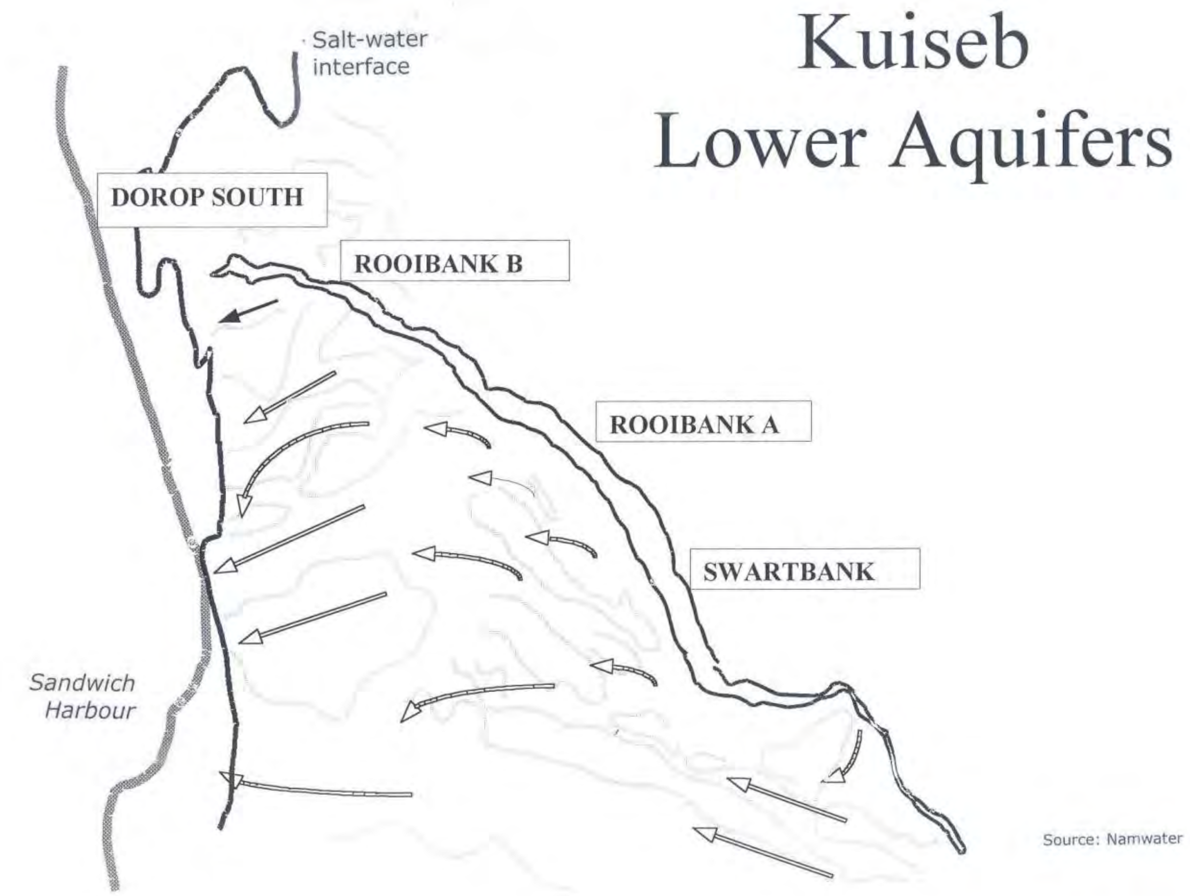


Figure 22: The different aquifers of the lower reaches of the Kuiseb River, the palaeochannels, groundwater movement and the saltwater interface (courtesy of NamWater)

Apart from maintaining the vegetation along these lower reaches of the river basin, these aquifers supply fresh water to the town of Walvis Bay and, until recently, Swakopmund and Arandis, as well as mining developments and a few small farms and in the area. In the late 1960s Rössing Uranium Mine came on line requiring 30–40 Mm^3 a year and the Swartbank aquifer was developed to meet these needs (NamWater pers. comm.). Rössing was supplied from the Kuiseb aquifer up until 1986/87. Abstracting water from these aquifers to all satisfy these needs lowers the water table significantly. The aquifers are only significantly recharged when exceptional rains produce substantial floods to these lower reaches of the basin (Figure 23), such as those rains in 1997 and 2000. Just how resilient the vegetation and the general functioning of the Kuiseb Basin are to these prolonged reductions in the water table is not well understood, but there is evidence that the vegetation in these lower parts is under stress.

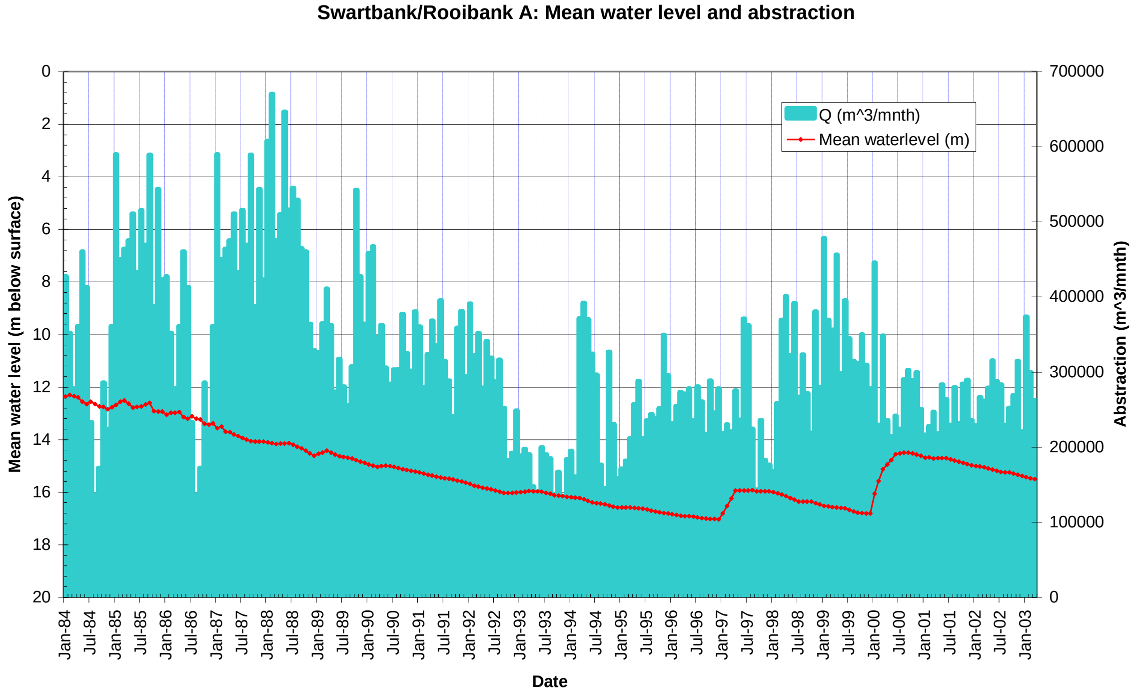


Figure 23: Mean water level of the Swartbank and Rooibank A aquifer and abstraction rates since the mid-1980s (courtesy of Namwater)

Riparian habitat

Based on the characteristics of the Kuiseb Basin described in the sections above, it is clear that the basin presents a variable habitat.

On a broad scale, the upper Kuiseb is located within the acacia tree and shrub savanna, specifically the highland shrubland, grading into the Nama Karoo to the west. The central Namib Desert occupies most of the western part of the basin with the southern Namib Desert extending south of the river course in its western reaches (Figure 24). Livestock and game graze the several vegetation types with livestock being replaced by game to the west.

The riparian ecosystem

Life in the riverbed and on the banks of the Kuiseb is heavily constrained by the harsh conditions of the area, but the ecosystem exhibits surprising species richness. Within 20 kilometres up- and downstream of Gobabeb, researchers have observed some 130 plant species occurring in the riverbed, representing 40 different plant families (Henschel *et al.* in press). Appendix B shows a full table of the plants found near Gobabeb. Note that all of the tree species listed are indigenous to southern Africa, but only *Acanthosicyos horridus* is ~~-tr~~uly desertic" (Seely *et al.* 1981: 63); the rest can only survive relatively close to the river, where they can access underground water sources.

While Appendix B suggests a richly diverse plant population in the Kuiseb, an estimated 80% of the vegetative biomass found in the river is made up of just four woody tree species:

Acacia erioloba, *Faidherbia albida*, *Euclea pseudebenus* and *Tamarix usneoides* (Bate & Walker 1993: 86). These four plant species will be considered in detail along with three other plant species common near Gobabeb: *Salvadora persica*, *A. horridus* and *Nicotiana glauca* (an invasive herbaceous species). These seven plant species are most likely to affect the Kuiseb's aquifer through evapotranspiration due to large leaf area and or large-scale tapping of deep groundwater, and deserve close attention. Although conspicuous where it grows, *Ficus sycomorus* occurs infrequently near Gobabeb.

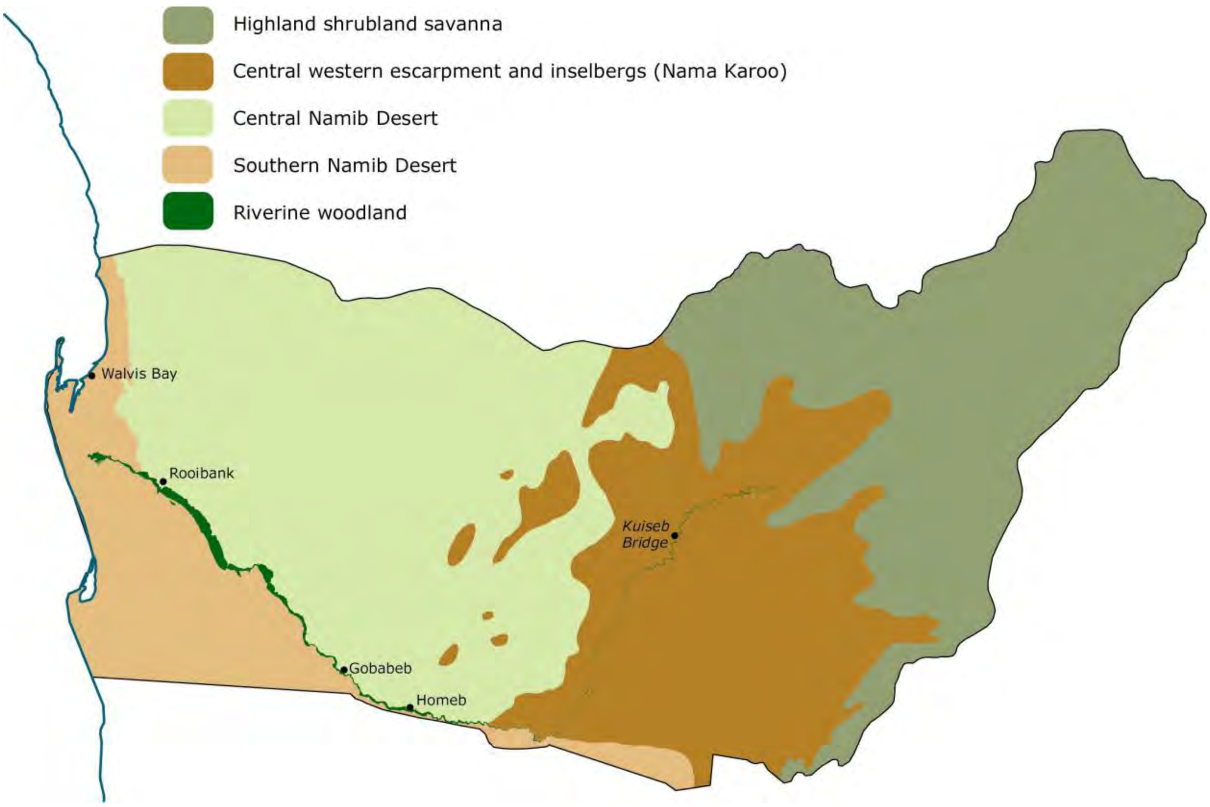


Figure 24: The biomes and broad vegetation types in the Kuiseb Basin (adapted from Mendelsohn *et al.* 2002)

Robinson (1976) was the first to group and classify plant stands of the Namib Desert Park (now the Namib-Naukluft Park). His study, which used the Zūrich-Montpellier classification system, suggested that the vegetation stands in the lower Kuiseb consisted of sub-communities of the *A. erioloba* community, as well as the *Datura spp. – Argemone ochroleuca* community[1]. Robinson recognizes both a ―typical" sub-community with *A. erioloba* forming a ―scattered tree stratum" and a more diverse ―acacia albida" (*F. albida*) sub-community of the *A. erioloba* community. The former sub-community is found both in and out of the riverbed, but always in situations where permanent water is available underground. Typical substrate for this sub-community is sandy soil of various grain sizes. Trees form the dominant stratum, although shrubs also comprise part of the cover in this community, and Robinson reports finding three vegetation strata for this community generally.

1 See Robinson (1976) pages 85-94 for detailed descriptions of each community, including accompanying species tables and cover values.

The *F. albida* sub-community consists of the trees *F. albida, T. usneoides*, *E. pseudebenus* and *S. persica,* as well as lower strata of *N. glauca* and *Chenopodium ambrosiodes*, a nanopherophyte and a therophyte, respectively. Robinson only found the *F. albida* sub-community along the river, principally on the banks of the river, but also in the bed itself in places where floods were not strong enough to uproot the trees. It is generally in a substrate classified as ―young flood-loam”, of loose to soft consistency with an upper crust on terraces and a fine texture, with mica present. According to Robinson, this sub-community seems to only grow where water is readily available, where water is in places less than a metre below the surface, although many of the sub-community's members have roots than can reach considerably deeper than that.

Robinson's *Datura spp. – A. ochroleuca* community is an ephemeral herbaceous community found in or near the river course, consisting largely of two *Datura* species and a number of other therophytes, as well as *Eragrostis trichophora (Cladoraphis spinosa)*, a hemicrytophyte that behaves as a therophyte, and *N. glauca.* It is found in the riverbed or on the edges of terraces bordering the river in a similar substrate to the *F. albida* sub-community, except the crust and litter layers occasionally found in that sub-community were generally washed or blown away in the more exposed conditions. Most of the plants found here are annuals and generally do not survive the flooding of the Kuiseb. This community also contains more invasive species than the others (Robinson 1976: 94).

A late 1970s study by Theron *et al.* using aerial photography and ground verification identified 14 communities in the lower Kuiseb – a finer classification than Robinson advocated. Theron *et al.* (1980) identified 14 plant communities in the lower Kuiseb:

- *Acacia erioloba*
- *Acanthosicyos horridus*
- Dead plant areas
- *Eragrostis spinosa*
- *Faidherbia albida*
- ―Knopduin” or knob dune community
- *Odyssea paucinervis*
- *Pechuel-loeschea leubnitziae*
- *Psilocaulon* sp. cf. *salicornioides*
- *S. persica – A. erioloba – T. usneoides – Euclea pseudebenus*
- *Salvadora persica*
- *Suaeda plumosa*
- *Tamarix usneoides*
- *Zygophyllum simplex* and *Zygophyllum stapffii*

According to Theron *et al.* (1980) the *F. albida* community is found largely along riverbanks, with pure stands common further upriver and an *F. albida – T. usneoides* variation most conspicuous near Gobabeb. Further downstream more variations of the community, mostly mixed with herbaceous species, become more common as the river grows wider. While Theron *et al.* report that *F. albida* is dominant in the narrower upper reaches of the river, *A. erioloba* thrives in the lower reaches of the river where the course is wider (and groundwater may be too low for other trees). The *A. erioloba* community also has a wider range; it is found not only on the banks but also outside the river itself, on the edge of the dunes and on the gravel plains. The other woody communities are less common, and occupy a variety of habitats within the river: floodplains, banks, and the edge of the sand dunes. With the exception of –dead plant areas” and *A. horridus*, the other ten communities identified by Theron *et al.* all consist of herbaceous species largely found in the lowest reaches of the Kuiseb. The dead plant community is found all along the river, mostly in the river-bed and is mostly made up of ephemeral plant species; it corresponds roughly to Robinson's *Datura spp.* – *A. ochroleuca* community. The *A. horridus* community is properly a dune community, but it occasionally occurs close to the river in the Gobabeb area and much more often in the delta. Even individuals found in dunes at the edge of the river may have roots long enough to tap the alluvial aquifer.

Appendix C contains more detailed descriptions of the most important riverine plant species, including what is known about each plant's adaptations to the Namib's extreme aridity and its relation to the Kuiseb's aquifer.

Distribution of plant communities

Table 5 shows estimates of percentage occurrence and densities of various tree species at Gobabeb, as well as *A. horridus*. At Gobabeb *A. erioloba* is by far the most common tree in the river valley. Recent estimates are that it constitutes some 47–57% of trees in the Kuiseb valley near Gobabeb (used in Nghishidi 2005; Kaaronda 2005; Gobabeb 2000). *Faidherbia albida* is the second most-prevalent species, followed by *T. usneoides*, *S. persica*, and *E. pseudebenus*, in that order. *Ficus sycomorus* is present but only represented by a few specimens within several kilometres of Gobabeb, while *A. horridus* only occurs occasionally in the river valley itself.

These frequencies compare well to values found for the Kuiseb as a whole, also summarized in Table 5, although some species are under- and some over-represented at the Gobabeb site: *E. pseudebenus* is markedly rarer at Gobabeb than in the Kuiseb as a whole, as is *A. horridus* (which is most prevalent at the lowest reaches of the river), while *A. erioloba*, *F. albida*, and especially *S. persica* all seem to be more common at Gobabeb than elsewhere.

Table 5: Frequencies and densities of trees found in 10 transects in the Gobabeb vicinity covering a total area of about 2 ha (n=162)

Tree species	Per cent	Tree density	Percentage occurrence in Kuiseb
Acacia erioloba	53	43	44
Acanthosicyos horridus	0	0	8
Euclea pseudebenus	5	4	12
Faidherbia albida	23	19	21
Ficus sycomorus	0.5	0.5	0.4
Salvadora persica	8	6.5	2
Tamarix usneoides	10	8	12

Adapted from Kaaronda 2005 and Nghishidi (2005)
Occurrence of N. glauca was not measured
Occurrence for Kuiseb as a whole from Seely et al. (1981)

As has been mentioned, there is a fairly clear pattern to the distribution of the various plant communities found in the Kuiseb. Figure 25 represents a stretch of river near Homeb, some 20 km upstream of Gobabeb: the *F. albida* community grows close to the active river channel, while the other, more drought-resistant communities are found further away. This figure fits with findings from Seely et al (1981), who found that only *A. erioloba*, *E.*

pseudebenus, and *T. usneoides* occur at a distance from the watercourse with any great frequency. *Faidherbia albida* had fully 50% of its canopy cover occurring within 100 m of the watercourse.

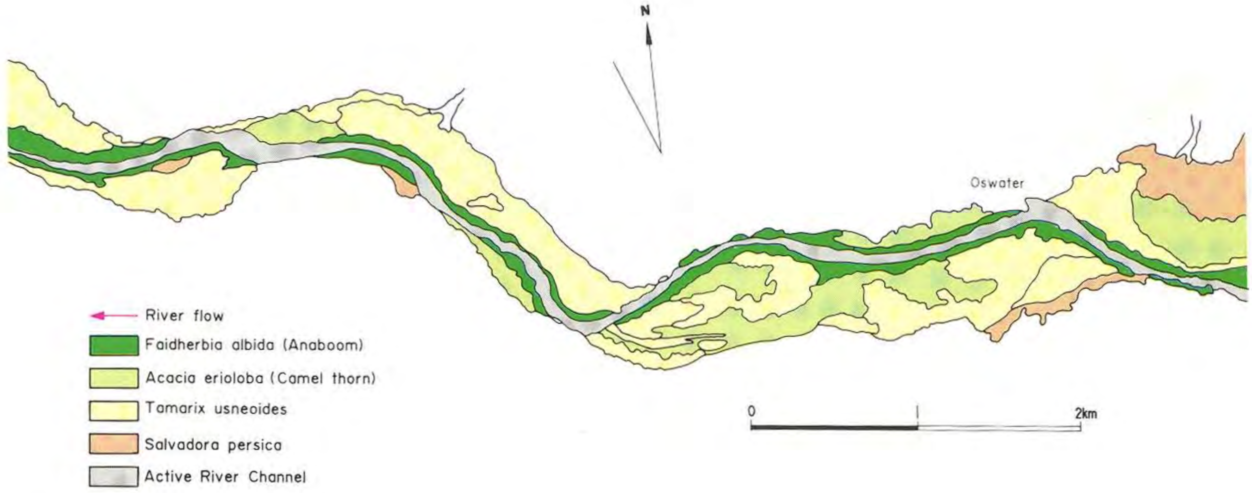


Figure 25: Vegetation map of Kuiseb upstream of Gobabeb (from Jacobson et al. 1995)

Recent tree mapping at Gobabeb, performed along the ten transects detailed in Appendix A, confirm this. *Faidherbia albida* is mostly clustered close to the active river channel (although some individuals occur farther in the floodplain), while *A. erioloba* occurs with higher frequency further from the watercourse. On the other hand, there are some *S. persica* individuals far from the watercourse at Gobabeb, which contradicts the general Seely *et al.* findings, and *T. usneoides* largely occurs next to the watercourse. As expected, almost all *N. glauca* individuals occurred in the main river channel.

The profile also shows that *A. erioloba* occurs much further from the active channel than any other species, and that *F. albida* in particular is found much closer to the channel. It also includes representatives of *A. horridus* and of herbaceous species, as well as grasses such *Stipagrostis sabulicola*, indicating that these plant communities do occur in the vicinity of Gobabeb (although, as is discussed below, these likely do not have a great overall effect on the ecosystem‘s relationship with the aquifer).

Evapotranspiration losses

In 1993, Bate and Walker carried out a study on evapotranspiration in the Kuiseb, using a model to estimate the total amount of water lost to transpiration and sand evaporation in a given year. Table 6 shows maximal transpiration rates (measured at noon) for the four tree species that make up the most vegetative biomass in the river. Note that *F. albida* and *A. erioloba* together have almost five times the leaf biomass of the other two species, making their rates much more important in determining overall transpiration losses.

Bate and Walker's model estimated that the total volume of water in the aquifer was some 10.7×10^5 m^3 water km^{-1} immediately after a flood, and that some 24% of this (2.59×10^5 m^3 km^{-1}) would be lost due to evapotranspiration. Of this 2.02×10^5 m^3 km^{-1} is due to vegetative transpiration, and 0.57×10^5 m^3 km^{-1} is caused by evaporative losses from sand in the riverbed. The authors do caution, however, that the 24% loss to evapotranspiration is likely an overestimate; for instance, on many days in the year morning fog can limit transpiration from leaves, and estimates for losses from sand do not take into account shaded areas. Accounting for these and other factors, they estimate that a –more realistic” figure for annual water loss is likely 15–20% of the total aquifer volume.

Table 6: Maximum transpiration rates for four species in the Kuiseb, standard error and sample size

Species	Transpiration rate ($g\ H_2O\ g^{-1}\ hr^{-1}$)	SE ($g^{-1}\ hr^{-1}$)	n (sample)
F. albida	1.50	0.05	145
A. erioloba	1.03	0.03	226
E. pseudebenus	0.54	0.04	202
T. usneoides	1.07	0.03	232

From Bate & Walker (1993)

They further estimate that this would lead to a –dry depth” of 2.92 m in the riverbed 51 weeks after a flood, although the capillary fringe above the water table means that the table itself should be slightly deeper than this.

Coppicing

One notable phenomenon in the lower Kuiseb is a relatively high incidence of coppicing, specifically the sprouting of new shoots off of a dead tree that has fallen down: Table 7 shows a estimate of how many trees in the river coppice based on a study over 22.4 ha near Gobabeb. Coppicing is of interest because of what it may reveal about past floods. In Israel, for instance, the age of fallen and coppiced tamarisk trees, as determined from tree rings, has been found to correlate strongly to previous large flood events (pers. comm. Y. Enzel). The data from the Kuiseb are supportive of a link between flooding and coppicing: most of the coppiced trees were found close to the active river channel (Nghishidi 2005). However, as expected from previous work in the Kuiseb, attempts to find a more precise link between flood occurrences and coppice ages using tree rings have not been successful.

Table 7: Estimated number of species and those coppicing as observed in a 22.4 ha study area adjacent to Gobabeb

Tree species	Estimated number of trees per species	Total number of coppicing trees	Percentage of trees coppicing
A. erioloba	843	2	0.2
F. albida	320	17	5.3
T. usneoides	139	22	15.9
E. pseudobenus	53	6	11.3
S. persica	128	0	0.0
Total	**1483**	**47**	**3.2**

From Nghishidi (2005)

Note also that a recent study found the water content in coppicing trees to be somewhat higher than in other trees; this relationship may be of further interest, although it could also be because trees more readily-identified as coppiced shoots tend to be younger, and younger trees generally have higher water content in leaves than do older trees (Mamili 2005).

Users

Users of water in the Kuiseb Basin are varied. In the upper reaches of the basin, commercial farmers raising livestock and game, with some tourism enterprises, are mainly dependent on water from hard-rock aquifers. Their farming activities influence runoff rates, while potential runoff is captured in small farm dams to help with recharge of the aquifers. Little or no use is made of water from alluvial aquifers in the Kuiseb River itself.

In the middle reaches of the Kuiseb, game from the Namib Naukluft Park and communal farmers from the Topnaar community, use the Kuiseb River temporary surface pools and the alluvial aquifer of the main watercourse. Game move in and out of the canyon area of the Kuiseb depending on water availability on the surface or in shallow excavations made by baboons or oryx. Livestock and people living in villages along the river course use solar-powered pumps to obtain water from the alluvium.

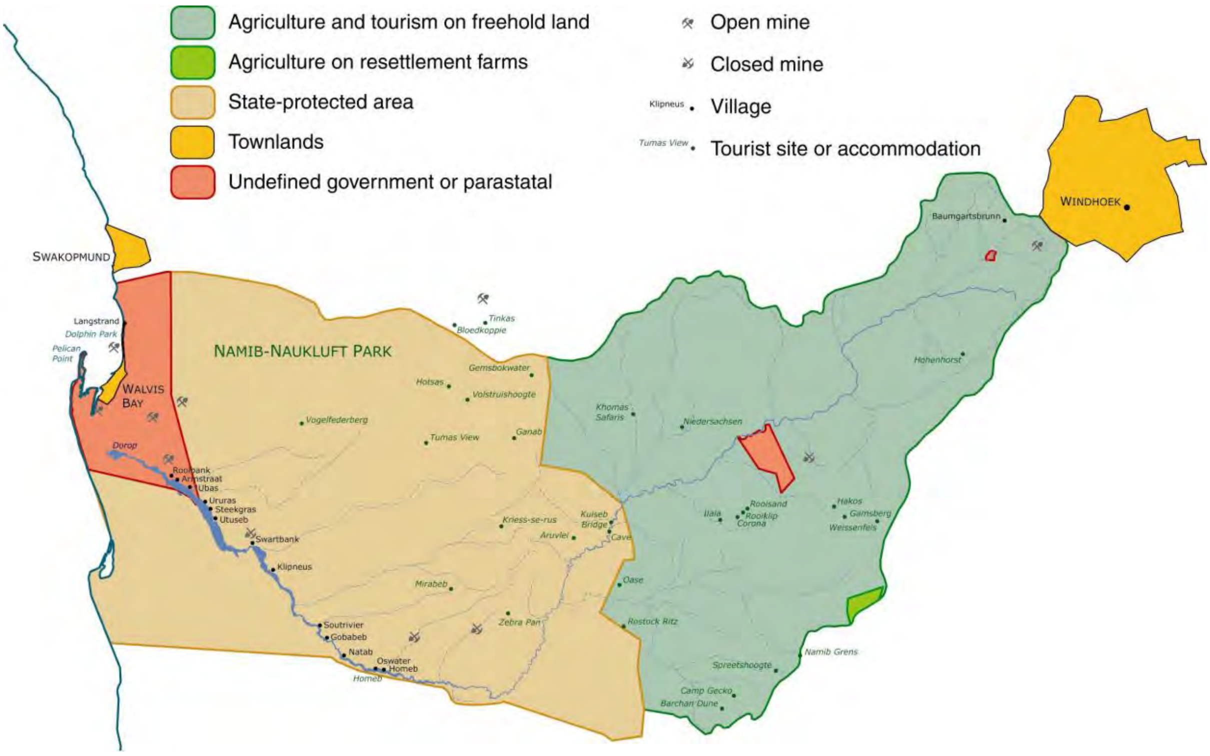


Figure 26: Use of land in the Kuiseb Basin (adapted from Mendelsohn *et al.* 2002)

The lower alluvial aquifer supplies water to the town of Walvis Bay and a small portion of Swakopmund's requirements, as well as to several mines and quarries in the area and a few Topnaar villages close to the abstraction scheme. For this water supply, the bulk water supplier, NamWater, manages the aquifer and its infrastructure. Water is then sold to the municipalities and other bulk users. The Municipality of Walvis Bay then charges users for supply of water according to a stepped tariff. The municipality also provides grey water for gardening and a part of town has a dual reticulation system.

Livestock

Livestock are the major water consumers in the upper and middle Kuiseb Basin. Although numbers of livestock are much lower in the middle Kuiseb (Table 8), the effective densities of these animals is greater because they are confined to the narrow strip of riparian vegetation supported by the river in these reaches. While numbers of livestock in the upper Kuiseb remain fairly stable or are even decreasing as farmers diversify into tourism, numbers of livestock in the lower Kuiseb continue to increase (Figure 27).

Table 8: Livestock numbers in the Kuiseb Basin

	Upper Kuiseb[1]	Middle Kuiseb[2]
Cattle	22,678	192
Goats	5,777	3,252
Sheep (meat)	11,558	143
Sheep (karakul)	2,575	0
Donkeys	n/a	301

[1] Calculated from densities and areas from data from Mendelsohn et al. 2002
[2] Average figures for 2002, 2003 and 2004 from DVS

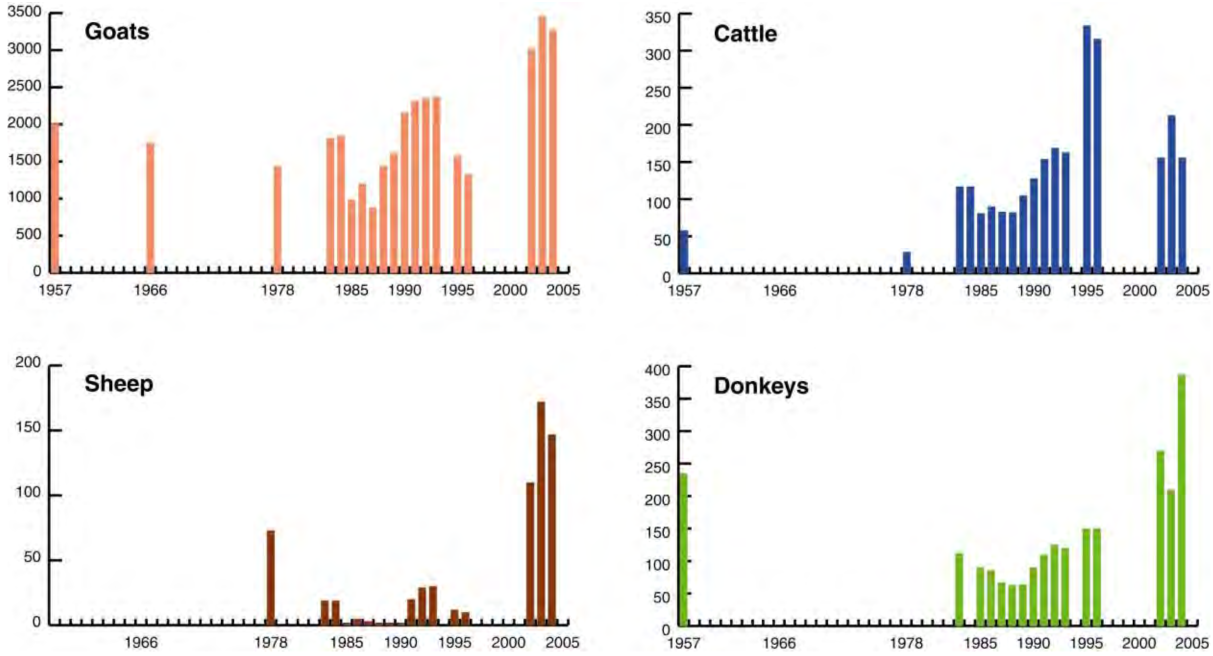


Figure 27: Change in livestock numbers over the years in the middle and lower Kuiseb areas

The Kuiseb River Basin is a diverse, multi-faceted basin supporting a variety of users. The system is driven by the rainfall in the upper catchment which provides differing amount of runoff depending on the amount of rain, the vegetation cover and impacts of land use in the upper catchment. The majority of users are neither the livestock and game farmers in the upper catchment or the livestock farmers and wildlife in the middle catchment, but the urban dwellers, harbour town and factories in the lower catchment. This major alluvial aquifer is recharged occasionally when the Kuiseb flow reaches the lower part of the basin. This dynamic and arid system requires extensive further study to elaborate the details of the people, vegetation, aquifer and surface flow of the Kuiseb basin.

References

Anderson, JR 2005. Sand Sieve Analysis. Accessed December 19, 2005. < http://gpc.edu/~janderso/historic/labman/sievean.htm>.

Barnes, RD., CW Fagg and S J Milton. 1997. *Acacia erioloba* monograph and annotated bibliography, 1st edition. Oxford Forestry Institute, Oxford.

Bate, GC and BH Walker. 1993. Water relations of the vegetation along the Kuiseb River, Namibia. Madoqua **18**:85-91.

Bourke, MC, A Child, S Stokes. 2003. Optical age estimates for hyper-arid fluvial deposits at Homeb, Namibia. Quaternary Science Reviews 22: 1099-1103.

Brown, CJ and AA Gubb. 1986. Invasive alien organisms in the Namib Desert, Upper Karoo and the arid and semi-arid savannas of western southern Africa, 1st edition. Oxford University Press, Cape Town.

Canadell, J, RB Jackson, JR Ehleringer, HA Mooney, OE Sala and E.-D Schulze. 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia **108**:583-595.

Craven, P and C Marais. 1998. Namib flora, 1st, reprinted edition. Gamsberg Macmillan, Windhoek.

Curtis, B and C Mannheimer. 2005. Tree atlas of Namibia, 1st edition. National Botanical Research Institute. Ministry of Agriculture, Water and Forestry, Windhoek.

Evenari, M and Y Gutterman. 1973. Some notes on *Salvadora persica* L. in Sinai and its use as a toothbrush. Flora **162**:118-125.

Hamilton, WJI. 1986. Namib Desert chacma baboon (*Papio ursinus*) use of food and water resources during a food shortage. Madoqua 14(4): 397-407.

Henschel JR, V Mtuleni, N Gruntkowski, MK Seely and Shanyengana ES. 1998. Namfog: Namibian Application of Fog-Collecting Systems, Phase I: Evaluation of Fog-Water Harvesting. Desert Research Foundation of Namibia, Occasional Paper No. 8: 81pp.

Henschel, JR, R Dausab, P Moser and J. Pallett, editors. 2004a. !NARA: fruit for development of the !Khuiseb Topnaar, 1st edition. Namibia Scientific Society, Windhoek.

Henschel, JR and P Moser. 2004b. ―!Nara ecology - an introduction”. In Henschel et al 2004a: 55-61.

Henschel JR, J Pallett, C Berry, M Griffin, B Hachfeld, O Makuti and MK Seely. In press. Checklists of the flora and vertebrates of Gobabeb. Journal of the Namibia Scientific Society.

Henschel, JR, MK Seely and J Zeidler. 2000. Long-term ecological research at Gobabeb: gaining and applying knowledge about a highly variable environment. Journal of the Namibia Scientific Society **48**:89-114.

Huntley, BJ, editor. 1985a. The Kuiseb environment: the development of a monitoring baseline, 1st edition. Council for Scientific and Industrial Research, Pretoria.

Huntley, BJ. 1985b. ―The Kuiseb environment”. In Huntley: 7-19.

International Arid Lands Consortium. 2001. Soil Properties. Accessed December 19, 2005. <http://cals.arizona.edu/OALS/soils/properties.html>.

Jabs, C. 1991. Alien invasives in the Kuiseb River, Namib Desert, Namibia. University of Oxford, Oxford.

Jacobson, PJ, KM Jacobson and MK Seely. 1995. Ephemeral rivers and their catchments, 1st edition. Desert Research Foundation of Namibia, Windhoek.

Kaaronda, D. 2005.

Katoma, L-N. 1989. A comparative analysis of the sand-trapping potential of two Namib desert shrubs: a case-study at Gobabeb. B. Sc. Honours. Fort Hare, University of Fort Hare**:** 1-84.

Lancaster, N. 1981. Grain size characteristics of Namib Desert linear dunes. Sedimentology **28**:115-122.

Lancaster, J, N Lancaster and MK Seely. 1984. Climate of the central Namib Desert Madoqua. 14:5–61.

Lenz, R, H Grobbelaar and M Djama. 1995. Reports on hydrogeological and isotope hydrological investigations. Vol D-1. Bundesanstalt für Geowissenschaften und Rohstoffe. Hannover, Federal Institute for Geosciences and Natural Resources.

Mamili, PK. 2005.

Marker, ME and D Muller. 1978. Relict vlei silt of the middle Kuiseb valley, South West Africa. Madoqua 11(2): 151-162.

Mendelsohn, J, A Jarvis, C Roberts and T Robertson. 2002. Atlas of Namibia, 1st edition. New Africa Books (Pty) Ltd., Cape Town.

Mizuno, K. 2005. Environmental changes in relation to tree death along the Kuiseb River in the Namib Desert. African Study Monographs **Suppl. 30**:27-41.

Mizuno, K and K Yamagata. 2005. Vegetation succession and plant use in relation to environmental changes along the Kuiseb River in the Namib Desert. African Study Monographs **Suppl. 30**:3-14.

Nghishidi, J. 2005.

Palmer, E and N Pitman. 1972. Trees of Southern Africa, 1ST edition. A.A.Balkema, Cape Town.

Phemelo, M. 2005.

Ritter, M. 2003. The Physical Environment. Accessed December 19, 2005. < http://www.uwsp.edu/geo/faculty/ritter/glossary/s_u/soil_texture_triangle.html>.

Robinson, ER. 1976. Phytosociology of the Namib Desert Park, South West Africa. Archive. University of Natal, Pietermaritzburg.

Seely, MK, WH Buskirk, WJI Hamilton and JEW Dixon. 1981. Lower Kuiseb River perennial vegetation survey. Journal of the South West Africa Scientific Society **35**:57-86.

Smith, RMH, TR Mason and JD Ward. 1993. Flash-flood sediments and ichnofacies of the Late Pleistocene Homeb Silts, Kuiseb River, Namibia. Sedimentary Geology 85: 579-599.

Theron, GK, N van Rooyen and MW van Rooyen. 1980. Vegetation of the lower Kuiseb river. Madoqua **11**:327-345.

Van den Eynden, V, P Vernemmen and P Van Damme. 1992. The ethnobotany of the Topnaar, 1st edition. Universiteit Gent, Gent, Belgium.

Van Wyk, AJ, DPJ Opperman and OB Kok. 1985. ―Availability, quality, and utilization of the riverine vegetation of the lower Kuiseb and canyon area." In Huntley: 107-112.

Vogel, JC. 1982. The age of the Kuiseb River silt terrace at Homeb. Palaeoecol. Afr., 15: 201-209.

Ward, JD. 1984. Aspects of the Cenozoic geology in the Kuiseb Valley, central Namib Desert. PhD Thesis. Department of Geology, University of Natal, Pietermaritzburg. 310 pp.

Ward, JD and CM Breen. 1983. Drought stress and the demise of *Acacia albida* along the lower Kuiseb River, central Namib Desert: preliminary findings. South African Journal of Science **79**:444-447.

Ward, JD and V von Brunn. 1985. ―Sand dynamics along the lower Kuiseb River". In Huntley: 51-72.

Wickens, GE. 1998. Ecophysiology of economic plants in arid and semi-arid lands, 1st edition. Springer, Berlin.

Wood, PJ. 1989. Faidherbia albida (Del.) A. Chev., 1st edition. Technical Centre for Agricultural and Rural Cooperation, Wageningen.

Yamagata, K and K Mizuno. 2005. Landform development along the middle course of the Kuiseb River in the Namib Desert, Namibia. African Study Monographs **Suppl. 30**:15-25.

Appendix A

Sediment Characterisation

1.1 Texture Analyis Study

Sediment sampling for texture analysis, i.e grain size, was done at three of the transects in Figure 5. Previous studies have shown that some 40-50% of the sand in the riverbed is dune-derived (Ward & von Brunn 1985). A detailed report of our recent analysis follows.

1.1.1 Study Area

Seven samples were taken near Gobabeb (Figure 1.1) at Transect 9, eleven samples approximately 300 m up river at Transect 5 and ten samples approximately 400 m further up river at Transect 2. The three samples shall be referred to as T 9, T 5 and T 2 respectively.

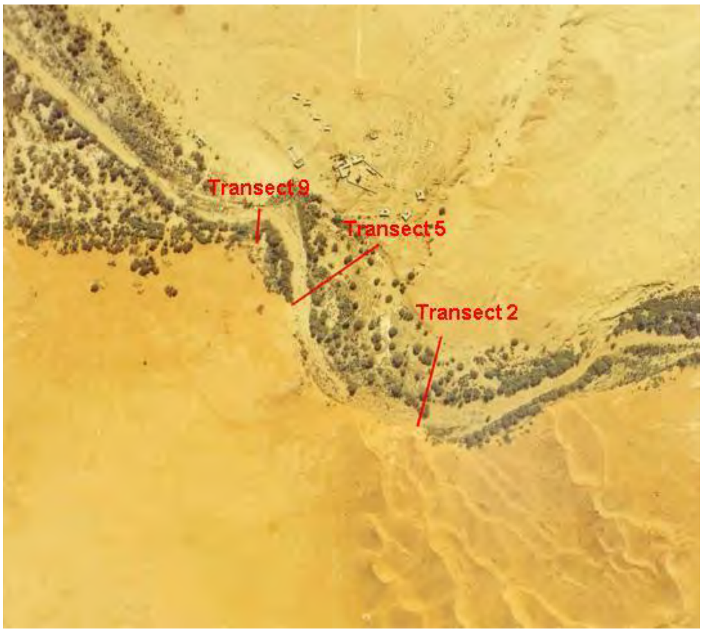


Figure 1.1: Study area with transects

The transects extend over the width of the riverbed, i.e. the flooded area during a flood event, with samples taken at greater proximity to one another within the main river channel where more frequent and intensive flow would occur.

At T1, as a result of an obstructing rock outcrop on the northern side, the main river channel takes up almost the entire width of the riverbed; therefore samples were taken at greater proximity to one another at this point compared to the other transects.

1.1.2. Methods

An auger was used to sample at a depth of approximately 35 cm. This depth was selected to ensure sampling of fluvial deposits and not of recent aeolian deposits. Test measurements in the riverbed showed no moist sediment even at a depth of almost 120 cm (the length of the available auger).

Each sample was placed in a plastic bag, taken to the laboratory and weighed. They were subsequently analysed according to the US Department of Agriculture system, which separates texture into four major classes: **gravel** (coarse fragments greater than 2 mm in diameter), **sand** (2 mm to 0.063 mm in diameter), **silt** (0.063 mm to 0.0039 or 0.002 mm in diameter) and **clay** (less than 0.0039 or 0.002 mm in diameter). Detritus, consisting mainly of small leaves and twigs, was removed by hand from the samples and weighed, while the sediment loss as a result of sieving or detritus removal was calculated.

As sand is the primary component of the river sediments, sieves with the following mesh sizes were used: 2000, 1000, 560, 250, 125 and 63 microns. The texture classes can be seen in Table 1.1, below.

Table 1.1: Texture classes used in this study

Texture classes	GRAVEL	SAND very coarse	SAND coarse	SAND medium	SAND fine	SAND very fine	SILT
[microns]	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63

Using this standard array of sieves, sediment greater than 2 mm and less than 0.063 mm was generally classified as gravel and silt/clay respectively. Sand was separated into five classes and classified as very coarse, coarse, medium, fine and very fine.

1.1.3. Results and Discussion

1.1.3.1 Texture comparison of Transects 1, 2, 3

The arithmetic mean of the percentage of the weighed texture classes is shown per transect in the table below (Table 1.2):

Table 1.2: Average grain size distribution for three Gobabeb transects.

Transect	GRAVEL [%]	SAND [%]	SILT/CLAY [%]	Detritus [%]	Sediment loss [%]
9	0.00	94.01	4.88	0.74	0.37
5	0.01	97.04	2.35	0.22	0.38
2	0.11	97.35	1.90	0.37	0.30

The samples of all transects comprise mainly sand, little silt/clay and very little to no gravel. All three transects‘ sediment can be classified as ‗sand‘ according to the soil textural triangle (Figure 1.2), as the sum of silt and clay does not exceed 10 %.

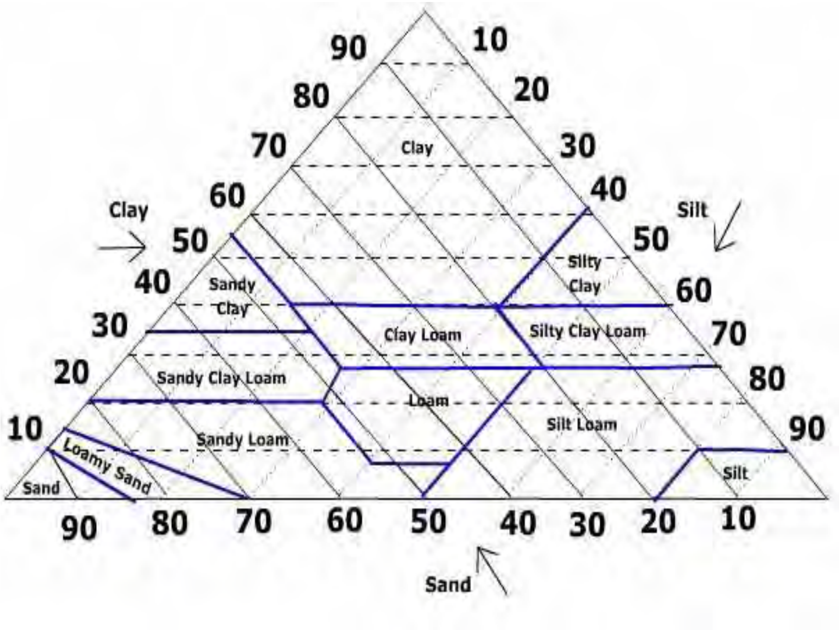


Figure 1.2: Soil textural triangle (from Ritter 2003)

Although it was not possible to further classify gravel, none of the grains appeared larger than 4 mm. T 9 contains no gravel and less sand than the other transects with the highest amount of silt/clay. The amount of detritus in all transects is relatively small, and consists mainly of leaves and twigs no greater than approximately 5 mm in their largest dimension. It is likely that the sediment lost during sieving is mainly the fine components of silt and clay.

The map below (Figure 1.3) shows the locations of the transects and sample sites in the riverbed and the measured texture classes in percentage.

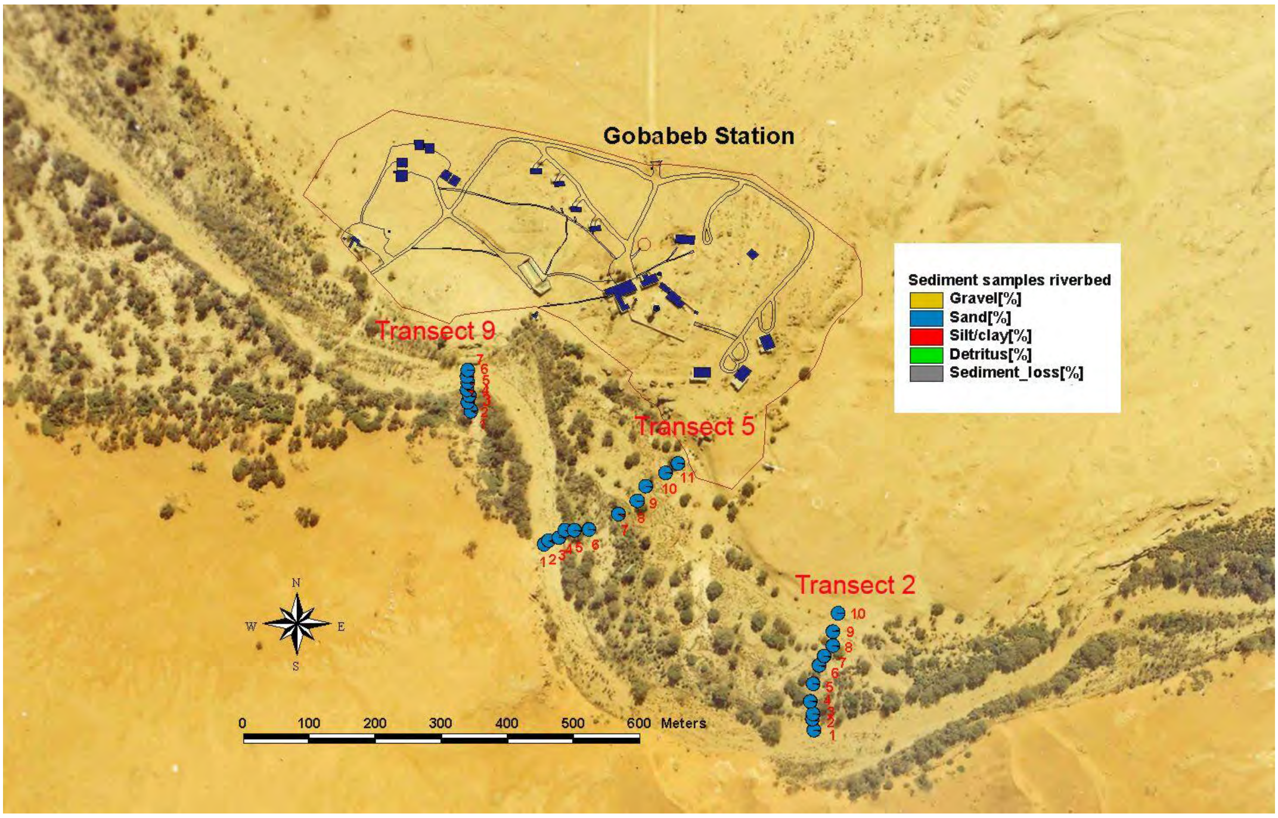


Figure 1.3: Transects 1, 2 and 3 with samples

1.1.3.2 Texture comparison of samples within each transect

Transect 9

The texture classes for each sample of T 9 are shown in Table 1.3 and in the corresponding graphs (Figure 1.4):

Table 1.3: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‗x' represents the sediment per class.

	GRAVEL [%]	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.00	0.00	0.98	28.76	43.04	20.01	4.10	2.67	0.46
2	0.00	0.00	3.11	34.05	45.64	13.39	2.87	0.27	0.68
3	0.00	0.00	0.10	11.80	59.08	23.93	4.22	0.82	0.06
4	0.00	0.00	2.93	6.58	43.61	34.80	10.99	0.67	0.41
5	0.00	0.00	1.33	8.78	53.68	27.58	8.16	0.39	0.08
6	0.00	0.00	2.08	30.50	49.75	14.05	2.68	0.11	0.83
7	0.00	0.00	0.86	39.87	46.66	11.17	1.13	0.24	0.08

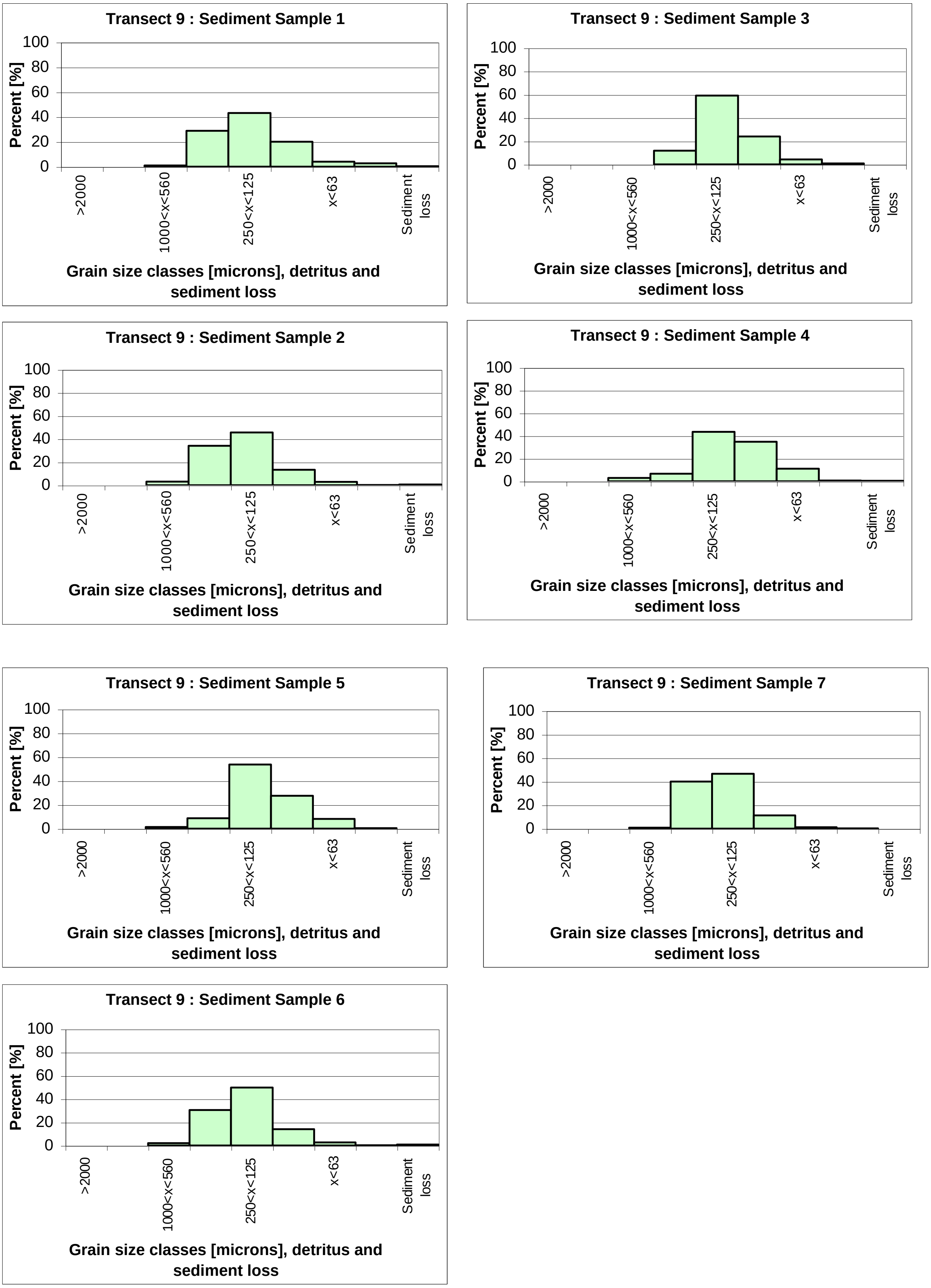


Figure 1.4: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‚x' represents the sediment per class.

As with the other transects, less detritus was found in the main river channel (samples 5, 6 and 7) and in areas with little vegetation. Sample 1 has a high amount of detritus, originating most probably from the Salvadora bushes (*Salvadora persica*) next to the sample site (Figure 1.5).

Figure 1.5: Detritus from *S. persica* at Sample 1 (K. Wouters, 2005)

As mentioned before, T 9 contains greater amounts of silt/clay (< 63 microns) than the other transects. In addition to that, Table 1.3 and the graphs (Figure 1.4) show that the greatest percentage of sand falls into the fine sand category (125 – 250 microns) and a relatively large percentage into the very fine sand category (63 – 125 microns) compared to the other transects.

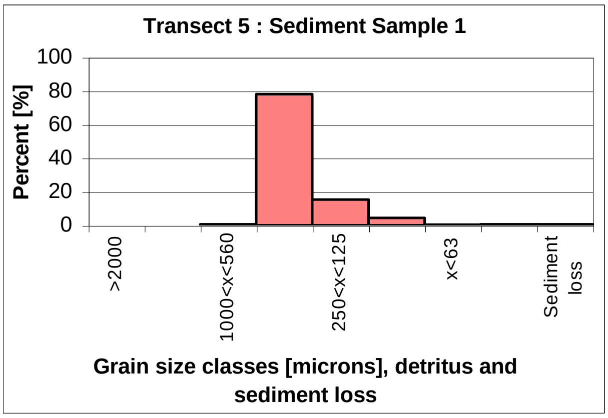
Figure 1.6: Silt/Clay deposits in the main river channel of T 9 *(Source: K. Wouters, 2005)*

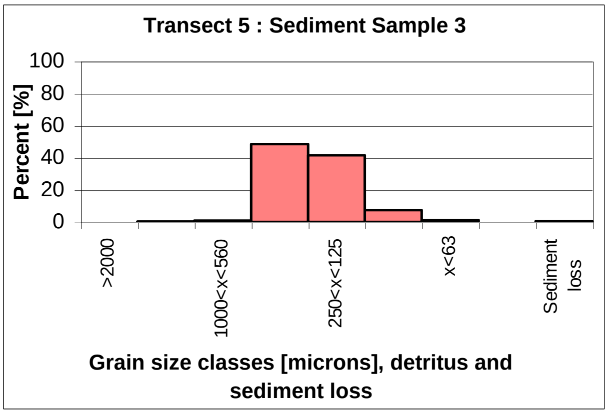
Transect 5

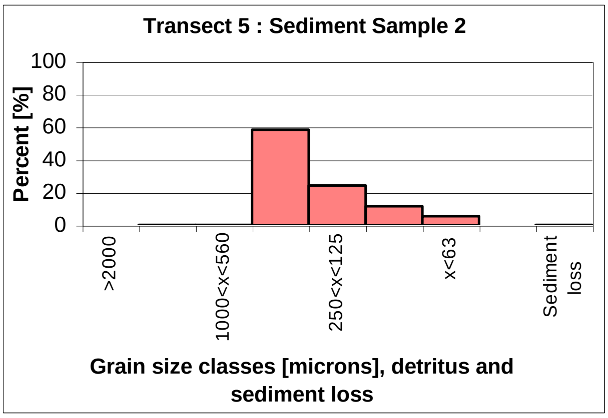
The texture classes for each sample of T 5 are shown in Table 5 and in the corresponding graphs (Figure 1.7):

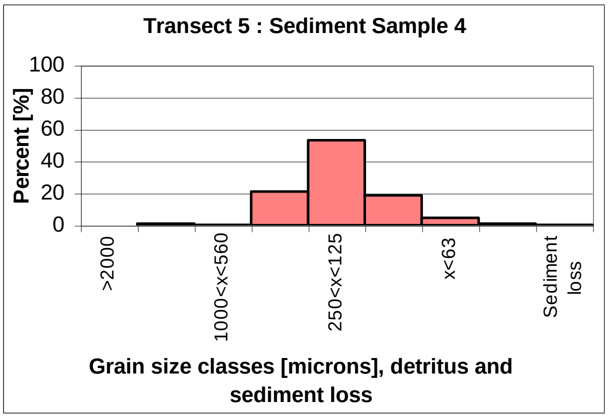
Table 1.4: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‗x' represents the sediment per class.

	GRAVEL[%] (Granules)	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.07	0.03	0.50	78.07	15.35	4.34	0.43	0.61	0.60
2	0.00	0.16	0.23	58.38	24.23	11.48	5.41	0.00	0.12
3	0.00	0.16	0.72	48.48	41.55	7.31	1.26	0.04	0.47
4	0.00	1.02	0.28	21.06	53.20	18.71	4.58	0.95	0.20
5	0.00	0.00	0.17	50.20	41.81	6.18	1.09	0.22	0.33
6	0.00	0.03	0.01	30.18	56.13	11.23	1.93	0.02	0.47
7	0.00	0.00	0.20	4.61	57.02	30.65	6.41	0.35	0.76
8	0.00	0.04	0.13	28.20	59.84	10.49	1.04	0.08	0.18
9	0.00	0.00	0.04	27.96	59.07	11.22	1.52	0.05	0.15
10	0.02	0.05	0.23	57.41	35.91	5.68	0.56	0.00	0.15
11	0.00	0.06	0.07	31.47	53.25	12.65	1.66	0.08	0.76









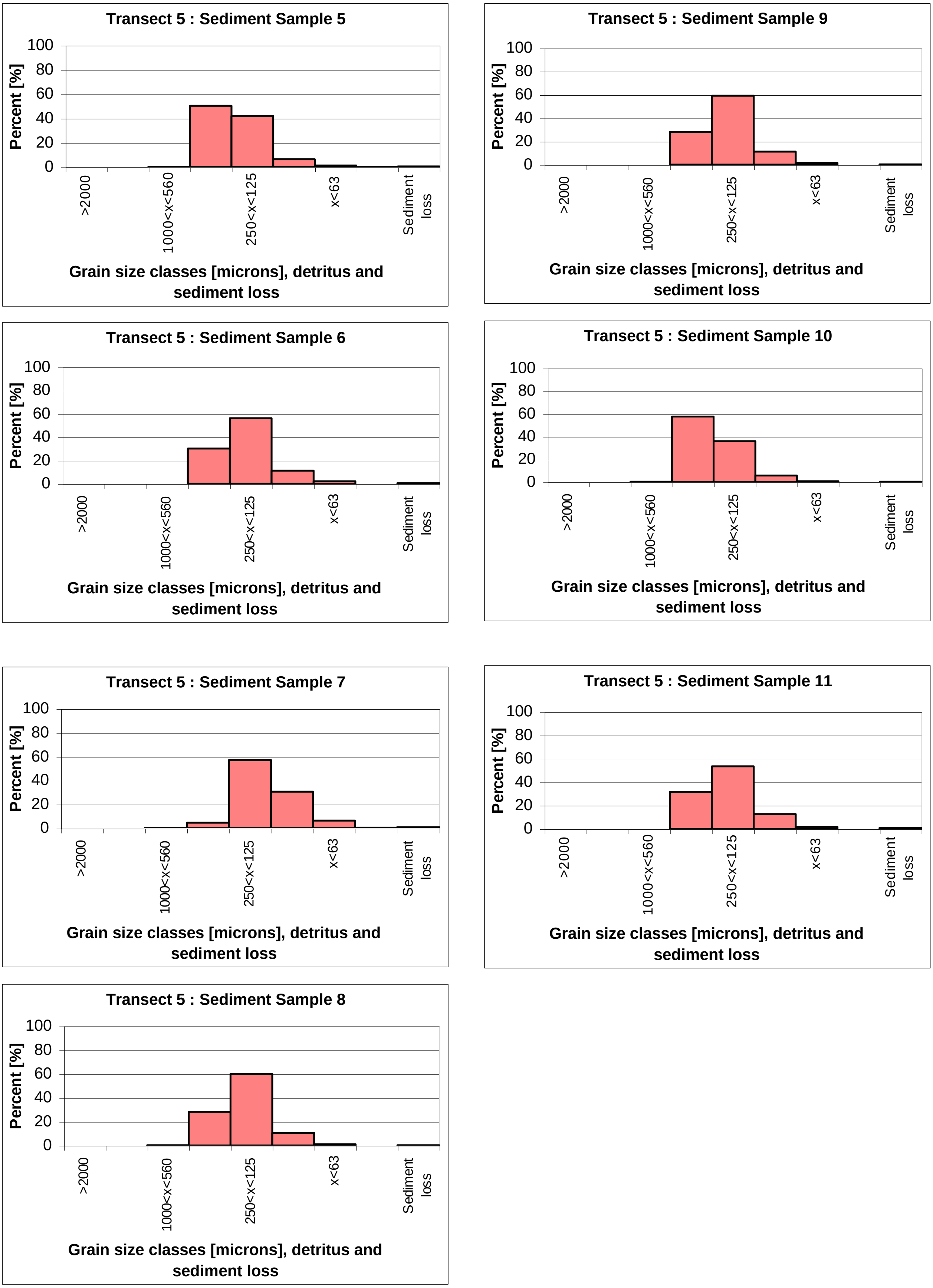


Figure 1.7: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‚x‘ represents the sediment per class.

Unlike T 9, the samples of T 5 show a high percentage of sediment in the fine as well as in the medium sand grain category.

As with the other transects, less detritus was found in the main river channel (samples 2 and 3) and in areas with little vegetation.

Sample 1 was taken at the base of the dunes (Figure 1.7–Sample 1, and Figure 1.8) and has the greatest amount of medium sand grains compared to the other samples, which agrees with previous observations that dune sand consists of larger grains than riverbed sediment (Lancaster 1981; Ward & von Brunn 1985).

Figure 1.8: Sample 1 from T 5 taken at base of dune (K. Wouters, 2005).

Sample 3 was the only sample of all transects to contain moist sediment. The sediment crumbled when touched.

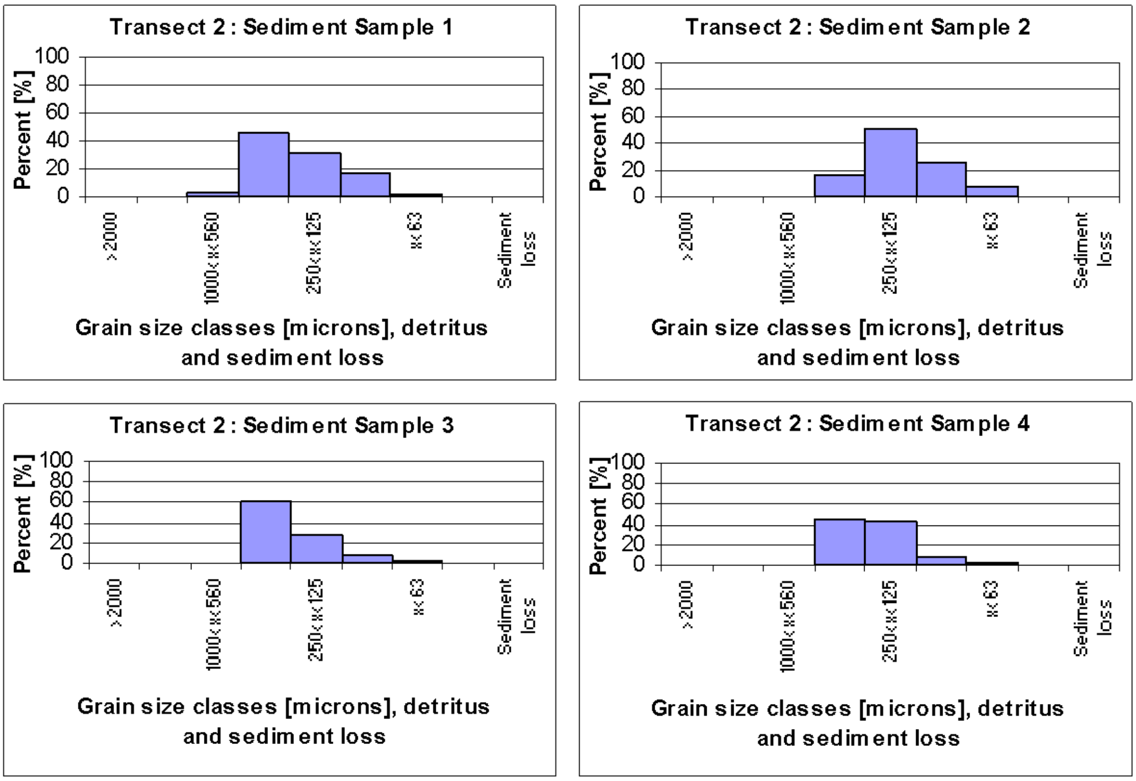
Figure 1.9: Moist sediment of sample 3 from T 5 (K. Wouters, 2005).

Transect 2

The texture classes for each sample of T 2 are shown in Table 1.5 and in the corresponding graphs (Figure 1.10):

Table 1.5: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‚x‘ represents the sediment per class.

	GRAVEL[%] (Granules)	SAND [%] very coarse	SAND [%] coarse	SAND [%] medium	SAND [%] fine	SAND [%] very fine	SILT/ CLAY [%]	Detritus [%]	Sediment loss [%]
sample no	>2000	2000>x>1000	1000<x<560	560<x<250	250<x<125	125<x<63	x<63		
1	0.00	0.11	2.35	45.71	31.62	17.55	2.06	0.30	0.31
2	0.05	0.21	0.19	16.15	50.47	25.48	7.20	0.06	0.18
3	0.01	0.30	0.87	60.49	28.08	8.22	1.47	0.00	0.56
4	0.00	0.15	0.11	45.15	43.29	8.75	1.61	0.50	0.44
5	0.01	0.17	0.17	45.76	41.45	10.09	1.83	0.39	0.13
6	0.03	0.17	0.38	35.79	44.23	14.64	3.54	0.78	0.43
7	0.08	0.24	0.96	82.69	11.80	2.52	0.43	0.98	0.53
8	0.00	0.14	2.04	84.76	8.29	3.07	0.72	0.72	0.27
9	0.63	2.61	47.04	41.14	7.70	0.70	0.07	0.00	0.10
10	0.29	0.23	13.92	75.90	8.85	0.76	0.04	0.00	0.02



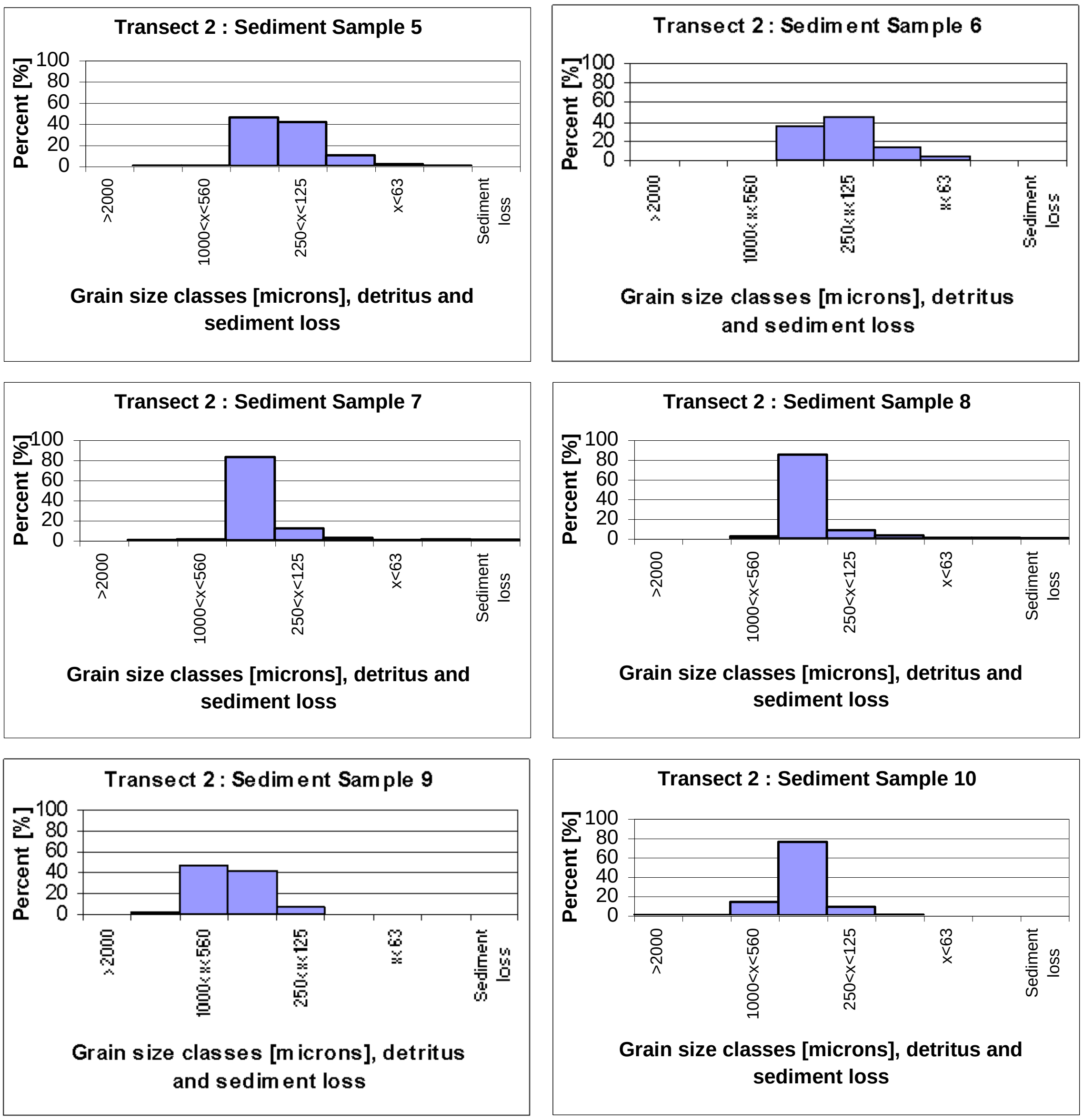


Figure 1.11: Percentage of sediment [% by weight] per texture class [microns], detritus and sediment loss. ‚x‘ represents the sediment per class.

Compared to T 9 and T 5, the samples of T 2 contain on average a higher percentage of medium sand grains than fine sand or silt/clay (Figure 1.12), with the exception of Sample 2, which comprises more silt/clay (Figure 1.13).

Figure 1.12: Sandy sediment along T 2 (K. Wouters, 2005).

Figure 1.13: Silt/Clay deposits at Sample 2 in the main river channel of T 2 (K. Wouters, 2005).

While T 9 and T 5 border on rock outcrops on the northern side and are situated at a greater distance to the gravel plains, the northern side of T 2 borders directly on the gravel plains with a gradual transition and relatively little difference in altitude. This could explain why samples 7, 8 and 10 have a larger percentage of medium sand (250 – 560 microns) and samples 9 and 10 a larger percentage of coarse sand (560 to 1000 microns), compared to the other samples. These could possibly be fluvial or wind-blown deposits originating from the gravel plains

As with the other transects, less detritus was found in the main river channel (samples 2 and 3) and in areas with little vegetation.

1.1.4. Conclusion

Almost all of the sediments analysed were comprised of sand particles with the silt/clay fraction representing less than 5% of every sample. Moreover, the sediment in the riverbed contains very little detritus, making it difficult to form an organic layer. It therefore has almost no A and B horizon; the solum or true soil. Most of the sediment forms the C-horizon, also called parent material, as it shows little biological activity or soil development other than mineral decomposition of rock.

It has been shown that there are small variations in the texture classes between and within the transects, depending on the width of the riverbed and main river channel as well as on geomorphologic areas bordering directly on the riverbed, e.g dunes, rock outcrops, gravel plains.

Appendix B

Plant species found near Gobabeb

Habitats are categorised as gravel plains (G), dunes (D) or riverbed (R). Perennial plants are classified according to their growth form: tree, shrub, succulent shrub (=succ), or grass. Table adapted from Henschel *et al.* (in press).

Family and species	Author	Perennial	Alien	G	D	R
Moraceae						
Ficus sycomorus	L.	tree				R
Urticaceae						
Forsskaolea hereroensis	Schinz					R
Polygonaceae						
Polygonum aviculare	L.					R
Polygonum plebeium	R.Br.					R
Rumex lanceolatus	Thunb.					R
Aizoaceae						
Aizoanthemum dinteri	(Schinz) Friedrich			G		R
Galenia africana	L.			G		R
Gisekia africana	(Lour.) Kuntze			G		R
Glinus lotoides	L.					R
Hypertelis salsoloides	(Burchell) Adamson					R
Limeum argute-carinatum	Wawra & Peyr.			G		R
Limeum sulcatum	(Klotzsch) Hutch.					R
Mollugo cerviana	(L.) Ser. ex DC.					R
Sesuvium sesuvioides	(Fenzl) Verdc.	succ		G		R
Trianthema hereroensis	Schinz	succ			D	R
Mesembryanthemaceae						
Psilocaulon salicornioides	(Pax) Schwantes			G		R
Portulacaceae						
Portulaca oleracea	L.					R
Illecebraceae						
Corrigiola littoralis	L.					R
Chenopodiaceae						
Atriplex lindleyi	Moq.					R
Chenopodium ambrosioides	L.					R
Suaeda plumosa	Aellen					R
Amaranthaceae						
Nelsia quadrangula	(Engl.) Schinz					R
Papaveraceae						
Argemone ochroleuca	Sweet		alien			R
Capparaceae						
Cleome carnosa	(Pax) Gilg & Benedict					R
Cleome foliosa	Hook. f.			G		R
Cleome gynandra	L.					R
Maerua schinzii	Pax	tree		G		R
Brassicaceae						
Coronopus integrifolius	(DC.) Sprengel					R

Vahliaceae						
Vahlia capensis	(L. f.) Thunb.					R
Fabaceae						
Acacia erioloba	E. Meyer	tree		G		R
Adenolobus garipensis	(E. Meyer) Torre & Hillc.	shrub				R
Cullen obtusifolia	(DC.) C.H. Stirton					R
Dichrostachys cineria	(L.) Wight & Arn.	tree				R
Faidherbia albida	(Del.) A. Chev.	tree				R
Indigofera auricoma	E. Meyer			G		R
Prosopis glandulosa	Torrey	tree	alien			R
Sesbania pachycarpa	DC.					R
Tephrosia dregeana	E. Meyer	shrub		G	D	R
Geraniaceae						
Monsonia umbellata	Harvey			G		R
Zygophyllaceae						
Tribulus cristatus	C. Presl					R
Tribulus terrestris	L.			G		R
Tribulus zeyheri	Sonder			G		R
Zygophyllum simplex	L.			G	D	R
Euphorbiaceae						
Chamaesyce glanduligera	(Pax) Koutnik			G		R
Euphorbia phylloclada	Boiss.	shrub		G		R
Ricinus communis	L.	shrub	alien			R
Salvadoraceae						
Salvadora persica	L.	tree				R
Sterculiaceae						
Hermannia modesta	(Ehrenb.) Masters			G		R
Tamaricaceae						
Tamarix usneoides	E. Meyer ex Bunge	tree				R
Loasaceae						
Kissenia capensis	Endl.			G		R
Cucurbitaceae						
Acanthosicyos horridus	Welw. ex Hook. f.	shrub		G	D	R
Citrillus ecirrhosus	Cogn.			G		R
Lythraceae						
Nesaea luederitzii	Koehne					R
Ebenaceae						
Euclea pseudebenus	E. Meyer ex A. DC.	tree		G		R
Asclepiadiaceae						
Asclepias buchenaviana	Schinz	shrub		G		R
Rubiaceae						
Kohautia lasiocarpa	Klotzsch					R
Boraginaceae						
Heliotropium oliveranum	Schinz	shrub				R
Heliotropium ovalifolium	Forsskal					R
Solanaceae						
Datura innoxia	Miller		alien			R
Datura stramonium	L.		alien			R

Lycium cinereum	Thunb.	shrub				R
Nicotiana glauca	Graham	shrub	alien			R
Solanum nigrum	L.					R
Scrophulariaceae						
Anticharis inflata	Marloth & Engl.			G		R
Anticharis linearis	(Benth.) Hochst. ex Asch.					R
Anticharis scoparia	(E. Meyer ex Benth.) Hiern ex Schinz					R
Aptosimum spinescens	(Thunb.) Weber	shrub		G		R
Diclis petiolaris	Benth.					R
Limosella grandiflora	Benth.					R
Sutera canescens	(Benth.) Hiern			G		R
Sutera corymbosa	(Marloth & Engl.) Hiern					R
Sutera lyperioides	(Engl.) Engl. ex Range					R
Sutera maxii	Hiern			G		R
Sutera pallida	(Pilger) Overk. ex Roessler					R
Veronica anagallis-aquatica	L.					R
Selaginaceae						
Walafrida saxatilis	(E. Mey.) Rolfe					R
Acanthaceae						
Petalidium setosum	C.B. Clarke ex Schinz	shrub		G		R
Pedaliaceae						
Rogeria longiflora	(Royen) Gay ex DC.					R
Sesamum abbreviatum	Merxm.				D	R
Campanulaceae						
Wahlenbergia androsacea	A. DC.					R
Lobeliaceae						
Lobelia angolensis	Engl. & Diels					R
Lobelia erinus	L.					R
Asteraceae						
Aspilia eenii	S. Moore					R
Berkheya spinosissima	(Thunb.) Willd.			G		
Blumea cafra	(DC.) O. Hoffm.					R
Blumea decurrens	(Vahl) Merxm.					R
Conyza bonariensis	(L.) Cronq.					R
Cotula anthemoides	L.					R
Dicoma capensis	Less.					R
Dimorphotheca polyptera	DC.					R
Emilia marlothiana	(O. Hoffm.) C. Jeffrey					R
Epaltes gariepina	(DC.) Steetz					R
Flaveria bidentis	(L.) Kuntze					R
Geigeria plumosa	Muschler					R
Helichrysum argyrosphaerum	DC.					R
Helichrysum gariepinum	DC.					R
Launaea intybacea	(Jacq.) Beauv.					R
Melanthera marlothiana	O. Hoffm.					R
Nicolasia stenoptera	(O. Hoffm.) Merxm.					R
Nidorella resedifolia	DC.					R
Osteospermum microcarpum/Tripteris microcarpa?	(Harvey) Norlindh			G		R
Pechuel-Loeschea leubnitziae	(Kuntze) O. Hoffm.	shrub		G		R
Pseudognaphalium luteo-album	(L.) Hilliard & Burtt					R
Pulicaria scabra	(Thunb.) Druce					R
Senecio apiifolius	(DC.) Benth. & Hook. F. ex.					R

	O. Hoffm.				
Senecio consanguineus	DC.				R
Senecio eenii	(S. Moore) Merxm.				R
Sphaeranthus peduncularis	DC.				R
Tagetes minuta	L.				R
Xanthium spinosum	L.				R
Poaceae					
Brachiaria glomerata	(Hackel) A.Camus		G	D	R
Cenchrus ciliaris	L.	grass			R
Chloris virgata	Sw.				R
Cladoraphis spinosa	(L.F.) S. Phillips	grass		D	R
Cynodon dactylon	(L.) Pers.				R
Dactyloctenium aegyptium	(L.) Willd.				R
Entoplocamia aristulata	(Hackel & Rendle) Stapf				R
Eragrostis lehmanniana	Nees				R
Eragrostis porosa	Nees				R
Eragrostis rotifer	Rendle				R
Eragrostis trichophora	Coss. & Dur.				R
Polypogon monspeliensis	(L.) Desf.				R
Setaria verticillata	(L.) Beauv.				R
Sporobolus consimilis	Fresen.				R
Stipagrostis lutescens	(Nees) De Winter	grass	G	D	R
Stipagrostis sabulicola	(Pilger) De Winter	grass		D	R
Stipagrostis subacaulis	(Nees) De Winter		G		R
Stipagrostis seelyae	De Winter	grass		D	R
Arecaceae					
Phoenix dactylifera	L.	tree			R
Cyperaceae					
Bulbostylis exilis	(Humb., Bonpl. & Kunth) Roemer & Schultes				R
Cyperus marginatus	Thunb.				R

Appendix C

Notable plant species in the Kuiseb

Acacia erioloba

Family: *Fabaceae*

Other names: Camelthorn (common name), *A. giraffae* (an old classification now out of favor)

Relevant characteristics and adaptations: This extremely hardy tree, which can grow to 15 m high in places and live for up to 300 years, is indigenous to southern Africa, and particularly common across Namibia. It is well-equipped to endure the highly-variable temperatures and hydrological conditions it faces in a desert environment; it can even survive in frosty conditions. It typically flowers in the Southern Hemisphere's early spring, and produces earlobe-shaped seed pods. (Barnes et al 1997)

A. erioloba is of socioeconomic interest due to the fodder-value of its seed pods and its usefulness as fuel, and also has come under investigation as potentially highly-important in “restoring and increasing productivity of non-arable lands”—in combating desertification (Barnes et al 1997: 1). The Topnaar particularly value the tree as a source of fuelwood (although they are not permitted to fell trees within the boundaries of the Namib-Naukluft Park), and while its wood is too hard to be used in construction, they do use it for building furniture and fences for their kraals. The goats and cattle of the Topnaar also enjoy eating the trees' pods (van den Eynden et al 1992: 45). The tree is also important to several animal species

Its importance in combating desertification is largely tied to two factors: its ability to improve the soil and its importance as a link to underground water sources.

Like all other acacias, *A. erioloba* is leguminous, and fixes nitrogen in the soil (Wickens 1998). However, it is unusual in two ways. First, studies indicate that its roots rarely nodulate: Barnes et al (1997: 14) report that less than 1% of acacia in a field test nodulated, against 64% of *F. albida* seedlings. Second, analysis of isotope ratios in its leaves indicates that it fixes mostly nitrogen obtained from groundwater rather than atmospheric nitrogen—although Barnes et al (1997: 15) point out that this is “no less valuable” to the ecosystem, as groundwater nitrogen would not come into surface circulation without *A. erioloba*'s long subterranean reach.

A. erioloba seems to be better-adapted to desert conditions than other trees in the Kuiseb. Even more than the other tree species found in the Kuiseb, *A. erioloba* is decidedly phreatophytic, relying on immensely long roots to provide it with water throughout the year; specimens in the Kalahari have been recorded with roots of up to 60 m, although more typically *A. erioloba*'s roots are not found much deeper than 45 m (Canadell et al 1996; Barnes et al 1997). This means that during extended dry periods, such as the lower Kuiseb experienced in the early 1980s, *A. erioloba* suffered nowhere near as severe a decline as other species (Ward & Breen 1985). Its long roots and subsequent tolerance of “drought” conditions affects its distribution in the river, a topic that will be further explored in section III.2.

Faidherbia albida

Family: *Fabaceae*

Other names: Ana tree (common name); Acacia albida (*F. albida* was re-classified into a stand-alone genus in the 1980s)

Relevant characteristics and adaptations: Formerly classified as a member of the acacia genus (it is distinguished from acacia primarily by its deeply-layered bark and its distinct phenology), *F. albida* was named for its distinctively white wood, twigs, and thorns (Wood 1989; van den Eynden 1992: 44). This tree, which can grow up to 30 m in height, is widely distributed across Africa: its range covers Southern, Eastern, and Western Africa and even extends north as far as Lebanon. Its distribution does not correspond to climatic zones; rather, this riverine species is found in areas with permanent surface groundwater or along ephemeral rivers with saturated alluvium (Wickens 1998; Wood 1989). It lives for up to 150 years, although 70-90 is a more typical lifespan, and has the curious habit of shedding its leaves at the beginning of the rainy season, producing new leaves and flowers at the beginning of the dry season. Botanists speculate that this adapation may help *F. albida* to withstand weeks to months of root water-logging that accompany rises in the water-table near rivers, but the question has not yet been settled (Wood 1989; Wickens 1998).

Like *A. erioloba*, *F. albida* has been identified as potentially of great developmental value. Its spiralled seedpods make good fodder, while studies have shown that *F. albida* can improve soil conditions considerably as far the needs of crops are concerned. *F. albida* is leguminous and, as was mentioned above, nodulates at a considerably higher rate than *A. erioloba*, the other dominant tree species in the Kuiseb, making it an important fixer of atmospheric nitrogen in the riparian ecosystem; field studies in other areas have found *F. albida* to increase levels of soil nitrogen by as much as 100%. It also increases soil pH and raises soil carbon levels (at a lower rate than nitrogen increases) (Barnes et al 1997; Wood 1989). In the Kuiseb, the Topnaar value the ―Ana tree" particularly for the fodder value of its pods—the most significant food source in the river for their livestock—as well for the value *F. albida*'s wood has in construction (Van den Eynden 1992).

While *F. albida* loses a great deal of water to evapotranspiration it has, like *A. erioloba*, evolved significantly smaller leaves that enable it to minimize these losses (van den Eynden 1992; Wood 1989). It has a taproot that grows very rapidly to as much as 40 m in depth (Wood 1989). However, *F. albida* is not often found far from water courses; it is not nearly as drought-resistant as *A. erioloba*.

Tamarix usneoides

Family: *Tamaricaceae*

Other names: Tamarisk (common name); Daweb (Nama-Damara)

Relevant characteristics: A southern African native, *T. usneoides* is halophytic, and thrives in the often-saline hydrological environment of the Kuiseb. *T. usneoides* can can grow to up to 9 m in height, although trees of such size are rarely found in the Kuiseb.

T. usneoides is evergreen, with small, scale-like leaves (Palmer & Pitman 1972). *T. usneoides* is notable for its networks of extremely shallow roots, which can lead to stands of smaller trees growing up around a parent tree (van den Eynden et al 1992).

It is perhaps most notable for its ability to excrete excess salt through pores in these leaves; it does this at midday and the salt deposits on the leaves serve to limit evapotranspiration (van den Eynden et al 1992). The leaves of the tamarisk can serve as fodder for livestock or other animals, although Van den Eynden et al do not note *T. usneoides* as an important fodder crop for the Topnaar's livestock. Instead, they report that the Topnaar most value the tree for its roots' medicinal properties.

T. usneoides is also a phreatophyte, although its tap root certainly does not reach as deep as that of *A. erioloba*. It is often found relatively close to the river, indicating that it requires relatively moist soil conditions, and in the Kuiseb individuals has even been known to colonize the entire width of the river course until washed away by floods; some have speculated that where it is found in the flood-plain this indicates a previous course of the river (Seely et al 1981; Theron et al 1980). The tamarisk is also heterophyllous; it copes with the Namib's aridity by reducing leaf size during the dry season.

Euclea pseudebenus

Family: *Ebenaceae*

Other names: Ebony tree, wild ebony (common names); tsawib/s (Nama-Damara)

Relevant characteristics and adaptations: This shrubby tree, which grows seldom higher than 8m, is widespread in western and southern Namibia, extending into the Namib along ephemeral rivers. It is abundant in the south and dominant in the southwest. It grows along dry rivers, sometimes on plains and floodplains or around pans (Curtis & Mannheimer 2005). It distinguishes itself by its characteristically thin, dropping branches and its gray to black-gray, rough and deeply fissured bark.

The leaves are linear and leathery (reducing evaporation), blue green above and pale olive green below. *E. pseudebenus* is a dioecious plant. The male flowers are found in groups of 3 to 7; the female flowers are single, and both are densely covered with wool (Craven & Marais 1998). The fruit, which is edible either by people or by animals, is colored red to dark brown to black when it is ripe, and is notably astringent. People can use the extremely hard wood with its jet-black heart for construction and carving, and the twigs are known to be used as toothbrushes (van den Eynden 1992). In some areas big, shady groves of Euclea pseudebenus grow, leading local people to name places after them e.g. Tsawisi in the Karibib district from the Nama name tsawib/s (Craven & Marais 1998). Animals benefit from this plant as they eat their fruits and their foliage, which both are a major water source for them. The fruits of *E. pseudebenus* are a favoured food of jackals, who in turn contribute to seed distribution. This tree is not resistant to frost, so its distribution is restricted to the lower Kuiseb.

Like the rest of the tree species found in the riverbed, *E. pseudebenus* is a phreatophyte.

Salvadora persica

Family: *Salvadoraceae*

Other names: Mustard bush, tooth-brush tree, salt bush, kerriebos (common names)

Relevant characteristics and adaptations: This bush-like tree, which can reach up to 5 m in height and grows in dense thickets, is indigenous to Southern Africa, although its natural range extends all the way to its namesake Persia (Evenari and Gutterman 1973). It is found largely in dry riverbeds and riverbanks, and in dry open woodland, and tends to grow in clay or sandy soils, as well as calcrete and other stony substrates; in the Kuiseb it is generally found on the banks and on the very lowest surfaces of dunes (Curtis & Mannheimer 2005; van den Eynden et al 1992).

S. persica is important ecologically and topographically: its dense branches provides cover from the sun and an ideal habitat for many insects, reptiles, small mammals, and birds, while they also trap wind- and water-borne sand and lead to the creation of small dunes in the middle of the river (Katoma 1989; Mizuno & Yamagata 2005). The leaves of *S. persica* decompose slowly, causing deep accumulations below the shrubs.

The fruit of the tree is edible, and the leaves can be browsed by livestock, although animals generally only browse the tree during droughts when other plants are not available, since *S. persica*'s leaves have reliably higher water content than other species (van den Eynden et al 1992; van Wyk et al 1985; Mamili 2005).

S. persica is also a phreatophyte, with a long tap root that allows the tree to access groundwater.

Acanthosicyos horridus

Family: *Cucurbitaceae*

Other names: !nara (Nama-Damara); nara (common name)

Relevant characteristics and adaptations: This remarkable plant is endemic to coastal areas of the Namib, and grows all along the Kuiseb, although as we have noted it is classified as properly and primarily a dune community (Robinson 1976). *A. horridus* is a spiny cucurbit, which grows dense tangles; like *S. persica*, the thick growth of the !nara causes sand to build up over it, meaning that over centuries large hummocks can accumulate around a single individual, with each plant often constituting its own miniature dune sometimes over ten metres in diameter and several meters high (Henschel pers. comm.; van den Eynden et al 1992). Each plant is either male or female, with males flowering all year round (Henschel pers. comm.).

The plant is enormously important to both the dune ecosystem and to the Topnaar. Animals and people value the !nara melon, which is both healthy and an important source of water. The Topnaar and other humans in the Namib have been using *A. horridus* as a food source for some 8000 years (van den Eynden et al 1992).

A. horridus has adapted to the Namib by losing all its leaves, photosynthesizing entirely throughts its bright green thorns and stems. Its tap roots have been measured at up to 40 m, allowing it access to water throughout the year and making it a crucial species for providing minerals and nutrients to surface animals (van den Eynden et al 1992; Henschel & Moser 2004b).

Nicotiana glauca

Family: Solanaceae

Other names: Wild tobacco, tree tobacco

Relevant characteristics and adaptations: N. glauca is an invasive alien species originally from Argentina, introduced into the South African region via horse fodder (Brown & Gubb 1986). It is a perennial shrub usually 1 m high but occasionally can exceed even 8 m (Curtis & Mannheimer 2005). N. glauca is considered a weed which impinges on other species, either endemic plants or animals, and therefore demonstrates a threat to the endemic wildlife; alien species such as N. glauca take up space and consume groundwater resources. It is difficult to control them mechanically because of their high number, biological and chemical removal would be undesirable and would affect the whole ecosystem (Jabs 1991).

N. glauca generally grows along ephemeral rivers, either in its riverbeds or on riverbanks and on alluvial sites but it also appears in lower frequencies at the escarpment catchment area in the Khomas Hochland. It prefers open, bare disturbed ground in open patches (usually areas which would be flooded when the river flows) although shade does not prevent it from growing (Jabs 1991).

N. glauca has blue green, leathery leaves with long petioles. The evergreen leaves contain alkaloids and sterols, which are known to kill ostrich and cattle. The fruit contain very fine, toxic seeds, which are dispersed by wind and water. It ripens mainly from November to May. The tubular, light yellow flowers, which grow in hanging clusters flower all year round but mainly in the rainy season (Curtis & Mannheimer 2005). The tough, waterborne seeds are transported down river during floods and left on the soil surface as the river dries out.

N. glauca is not a significant food source for animals; its toxic leaves make it inedible. It can be used by baboons but only on rarely (Hamilton 1986; Jabs 1991). For the Topnaar N. glauca represents a source of firewood and its green stems are used for minor constructions (e.g. to secure hut frames) (van den Eynden 1992).

Beside its deep roots which can access the ground water, N. glauca has a number of advantages over indigenous vegetation in the Kuiseb: for one, it has a long flowering season with a high seed production and widespread dispersal opportunities. The seeds are able to survive over several years to wait for conditions, which allow them to germinate. In addition to that seeds may germinate more rapidly at an earlier stage or may be xerophytic, germinating when moisture levels are too low for the indigenous vegetation, allowing the plant to dominate the community. The seeds are distributed underneath and around the canopy of the parent plant forming dense monospecific stands. Also, N. glauca can survive in frosty conditions, it is halophytic, and it benefits from a high water absorption ability, which makes it to a well-adapted plant in environments with extreme climatic conditions such as the Namib desert. Observations in the Kuiseb, however, suggest that N. glauca does not tolerate root-flooding: plants growing in the riverbed or near it die off right after floods, even after suffering no apparent damage (Robinson 1976: 94).