as bed-load that is not measured by conventional techniques, and the high value of 22.8% represents an extreme value, an average silt content of 5% for flood waters seems reasonable (Hydrology Division, 1988). Seydel (1951) and Stengel (1964) described periodic floods in the Khan and Swakop rivers during the early part of the twentieth century. These authors reported that floods were infrequent and were seldom large enough to breach the mouth of the Swakop River.

In the late summer months, a few shallow pools may develop in the otherwise dry bed of the Khan River some 25 km upstream of its junction with Dome Gorge. Here, a band of impervious rock traverses the river bed beneath the sediments and acts as an underground dam, forcing sub-surface flows to the surface (P. Marais, personal communication).

2.6.2.2 *Permanent springs*

Only one natural perennial spring is known to occur in the Rössing area; this is located in a side-arm of Panner Gorge and is named Piet-se-Gat. The slow-flowing outflow from the spring fills a small (approximately 1.5 m by 4.0 m), shallow (maximum depth = 10cm) pool before overflowing. The overflow consists of a shallow (< 5 cm) stream that meanders over a sand and gravel bed for some 15 metres before disappearing underground. Occasionally the spring does not overflow though the water level in the pool remains more or less constant (Day, 1989). Flow rates from the spring increase for a short period after local rainfalls, though dry season (winter) flow rates average about 0.005 litres per second (P. Marais, personal communication). Several highly saline permanent springs occur at various points around the margin of the gravel plains of the Namib Desert Park (Day & Seely, 1988) and provide important sources of drinking water for game animals, despite their salinity.

2.6.2.3 *Ephemeral springs*

Several ephemeral springs occur at points along the Khan River and in the gorges that drain into the Khan River, apparently at local fracture points or at the interface of porous and impervious rocks. Their flows are very small and persist for short periods after local rainfalls before drying up.

2.6.3 Water Quality

Relatively few chemical analyses have been made of surface water flows in the Khan River; the data available relate to the floods recorded during the 1962/1963 summer (NIWR, 1966). The total dissolved solids (TDS) content of the flood waters is variable, increasing with distance downstream. The TDS values range from 261 mg litre^{-1} at Usakos, to 877 mg litre^{-1} just upstream of the junction of the Khan and Swakop Rivers (Table 2.2). Whilst the ionic ratios of flood waters in the Khan River are dominated by calcium and carbonate/bicarbonate, the sodium and chloride content of flood waters increases with distance downstream (Table 2.2).

Much more data is available for the nearby Swakop River, where a far higher number of samples have been collected (NIWR, 1966). The TDS values of flood water samples collected in the Swakop River above and below its junction with the Khan River, are higher than the TDS values reported for the Khan River (Table 2.2). In the Swakop River, the TDS content is much ranged from 935 mg litre^{-1} upstream of the Khan junction to 2370 mg litre^{-1} some 3 km downstream of the junction (Table 2.2). At both sites, sodium and chloride dominated the cations and anions, respectively, whilst calcium showed a slight increase and carbonate/bicarbonate a slight decrease with increasing distance downstream.

TABLE 2.2: Chemical composition of flood water samples collected from four sites on the Khan and Swakop Rivers during January 1963. (All values given in milligrammes per litre, except Total Alkalinity (T. Alk.) which is given in milligrammes $CaCO_3$ per litre; "n" = No. of samples analyzed; Data extracted from NIWR, 1966).

	Constituent						
Sampling Site	TDS	Na^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	T. Alk.
Khan River at Usakos (n = 16)	261	8	64	11	0	14	278
Khan River 1 km above junction with Swakop River (n = 21)	877	110	139	40	43	225	507
Swakop River 1 km above junction with Khan River (n = 30)	935	164	121	26	49	317	326
Swakop River 3 km below junction with Khan River (n = 59)	2379	528	216	64	156	1091	280

A few chemical data are available for the perennial spring at Piet-se-Gat from 1984 and 1985, after the mine had been in operation for at least six years. The chemical constituents of these samples indicate that they were not contaminated by seepage water from the mine and the samples can therefore be regarded as representing natural conditions. These data show that salinity values range between 14000 and 18000 mg litre^{-1} while pH values vary from 6.0 to 8.0. Sodium is the dominant cation, while chloride is the dominant anion, with sulphate sub-dominant (Day, unpublished data).

2.6.4 Patterns of Water Utilization

Prior to the start of mining activities at Rössing, the only water abstracted from the Khan River water was that used for farming activities in the upper reaches downstream to about Usakos, plus domestic water supplies for the town of Usakos. The major use was for stock watering though farmers and residents of small communities along the river also supplemented their domestic supplies with river water. The episodic rainfall and lack of perennial surface water in the vicinity of the present Rössing Uranium Mine has restricted earlier settlement in the area. However, based on the evidence of game tracks at Piet-se-Gat, this perennial spring would have provided an important source of water for animals during the dry season (P. Marais, personal communication).

Surface floods in the lower Khan River occasionally augmented the flows in the Swakop River, which contains more frequent surface flows (NIWR, 1966). However, flows were seldom recorded simultaneously in both rivers due to the erratic and localized rainfall patterns of the region (Stengel, 1964; NIWR, 1966). The slightly lower TDS content of Khan River flood waters suggests that Khan River water might tend to improve the quality of the *less* saline Swakop River (Table 2.2). However, the rapid rise in Swakop River TDS values downstream of its confluence with the Khan River does not support this view.

Flood waters in the lower Swakop River were used primarily as a temporary supplement for the sub-surface waters that were extracted for domestic water supplies in Swakopmund and for the irrigation of vegetable produce and date palms at Goanikontes and Palmenhorst, located some 20 km and 45 km upstream of Swakopmund, respectively (Myburgh, 1971).

2.7 Geohydrology and Groundwater Quality

The rivers that flow across the Namib Desert contain very little surface water but do contain appreciable quantities of sub-surface water in their beds (Stengel, 1964; Myburgh, 1971; Ward & Breen, 1983; Huntley, 1985; SWA DWA, 1987). The Khan River is no exception (Dames & Moore, 1983a; Ashton, 1988a; Hydrology Division, 1988). This sub-surface water is of vital importance since it sustains the permanent riparian vegetation growing in the river beds and provides virtually all the water used for domestic and industrial purposes in the coastal area at Walvis Bay and Swakopmund (Myburgh, 1971; Huntley, 1985; SWA DWA, 1987; Ashton, 1988a). Some groundwater is present in localized areas away from the rivers though this is often very deep and saline (Myburgh, 1971; SWA DWA, 1988).

2.7.1 Sub-surface Flow Patterns

The river beds of both the Khan and Swakop rivers contain relatively deep deposits of alluvial material. These deposits vary in thickness from 4 to 6 metres in the headwaters of the two rivers to some 16 to 20 metres near the mouth of the Swakop River (NIWR, 1966). Seismic surveys and boreholes in the bed of the Khan River show that the sediments average some 20 metres in depth near the Rössing Uranium Mine, with a mean gradient of 1:166 (Hydrology Division, 1988).

The alluvial deposits are also highly permeable (averaging 150 m day^{-1}) and have a high storage capacity (20% by volume; P. Marais, personal communication). These alluvial deposits are saturated with underground water to within 2 to 3 metres of the sand surface (NIWR, 1966). The combination of a relatively steep gradient with the high permeability of the alluvial material facilitates sub-surface flows within both the Khan and Swakop rivers. Calculated rates of flow in the Khan River average 1 m day^{-1} over the entire saturated thickness of the deposits.

The regional drainage patterns in the vicinity of the Rössing Uranium Mine are particularly well defined by structural and lithologic features. Local geological formations show extensive patterns of folding, jointing and cracking, trending predominantly in a NW-SE or NNW-SSE direction, usually perpendicular to the strike of the regional fold structures. In general, fracturing in the gneissic-type rocks is highly developed, with joint planes exhibiting well-defined blocky and rectangular patterns. In the schistose rocks, fracture density is more intensive. Many of these fracture zones intersect valley walls and thus provide local pathways for seepage flows. Seepage flow is mainly along fractures in the bedrock. The permeability of the bedrock ranges between 1×10^{-8} cm sec^{-1} and 4×10^{-6} cm sec^{-1}. The porosity is low, being less than 0.01. Localized, north-west trending strike-slip faults also facilitate the movement of seepage water (Dames & Moore, 1981).

The watershed of Pinnacle Gorge is characterized by an intensely dissected drainage reflecting local fracture density. The Panner Gorge watershed area is characterized by a strong linear dendritic pattern reflecting strong structural and lithologic controls in the underlying strata (Dames & Moore, 1981). Groundwater flows and rainfall seepage is thus focused towards these Gorges which then drain into the Khan River (Knight, Dames & Moore, 1987a).

2.7.2 Water Quality

Information available from a detailed survey of the underground water supplies of the Khan and Swakop Rivers (NIWR, 1966) indicates that there is often a considerable variation in water quality with depth in both rivers. These differences have been attributed to a deep, more saline, base flow which is periodically recharged by fresher surface-flowing flood waters. Where silt layers have been deposited by receding flood waters, recharge (and thus dilution) of the deeper, more saline waters is retarded and distinct layering occurs (Wheeler *et al.*, 1987).

TABLE 2.3: Chemical composition of sub-surface water samples collected from three sites in the beds of the Khan and Swakop rivers during January 1963. (All values given in milligrammes per litre, except Total Alkalinity (Tot. Alk.) which is given in milligrammes $CaCO_3$ per litre. "n" = number of samples analyzed; Data extracted from NIWR, 1966).

	Constituent						
Sampling Site	TDS	Na$^+$	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl$^-$	T. Alk.
Khan River 1 km above junction with Swakop River (n = 37)	10308	2144	1002	335	1218	4950	224
Swakop River 1 km above junction with Khan River (n = 29)	1673	342	152	52	207	668	242
Swakop River 3 km below junction with Khan River (n = 12)	11680	2640	1056	352	1162	5870	437

The lack of any continuous stratification of TDS with depth along the river profile suggests that the processes of underground flow and flood-water recharge are very variable. Profiles of the major chemical constituents of sub-surface water in the Khan and Swakop rivers have been averaged for convenience and are compared in Table 2.3. Additional water quality data reported by Dames & Moore (1981) show that sub-surface water in the Khan River near the present Rössing Uranium Mine has an average TDS value of 7500 mg litre^{-1}. This would suggest that sub-surface waters in the Khan River increase in salinity with increasing distance downstream.

However, the water quality data for a seven year period shown in Table 2.4 are lower than the high values reported by Dames & Moore (1981); average and median TDS values being 5805 and 5920 mg litre^{-1}, respectively. In addition, the data in Table 2.4 support the view that the concentrations of several water quality variables in sub-surface waters of the Khan River tend to increase with distance downstream. However, this pattern appears to be complicated by the presence or absence of rainfall in the period preceding collection of the water samples. An additional feature of the data in Table 2.4 is the very wide range of values for almost all of the water quality variables.

TABLE 2.4: Minimum, mean, maximum and median values for 15 water quality variables measured in 23 borehole water samples collected from the bed of the Khan River at irregular intervals between 21 June 1967 and 19 June 1974. (All data are given in milligrammes per litre, except for pH and conductivity values; all alkalinity and hardness values marked with an asterisk (*) are given in milligrammes $CaCO_3$ per litre; data provided by Mr P. Marais, Rössing Uranium Mine).

Chemical Variable	Minimum	Mean	Maximum	Median
T.D.S. *dried at 180 °C	3465	5805	8550	5920
Sodium (as Na)	788	1240	1465	1265
Potassium (as K)	34	66	120	64
Sulphate (as SO_4)	428	822	2280	760
Nitrate (as N)	0	20.8	312	7.7
Nitrite (as N)	0	0.6	3.6	0
Silica (as Si)	2	23.6	40	25
Fluoride (as F)	0.8	6.2	113	1.3
Chloride (as Cl)	1538	2643	3150	2750
Total Alkalinity*	105	235	335	240
Total Hardness*	1150	2208	3600	2125
Calcium Hardness*	556	1276	2346	1275
Magnesium Hardness*	270	800	1254	850
pH	6.6	7.2	8.2	7.3
Conductivity (mS m^{-1})	4300	7910	11000	7700

2.7.3 Groundwater Abstraction

Prior to the start of mining operations at Rössing, a few farm boreholes abstracted small quantities of groundwater from the bed of the Khan River in the region around Usakos. The high TDS content of this water restricted its use to occasional stock watering (NIWR, 1966). A few scattered farms and railway sidings, located away from the Khan River, also obtained their water via boreholes into localized aquifers (Myburgh, 1971).

Extraction of groundwater from the bed of the Swakop River near Swakopmund provided the main source of water for this town during the early part of the Twentieth Century (Seydel, 1951; Stengel, 1964). However, rapid rates of withdrawal raised the TDS content of the water rendering it unfit for human consumption. This phenomenon was caused by the presence of freshwater layers or lenses, perched above more saline layers due to their density differences (Myburgh, 1971).

During the 1960's, a series of water extraction wells were drilled at Rooibank (Rooibank Area A), located on the middle delta of the Kuiseb River (Figure 2.7). While the prime purpose of this scheme was to supply water to the town of Walvis Bay, the scheme was extended to include a pipeline to supply the needs of Swakopmund. Rapid increases in the rates of water consumption in these two towns placed heavy demands on these underground water supplies. The situation was exacerbated by the prevailing drought conditions and the planned developments at Rössing (Myburgh, 1971). Eventually, two sets of additional well fields were drilled in the lower Kuiseb River, the first of these was located some 13 km downstream of Rooibank (Rooibank Area B), whilst the second well field was located in the Swartbank compartment, a 14 km stretch of the Kuiseb River upstream of Rooibank, in Namibia (SWA DWA, 1988). Full scale extraction from these additional well fields started in 1977 to supply the increased needs of the Rössing Uranium Mine. The quantities of water extracted from these three well fields are shown in Table 2.5.

Progressive lowering of the water table in the lower Kuiseb River was noted and it was decided to develop an additional well field in the delta close to the mouth of the Omaruru River, some 100 km to the north of Swakopmund (Myburgh, 1971). The Omaruru State Water Scheme at Neineis some 100 km upstream of the mouth had been in existence since the 1950's, supplying approximately 500 000 m^3 of water each year to the Uis Tin Mine and other small developments in the Brandberg region (Figure 2.7; Myburgh, 1971). Preliminary calculations suggested that an additional 1.5 Million m^3 of water could be extracted each year from the Omaruru River delta and delivered to the Rössing Uranium Mine and the small township of Henties Bay at the mouth of the Omaruru River (Myburgh, 1971).

TABLE 2.5: Annual water extraction (in millions of cubic metres) from the well fields in the lower Kuiseb River. (Each "year" runs from 1 October to 30 September; * = Inaccurate figures; Data extracted from SWA DWA, 1988).

Year	Swartbank	Rooibank A + B	Total
75/76	1.69	4.44	6.13
76/77	9.05	4.17	13.22
77/78	13.00	3.53	16.53
78/79	9.37	3.63	13.00
79/80	6.54	3.22	9.76
80/81	5.81	2.99	8.80
81/82	6.21	2.79	9.00
82/83	6.59	3.46	10.05
83/84	5.76	3.13	8.89
84/85	3.93	3.43	7.36
85/86	3.62	0.10*	3.72*
86/87	3.71	2.55	6.26

Since 1979, both the Rooibank A and B well fields, located in the Walvis Bay enclave, have been operated by the Walvis Bay municipality to supply the needs of Walvis Bay. The Swartbank well field and the Omaruru Delta well field now comprise the Central Namib State Water Scheme (CNSWS) and are operated by the Namibian Department of Water Affairs to provide water for Swakopmund and the Rössing Uranium Mine (SWA DWA, 1988). The Namibian Department of Water Affairs is responsible for maintaining water abstraction rates within the rate of recharge of the Swartbank aquifer. Therefore, any increased demand for freshwater by Swakopmund or the Rössing Uranium Mine have to be carefully evaluated.

2.8 Ecological Features

Scientific attention on features of the Namib Desert was mostly confined to the climatological, geographical and geological characteristics of the region during the first 60 years of the Twentieth Century. Very little attention was paid to the biology of this area, and most of the observations relate to those areas to the west and south of the present Rössing Uranium Mine. However, since the early

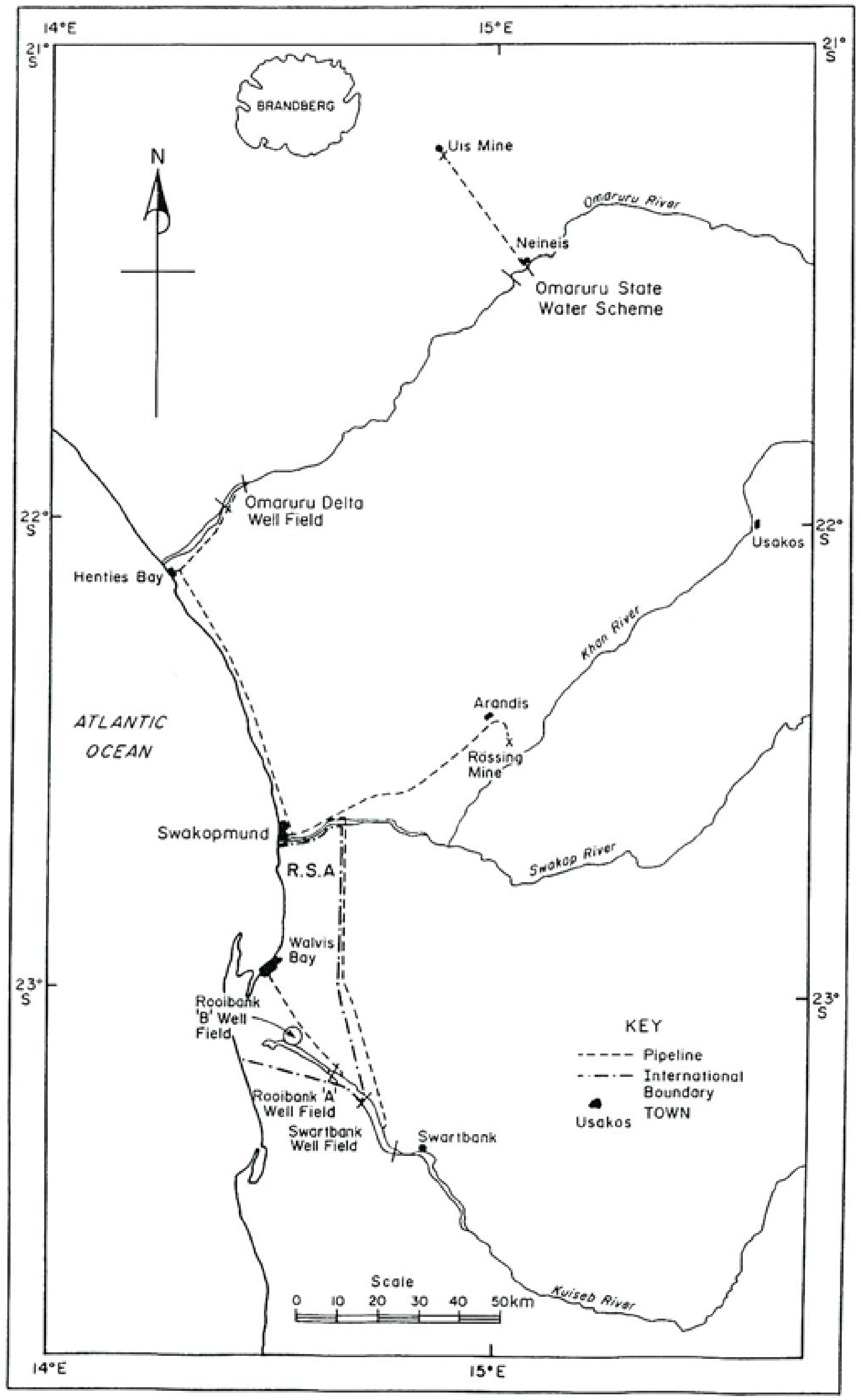


Figure 2.7: Diagrammatic map of the western portion of the central Namib Desert, showing the locations of water supply pipelines and the positions of water extraction well-fields on the Omaruru and Kuiseb rivers in relation to nearby towns. (Redrawn from Myburgh, 1971).

1960's, considerable attention has been focused on the ecological features of the Namib Desert Park, in particular those areas in the immediate vicinity of Gobabeb on the Kuiseb River and the gravel flats to the north. Only the geological characteristics of the area around the present Rössing Uranium Mine received more than a passing mention and the ecological features of this region were not described in detail before mining operations started.

Approximately eight years after the start of mining operations at Rössing, the Company commissioned the State Museum in Windhoek to carry out detailed ecological surveys of the region around the mine. Any unique features of the habitats or organisms that may have been present at the mine site are therefore largely unknown.

Appropriate portions of earlier published information, supplemented with studies made by the National Museum staff and personal observations, have been used to compile a hypothetical "baseline" description of the conditions that must have prevailed prior to the start of mining operations at Rössing.

2.8.1 Vegetation

2.8.1.1 *Regional distribution patterns*

The Namib Desert comprises a relatively narrow tract of land, some 2000 km long and mostly less than 200 km wide, lying between the Atlantic Ocean to the west and the Great Escarpment to the east (Huntley, 1985). The desert conditions are closely linked to the interacting, aridifying effects of the South Atlantic anticyclone, the cold northward-flowing Benguela Current with associated upwelling and with the divergence of the South-East Trade Winds along the coast (Louw & Seely, 1982; Huntley, 1985). The Eastern Escarpment marks the western edge of the higher interior plateau where higher rainfalls result in the development of savanna conditions. Geiss (1971) has provided a detailed description of the major vegetation zones of South West Africa/Namibia.

The Rössing Uranium Mine is located towards the eastern edge of the Central Namib Desert vegetation zone (Figure 2.8; Geiss, 1971). This Central Namib zone extends southwards to the Kuiseb River, where the so-called "sand sea" of the Southern Namib Desert and to the east by Semi-desert and Savanna Transition vegetation otherwise referred to as the Escarpment Zone. Further eastwards, the Escarpment Zone grades into three upland savanna zones, namely: Thornbush Savanna, Highland Savanna and Dwarf Shrub Savanna (Figure 2.8). The extent of each vegetation zones is largely determined by altitude and the regional rainfall patterns, which increase from west to east and decrease from north to south-east (Geiss, 1971; Brown *et al.*, 1985; Huntley, 1985).

Although botanists (e.g. Geiss, 1971) regard the Central Namib Desert zone to be a distinct vegetation zone, there is a marked east-west distribution pattern within the zone. This east-west vegetation distribution pattern is closely related to the inland distribution of coastal fogs, which can penetrate as far inland as the present Rössing Uranium Mine (Louw & Seely, 1982; Huntley, 1985). All the plant species found here are considered to be drought-tolerant, drought-resistant or succulent (Craven, 1986).

Close to the coast, there is a narrow (approximately 200 m wide) strip of vegetation, consisting primarily of *Zygophyllum clavatum, Psilocaulon salicornoides* and *Salsola* spp., around which small hummock dunes have formed (Geiss, 1971). Further inland, the vegetation thins out rapidly, with *Zygophyllum stapffii* and *Arthraerua leubnitzae* the predominant species, and a few individuals of *Hypertelis caespitosa*. These two species often occur as single specimens, often widely spaced on the

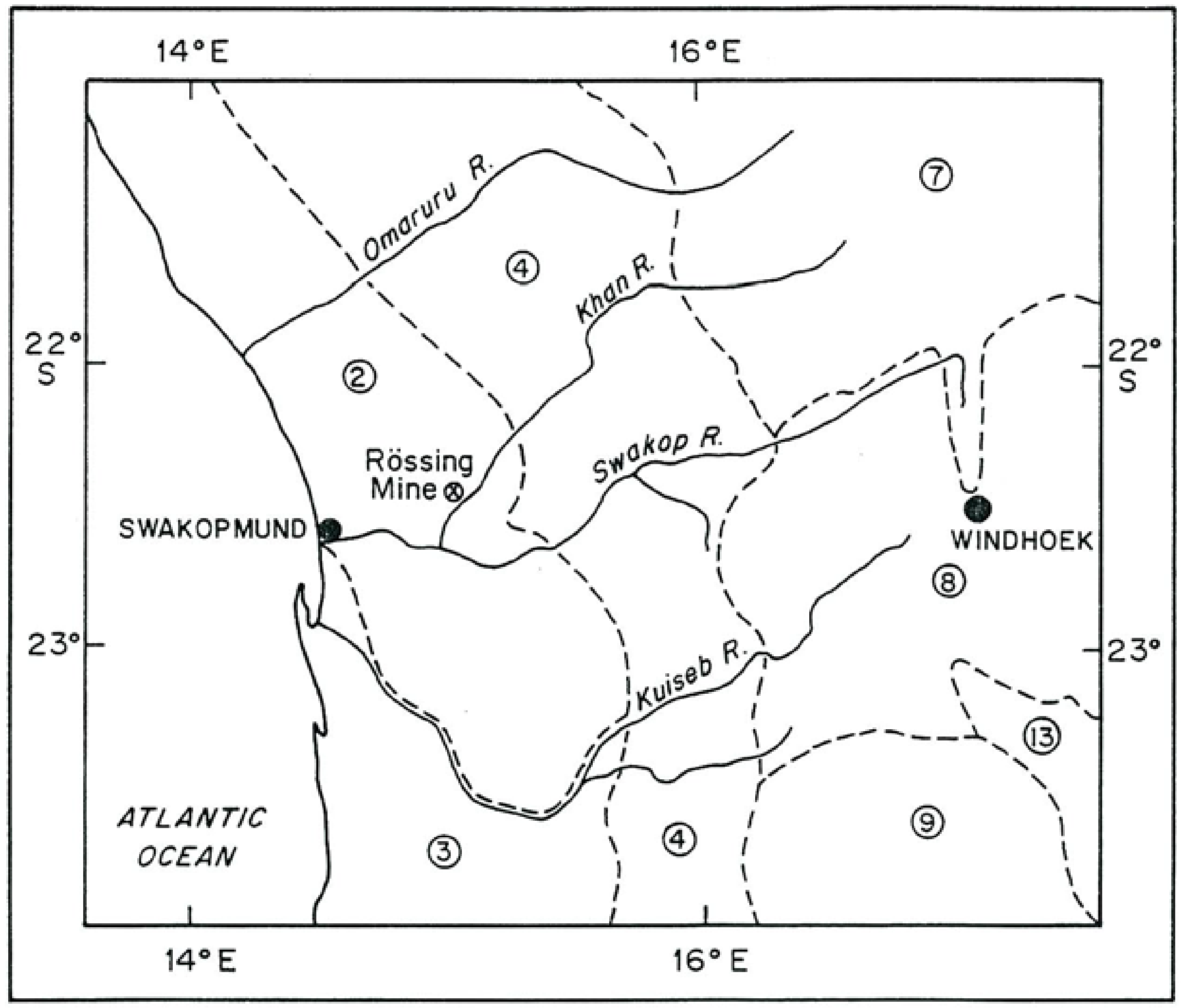


Figure 2.8: Diagrammatic map of the central portion of the Namib Desert, showing the position of the Rössing Uranium Mine in relation to the major vegetation zones and rivers in the region. (Key to vegetation zones: 2 = Central Namib; 3 = Southern Namib; 4 = Semi-Desert & Savanna Transition (the Escarpment Zone); 7 = Thornbush Savanna; 8 = Highland Savanna; 9 = Dwarf Shrub Savanna; 13 = Mixed Tree & Shrub Savanna). Map adapted from Geiss (1971).

gravel flats (Plate 1; Craven & Marais, 1986). The large gravel and gypsum flats, located further inland but still relatively close to the coast, are in places densely covered with lichens, such as *Parmelia* spp., *Telochistes capensis* and *Usnea* spp. These lichens are usually attached to small fragments of stone or flakes of gypsum crust. *Arthraerua leubnitzae* often forms relatively dense stands in the shallow depressions and gullies, as well as on the slopes of low ridges.

Proceeding further inland, the vegetation found in shallow depressions such as water courses and small river beds becomes progressively denser (Geiss, 1971). Shrub forms of *Acacia reficiens* occur within about 30 km of the coast and *Asclepias buchenaviana* is widespread. White desert grasses are especially plentiful after the sporadic rainfalls. Several annual species of *Stipagrostis*, namely *S. namibensis*, *S. hirtigluma* and *S. uniplumis*, are the most conspicuous and common (Muller, 1983). Further to the east, grass plains develop between the true desert and the Escarpment. These are covered mainly by the annual species *Stipagrostis obtusa*, while *S. ciliata* grows on more sandy areas. *Eragrostis nindensis*, a perennial grass, grows mainly on the stony, gravelly and limestone areas (Geiss, 1971). Whenever rains have fallen, large numbers of annual species appear and completely transform the vegetation of this region (Craven & Marais, 1986).

The nara melon, *Acanthosicyos horrida*, is common both at the mouth of the Kuiseb River and further upstream, as well as portions of the Swakop River, but has not been recorded from the Khan River (Craven & Marais, 1986). *Welwitschia mirabilis* occurs at various sites in the Namib Desert, but is particularly plentiful on the Welwitschia Flats in the Khan-Swakop river triangle. However, neither the nara melon nor *Welwitschia mirabilis* occur in the vicinity of the Rössing Uranium Mine (Craven, 1986).

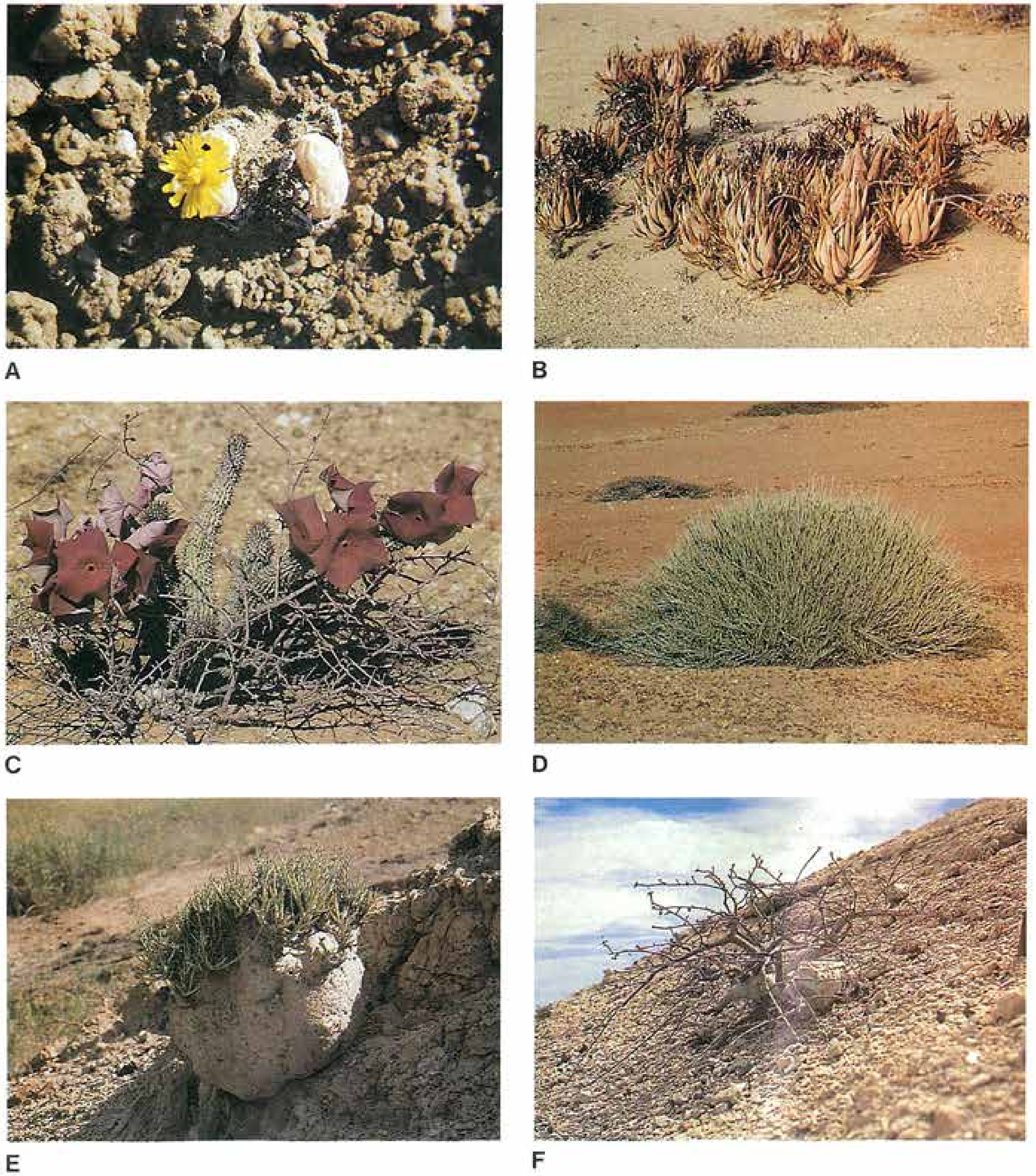
The Escarpment Zone is characterized by a great variety of species, many of which are endemic (Geiss, 1971). Species with succulent stems or leaves (such as *Moringa ovalifolia* and *Adenolobus pechuelii*), are particularly plentiful at the foot of the escarpment, in the western portion of this zone. This grades up the Escarpment and eastwards, through communities dominated by shrubs and half-shrubs, towards the eastern portion of the escarpment zone where woody species (particularly several species of *Acacia* and *Commiphora*) predominate (Geiss, 1971).

The episodic rivers draining the interior plateau and flowing towards the coast have eroded deep channels into the surrounding countryside. Their alluvium-filled beds provide the major sources of water for perennial vegetation. In this way, species that are more characteristic of the Escarpment Zone can colonize these drainage lines and extend their range into the Central Namib Desert. Several tree species flourish along these river beds, their distribution often extending for several tens of kilometres beyond the foot of the Escarpment and almost reaching the coast (Huntley, 1985). The commonest tree species found along these river beds are: *Acacia erioloba, A. albida, Tamarix usneoides, Euclea pseudebenus, Ziziphus mucronata, Salvadora persica* and *Prosopis glandulosa* (Plate 3; Huntley, 1985; Craven, 1986).

The woody plant communities along the rivers are of great importance to the survival of animals, providing shelter and food to plains game during critical periods (Huntley, 1985). Variations in the frequency, intensity and duration of floods cause constant fluctuations in the structure and vitality of these plant communities (Theron *et al.*, 1985). In addition, several species of annual plants, whose seeds have been washed down from the Escarpment by floods, colonize the river beds. These plants do not normally grow for prolonged periods in the river beds, unless the water table is near to the sand surface. They are mostly short-lived species and are only plentiful shortly after floods or rainfalls (Craven, 1986).

The vegetation in the immediate vicinity of the present-day Rössing Uranium Mine received only cursory attention during the early part of the Twentieth Century. James (1985) noted that Dinter studied the vegetation of a white marble ridge near Rössing siding early in the 1900's. This ridge was again studied at irregular intervals from the 1930's to the 1950's when 13 plant species were recorded (Merxmuller, 1966-1972; Walter, 1971). The importance of local rainfall events to the vegetation was evident when Logan (1960) noted 26 plant species from a number of sites close to Rössing after the 1957/58 rains. This was followed by a study during the dry period of the early 1970's, when 11 species of indigenous plants and 3 species of introduced weeds were recorded from the Khan River area (Geiss, 1971). Robinson's phytosociological study of the Namib Desert Park provided the first detailed description of the plant communities that occur in the region (Robinson, 1976).

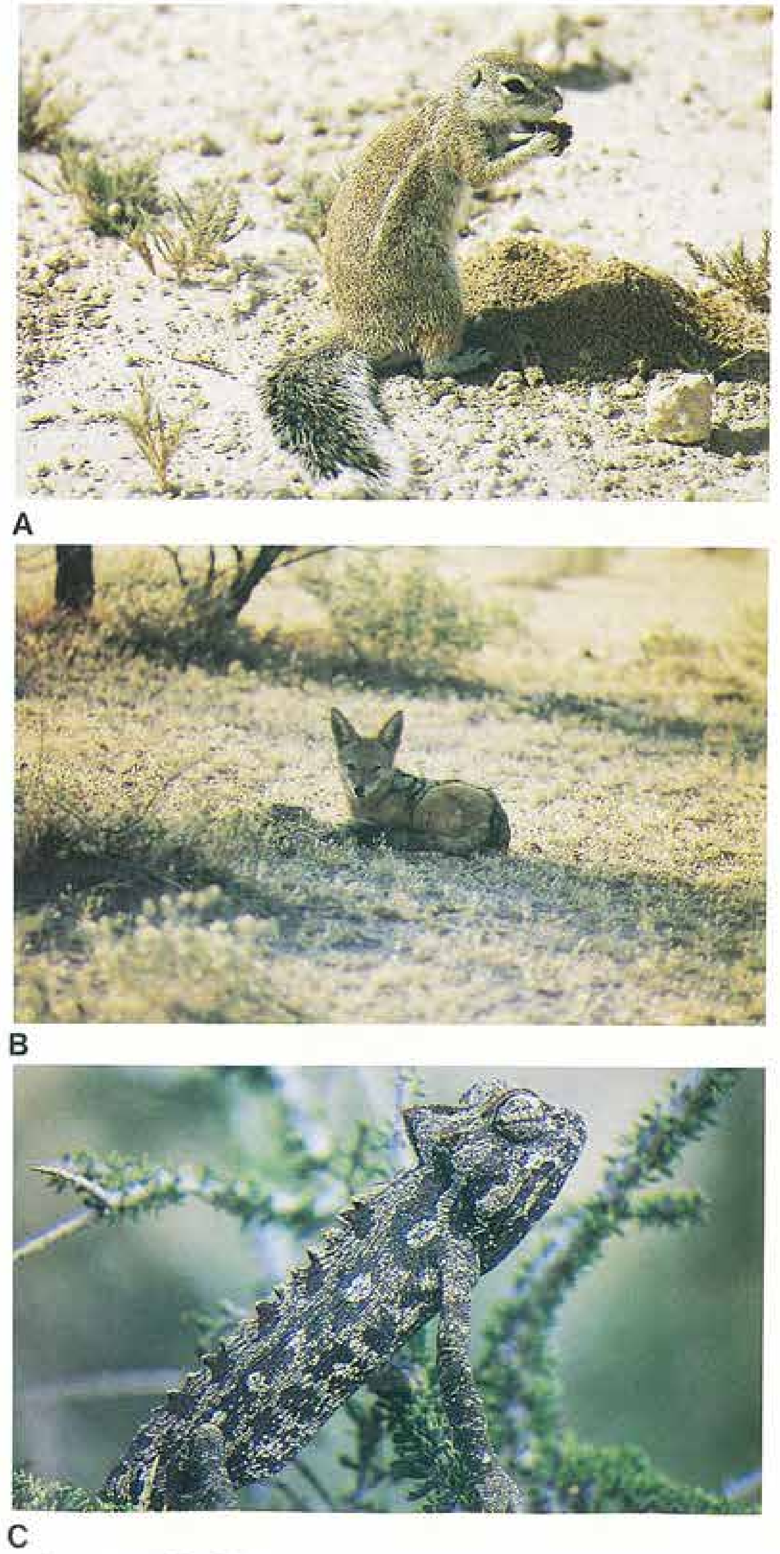
Plate 3



Typical elements of the Namib Desert flora found near the Rössing Uranium Mine:

(A) *Lithops ruschiorum* amongst marble chips; (B) *Aloe asperifolia*;
(C) *Hoodia currori* in flower; (D) *Euphorbia damarana*
(E) *Adenia pechuelii;* (F) *Commiphora saxicola.*

Plate 4



Typical examples of the Namib Desert fauna found in the vicinity of the Rössing Uranium Mine:

(A) Ground squirrel (*Xerus inauris*)
(B) Black-backed jackal (*Canis mesomelas*)
(C) Desert chamaeleon (*Chamaeleo namaquensis*).

The first detailed botanical survey of the area around Rössing Uranium Mine was carried out by Craven (1986). This study was initiated in 1984, shortly after rains had been recorded for the first time in many years. While this was after mining operations had already started, the species recorded in areas away from the mine can be considered representative of the type of vegetation that would occur in the absence of mining activities.

Four different habitat types were examined by Craven (1986), namely: depressions and washes; flat areas of ground; hills, rocky outcrops and inselbergs; and riverbeds. Each of the four habitats examined was characterized by a particular suite of species, with only 2 species recorded at each of five sampling sites. Sixty-five species were represented by records from single sites. A total of 196 plant species was recorded, comprising: 1 fern, 35 monocotyledons and 160 dicotyledons. Whilst no new species were found, Craven (1986) identified 9 alien invasive plants, 3 other species of exotics and 10 rare species that are protected in Namibia.

2.8.1.2 *Seasonal changes*

The most obvious seasonal changes in the vegetation are those brought about by sporadic rainfalls. While the effects of these events has been mentioned above (Section 2.8.1.1), their importance to the vegetation of the Central Namib Desert cannot be over-emphasized.

The numerous gullies and river beds scattered across the region serve to collect the rainwater from large, virtually unvegetated expanses of the coastal gravel plains and rocky hillsides into far smaller areas. Here, the alluvial soils are relatively deep and thus able to retain moisture for longer periods. These gullies and river beds provide a refuge for the perennial vegetation which relies largely on sub-surface water, drawn up via their tap roots.

The summer rainfalls of the interior plateau region of Namibia provide the major source of water for the riverine vegetation on the Central Namib Desert (Huntley, 1985). Consequently, most seasonal variations in the vegetation are related to the frequency, intensity and duration of river flows (Theron *et al.*, 1985; Huntley, 1985). Examinations of the population structure of the larger tree species, particularly *Acacia erioloba* and *Acacia albida*, have shown that most riverine populations are composed of distinct cohorts, each consisting of trees of virtually equal age (Ward & Breen, 1983; Theron *et al.*, 1985; Hydrology Division, 1988). This feature reflects the extent to which these two species rely on sporadic flood events to stimulate germination.

The flush of short-lived annual species after local rainfalls and floods is another very obvious result of seasonal change. While these rainfall events are both infrequent and localized in extent, they provide a vital source of good-quality grazing for plains game.

2.8.1.3 *Aquatic vegetation*

The halophytic aquatic plant *Ruppia maritima* has occasionally been recorded from permanent and semi-permanent pools in the Namib Desert (C.J. Ward, personal communication). While *Ruppia maritima* has been recorded by Craven (1986) and Day (unpublished data) from the man-made crusher and seepage ponds at Rössing Uranium Mine, there is no evidence to suggest that this species would have occurred here prior to the start of mining activities. The only other truly aquatic higher plants recorded for the Rössing area are the emergent species, *Cyperus marginatus*, *Phragmites australis* and *Typha capensis* that have been found growing on patches of wet soil in the beds of the Khan and Swakop Rivers.

Microscopic diatoms and other algae are the only other aquatic plants growing in natural and wastewater pools at the Rössing Uranium Mine (Archibald, 1987). At Piet-se-Gat, the only natural pool in the area, Archibald (1987) found 15 species of diatoms, noting that large numbers of diatoms were present despite the low species diversity. This situation is typical of stress conditions; in this case, the stress is high salinity levels. All the diatom species identified were considered to be cosmopolitan and had previously been recorded from other semi-saline or brackish water localities in Namibia and South Africa (Ashton & Schoeman, 1984; Schoeman & Archibald, 1988).

2.8.1.4 *Introduced species*

Tarr & Loutit (1985) listed 8 invasive species in the Skeleton Coast Park and Western Damaraland, while Brown & Gubb (1986) listed 10 invasive species in the Northern and Central Namib Desert. Vinjevold *et al.* (1985) noted that 8 invasive species occurred in the Namib-Naukluft Park, primarily along the Kuiseb and Swakop rivers. Craven (1986) reported the presence of 9 invasive species and 3 other introduced species in the environs of the Rössing Uranium Mine. Each of these reports listed the invasive species involved and stated that their impact was primarily along the river courses.

It has long been known that rivers form corridors of dispersal for vegetation, particularly in regions of high rainfall. In more arid regions such as the Namib Desert, ephemeral rivers carry large numbers of plant seeds, including those of invasive species, from the interior plateau to the coastal plain. However, further colonization away from the river courses is dependent on climatic conditions, particularly the availability of rainfall. In the virtual absence of rainfall that is so characteristic of the Central Namib Desert, populations of invasive species remain confined within the river beds and compete with indigenous species.

The majority of the invasive plants encountered along ephemeral rivers in the Namib Desert appear to be either drought-tolerant or possess seeds that are adapted to withstand long periods of desiccation (Tarr & Loutit, 1985; Vinjevold *et al.*, 1985; Brown & Gubb, 1986). The seeds of those species which are not as well adapted to drought conditions are able to germinate rapidly after floods and take advantage of the available water. This was illustrated clearly after the 1985 floods when exotic plant species such as *Nicotiana glauca* (Wild tobacco), *Ricinus communis* (Castor-oil plant) and *Datura innoxia* (Thorn apple) germinated rapidly in the Khan river bed (Craven,1986).

The vegetation of the lower Swakop River has been extensively modified by livestock ranching up to 1977 when the small-holders were bought out and their land incorporated into the Namib-Naukluft Park (Vinjevold *et al.*, 1985). The vegetation around well points along the lower Kuiseb River has also been extensively modified by the large herds of goats, cattle and donkeys kept by Topnaar farmers. Overgrazing by domesticated stock creates ideal conditions for the development of many invasive alien species which are primary colonizers of disturbed areas (Brown & Gubb, 1986).

2.8.2 Large Mammals

No detailed large mammal surveys have been conducted around the site of the Rössing Uranium Mine; rather, attention was focused on the Namib Desert Park to the south. Twenty nine species of large mammal have been listed from the Namib Desert Park (Stuart (1975); more than half of these being carnivores. Three other species, namely *Loxodonta africana*, the African elephant, *Lycaon pictus* (Wild dog) and *Panthera leo* (Lion) were formerly present in the area but have been hunted out. Many of the species listed by Stuart (1975) are considered to be nomadic, moving widely throughout the area, only entering the Namib Desert Park when food is more plentiful after rains.

These species may not form a part of the area's permanent populations.

Klipspringers are frequently seen around the Khan River gorges and are thought to be the only antelope species that is resident in the area around the Rössing Uranium Mine. Gemsbok, Springbok and Hartmann's Zebra are occasionally seen at seepage points along the Khan River, while Dassies (*Procavia capensis*), Black-backed jackal (*Canis canis*; Plate 4) and troops of Chacma baboon (*Papio ursinus*) have been seen in Panner and Pinnacle Gorges (James, 1985).

2.8.3 Small Mammals

Four species of shrew, six species of bat, two species of hare and 16 species of indigenous rodent have been recorded from the Namib Desert Park and may also occur in the vicinity of the Rössing Uranium Mine (Withers, 1979). Many of the rodent species found in the Namib Desert Park occupy rocky habitats or wooded areas. Similar habitats occur along the Khan River and several of these species should occur there. There is also an unconfirmed description of a new sub-species of the Golden mole found in the Swakop River bed (James, 1985).

Two species of introduced rodent have been recorded in the mine area due to human activity (James, 1985), namely *Mus musculus* (House mouse) and *Rattus rattus* (Brown rat). The introduced Black rat (*Rattus norvegicus*) was introduced to South West Africa/Namibia off early sailing ships, but its distribution appears to have been confined to coastal ports (Griffin & Panagis, 1985).

2.8.4 Birds

The desert environment, with its shortage of water, extremes of temperature, and paucity of food and vegetative cover, presents special difficulties for the survival of terrestrial animals. Despite these features, the Central Namib Desert is inhabited by a number of avian species whose feeding and reproductive habits are specially adapted to their desert environment. These species are normally resident in the area and their numbers increase dramatically with the influx of other, locally migratory species that appear in large numbers following the sporadic rains, to take advantage of the increased numbers of insects and plants (Willoughby & Cade, 1967; Willoughby, 1971).

Throughout this region, the reproductive cycle of each species coincides with the seasonal rainfall which brings about an abundance of succulent foods (Willoughby, 1971). This feature is also found in the avian populations inhabiting other arid areas in Africa (Moreau, 1950). It appears that rainfall is the environmental "trigger" that stimulates the onset of breeding (Willoughby & Cade, 1967).

The avifauna is comparatively rich within the different habitat types that occur in the Central Namib Desert. However, Willoughby's (1971) statement that "the avifauna of the Namib Desert is relatively poorly known" still applies today (Colahan, 1987). Molyneux (1976) recorded 97 species of bird from the eastern Swakop River north of Groot Tinkas, on the eastern edge of the Central Namib Desert. Clinning has studied the Lappet-faced vulture (*Trogos traceliotus*) in the Namib Desert Park (James, 1985). This species ranges over enormous distances and is very likely to be found in the Khan area, though it is very wary of human interference. Tilson observed the tick-eating behaviour of Pale-winged starlings (*Onychognathus nabouroup*) present on Klipspringers in the Kuiseb River. Five species of owl may be present in the Khan area (Maclean, 1985).

The only published survey of the birds in the vicinity of Rössing Uranium Mine was that of Colahan (1987) who carried out an opportunistic survey of the bird species around Rössing and Arandis during 13 visits, each of three days duration, during 1984 and 1985. Four survey sites were visited and other bird sightings were also recorded. Three of the seven "avian habitats" referred to by Willoughby & Cade (1967) and Willoughby (1971) for the Central Namib occur at the Mine. They are "Inner gravel flats - barren or sparsely vegetated gravel plains"; "Open bush - scattered bushes 60 cm to 3 m tall" and "Rocks - large boulders, crevices and ledges with or without vegetation". However, Colahan (1987) also examined the scattered *Acacia erioloba* trees in the Khan River and areas that were man-modified, such as the mine buildings, gardens in the town of Arandis and artificial waterbodies on the mine property. Colahan's (1987) list contained a total of 75 species, of which 21 were associated with artificial waterbodies. Nine species of bird were thought to be breeding in the area.

2.8.5 Reptiles and Amphibians

Several studies have been conducted on the reptile fauna of the Namib Desert Park, including details of behavioural and physiological adaptations (Louw, 1971; Louw & Seely, 1982). However, it is not certain just how many of the reptiles that have been recorded in the Namib Desert Park actually occur around the Rössing Uranium Mine.

The staff of the State Museum, Windhoek, surveyed the reptile and amphibian fauna around Rössing during the period February 1984 to August 1985, recording a total of 34 species of reptiles and 2 species of amphibians (Berger-Dell'mour, 1985). The full list of the reptile and amphibian species collected and observed around the Rössing Uranium Mine is given in Table 2.6. An additional 7 to 10 species are also expected to occur in the area around the mine and one species new to science has recently been described from the nearby Husab Mountains (Berger-Dell'mour, 1989).

Channing (1974; 1976) recorded four species of frog in the Namib Desert during the 1974 rains, one of which (*Xenopus laevis*) is not a permanent resident of the Namib (Channing & Van Dijk, 1976). Adults and juveniles of *X. laevis* are washed downstream from the upper Kuiseb River during summer floods to temporary pools where they survive until the pools dry out. Similar situations are expected to occur along the Swakop and Khan Rivers.

One of the other species of frogs (*Tomopterna delalandei*) has only been found along the bed of the Kuiseb River and may also be washed away during floods. This species burrows under the mud at the bottom of drying out pools to await the return of favourable conditions (Channing, 1976).

The two other species (*Bufo vertebralis hoeschii* and *Phrynomerus annectens*) are unusual in that they inhabit cracks in the rocky outcrops and inselbergs of the drier plains. Both species require water to breed and they lay their eggs in pools of rain water (Channing, 1974; 1976). These two species have been recorded at Blutkoppie near the Swakop River and both species should also occur in the vicinity of the Rössing Uranium Mine. So far, however, only *Bufo v. hoeschii* has been recorded from Rössing (Berger-Dell'mour, 1985).

Greig and Burdett (1976) reported on the distribution of tortoises in southern Africa. Four genera of tortoises have been recorded from Namibia, but Greig & Burdett (1976) consider that the records of at least one of those genera is open to question. Further uncertainty also surrounds two other genera that were recorded from a single farm, since the alleged sympatry of species in the genera is unlikely to occur. Two species of tortoise (*Geochelone babcocki* and *Psammobates occulifer*) were recorded from the Swakopmund area (Greig & Burdett, 1976) and may also occur further inland near the Rössing Uranium Mine.

TABLE 2.6: List of reptile and amphibian species found within a 20 km radius of the Rössing Uranium Mine, during the period February 1984 to August 1985. (Data obtained from Berger Dell'mour, 1985).

Species Name	Group
Pachydactylus punctatus *Pachydactylus bicolor* *Pachydactylus bibronii* *Pachydactylus laevigatus* *Pachydactylus werneri* *Pachydactylus kochii* *Ptenopus garrulus maculatus* *Narudasia festiva* *Chondrodactylus angulifer namibensis* *Rhoptropus afer* *Rhoptropus b. Bradfieldi* *Rhoptropus barbardi*	**Geckoes** 12 species found, 1 more expected
Agama anchietae *Agama p. planiceps*	**Agamas** - 2 species found
Chamaeleo namaquensis	**Chamaeleons** - 1 species found
Meroles suborbitalis *Mesalina u. undata* *Mesalina* sp. nov. *Mesalina breviceps* *Mesalina namaquensis*	**True Lizards** - 5 species found
Mabuya hoeschii *Mabuya occidentalis* *Mabuya spilogaster* *Mabuya v. variegata* *Mabuya acutilabris* *Mabuya s. sulcata*	**Skinks** - 6 species found
Cordylosaurus subtessellatus	**Plated Lizards** - 1 species found
Leptotyphlops occidentalis *Bitis caudalis* *Psammophis leightonii namibensis* *Psammophis trigrammus* *Typhlops lalandi* *Dipsina multimaculata* *Lamphrophis f. fuliginosus*	**Snakes** 7 species found, 3 more expected
Xenopus l. laevis *Bufo vertebralis hoeschii*	**Frogs and Toads** 2 species found, 2 more expected

2.8.6 Aquatic Fauna

A survey of the aquatic fauna of Rössing Uranium Mine was carried out in 1987/88 (Day, unpublished data). Six sites were visited although only one (Piet-se-Gat) was a natural pool. Handnet collections and core samples of the benthic algal mat in Piet-se-Gat revealed the presence of 12 taxa of aquatic invertebrates. The taxa represented were Copepoda, Ostracoda (Seed shrimps), Hydracarina (water mites), Ephemeroptera (mayflies), Odonata (dragonflies), Hemiptera (bugs), Coleoptera (beetles) and Diptera (flies). Day (1989) states that the aquatic invertebrate populations found in the Namib Desert ephemeral waters are dominated by crustaceans whilst the immature stages of insects dominate permanent water bodies.

2.8.7 Insects

Holm's (1970) survey of the diversity of terrestrial insects in a very small area of dunes in the Namib Desert Park highlighted the enormous variety of insects in the area. Subsequent studies have revealed that more than 200 species of tenebrionid in the Namib Desert Park are endemic (Louw & Seely, 1982). Collections made by the staff of the State Museum, Windhoek, around the Rössing Uranium Mine have also indicated this area to have an extremely rich insect fauna.

During the period March 1984 to May 1985, some 69 000 terrestrial insects were collected in pit traps located around the Rössing Uranium Mine. These terrestrial insects represented some 160 species from seven different taxonomic orders. To date (E. Marais, In Litt.), seven new insect species have been described from these collections and the descriptions of at least three others are currently being prepared. Many of the insect specimens collected during this survey are only known from the vicinity of the Rössing Uranium Mine and their formal identification awaits examination by appropriate insect taxonomists. A list of the new terrestrial insect species that have been described or whose descriptions are awaiting publication is given in Table 2.7. No information is currently available on the flying insects other than the observation by John Leggatt that a number of types of moth are present at the mine (James, 1985).

Coaton and Sheasby (1972) surveyed the termite fauna of Namibia, reporting one species of termite within the boundary of the Swakopmund Magisterial District. In contrast, the State Museum survey of the terrestrial insects around the Rössing Uranium Mine recorded 3 termite species.

2.8.8 Arachnids

The staff of the State Museum, Windhoek, surveyed the arachnid fauna in the vicinity of the Rössing Uranium Mine between March 1984 and May 1985. During this period, some 5000 specimens of spiders, scorpions, pseudoscorpions and other arachnids were collected by means of pitfall traps and a variety of hand collection techniques. The numbers of species recorded in each group were: 89 species of spiders from a total of 30 different families, 17 species of solifuges from 5 families, 11 species of scorpions from 3 families, at least 2 species of pseudoscorpions and 1 species of opiliones, respectively (Griffin, 1988). To date, 10 new species of spiders have been described from the Rössing area (Table 2.8) and further examination of the material collected during the Rössing survey is continuing (Ms Eryn Griffin, personal communication).

The highest numbers of spiders were found in the dry water courses leading towards the Khan River, whilst the greatest numbers of solifuges (hunting spiders) were found on rocky hillsides (Griffin, 1990). Scorpions did not show any preference for a particular habitat type.

TABLE 2.7: List of new terrestrial insect species collected from the vicinity of the Rössing Uranium Mine. (Information provided by E. Marais, Curator of Entomology, State Museum of Namibia, Windhoek).

Insect Name	Reference
Order Thysanura - Family Lepismatidae	
Ctenolepisma namibensis	Irish, 1987
Thermobia nebulosa nebulosa	Irish, 1989
Order Coleoptera - Family Buprestidae	
Acmaeodora decemguttata namibensis	Holm, 1986b
Acmaeodora liessnerae	Holm, 1986b
Notomorphoides irishi	Holm, 1986a
- Family Malachiidae	
Hedybius irishi	Wittmer, 1988
Metaphilhedorus swakopmundensis	Wittmer, 1990
- Family Dermestidae	
Attagenus sp. nov.	Kalik, (in preparation)
- Family Ptinidae	
Damarus sp. nov.	Irish, (in Preparation)
- Family Tenebrionidae	
Pachyteles sp. nov.	Penrith, (in preparation)

TABLE 2.8: List of new spider species described from specimens collected near the Rössing Uranium Mine, Namibia. (Information supplied by Ms E. Griffin, Curator of Arachnology, State Museum of Namibia, Windhoek).

Name	Reference
Family Ammoxenidae	
Rastellus narubis	Platnick & Griffin, 1990
Rastellus struthio	Platnick & Griffin, 1990
Family Migidae	
Moggridgea eremicola	Griswold, 1987
Family Eresidae	
Seothyra griffinae	Dippenaar-Schoeman, 1991
Seothyra longipedata	Dippenaar-Schoeman, 1991
Seothyra annettae	Dippenaar-Schoeman, 1991
Family Zodariidae	
Cyrioctea namibensis	Platnick & Griffin, 1988
Heradida griffinae	Jocqué, 1987
Diores namibia	Jocqué, 1990
Diores damara	Jocqué, 1990

The trapping study results showed that consistently high numbers were trapped in Panner Gorge, probably due to the higher soil moisture (Griffin, 1988). The overall trapping results suggested that low minimum temperatures and low humidity levels decreased the activity of spiders. Similarly, colder weather inhibited the activity of solifuges (Griffin, 1988; 1990). The activity of scorpions increased markedly after rainfalls in January 1985.

2.9 Demographics, Socio-Economics and Patterns of Land Use

2.9.1 Demographics and Socio-Economics

Prior to the German colonization of Namibia during the last century, the Central Namib Desert was occupied by widely-scattered groups of nomadic hunter-gatherers. These peoples were mainly of Bushman and Topnaar Hottentot origin, though there is some evidence that Strandlopers also exploited the shellfish and bird-life along the coast. Further inland, Damara and Herero tribespeople raised goats, sheep and cattle along the river courses and on the interior escarpment and plateau (Jacobson, 1976).

The German military occupation also brought with it the first architects, engineers and missionaries, who proceeded to develop the town and port facilities at Swakopmund. Many of the older buildings in Swakopmund have been retained to this day and their architectural character provides a reminder of the earlier German influence.

Early discoveries of copper and other minerals in the Namib Desert and in the interior of Namibia spurred on the development of formal settlements as well as rail and road links. However, travel to the interior was greatly hampered by the inhospitable terrain and the lack of water. Farming enterprises and Lutheran mission stations concentrated around the few perennial water sources and these points also became the foci for the construction of military outposts. These settlements later expanded to include trading stores which bartered trade goods for game products and livestock with the local peoples, and became the first towns.

The completion of reliable road and rail links between the coast and Windhoek, facilitated the development of Swakopmund as a fishing port and seaside resort. However, safer and more sheltered harbour facilities were developed at the South African port of Walvis Bay, some 40 km to the south. This led to a rapid decline in the use of the exposed berthing at Swakopmund, and fishing activities became concentrated at Walvis Bay. During the 1970's, commercial fishing stocks off the Namibian coast declined drastically and are now regulated strictly by the Directorate of Sea Fisheries. Today, Swakopmund is still an important resort town and its cool and invigorating climate provides visitors with a pleasant change from the heat of the dry interior regions.

Prior to the development of uranium mining at Rössing, the economy of Swakopmund centred around the tourist industry and the production of leather goods from the skins of game and domestic animals. Other important local industries included beer brewing and the production of a variety of meat and other food products.

Apart from Swakopmund and the town of Usakos some 135 km inland, the area is very sparsely populated. Outside of Swakopmund, there were virtually no inhabitants other than a few farmers along the lower Swakop River. Further inland, beyond the escarpment, large areas of land (up to 400000 hectares per farm) were given over to sheep and cattle farms. Only the hardy Karakul sheep could be raised in the drier central areas bordering the eastern edge of the Namib Desert.