DIVISION OF WATER, ENVIRONMENT AND FORESTRY TECHNOLOGY, CSIR

DRAFT FINAL REPORT

AN ASSESSMENT OF THE POTENTIAL ENVIRONMENTAL IMPACTS OF THE PROPOSED AQUIFER RECHARGE SCHEME ON THE KHAN RIVER, NAMIBIA

Prepared by

CSIR

for

RÖSSING URANIUM LIMITED, NAMIBIA

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EXECUTIVE SUMMARY

1. INTRODUCTION AND STRUCTURE OF THE REPORT

This report provides details of an Environmental Impact Assessment (EIA) of the Khan Aquifer Recharge Scheme (KARS) Project in Namibia proposed by Rössing Uranium Limited, and is based on information which has been synthesized from a wide variety of published sources as well as specific investigations conducted during the project.

Rössing Uranium Limited has advised that the KARS project results from continued investigations that seek to ensure the most efficient use of Namibia’s available water resources. The construction of a dam in the Khan River, as part of an artificial ground water recharge scheme, is proposed in order to increase the volume of brackish water being extracted from the alluvial aquifer for industrial purposes in terms of a Department of Water Affairs (DWA) permit. Rössing would thereby reduce their reliance on the Central Namib State Water Scheme (CNSWS). The proposal aims to capture a portion of the occasional floodwaters in the dam, settle the silt out, and then channel clear water into the downstream alluvial aquifer in the river bed at a rate which ensures maximum infiltration into the aquifer. The proposed site for the dam is approximately 10 kilometres upstream of the present mining activities. It is envisaged that this scheme will allow increased extraction of brackish water from the aquifer on a controlled and sustainable basis over the long periods between floods, thereby relieving the pressure on the already stressed fresh water resources of the West Coast area of Namibia.

After a brief introduction providing the background to the project (Chapter 1), a description of the scope of the impact assessments is given (Chapter 2), followed by a description of the methods used to assess and evaluate the magnitude and importance of the impacts associated with the proposed project and identified by Interested and Affected Parties (I&APs) (Chapter 3).

A description of the regional setting and environment in which the proposed scheme is to be constructed follows in Chapter 4, providing background information on items such as Khan and Swakop River catchment characteristics, data availability, geohydrology, ecological characteristics and general land use. The hydrology of the river systems and the geohydrology of the associated alluvial aquifers is of primary importance to a project of this nature, and extensive coverage of the hydrological simulations and their effects on the water systems are given in Chapter 5 of the report. Against the baseline described in Chapter 5, the report describes the main findings of the work carried out, and lists the Key Issues and Concerns that have been identified during the project. This is followed by an assessment of the potential magnitude and importance of the possible and identified impacts within the area between the proposed aquifer recharge site and the mouth of the Swakop River at Swakopmund (Chapter 6). In addition, this information is placed in context by appropriate references to the remainder of the Khan and Swakop River catchment. Finally a summary of the impacts, recommendations and monitoring requirements are provided in Chapter 7.
This Executive Summary provides a brief overview and summary of the main findings of the studies. Finally, a matrix is presented which provides a graphical summary of the Key Issues, as well the level of significance of the impacts which may be expected to occur if the proposed aquifer recharge scheme proceeds.

2. THE ENVIRONMENTAL EVALUATION PROCESS

The Terms of Reference for the KARS feasibility study included a requirement for an EIA of the proposed scheme. An environmental assessment was undertaken to a level of detail sufficient to satisfy Namibian and international norms and policies. The environmental assessment was conducted in parallel with the engineering feasibility studies. The programme of work was split into two main phases:

- an initial public scoping and consultation exercise, which was followed by
- detailed evaluation of the anticipated environmental impacts.

Attention was directed towards key environmental issues and potential fatal flaws, and issues that have been identified during public scoping sessions. This procedure also enabled the Environmental Team to provide key information required for the engineering feasibility studies. This EIA also identifies information gaps and provides the basis for future studies which would not only complement these earlier studies, but would also form the basis for decommissioning of the aquifer recharge scheme once it has reached the end of its useful life.

The environmental work reported here has been focused mainly on project-specific issues, impacts and concerns. It does not address wider national issues such as the strategies of water resource management in Namibia, nor scenarios greater than the scale proposed by the engineering feasibility studies. Nevertheless, the arid environment of the Central Namib Area of Namibia has been briefly described to provide an overview of the broader context in which this proposed project may take place.

The primary study area stretched from some 15 kilometres upstream of the Rössing Mine property down to the mouth of the Swakop River at Swakopmund. However, for completeness, the proposed aquifer recharge scheme has been placed in the wider context of water resource issues in the entire Swakop River catchment. This allows an evaluation to be made of potential incremental effects which could be attributed to the KARS Project.

The environmental evaluation process followed in this project, as well as the technical findings which have arisen during the process, will be reviewed by independent external evaluators. This follows the Namibian Environmental Policy and is designed to ensure that studies such as those recorded here fulfil national and international requirements for public participation and for technical competence.

The draft final report will be presented to all stakeholders at public meetings. Interested and Affected parties (I&APs) are able to comment on the findings and their concerns are then incorporated into the final report. Any decision to proceed or cancel the KARS
project rests, ultimately, with Rössing Uranium Management, the Namibian Department of Water Affairs and the Namibian Ministry of Environment and Tourism.

3. IDENTIFIED KEY ISSUES

During public meetings, interviews with and written comments from I&APs on the proposed project, a number of primary issues of concern were raised which needed to be addressed during the EIA. These can be grouped in the following four main categories:

- **Project motivation;**
  - A need and desirability statement for the project;
- **Technical issues**
  - The impact on the water management systems upstream of the proposed Khan dam;
  - The design and engineering features of the dam and associated aquifer recharge mechanism;
- **Ecological issues**
  - The impact on fauna and flora above and below the dam wall;
  - The impact on ecology during construction of the dam;
  - The potential for sand dunes to migrate across the Swakop River;
  - Potential changes (especially erosion) to the beach front in Swakopmund;
- **Socio-economic issues**
  - The impact on the quality and quantity of ground and surface water available for downstream water users;
  - Sand mining activities near Swakopmund;
  - Impact on the economic viability of sea water desalination project for improved fresh water supplies to the region;
  - The financial viability of the project; and
  - Impact on the public leisure activities in the Khan River bed in the vicinity of the reservoir.

It was further recommended by the I&APs that an independent review of the Draft EIA report should be done by a credible Namibian authority with specialist knowledge of the local ecology and hydrology.

3.1 Project motivation

The present total water demand of Rössing Mine is about 3 million m³/year which is expected to increase to approximately 4.5 million m³/year during 1998. Of the current total water consumption, about 250,000 m³/year is obtained from the alluvial aquifer in the Khan River. The rest is also supplied from ground water resources, namely the Kuiseb and Omaruru Delta aquifers through the Central Namib State Water Scheme (CNSWS). Over-exploitation of these aquifers has forced the Government to consider seriously the installation of a large desalination plant to supply the major users along the West Coast with potable supplies. Despite the likelihood of a desalination plant being built, other options to protect the limited potable water resources of the area need to be
investigated continuously. The KARS project is one of these options proposed by Rössing to reduce their overall abstraction from the CNSWS. For the remaining life of the mine, Rössing will be required to use substantial volumes of water from the CNSWS, basically for two reasons: (i) the ground water resources of the Khan River alluvial aquifer will not be able to supply in the total demand of Rössing, and (ii) the quality of the Khan River ground water is not of an acceptable quality and needs to be mixed with a large proportion of potable water. Rössing has advised therefore that it fully supports the desalination concept for supplying the West Coast consumers with potable water and is actively cooperating with and assisting the authorities in this regard.

3.2 Technical issues

Upstream water management

Investigations for alternative water supplies for the town of Usakos upstream of the proposed dam, have been carried out by the Department of Water Affairs since 1972 when two possible dam sites were investigated. The Department is not presently considering upgrading the water supply to Usakos from local resources and rather sees further demand at Usakos being met by piping water to the town from other state water supply schemes. However, should the Department decide to build a similar recharge scheme near Usakos within the 20 year lifespan of the KARS project, it would undermine the viability and objective of the KARS project and Rössing Mine would not benefit from the project. At comparable capacities, the two dam sites previously investigated at Usakos will have approximately double the surface area of the KARS dam, with associated high potential for evaporation. The net gain of such a scheme at Usakos would therefore be significantly lower.

The KARS project will have no influence on the ground water conditions in the vicinity of Usakos, but will only influence ground and surface water conditions below the dam in the Khan and Swakop Rivers.

Dam wall

Calculations have indicated that the optimum capacity of the KARS dam will be of the order of 9 million m$^3$. This will result in a dam wall of 25 metre maximum height and includes a 5.5 metre allowance for freeboard during flood events. A main and an emergency spillway on the northern and southern bank of the river, respectively, will be constructed. When operated together, these spillways will be able to accommodate a 1:200 year flood event.

Following evaluation of a range of alternatives it is proposed to construct a zoned earth fill embankment comprising alluvial fill and a core of compacted decomposed gneiss. The core material is to be borrowed some 6.5 kilometre from the site just off the desert plain. The previously anticipated construction of a permanent cut-off under the dam wall is omitted in the latest design.
Dam wall failure

Major flood events are the most likely cause of dam failure. The effect of a flood of 1,100 m$^3$/second was investigated and studies indicated that a dambreak flood wave will have largely dissipated by the time it reaches the farming zone. The major influence will be the level of the flood when it passes through the spillway at the time of the dambreak.

The consequences of failure of the dam are unlikely to be severe due to the absence of people and publicly owned infrastructure along the river all the way down to Goanikontes. Assessments of the dam break flow characteristics indicate that the flow depth by the time the flood wave reaches Goanikontes will be less than 1,8 m and the flow depth negligible by the time it reaches Swakopmund. Damage to Rössing’s boreholes in the Khan River will be similar to that experienced during a major flood event.

Aquifer recharge mechanism

The primary objective of the KARS project is to capture surface run-off and effect controlled infiltration of the water into the alluvial sands. Since the longer the water is kept at surface, the greater will be the evaporative losses, and therefore as soon as the water has had the opportunity to clarify it will be decanted from the dam via a decant system and an outlet pipe. This water will be routed down the river via a system of cross-bunds orientated so as to detain the water and enhance infiltration. A series of natural occurring compartments, as well as some artificially constructed ones, will be installed downstream of the dam wall to allow proper management of the resource.

3.3 Ecological issues

Fauna and flora

Loss of small- and medium-sized floods to the lower Khan River will reduce the quantity of water available to shallowly-rooted “riparian” vegetation downstream. This will result in fewer grasses and forbs being found, though it will not affect the numbers of larger (perennial) trees and shrubs. Fewer young trees will be found and then only after larger floods have occurred. The construction of the dam and the subsequent capture of occasional floods, will directly impact on the riparian habitat on a local scale but it will only be of low to medium significance. Once the dam basin starts to fill with silt, habitat areas of some species of fauna and flora will be affected. Eventually the silt covered area will be approximately 100 hectares in extent.

The inundation basin behind the dam will trap large numbers of plant seeds, as well as flood-borne debris and silt. Thus, it can be expected that the inundation basin will be colonised by a wide range of plant species. Over time, it is anticipated that a distinct “riparian” zone will develop along the high-water line. This, in turn, will provide improved habitat for a wide range of birds and small mammals.
No protected plant species have been recorded in the bed of the Khan River. However, a number of sensitive animal, bird and reptile species do occur along the bed of the Khan River. These could be adversely affected by construction activities. However, any floods trapped by a dam will create a new, though temporary, source of surface water, which could well attract additional bird and animal species to the vicinity of the dam. The overall potential impact on sensitive animal and plant species in the areas where construction or inundation could occur, is likely to be minor at most.

When floods are trapped by the proposed dam wall, the resulting open water habitat will attract waterfowl to the area. This will be temporary though, as this trapped water will partly be lost through evaporation and partly be decanted to downstream spreading grounds where the aquifer is to be recharged. It is anticipated that the proposed dam will not significantly alter the long-term distribution patterns of plants or wildlife in the area.

Erosion

The accumulation of silt and alluvium within the dam basin will reduce the capacity of the dam, as well as its ability to trap floodwaters. Thus, with time, greater quantities of floodwater will pass over the spillway and enter the lower Khan River. If these floodwaters have lost portions of their loads of suspended silt, they will have an increased erosion potential because of the potential to regain suspended matter in the flood water. In the short term, this will lead to erosion of riverbed sediments from the river reach downstream of the dam wall.

Construction activities

Construction of the dam wall and spillway will cause localized short-term disturbance around the dam site. The dam wall will interfere with existing practices of off-road vehicles driving along the Khan River bed. An alternate route around the dam wall and inundation basin may be required if this practice is considered to be important.

Ground water abstraction

Recharge of the aquifer downstream of the dam wall will increase the quantity of ground water available for abstraction in this sector. Abstraction of this ground water should be controlled so that sufficient base flow continues to sustain the riparian vegetation downstream of the mine property and contribute to the lower Swakop River alluvial aquifer. Lowered water table depths will reduce water loss via evaporation and retard the rate at which salt concentrations increase.

Sand dune encroachment

Examination of aerial photographs taken over the last 35 years show the sand dunes south of the Swakop River to be stable. Therefore, despite decreased flow volumes in
the Swakop River at the coast, the sand dunes are unlikely to migrate across the Swakop River towards Swakopmund.

**Beach erosion**

The modelled average annual sediment contribution to the coast by the Swakop River is about $1.3 \times 10^6$ m$^3$, whereas the contribution from the Kahan River is only $0.1 \times 10^6$ m$^3$. The patterns of erosion and deposition along the coastline are affected by the northward directed longshore drift and to a minor extent by material brought down the local rivers during floods. The erosion of beaches in Swakopmund is similar to the erosion pattern at Sandwich Harbour to the south of Walvis Bay. Sediments brought down by floods in the Swakop River are eroded by a potential longshore sediment transport rate of between 0.5 million m$^3$/year and 1.4 million m$^3$/year to the north although indications are that this rate has increased substantially during the last few years. The reduction in the total sediment yield to the coast as a result of the KARS project, will thus not negatively influence the beaches at Swakopmund. Floods in the Swakop River are generally believed to be of minor significance in terms of sediment yield to the coast and will have only a very minor influence on the coastal erosion and depositional processes. The calculated reduction in the annual sediment yield provided by the Kahan River at the coast, is minimal and would not affect the distribution of sand along the Swakopmund beaches.

3.4 **Socio-economic issues**

Information on socio-economic issues was obtained from published sources, public meetings, interviews with selected individuals and, in the case of smallholdings along the Swakop River, interviews with land-owners.

**Surface and ground water downstream of the dam**

The Swakop River catchment is the largest river catchment which is located entirely within the borders of Namibia. Given that the catchment includes the City of Windhoek, as well as the towns of Walvis Bay and Swakopmund, together with other minor towns and extensive infrastructure, it is considered to be the most important catchment in Namibia. The Khan River is the largest tributary of the Swakop River. Virtually all run-off is generated in the headwaters of these rivers and only occasionally run-off from the desert environments contributes to the total flow in these rivers. Construction of the Von Bah and Swakoppoort Dams in the upper reaches of the Swakop River has resulted in a reduction in run-off along the Swakop River. In consequence, the relative importance of run-off contributed by the Khan River has increased. Modelling results indicate that the mean reduction in the flood volumes flow in the Swakop River since the construction of the Von Bach and Swakoppoort Dams, is of the order of 16 million m$^3$/year. A further reduction of only 0.35 million m$^3$/year is anticipated to be attributed to the construction of KARS. Similarly, reduced figures for the reduction in sediment yield, after commissioning of the Von Bach and Swakoppoort Dams were obtained from
the modelling. The absolute quantities of surface and ground water, and sediment which the Khan River contributes to the lower Swakop River, are therefore small.

As a result of the construction of the Von Bach and Swakoppoort Dams and the resultant reduced surface (floodwater) flows in the middle and lower reaches of the Swakop River there is now less recharge of ground water. This has led to the lowering of the water table and fewer occurrences where standing water is found on the surface or where the water level is close to the surface of the river bed ("nat kolle" or wetlands). In the lower Swakop River, water levels have dropped by up to three metres in the farming areas and continue to drop at an average rate of about 7 centimetres/year.

The modelling results indicated that further reductions in ground water recharge to the lower Swakop River can be expected as a consequence of the KARS scheme holding back small- and medium-sized surface floods. The overall impact will be to lower the water table in the farming zone when these floods are captured by the KARS dam by a further 0.1 to 0.4 metres as a result of reduced surface recharge.

Sea water infiltration into the aquifer in the farming zone as a result of reduced ground water recharge and over-exploitation of aquifers, will not occur as the base of the aquifer is still above the present day sea level.

Given that the KARS project has an expected useful life of 20 years before decommissioning, and apart from changes in water level directly below the dam, localised changes to ground water in the Khan River will be minor. Ground water flow rate in the Khan River is between 400 and 500 metres per year. Therefore, local changes will not have reached the confluence of the Swakop River (approximately 35 kilometres downstream) by the time that the KARS project has to be decommissioned (20 years).

Using a ground water flow velocity of 500 metres/year, the effect of the KARS dam on the ground water baseflow of the Khan River, is unlikely to be observed in the farming zone within the next 70 years. The model used for the simulation of the effects on the river system, however, instantaneously transmits the effects at the dam wall to the section directly downstream of it. In addition, the modelling predicts a further drop in the Swakop River ground water level in the farming zone of the order of 0.1 metre to 0.4 metre due to the reduced recharge by surface water once KARS is operational. This effect should be interpreted as a worst case scenario. After decommissioning, surface flood waters will, depending on flood frequency, rapidly restore ground water conditions in the Khan and Swakop Rivers below the dam to the level it had been before the commissioning of KARS. In terms of the likely DWA permit requirements, the current ground water baseflow component of 650 m³/day must not be compromised.

Ground water quality

Information contained in the 1966 CSIR report on the Swakop River can be taken as baseline information as the Swakoppoort and Von Bach dams had not been constructed at the time the data was collected. The total dissolved salt (TDS) content of surface and ground water in the Swakop River deteriorates naturally from about 150 mg/l near
Okahandja to 18,000 mg/l at the coast. This deterioration of quality is almost exclusively attributed to evapotranspiration since the 1934 flood event. The simulation of the system using the actual synthetic flow record starting with the flood in 1925, predicts the following average water qualities in the farming zone:

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<td>6,069 mg/l</td>
<td>9,911 mg/l</td>
<td>11,334 mg/l</td>
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The modelling indicates that on average the TDS will increase by about 1,400 mg/l in the farming zone as a result of the KARS project. Smallholdings along the lower Swakop River tend to utilize ground water from boreholes developed near the river banks. This water is less frequently recharged and as a result much more brackish than ground water near the middle of the river bed.

Uranium isotope and concentration analyses of ground water samples from the mining area at Rössing, and the Khan and Swakop Rivers, indicate that, if any uranium containing effluent from Rössing has previously entered ground water in the Khan River, it is too small a quantity to significantly change the background radioactivity levels in the Khan River. No evidence could be found of any ground water pollution by uranium from the mines' tailings dam operations. The KARS project is unlikely to change this status quo with respect to ground water pollution.

**Sand mining in the lower Swakop River**

Using modern luminescence dating techniques, it was established that the bulk of the approximately 600,000 m³ of sand excavated for building purposes by sand-mining activities over the last few years and affecting a surface area of about 240,000 m², is between 340 and 8,700 years old. No evidence was found that substantial amounts of material is brought down by the small- or medium-sized floods which occur in the Swakop River. It appears that the smaller floods reaching the Swakop Delta cause erosion of sediments rather than deposition. From the modelling it is also evident that the absolute quantities of sediment which the Khan River contributes to the lower Swakop River, is small. Therefore, any alteration of the current flooding regime of the lower Swakop River as a result of the KARS project, will have little effect on the material available for sand-mining. Instead, the sand-mining activities are uncontrolled along a large front in the Swakop River bed and cause unnecessary water loss through evaporation, thereby further increasing the salt content of local ground water.
5. KEY FINDINGS

As with all aquatic systems, the hydrological and hydraulic features of the Khan and Swakop Rivers create and maintain the diversity of habitat types within and along the system. A proper understanding of the river system is impossible in the absence of detailed knowledge of these processes.

The construction of the dam and the subsequent capture of occasional floods, will directly impact on the riparian habitat on a local scale but it will only be of low to medium significance. The impact is expected to be partially off-set by the development over time of some form of replacement riparian vegetation.

From the hydrological simulations carried out, the KARS project will trap all small floods (< 3-4 Mm³) and most of the medium-sized floods (5-10 Mm³). This will lead to loss of recharge in downstream sectors of the Khan River and will slightly accentuate the effects on the lower Swakop River caused by the Swakoppoort and Von Bach dams. This effect will persist for the life of the KARS project though, as sediments accumulate in the dam, progressively larger quantities of floodwater will pass over the spillway.

The forced recharge of floodwater into the aquifer will improve the quality of the ground water available for Rössing to abstract.

Water table levels in the lower Swakop River are expected to continue dropping. In addition, water quality will continue to decline as salt concentrations increase. However, a large proportion of this is due to changes which have taken place in the upper catchment of the Swakop River causing reduced flood volumes in the Swakop River. The KARS project is expected to contribute very little to this change.

Irrigation water drawn from boreholes and wells in the lower Swakop River will continue to worsen in quality over time. Implementation of the proposed KARS project is expected to cause a slight acceleration in this trend. Better quality water could be drawn from the centre of the river bed. A detailed management and monitoring plan should be drawn up after consultation with all landowners along the lower Swakop River.

Current patterns of coastal sediment deposition and erosion will not change as a result of the proposed KARS project. The sand dunes south of the Swakop River appear to be stationary. Implementation of the proposed KARS project will not influence these dunes.

The KARS project will have little effect on the replenishment of sand in the sand mining areas. Most of the sand presently being excavated is between 340 and 8700 years old and there is no evidence that floods of the magnitude experienced in recent history would replenish this material. Uncontrolled mining activities cause unnecessary water loss through evaporation.

Isotope studies on ground water samples from the Khan and Swakop rivers indicate that there are no signs of ground water pollution by uranium from the mines' tailings dam operation.
6. CONCLUSIONS AND RECOMMENDATIONS

Taking all the findings into consideration, it has been concluded that there do not appear to be any "fatal flaws" which would prevent the proposed KARS project from proceeding. The key environmental issues associated with the proposed KARS project and their level of significance, are summarized in matrix format in Figure 1 attached to this Executive Summary.

However, despite this conclusion, many people will still have the perception that the KARS project will have undesirable detrimental effects. In order to minimize the risks that people may attribute any adverse or unwanted effect, whatever their origin, to the KARS project, a comprehensive process of communication must be continued.

The issues identified relating to the different aspects of water, for example flood frequency, flood volume, ground water quality and availability are responsible for the most important impacts. Several mitigation measures and recommendations are highlighted in the report. Some of the most important items are referred to below.

A number of new and properly designed monitoring boreholes should be installed in the Swakop River section located between the Khan River confluence and Nonidas to monitor any possible effect of the KARS project on the geohydrological conditions in this area. Of particular importance is the establishment of baseline water levels as these control to a large degree, both the availability and quality of ground water in the lower Swakop River. The installation of these boreholes must receive urgent attention as the establishment of truly representative baseline values for water levels and ground water quality is of utmost importance. Guidelines for when mitigatory or management decisions have to be taken are included in the main report. Current ground water monitoring programmes in the Khan and Swakop Rivers should be continued.

Another serious issue that was revealed during the investigations, although it is not currently directly associated with the KARS project, is the uncontrolled mining of sand in the Swakop River bed. The volume of water contributed by the Khan River to the recent 1997 flood events in the Swakop River, was of a comparable magnitude as that for which the KARS dam is being designed. Nevertheless, the volume of silt deposited in the sand pits only amounted to a smaller proportion than was eroded at the upstream side of the pits. The large open pits created by the mining operations are filled by the initial flood waters before the flood advances to the ocean. As a result evaporation increases and further water quality deterioration can be expected, unless proper planning and management of the mining activities are implemented.

It appears that natural processes along the coast, such as the northerly longshore drift, have a dominating effect on the condition of the beaches at Swakopmund. The issue of sediment supply to the beaches during large floods in the Khan and Swakop Rivers, needs to be monitored at least yearly by establishing baseline profiles of the gradient of different beaches in Swakopmund. In addition, the surface profiles of the Swakop and Khan Rivers should be determined along a fixed line after each flood event to determine the amount of sediments deposited in the lower reaches of each of these rivers. In this way the individual contribution to beach erosion, whether it be from longshore drift action or due to a lack of sediment transported down the Swakop River, could be determined.
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**Figure 1:** Graphical summary of the key issues associated with the proposed KARS project and their level of significance.

**Legend:**
- Area 1 = Usakos to dam site; Area 2 = dam site; Area 3 = dam site to mine frontage; Area 4 = mine frontage to confluence with Swakop River; Area 5 = Swakop River upstream of confluence; Area 6 = Swakop-Khan confluence to Goanikontes; Area 7 = Goanikontes to coastline; Area 8 = coastline.
- **Colours:** Blank = No effect or no discernible impact; Yellow = Minor negative impact; Red = Moderate negative impact; Green = Minor positive impact; Blue = Moderate positive impact; "?" = Uncertain of impact, probably low. Numerals in blocks indicate level of certainty, e.g. "80" = 80% certain that effect will occur.
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1. INTRODUCTION AND BACKGROUND INFORMATION

Namibia is a dry country with low rainfall and high evaporation rates. Rainfalls are erratic, unevenly distributed and often localized in extent; average annual rainfall varies from less than 25 mm/year over the coastal Namib Desert to around 700 mm/year in the north-eastern Caprivi Region (Figure 1.1). Potential A-pan evaporation rates can exceed 3,800 mm/year and drop below 3,000 mm/year in the coastal zone (Crerar & Church, 1988). This excess of evaporation over rainfall leads to a marked water deficit in all months of the year and droughts are a common occurrence throughout the country (Heyns, 1992; Bethune, 1996).

![Map of Namibia](image)

**Figure 1.1:** The annual rainfall over the north-western part of Namibia.
Surface runoff is both erratic and sporadic, following seasonal rainfalls. The rivers in the interior of Namibia are episodic or ephemeral rivers that flow only after good rains in their catchment areas (Jacobson et al., 1995; Bethune, 1996) (Figure 1.2). Most of these rivers are west flowing, such as the Kuiseb, Swakop and Omaruru Rivers and serve as life-giving linear oases in the otherwise dry Namib desert. Namibia is characterized by an almost complete lack of perennial rivers or other perennial surface water resources, except for the Orange River along its border in the south and the Kunene, Okavango, Kwando, Linyanti/Chobe and Zambezi rivers on its northern borders (Heyns, 1992; Bethune, 1996).

Figure 1.2: The central part of the perennial river systems all directed towards the West Coast.
The surface waters supplying the central area of Namibia are dependent on local rainfall and runoff which is erratic. Over the past ten years, runoff volumes have been well below average and have been particularly poor in the 1994-1995 (Heyns, 1995) and 1995-1996 rainy seasons. This has coincided with a time when water consumption in the region is approaching the theoretical limits of the capacity of the developed resources (Heyns, 1992; JVC, 1993a; Bethune, 1996). In consequence, the central area of Namibia has experienced severe water shortages during 1996. Substantial widespread rains were recorded during the current summer period over large parts of the country. The four ephemeral rivers on which the main coastal towns and surrounding communities rely for their water supply, namely the Omaruru, the Swakop/Khan and the Kuiseb Rivers, were all in flood this year. The Swakop River also flowed into the sea.

As overall rainfall volumes decrease towards the west, the variability in the size of each occurrence increases. The rainfall distribution in the Swakop River catchment, which reflects the decrease from east to west is a good example (Figure 1.3). Because of this variability the mean annual rainfall is not a good indicator of the rainfall that can be expected every year which in turn makes long term planning more difficult. In addition, the dearth of reliable long term rainfall records, limits understanding the variable climate in arid and semi-arid regions. A good rainfall measuring network in western Namibia, coupled with flow gauging stations along the rivers, would not only contribute to the better understanding of the hydrology of ephemeral river systems but is essential to the calculation of recharge volumes in the alluvial aquifers associated with most of these rivers.

![Rainfall distribution in the Swakop River catchment](image)

**Figure 1.3:** The variation in rainfall over the Swakop River catchment
Extensive alluvial aquifers are associated with all these rivers; of particular importance are the alluvial aquifers of the Kuiseb and the Omaruru Rivers. These contain large volumes of potable water which are the source of almost the entire current demand of the coastal towns of the Central Namib and the mining industry. Extensive alluvial aquifers are also associated with the Kahn and Swakop Rivers but the quality of the ground water stored, especially the lower reaches of these aquifers, renders them mostly unsuitable for human consumption.

1.1 Water supply issues in the Central Namib Area of Namibia

In 1995, the Department of Water Affairs of Namibia in 1995 commissioned a consortium of companies consisting of overseas and local expertise (GKW Consult, Bicon Namibia and Parkman Namibia), to establish the demand for and identify the most feasible source of fresh water to supply the inhabitants of the Central West Coast region with fresh water until the year 2020 (KfW, 1996). The largest water consumers in the region are the towns of Walvis Bay and Swakopmund with estimated populations of 34,000 and 21,600 respectively in 1995 (DANCED, 1996; KfW, 1996), and the Rössing Uranium Mine. Two additional water consumers are Henties Bay and Arandis, with estimated 1995 populations of 3,200 and 4,400 respectively. The present total population for the area, estimated to be at 65,000, is expected to increase to 163,000 by the year 2020 (KfW, 1996).

The fresh water resources of the region presently being exploited are limited to two large alluvial ground water systems; the Kuiseb aquifer south of Walvis Bay and the Omaruru aquifer in the delta of the Omaruru River at Henties Bay. The water from these two aquifer systems is distributed by pipeline to the major consumers, Walvis Bay, Swakopmund, Rössing Mine, Henties Bay, Arandis and the farming community in the lower reaches of the Swakop River (Figure 1.4). Both these aquifers show signs of over-exploitation. The combined sustainable yield of these two aquifers has been determined during extensive investigations by DWA over many years to be 11.4 Mm³/year (KfW, 1996). By 1994, water consumption had reached 10.5 Mm³/year and is expected to increase to 18.2 Mm³/year by 2020. During 1994/95 the domestic water consumption for Walvis Bay was 1.85 Mm³, for Swakopmund 1.10 Mm³ and for Arandis 0.21 Mm³ (KfW, 1996). During the same period the Rössing domestic water consumption was 2.5 Mm³/year. The total forecasted demand from the two alluvial ground water sources, the Kuiseb and the Omaruru Delta, amounts to 10 Mm³/year. At current rates of growth in demand for fresh water, the calculated sustainable yield of these two aquifers will match the demand by the year 1999.

Other sources of ground water currently being exploited include the lower Swakop River and the Khan River at Rössing. Farmers along the Swakop River, downstream of the confluence with the Khan River, abstract approximately 529,000 m³/year brackish water from the alluvial Swakop River aquifer for farming purposes. To supplement their fresh water supply from the CNSWS, Rössing presently abstracts about 250,000 m³/year from the alluvial aquifer opposite the mine in the Khan River (Figure 1.4).
During the past decade the calculated safe yield of the Omdel aquifer of 4.5 Mm³ has been exceeded: by 1991 ground water abstraction was 6 Mm³. The forecast demand for 1997 is 10 Mm³ (Tordiffe, 1996). Surface water recharge to the aquifer is sporadic. Until recently, the last major flood to benefit the Omdel aquifer significantly occurred in 1985 when the aquifer was recharged with approximately 11.5 Mm³. Infiltration tests indicated that the aquifer could be recharged by a maximum of 8 Mm³/year. Average annual natural seepage from the aquifer to the Atlantic ocean is estimated to be 14 Mm³ (Tordiffe, 1996), whilst recharge by throughflow from the upstream alluvial layers, is estimated at 3.5 Mm³ (Nawrowski, 1990).

As part of a strategy to increase the ground water reserves along the West Coast, the Department of Water Affairs completed a 40 Mm³ dam in the Omaruru River in 1994. The dam is some 4.5 kilometres upstream of the Omaruru Delta (Omdel) aquifer (Tordiffe, 1996) (Figure 1.4). The purpose of the dam is to allow the silt in the retained flood water to settle, and then divert the clear water to a suitable downstream infiltration system. Due to the high evaporation rate, it is not considered viable to retain the water in the dam. In 1997 the first floods were captured by the dam. No detailed information about the impact of the recent floods on the recharge to the aquifer is yet available. Nonetheless, the DWA expects the Omdel scheme to enhance the currently available fresh water supplies of the CNSWS by approximately 4 Mm³/year.

Three well fields, Swartbank, Rooibank and Dorop, are operated in the Kuiseb aquifer (Figure 1.4). These have been over-exploited in recent years and the effect on the riparian vegetation is clearly visible. Based on additional information collected over many years, the safe yield of the Kuiseb aquifer was reduced to 3 Mm³/year in 1990, compared to the 30 Mm³/year determined in 1960 (Jacobson et al., 1995).

As mentioned previously, projections are that the overall fresh water demand of the region will rise steadily to exceed the sustainable long term yield of the ground water aquifers within about 5 years. Several alternative water source options for the West Coast have been therefore been investigated by KfW (1996) and DWA (1997). These include iceberg harvesting, solar distillation and the utilization of coastal fog, importing water by tanker from the Zaire River, reclamation of treated wastewater, construction of additional; surface water and ground water recharge dams, and salt water desalination. The study concluded and recommended that desalination of saltwater be considered as the most feasible future water source and it is estimated that the desalination plant should be operational by 2000.

1.2 History of and motivation for the KARS Project

In all metallurgical plants processing ore from mines, water has to be used in large quantities. In addition, the mining operation itself also requires substantial amounts of water, for example in dust suppression and ore processing. The Department of Water Affairs was contracted in 1973 to supply up to 22,000 m³ of water to Rössing a day, inclusive of 2,000 m³/day for the town of Arandis. In the early stages of development of the mine consumption was much greater; in-plant water consumption amounted to
some 0.95 m³ per tonne of ore milled. However, Rössing has focused considerable attention on the whole issue of water consumption and current total water consumption at the mine amounts to 2.8 m³/year. This translates to 0.298 m³/tonne of ore milled which is extremely low by world standards. The historical pattern of annual water consumption at Rössing and in the Central Namib is shown in Figures 1.5a and 1.5b. Whereas the water consumption of the two larger towns, Swakopmund and Walvis Bay, has not changed substantially over the last 15 years (Figure 1.5a), that of Rössing has been reduced drastically. The mine is longer the major consumer of fresh water from the Kuiseb and Omaruru ground water schemes (Figure 1.5b).

![Graph showing water use (million cubic metres) from 1980 to 1995 for Rössing, Swakopmund, and Walvis Bay.](image)

**Figure 1.5a:** Water consumption of Walvis Bay, Swakopmund and Rössing since 1977

The present total water demand of Rössing Mine is about 3 million m³/year which is expected to increase to approximately 4.5 million m³/year during 1998. Of the current total water consumption, about 250,000 m³/year is obtained from the alluvial aquifer in the Khan River.

Rössing started using brackish ground water from the alluvial aquifer in the Khan River in 1973 to supplement the fresh water obtained from the Central Namib State Water Scheme (CNSWS). Over the years the relative contribution of Khan River ground water to the mine’s total needs has increased and is currently about 8% of the total water consumption.

The first production boreholes in the Khan River were drilled in 1973. Some of these were washed away in the 1985 floods and were re-established in 1986. Presently there are seven production boreholes in operation, spread over approximately 10 kilometres.
of riverbed from just upstream of Dome Gorge down to Panner Gorge. Peak total abstraction from these boreholes was close to 1 Mm³/year during 1988-1990, but had to be reduced in 1991 due to the decline in the water table. The extension of the well field into the river compartment upstream of Dome Gorge in 1993 again resulted in an increase in abstraction.

![Water usage chart](image)

**Figure 1.5b:** Water consumption of Rössing since 1977

Abstraction of brackish water from the Khan River is regulated by permits issued from time to time by the Department of Water Affairs. The current permit makes provision for the maximum abstraction of 870,000 m³/year. In addition, a maximum drawdown of the water level was provisionally set not to exceed 15 metres below surface, with the requirement that vegetation monitoring must be carried out on a regular basis. The DWA must also be informed if the water level drops below 10 metres or if the vegetation is affected by the abstraction. Due to low rainfall over the past decade, the DWA recommended in 1995 that the maximum abstraction rate be reduced to 600,000 m³/year. In recent years Rössing was obliged to reduce total abstraction from the Khan aquifer to approximately 250,000 m³/year to comply with the permit requirements.

Two alternative schemes to enhance ground water supply to the mine have been investigated. One option is to extend the well field further upstream and the other was to construct a dam in the Khan River and use the trapped water for artificial recharge of the aquifer. The wellfield option was calculated to produce up to 1.75 Mm³ over a two year period with water levels being maintained at not less than 10 metres below surface. The 10 metre level was predicted to be exceeded within two years after pumping starts if no recharge occurred to the aquifer.
The second option was to construct a dam in the Khan River to temporarily capture small to medium floods and, once the flood water had deposited the silt load in the dam, decant the clear water into the downstream alluvial aquifer. The concept is similar to that of the OMDEL aquifer recharge scheme established recently in the Omaruru River by the DWA to artificially recharge the Omaruru Delta Aquifer.

Rössing Uranium Limited therefore proposes to construct an aquifer recharge scheme in the Khan River. The scheme would be upstream of current mining activities and would be designed to replenish the aquifer opposite the mine frontage. It is anticipated that through this scheme Rössing will be able to increase their supply from the Khan River without compromising the existing DWA permit requirements in terms of water levels and impacts on vegetation.

Despite the likelihood of a desalination plant being built to enhance supplies to the coastal region, Rössing believes that other options to protect the limited potable water resources of the area need to be investigated.

The KARS project is one of these options proposed by Rössing to reduce the mine's overall abstraction from the CNSWS. Nonetheless, Rössing will continue to be dependent on the CNSWS for substantial volumes of water for the remaining life of the mine. There are two main reasons for this: (i) the ground water resources of the Khan River alluvial aquifer will not be able to supply in the total demand of Rössing, and (ii) the quality of the Khan River ground water is not of an acceptable quality and needs to be mixed with a large proportion of potable water.

Rössing has therefore advised that, in addition to the KARS project, the company fully supports the desalination concept for supplying the West Coast consumers with potable water and is actively cooperating with and assisting the authorities in this regard.

1.3 The proposed Khan Aquifer Recharge Scheme (KARS)

The concept of a dam in the Khan River to enhance ground water recharge, was first investigated in 1991 when a feasibility study was initiated for two identified dam sites in the Khan River along the mine frontage. Although the outcome of this investigation was positive, the project was not continued beyond the technical design phase.

However, drought conditions in the catchment of the Swakop and the Khan Rivers, with the resultant reduction of the water levels in the Khan River during the mid 1990’s, prompted a reexamine the feasibility of an artificial recharge scheme. Gordon McPhail and Associates were commissioned in 1995 to carry out preliminary modelling to assess the financial risks associated with the implementation of a scheme involving the construction of one large dam, or a number of smaller dams, on the Khan River in the vicinity of the mine. The proposal was to capture flood waters and to use these waters to artificially recharge the alluvial aquifers. The results were promising and indicated that a single large dam was favoured as it would have a more beneficial cost/storage capacity relationship than a series of smaller dams with the same overall capacity.
The proposed site for the dam is approximately 10 kilometres upstream of the present mining activities. The total holding capacity of the dam would be approximately 9 Mm$^3$ resulting in a dam wall height of about 25 metres. A main spillway on the north-western bank as well as an emergency spillway on the south-eastern bank is proposed. The primary objective of the KARS project is to capture part of the occasional surface run-off in the Khan River. Once the silt has settled out, the water will be channelled into the downstream alluvial aquifer through controlled infiltration in the river bed at a rate which ensures maximum infiltration into the aquifer. It is envisaged that this scheme will allow increased extraction of brackish water from the aquifer on a controlled and sustainable basis over the long periods between floods, thereby relieving the pressure on the already stressed fresh water resources of the West Coast area. The concept of the recharge scheme is schematically depicted in Figure 1.6. Once the water is infiltrated into the aquifer, it is protected from further evaporation and will slowly move downstream towards the existing production well fields where controlled extraction can occur. The water will be piped from the wellfield via a short (< 2 kilometre) pipeline to the mine for use in their production circuits as well as for dust suppression. The current ground water baseflow would be maintained for the benefit of the downstream users.

![Diagram](image)

**Figure 1.6:** Schematic diagram illustrating the KARS dam and infiltration concept

### 1.4 Anticipated scale of the KARS Project

It is anticipated that the average annual volume of water abstracted from the Khan River would not exceed 0.99 million cubic metres (0.99 Mm$^3$/year is equivalent to a continuous flow rate of approximately 0.03 m$^3$/sec). However, in this study, the conservative upper limit figure of 1.28 Mm$^3$/year has been used as the basis for calculating the magnitude and importance of potential impacts on components of the downstream ecosystems and communities. This figure also allows for higher than average abstraction during the year.
This study is specific to the current project proposal. Should the scope of the project be increased, further studies would be needed to cover a much wider catchment area.

1.5 Structure of the report

This report provides details of an Environmental Impact Assessment (EIA) of the Khan Aquifer Recharge Scheme (KARS) Project in Namibia proposed by Rössing Uranium Limited, and is based on information which has been synthesized from a wide variety of published sources as well as specific investigations conducted during the project.

The main report consists of seven chapters arranged according to the descriptions below. Chapter 1 contains a brief introduction providing the background to and motivation for the project in the context of the water supply situation along the West Coast, and a short description of the project. A description of the scope of the impact assessments is given in Chapter 2, followed by a description of the methods used to assess and evaluate the magnitude and importance of the impacts associated with the proposed project and identified by Interested and Affected Parties (Chapter 3).

A description of the regional setting and environment in which the proposed scheme is to be constructed and operated follows in Chapter 4, providing background information on items such as Khan and Swakop River catchment characteristics, data availability, geohydrology, ecological characteristics and general land use. The hydrology of the river systems and the geohydrology of the associated alluvial aquifers, is of primary importance to a project of this nature, and extensive coverage of the hydrological simulations and their effects on the water systems is given in Chapter 5 of the report. Against the baseline described in Chapter 5, the report describes the main findings of the work carried out, and lists the Key Issues and Concerns that have been identified during the project. This is followed by an assessment of the potential magnitude and importance of the possible and identified impacts within the area between the proposed aquifer recharge site and the mouth of the Swakop River at Swakopmund (Chapter 6). In addition, this information is placed in context by appropriate references to the remainder of the Khan and Swakop River catchment. Finally a summary of the impacts, recommendations and monitoring requirements is provided in Chapter 7.

An Executive Summary is provided at the beginning of the report giving a brief overview and summary of the main findings of the studies. The Executive Summary also contains a matrix which provides a graphical summary of the Key Issues, as well the level of significance of the impacts which may be expected to occur if the proposed aquifer recharge scheme proceeds.
2. THE ENVIRONMENTAL ASSESSMENT

The Namibian Department of Water Affairs has contributed to the Environmental Impact Assessment process for the Khan Aquifer Recharge Scheme (KARS) project by making available invaluable information collected through monitoring programmes over decades and by providing the results of several studies of the Khan and Swakop River systems. This information contributed to comprehensive technical, economic and environmental studies covering both the site of the proposed aquifer recharge scheme, and downstream areas which could potentially be affected by the project proposal. The environmental studies focus on assessments of the potential direct and indirect impacts of the proposed project.

In addition, an independent review will be conducted of the study findings to evaluate the impact assessment process, as well as the extent and magnitude of anticipated impacts. This external review is designed to ensure that the all aspects of the Environmental Impact Assessment have been conducted thoroughly and professionally, and that the study findings can stand up to international review, if required.

2.1 The legislative and policy context

Given that the entire area of interest to the KARS Project falls within Namibian borders, no considerations of international legal and policy frameworks are applicable to the project. Instead, the KARS Project must be evaluated within the context of appropriate policies and statutory regulations which prevail in Namibia.

2.1.1 The context of national policies and legislation

In the context of national policy and legislation, Namibia has instituted and accepted laws which govern the ownership and use of water and land. In Namibia, the National Constitution considers all water to be a common, national good which is owned by the state and whose use is administered by the state (Heyns, 1991).

The control, conservation and use of water in Namibia is regulated by the Water Act No. 54 of 1956 (including amendments up to 1979) and the Water Amendment Act No. 22 of 1985 (Water Act, 1956, 1985). These two Acts were originally promulgated in South Africa and were applied during the period prior to, and shortly after, Namibia's transition to independence. A new Water Act for Namibia is still in the process of being drafted (Heyns, 1995). In the original (South African) Water Act, (which still holds in Namibia, until the new Act is passed by Parliament), ground water can be owned by individuals and this ownership is linked to the ownership of land.

Riparian land owners also have a right to use surface water that flows across their land or which lies adjacent to their land. However, the building of a dam of the size envisaged for the KARS Project, requires the approval of the Department of Water Affairs, which will also analyze the technical details and feasibility of the total project.
The Namibian Department of Water Affairs, part of the Ministry of Agriculture, Water and Rural Development, is charged with the responsibility of acting as custodian for the country's water resources (Heyns, 1991). The line function activities of several other Ministries (e.g. Ministry of Lands, Resettlement and Rehabilitation, Ministry of Environment and Tourism, Ministry of Works, etc.) can have major impacts upon the country's water resources and these activities need to be co-ordinated through the Department of Water Affairs (JVC, 1993b). This is in line with the concern for environmental issues, and the prevention of natural resource degradation, as expressed in the Constitution of the Republic of Namibia (Republic of Namibia, 1989).

Until 1995, there was no overall development plan or co-ordinating body which was responsible for co-ordinating development within Namibia. This situation precluded the possibility for co-ordinating the planning and development of water projects with those of other natural resources. As a consequence, many development projects were launched (and some have already been completed) by various Ministries, often without due regard for the consequences upon the natural resources under the jurisdiction of other Government bodies.

This situation has, to a large extent, been resolved with the publication of Namibia's First National Development Plan (NDP1) which covers the period up to the year 2000 (National Planning Commission, 1995). A National Water Master Plan for Namibia is expected to be produced during the next four years (National Planning Commission, 1995).

2.1.2 The context of this Project

The environmental management and conservation policies in Namibia (Brown, 1992; Republic of Namibia, 1995) require that all development projects should incorporate an Environmental Impact Assessment (EIA). This process is designed to ensure that all environmental issues (i.e. ecological plus social issues) are examined carefully to ensure that potentially adverse effects (costs) are minimized or mitigated whilst positive effects (benefits) are maximized. In addition, this process seeks to ensure that no development project will be allowed to proceed where unacceptable adverse impacts are likely to occur.

Related to this aspect, it was accepted at the Public meetings that the Draft Environmental Evaluation Report for the KARS Project will be evaluated by at least one reputable and independent external evaluator appointed in consultation with the public to ensure that the process which has been followed and the technical findings which arise are acceptable in terms of current Namibian environmental policies.

2.2 Purpose and scope of the environmental assessment

The purpose of the environmental assessment is to assess the potential positive and negative impacts on the Khan and Swakop River systems and its people, which may
arise as a result of the proposed KARS Project. The scope of the downstream environmental assessment includes all those direct and indirect impacts which could arise downstream of the KARS dam as a result of which, or which may be associated with, construction and operation activities forming part of the proposed project. The original scope of work for this Study was revised to incorporate the concerns and issues raised by members of the public who attended the public meetings that were held in Swakopmund and Arandis and through written and verbal submissions (BGIM, 1997).

2.2.1 Scope of the study

In consultation with Interested and Affected Parties (I&APs) through interviews, Public Meetings at Swakopmund and Arandis, Key Issues to be dealt with in the EIA report were identified. These are listed in the preliminary and the final Issues Report compiled by BGIM (1996, 1997). According to these reports the issues and environmental impacts that must be addressed in the EIA of the KARS Project have been grouped under four main headings. These categories, and the primary items of concern, as listed in the BGIM reports, are the following:

- **Project motivation**
  - A need and desirability statement for the project;

- **Technical issues**
  - The impact on the water management systems upstream of the proposed Khan dam;
  - The design and engineering features of the dam and associated aquifer recharge mechanism;

- **Ecological issues**
  - The impact on fauna and flora above and below the dam wall;
  - The impact on ecology during construction of the dam;
  - The potential for sand dunes to migrate across the Swakop River;
  - Potential changes (especially erosion) to the beach front in Swakopmund;

- **Socio-economic issues**
  - The impact on the quality and quantity of ground and surface water available for downstream water users;
  - Sand mining activities near Swakopmund;
  - Impact on the economic viability of the sea water desalination project for improved fresh water supplies to the region;
  - The financial viability of the project; and
  - Impact on the public leisure activities in the Khan River bed in the vicinity of the reservoir.

This EIA report will also propose any measures that may be required to mitigate negative impacts and maximize positive benefits associated with the project, and will also make recommendations as to the most appropriate monitoring programmes which
can be used to evaluate any predicted impacts and assess the success or failure of management options, together with recommendations for future research.

2.2.2 Study structure

To meet the formal objectives of the Study, the work programme consisted of different stages, listed below:

- a public consultation and scoping phase, designed to elicit the concerns of interested and affected parties in Swakopmund, Arandis and Usakos and the surrounding areas;
- collection of relevant technical information to address the concerns raised during the public meetings;
- various field surveys and special sampling surveys to address specific concerns identified during the scoping and public meeting phases;
- an evaluation of all aspects of the geohydrology of the Khan and Swakop Rivers relevant to the KARS project;
- modelling the hydrology and geohydrology of the Swakop and Khan Rivers with and without the KARS dam in place;
- geotechnical investigations at the dam site;
- the engineering design of the dam structure, spillways and ground water recharge scheme;
- assessment of impacts; and
- compilation of a Draft EIA report (this document).

2.2.3 Study area

The study area for the environmental impact assessment is located in the lower portion of the Khan and Swakop River catchment. It includes the proposed dam site in the Khan River, some 10 kilometres upstream of the existing mining activities of Rössing Mine, the Khan River Gorge down to the confluence with the Swakop River and finally the lower Swakop River up to where the Swakop River flows into the Atlantic Ocean.

The extent of the study area can be seen in Figures 2.1 and 2.2 which illustrate the larger catchment of the Swakop and Khan Rivers, and an enlarged area indicating the dam site and its relation to the Khan and lower Swakop rivers and the mining area respectively.

2.2.4 Study team

The Study team consisted of specialists selected from with a wide variety of technical disciplines. The environmental team has worked closely with the engineering consultants to ensure that all environmental issues were investigated in relation to the scope and scale of the engineering plans, and to ensure that any engineering plans which may be developed took account of key environmental considerations.
The members of the Environmental team were:
Dr Peter Ashton, Water Resources Specialist and Project Leader, CSIR;
Mr Reinie Meyer, Geohydrologist, CSIR;
Ms Linda Godfrey, Geohydrochemist, CSIR;
Dr John Vogel, Isotope Physicist, CSIR;
Dr Stefan Woodbourne, Isotope Physicist, CSIR;
Mr Siep Talma, Stable Isotope Physicist, CSIR;
Dr Peter Wade, Isotope Chemist, CSIR.

Others who assisted in field surveys and data collection, or were contacted for their expert knowledge of selected aspects relating to the project, included:

Mr Piet Marais, Geohydrologist, Swakopmund (ex Rössing);
Mr Piet Hamman, Hydrologist (ex DWA);
Dr John Ward, Chief Geologist, NAMDEB;
Mr Koos Schones, Coastal Engineer, CSIR;
Various staff members of the Department of Water Affairs in Windhoek;
Mr Rainer Schneeweiss (Environmental Geologist) and Ms Sandra Kehrberg (Geohydrologist) of Rössing Uranium Limited.

The engineering consultants from the firm Metago Environmental Engineers responsible for the technical design of the dam and related infrastructure, and the modelling of the effect of the KARS dam on the hydrology of the river systems were Dr Gordon McPhail and Mr Alistair James.

2.2.5 Study period

A preliminary scan to identify the main issues related to the KARS project began in November 1996 in Windhoek and Swakopmund, Namibia. As Rössing Management considered the project to be urgent in view of their assessment of the water requirements for the mine and that the drought cycle was about to be broken, BGIM prepared a preliminary list of issues so that specialist studies could start as soon as possible if required. At this time a suitable site for the proposed dam had already been identified and the engineering consultants had been busy with a number of engineering issues relevant to the project. The preliminary scoping was followed by public meetings in Arandis and Swakopmund on 30 and 31 January 1997, respectively, followed by a site visit the following day. The outcome of the personal interviews, public meetings and comments received, is compiled in an Issues Report by Brian Gibson Issue Management (BGIM, 1997) which was submitted to the CSIR in February 1997.

Throughout the project extensive coverage of the project was given in the media. A briefing paper in English, Afrikaans and German, describing the main features of the KARS project, was distributed to all I&APs and employees of Rössing. Advertisements for the public meetings were placed in the major Namibian newspapers and newsletters were distributed to I&APs throughout the project to keep them informed about progress on the project. The findings of the study, as compiled in the Draft EIA report, will be
presented to I&APs at a series of public meetings during the period 27 to 29 May 1997. Copies of the Draft EIA report will be distributed at selected places in the main towns of the region to invite the public to comment on the contents. Comments on the report have to be submitted by the end of June 1997 for incorporation in the final report.

2.3 The role and scope of the EIA report

The main purpose of this Draft EIA Report is to identify, on the basis of available information and the collection of new data in the field, those potential key issues and possible fatal flaws which could prevent the proposed KARS Project from proceeding. In this context, the term "fatal flaw" is used to describe an impact or set of circumstances which would be so adverse as to require the project to be abandoned or re-formulated. In addition, the EIA Report must be able to identify potential environmental impacts which may have a financial or engineering implication and should thus be taken into consideration in the design of the KARS Project.

The EIA Report also includes recommendations for mitigatory actions which can be identified at an early stage, as well as recommendations for the monitoring of those activities or environmental components where the information will be required to provide guidance to management.

The EIA studies have been completed under severe time constraints. They have been carried out in parallel with the engineering feasibility studies in order to provide the engineering team with information which may be relevant to the design phase of the KARS Project. It is anticipated that the next phase of the KARS Project, that of the final engineering design, will proceed once agreement has been reached that the environmental issues have been dealt with satisfactorily.
3. METHODS USED TO ASSESS AND EVALUATE THE MAGNITUDE AND IMPORTANCE OF IMPACTS

3.1 General introduction

In common with any development project, the construction and operation of an aquifer recharge scheme can have a wide variety of different impacts which may occur over different time and spatial scales. Certain impacts will occur immediately, whilst others will take place gradually; the extent of these impacts can also range from scarcely perceptible to highly intrusive. Similarly, the nature of the impact can also vary widely depending on the type of physical environment, the size or scale of the development and the perceptions and values of each of the affected parties.

Ideally, an assessment of the extent of any disruption of the natural and social environment that can be attributed to a particular operation or project, should follow a logical sequence of procedures:

- Define acceptable standards and criteria for quantifying the extent and importance of an impact in a comparable manner;
- Identify and express the nature and extent of each impact with reference to this rational and consistent system of measurement;
- Compare the measured (or predicted) impact with the relevant standards;
- Propose and implement remedial measures, if necessary, to reduce the impact to conform with the accepted standards, or to enhance positive benefits; and
- Design and implement an appropriate monitoring programme to ensure compliance with agreed standards, or to validate predicted trends.

However, it is often difficult to carry out this idealized sequence of procedures. Typical difficulties that are encountered include:

- **The lack of accepted techniques with which to quantify the extent of an impact.** This is particularly evident when loss of amenity occurs, such assessments are frequently both qualitative and subjective. The most suitable approach is usually to involve all affected and interested parties in the process of impact assessment and to employ suitable group decision-making techniques to reach consensus among all the parties concerned.

- **The absence of well-defined and generally accepted criteria for particular types of environmental problems.** Visual or aesthetic impacts, for example, are inevitably concerned with subjective criteria which, by their very nature, are dependent on the judgement of individuals. In a typical example, there is very little agreement between people as to the degree or acceptability of the visual impact of a particular project. Other cases, such as the quality of potable water, are well suited to measurement and yet, because there exists an enormous range of differing national and international standards and criteria, agreement on acceptability is often difficult.
The absence of widely accepted and consistently applied techniques capable of reducing a particular problem to generally acceptable levels of complexity. In the case of a new mine, for instance, a choice has to be made between accepting the situation in favour of the expense of depriving society of high value raw materials or an important source of National income.

The majority, although not necessarily all, of the environmental problems associated with development projects tend to diminish with increasing distance from the construction site. Consequently, the most easily noticeable environmental problems are usually identified adjacent to the site of operations. Whilst the parties most likely to be affected will be those in close proximity to a particular construction activity, the full environmental impact of such an operation will often extend far wider.

However, in the context of water resources projects on river systems, the impacts are almost always transferred, transformed and propagated downstream. Thus, any evaluation of the potential environmental impacts likely to be caused by the construction and operation of the proposed KARS project in the Khan River must include both localized impacts and those dispersed impacts which may occur further downstream in the Khan and lower Swakop rivers.

It is also important to remember that the potential to transfer impacts often has a cumulative effect. The greater the potential of a project to transfer impacts away from the original site, the more important it is for the assessor to recognize and take account of the cumulative effects. In several cases, these indirect or dispersed impacts may also have ramifications on political and legal issues.

3.2 Definitions used in the assessment and evaluation of impacts

The assessment and evaluation of environmental impacts is often complicated by the subjective nature of these impacts. Ideally, the degree of severity or significance of a particular impact should be expressed in quantitative terms while the conditions that pertained before the particular activity started should be quantified. In addition there must also be some expression as to whether a particular impact is desirable or not. Clearly, the assessment of an impact will depend largely on the attitude and experience of the assessor or assessment team; there is always an unavoidable component of subjectivity in the analysis.

In order to address these issues and to provide a basis for comparison of the different impacts associated with the proposed aquifer recharge scheme, a number of standard definitions and approaches were used by the project team. These different terms are described in Table 3.1.
<table>
<thead>
<tr>
<th>Category</th>
<th>Description or Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>A brief written statement, stating which environmental aspect is impacted by a particular project activity or consequence of project activities.</td>
</tr>
<tr>
<td><strong>Sign</strong></td>
<td>Denotes the perceived effect of the impact on the affected area.</td>
</tr>
<tr>
<td>- Positive (+)</td>
<td>Beneficial impact.</td>
</tr>
<tr>
<td>- Negative (-)</td>
<td>Deleterious impact.</td>
</tr>
<tr>
<td><strong>Scale</strong></td>
<td>The area over which the impact will be expressed. Typically, the severity and significance differ at different scales and a bracketing range is needed. For example, high at the local scale, but low at the regional scale.</td>
</tr>
<tr>
<td>- Site</td>
<td>A dam basin; realigned road; environs of a dam wall, water purification plant.</td>
</tr>
<tr>
<td>- Local</td>
<td>The home range of resident organisms that will be impacted (i.e. within about a 2 kilometre radius of the project site).</td>
</tr>
<tr>
<td>- Regional</td>
<td>The bio-climatic / vegetation / agro-economic region of the area.</td>
</tr>
<tr>
<td>- National</td>
<td>Namibia.</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>The term or time period during which the impact is expressed, not the time until the impact is expressed. Where necessary, the latter is separately specified.</td>
</tr>
<tr>
<td>- Short-term</td>
<td>0 - 1 years (construction phase only).</td>
</tr>
<tr>
<td>- Medium-term</td>
<td>1 - 5 years (early operations phase).</td>
</tr>
<tr>
<td>- Long-term</td>
<td>5 - 20 years (late operations phase).</td>
</tr>
<tr>
<td>- Very long-term</td>
<td>&gt; 20 years (post-decommissioning or closure phase).</td>
</tr>
<tr>
<td><strong>Severity</strong></td>
<td>The intensity of the impact:</td>
</tr>
<tr>
<td>- Very high</td>
<td>Complete disruption of process, death or loss of all affected organisms.</td>
</tr>
<tr>
<td>- High</td>
<td>Substantial process disruption, death or loss of many affected organisms.</td>
</tr>
<tr>
<td>- Moderate</td>
<td>Real, measurable impact, which does not alter process or demography.</td>
</tr>
<tr>
<td>- Low</td>
<td>Small change, often only just measurable.</td>
</tr>
<tr>
<td>- No effect</td>
<td>No measurable or observable effect.</td>
</tr>
<tr>
<td>- Unknown</td>
<td>Insufficient information available with which to make a judgement.</td>
</tr>
<tr>
<td><strong>Certainty</strong></td>
<td>A measure of how sure we are that the impacts will occur or that the proposed mitigatory actions will be effective.</td>
</tr>
<tr>
<td>- Definite</td>
<td>&gt; 90 %</td>
</tr>
<tr>
<td>- Probable</td>
<td>70 - 90 %</td>
</tr>
<tr>
<td>- Possible</td>
<td>30 - 70 %</td>
</tr>
<tr>
<td>- Unsure</td>
<td>&lt; 30 %</td>
</tr>
<tr>
<td><strong>Significance</strong></td>
<td>This is an integration (i.e. an opinion) of the severity, type, scale and duration of the impact. It is the best professional judgement of whether the impact is important or not within the broad context, once mitigation is taken into account.</td>
</tr>
<tr>
<td>- High</td>
<td>Probably a fatal flaw; could (or should) block the project.</td>
</tr>
<tr>
<td>- Medium</td>
<td>Requires detailed study and often substantial mitigatory actions.</td>
</tr>
<tr>
<td>- Low</td>
<td>Real, but not sufficient to alter the project or require detailed study.</td>
</tr>
<tr>
<td>- Zero</td>
<td>No noticeable or measurable effects, or very minor effects with no significance.</td>
</tr>
</tbody>
</table>
3.3 The scale and importance of impacts

Any assessment of the impact of a particular activity must take into account the type of activity, the location or site in which the activity takes place and its extent (in comparison to the area, habitat or community affected). It is important to remember that a single activity can often have both strongly positive and strongly negative effects on different components of the system.

An excellent example of this situation is provided by the construction of a roadway, where the scale of the impact is expressed in terms of the degree of change to the existing environment. In the case of the road construction example, the road will have a negative impact on local vegetation, though the extent of this impact would be in proportion to the size of the road and its associated fringe areas and borrow pits. In contrast, the same road could have a strongly positive impact on regional communications and infrastructure that is quite out of proportion to its size.

In this study, impacts are classified as being of minor, moderate or major significance. The different definitions are given in Table 3.1 whilst qualitative descriptions of each of these categories are listed below.

- **Minor significance** implies that the impact or impacts will be of short duration and restricted to the area of the construction site. The effects will not be serious, particularly if mitigatory management actions are carried out.

- **Moderate significance** indicates that the impacts will have, or are very likely to have, a greater effect. These effects will be experienced over both the short-term and long-term time scales and will probably extend beyond the construction site. The importance of effective mitigatory actions increases.

- **Major significance** indicates that the impacts are very important, usually both in a local and regional context, and occasionally in a national context. Very often there are negative effects on people or ecosystems beyond the construction site boundaries. Active resistance by affected parties could also be a significant factor. Mitigatory management actions are essential; the resources required to effectively implement these actions could be substantial and could be required throughout the life of the project.

3.4 Evaluation of ecosystem impacts

Impacts on ecological systems may result in an increase in species diversity, which is regarded as a benefit or positive impact. Conversely, a decrease in species diversity, would be a negative impact. However, biological responses to an altered ecosystem are usually far more complicated than a simple change in species diversity. They include the loss and gain of species or whole communities as well as changes in the abundance (or population size) of individual species.
The importance of changes in species composition or of biotic communities depends on the conservation status both of the species or community which is replaced and of the "new" species or community which becomes established. The decrease or loss of a rare or endangered species or community is considered to be an important negative impact; an increase in the abundance of a rare or endangered species or community is an important positive impact.

The importance of impacts which result in changes of population sizes depends also on the secondary effects these population changes may have on other ecosystem components. The importance of a particular change is usually evaluated in terms of mankind's perceived direct interests. Thus a change which resulted in the disappearance of a noxious weed is regarded as an important benefit, whereas an increase in the abundance of a nuisance organism (e.g. housefly) is regarded as a negative impact. Simple changes in the abundance of many species would likely be benign or of little consequence to the ecosystem. In many cases, the anticipated changes in abundance likely to be caused by a particular project may be smaller than the natural year-to-year variation in the population concerned.

In common with other desert ecosystems, the terrestrial fauna and flora of the Namib Desert system are known to be very sensitive to a variety of environmental changes, including climatic variations. The disappearance or extinction of any of these fragile communities as a direct or indirect result of a particular project activity would be considerable cause for regret; this would be regarded as a negative impact of major significance. However, if similar communities occur commonly nearby, then the impact would be considered as localized and therefore have a lower significance.

### 3.5 Evaluation of socio-economic impacts

The wide variety of sociological and economic problems which can arise from development projects can be categorized in a number of different ways. Ideally, however, the system used should be directly comparable with that used to express the severity of impacts on ecological components of the system.

Clearly, where a particular impact poses a direct or indirect hazard to the safety of people, this is considered to be severely negative. Such impacts would include emission of toxic effluent and gases, dangerously excessive noise, vibration and dust levels, loss of income or arable land and extreme visual intrusion. Strongly positive impacts would include improved health and welfare services, greater assurance of safe water supplies, creation of additional job opportunities with associated advanced training, as well as the construction of housing, hospitals, schools and recreational facilities for local communities.

Additional features of a large-scale activity include direct and indirect socio-economic impacts which are manifest most clearly in a regional and National context. Very often these impacts are not easily assessed, and include improved regional and National literacy levels, a broader taxation base and improvements to regional infrastructure.
3.6 Approach followed in this study

After the initial scoping phase of public meetings in Arandis and Swakopmund, together with field visits to the study area and the collection of material for detailed analyses, technical specialists reviewed the available information which related to the study area. This information provided the baseline for the development of a statement which summarized the present status of the lower Khan River and Swakop River system and the extent to which it had already been modified by human activities. In turn, this background formed the basis against which the scale and magnitude of the potential impacts which could arise from the KARS project could be determined. For added perspective, details of the anticipated impacts expected to arise from other water resource management projects elsewhere in the Khan and Swakop River catchments which also have an impact on the lower Swakop River provided a useful basis for comparison. This has been described in Chapter 4 of this Report.

All ecological components and existing human activities in or near the study area, and which could be affected by the proposed aquifer recharge scheme, were identified. In particular, all current agricultural, domestic and commercial practices within the study area were reviewed to assess the possibility of positive and negative impacts caused by the proposed aquifer recharge scheme. This assessment was conducted in consultation with the relevant authorities and with the local communities who could possibly be affected.

A cross-impact matrix was then used to summarize the positive benefits and negative impacts caused by each component of the proposed construction and/or operation activities on the environmental components. This matrix indicates the primary (direct) impacts on environmental components that are likely to occur as a result of project activities. These impacts can, in turn, lead to other indirect effects or secondary impacts on other environmental components. Specific details of both the primary and secondary impacts are described, and the overall impact assessment is summarized in Chapter 5 of this report.

The cross-impact matrix illustrates in colour those impacts that have been identified as either adverse or beneficial, and as either major or minor. Blank cells in the matrix indicate that no impact has been identified for the specific interaction. Blank matrix cells which contain a "?" indicate either that insufficient information is available or that more detailed studies to collect the information are still underway, or are still required. While most of the issues have been identified during the early stages of this study, they can only be addressed once construction is underway. In addition, they would also be the subject of monitoring and post-construction auditing programmes.

In summary:

- **Minor impacts** are generally small-scale, providing slight concern when adverse, in which case they are undesirable but acceptable; and
- **Moderate impacts** are generally of small- to medium-scale and are a cause for concern when they are adverse. Such impacts would normally require some form of mitigatory management action designed to minimize either (or both) the intensity and duration of the impacts.

- **Major impacts** are large-scale, providing great concern when adverse, in which case they are generally unacceptable.

Recommendations are then made as to the appropriate measures that might be necessary to ameliorate negative impacts or enhance positive benefits. While attention is paid to the proposed construction site for the KARS project in the Khan River, the greatest focus is placed on the downstream sectors of the lower Khan and Swakop Rivers.
4. REGIONAL SETTING AND DESCRIPTION OF THE ENVIRONMENT

4.1 Catchment characteristics

4.1.1 General overview

The Swakop River catchment is the largest of a number of westward-draining catchments in Namibia. It is flanked in the south by the catchment of the Kuiseb River and in the north by that of the Omaruru River. The latter two catchments are of primary importance to the water supply of the Central Namib Area, since the major towns of Walvis Bay, Swakopmund, Henties Bay and Arandis are provided with water from ground water resources recharged by these rivers. The main rivers and their tributaries are shown in Figure 1.2.

The Khan River, in which the proposed aquifer recharge scheme is to be established, is a tributary of the larger Swakop River catchment (Figure 2.1). The Swakop River catchment is the largest catchment located entirely within Namibia (30,100 km²) and has the most well-developed infrastructure. It drains an area where the precipitation ranges between 0 and 475 mm/year and the topography varies between sea level and almost 2,500 metres. Rainfall in the Swakop River catchment, as well as for most of the western catchments (Figure 1.1) decreases markedly from east to west as illustrated in Figure 1.3 (Jacobson et al., 1995).

Two large dams in the upper reaches of the Swakop River, the Swakoppoort Dam and the Von Bach Dam, supply a large percentage of Central Namibia's water. The catchment stretches from some 70 kilometres east of Okahandja and includes the capital Windhoek and the smaller towns of Okahandja, Karibib, Usakos, Otjimbingwe and Swakopmund. The Khan River catchment forms the northern sub-catchment of the Swakop River catchment from where it drains the area north of the Okahandja-Swatopmund road. The Khomas Hochland forms the south eastern part of the Swakop River catchment.

The Khan River, the largest tributary river in the Swakop catchment, joins the Swakop River some 40 kilometres from the coast. The Rössing Uranium Mine is situated to the north of the Khan River, approximately 25 kilometres upstream of the confluence with the Swakop River, and falls within the Khan River catchment.

4.1.2 Topography

The Rössing Uranium Mine is located at approximately 15°02'30" East Longitude and 22°27'50" South Latitude, and is approximately 65 kilometres by road from the town of Swakopmund on the Atlantic coast of Namibia. The mining permit covers an area of some 123 km² of which 91 % is on the north bank of the Khan River.
Broad peneplains with low relief characterise the north and northeastern part of the mining lease area, and are at an average elevation of approximately 600 metres. These peneplains are traversed by shallow south to south-west trending drainage lines and storm-wash gullies, which drain towards the Khan River and are interspersed with ridges of resistant rock and isolated inSELBelgs. The terrain rapidly becomes hilly and more rugged closer to the Khan River, and the drainage lines coalesce and deepen to form gorges. Four of these gorges, Khan Mine Gorge to the west, followed by Panner, Pinnacle and Dome Gorges to the east, drain the mine property and discharge into the Khan River. Additional gorges drain into the Khan River from both the south and the north banks before it eventually meets with the Swakop River some 20 kilometres downstream of the south-western boundary of the mine property.

The relatively hilly mine site is divided into two sections by a steep-sided north-easterly trending ridge of hills between Pinnacle and Dome Gorges, which rises to an altitude of 707 metres at Westdome Hill. The areas north and west of this ridge consist of rolling hills with an average altitude of 600 metres whilst the area to the east of the ridge is more rugged, with jagged-crested, steep-sided hills ranging in elevation from 550 to 600 metres.

The south bank of the Khan River is demarcated by a range of north-east trending, steep-sided hills. Further south, these hills give way abruptly to the almost flat gravel plains of the Welwitschia Flats. This area covers virtually the entire area between the Khan and Swakop Rivers and lies within the Namib Naukluft Park.

4.1.3 Climate

Diurnal, seasonal and long-term variations in climatic conditions interact to control the occurrence and distribution of organisms in an area. A basic understanding of local climatic features and their variability is therefore essential for any evaluation of environmental impacts.

Detailed meteorological data is collected by Rössing Uranium staff from weather stations located at three sites, namely: Arandis Airport, Point Bill (in the plant area) and the visitors lookout point at the open pit. All data is stored on the mine's environmental data base. A generalized climatogram for the Rössing Uranium Mine is shown in Figure 4.1.

4.1.3.1 Winds

Winds are a vitally important component of any desert environment, though their effects are modified by a variety of local geographical features (Goudie, 1972; Huntley, 1985). The distinguishing features of the local winds at Rössing are the strength of the near-surface circulation and the interactions between winds of the interior desert with the sea breeze regime and with regional winds. When synoptic pressure gradients are
strong, local and regional winds may be obliterated by continental circulation systems. Local effects are dominant and frequently modify the near-surface winds of the general circulation pattern. The strength of these local winds is sufficient to mobilize fine sand and mica particles from the ground surface giving rise to the dusty conditions that are so often seen in the Namib desert.

![Figure 4.1](image)

**Figure 4.1** Generalized climatogram for the Rössing Uranium Mine, showing monthly variations in rainfall, gross evaporation and minimum, mean and maximum air temperatures. (Data derived from Earth Science Services (1987) and Hydrology Division (1988)).

The predominant wind direction during summer is southerly to south-westerly, occasionally changing to north or north-west winds. During winter, wind direction is mainly south-east to north-east.

Berg winds, an important wind system at Rössing, are formed when air displaced from the inland plateau to the coast becomes heated due to a drop in altitude. Berg winds occur approximately 50 times per year, mainly during April to September, with the curious anomaly that the coastal areas often record their highest temperatures during the winter months. During Berg winds, monthly average wind velocities reach 27 km/h
with average hourly velocities of 43 km/h. Peak wind velocities can exceed 125 km/h (W. Jooste, personal communication). The strength of these winds enables them to transport great quantities of dust, sand and fine gravel; they are important in wind erosion and the development of the dust storms so characteristic of the Namib Desert.

4.1.3.2 Precipitation

In the Central Namib Desert, mean annual rainfall decreases from east to west and from north to south. Rainfall is generally low and its distribution is highly erratic; the long-term average for the entire region is less than 100 mm, and much of the area receives less than 50 mm per year. In addition, the reliability of rainfall varies greatly and variability increases sharply to the west (Logan, 1960; Tyson, 1978).

This pattern of decreasing rainfall from east to west is clearly shown in the catchment of the Khan River, where annual rainfall varies from 400 mm in the head-waters to 200 mm at Usakos and 35 mm at the Khan Mine (Hydrology Division, 1988). Rainfall measurements at the Rössing Uranium Mine indicate that the mine receives on average some 30-35 mm per year (Figure 2.2). Most rainfall occurs as late summer and autumn showers or thunderstorms of high intensity and short duration. Virtually no rainfall is recorded during the winter months, though occasional rainfalls contribute up to 1 mm per month (Richardson & Midgeley, 1979; Brown & Gubb, 1986; Craven, 1986; Earth Science Services, 1987; SWADWA, 1987).

Fog is an important source of water for the coastal vegetation of the Namib Desert though the amount of water derived from fog is difficult to measure (Louw & Seely, 1982). Brown & Gubb (1986) report that fog is recorded on about 102 days per year at the coast. Fog precipitation usually amounts to some 30-45 mm/year at the coast (three times the annual rainfall) and decreases to about 20 mm/year on the open gravel plains some 40 kilometres inland.

However, very much higher quantities of fog precipitation have occasionally been measured along the Kuiseb River to the south of Rössing (up to 184 mm/year at Swartbank; Ward & von Brunn, 1985). On occasion, fogs have been reported to extend as far as 70 kilometres inland from the coast (Scholtz, 1972). The scarcity of "fog-dependent" plants such as Arthraeura leubnitziae at Rössing (Craven, 1986) suggests that suggests that fogs are unlikely to be an important source of moisture for vegetation around the mine.

4.1.3.3 Evaporation

Evaporation rates are very high over most of the central Namib Desert and any moisture that does not soak into the soil soon after falling will be lost. Daily A-pan evaporation rates measured near Rössing range from 6 to 15 mm per day, whilst monthly evaporation rates reach a maximum in mid-summer (December) with a minimum in mid-winter.
(June). Gross annual potential evaporation at Rössing amounts to 3,150 mm (Figure 4.1), while net evaporation (after subtraction of rainfall and conversion to an open water surface) amounts to 2,170 mm (Hydrology Division, 1988).

4.1.3.4 Temperature

As can be expected from its location in a desert, air temperatures at Rössing are often extreme, with cold nights and hot days. Mean diurnal temperatures range from 23.8 °C in late Autumn (May) to 15.4 °C in Spring (October), an annual range of 8.4 degrees. This is very similar to the 9 degree range reported for both Gobabeb and Swakopmund (Goudie, 1972). Minimum temperatures are usually recorded in the early morning and range from 2.0° C in August to 12° C in March (Earth Science Services, 1987; Figure 4.1).

In contrast to the frequent and large variations in day-to-day temperatures, seasonal variations are less marked. Maximum diurnal temperatures show very little month-to-month variation, ranging from 31.8 degrees centigrade in July (due to the occurrence of hot berg winds) to 39 degrees in January. Air temperatures measured in the Khan River gorge near Rössing may reach 44 degrees, some 5 degrees higher than those measured at the mine (P.J. Ashton, unpublished data). Monthly temperature ranges vary from 28 degrees in summer to 32.9 degrees in winter (Earth Science Services, 1987; Figure 4.1).

Whenever air temperatures are high, dark coloured soils and rocks can reach even higher temperatures. For example, soil surface temperatures up to 60 degrees and even 70.5 degrees were recorded on a few occasions on the gravel plains of the central Namib Desert, where air temperatures are similar to those measured at Rössing (Goudie, 1972; Robinson, 1976; Craven, 1986).

4.1.3.5 Humidity

Atmospheric humidity levels at Rössing are very variable, both on an hour-to-hour and day-to-day basis (Earth Science Services, 1987). The lowest values (5 to 8 %) are recorded during midday whilst the highest values (up to 84 %) are usually recorded during the early morning. Humidity levels rise rapidly after one of the infrequent rainfalls and afternoon sea breezes also contain appreciable humidity levels. However, high humidity levels seldom last very long and the diurnal average humidity level is usually below 15 %.

4.1.3.6 Insolation

As would be expected from its desert environment, insolation levels at Rössing are very high and cloudy or overcast periods usually have a very short duration (Earth Science
Services, 1987). The presence of early morning fogs, which can extend to Rössing from the coast during the winter months, leads to a slight reduction in the effective daylength on approximately 50 days per year. However, these fog patches are relatively thin and dissipate by mid-morning.

Maximum insolation levels show a distinct cycle, varying from 1,051 W/m² in summer to 599 W/m² in winter. The absence of appreciable cloud cover for sustained periods ensures that most days are bright. However, the mean daily insolation values recorded during summer are usually slightly lower than winter values due to the higher frequency of cloudy periods in summer.

4.1.3 Geology

4.1.3.1 Regional geological setting

The Rössing uranium deposit lies within the Central Zone of the late Precambrian Damaran orogenic belt that occupies much of northern and western Namibia, lying between the Congo and Kalahari Cratons (Gevers, 1936; Ward, 1984; Mouillac et al., 1986). The geology of the central part of the Damara Belt has attracted considerable attention and has been described in detail by several authors (Wagner, 1921; Smith, 1965; Miller, 1983; Jacob et al., 1986; Schreiber, 1996). The Central or Swakop Zone of the Damara Belt is characterised by high temperature - low pressure metamorphism, numerous granitic intrusives and intense deformation typified by D₃ domes. Two prominent north-east striking lineaments, the Okahandja and the Omaruru Lineaments transect the area. The Central Zone is divided into a Northern and a Southern Zone separated by the Omaruru Lineament. The Okahandja Lineament on the other hand separates the Khomas Zone in the south from the Central Zone (Schreiber, 1996).

Along the Swakop and Khan Rivers a number of basement domes and antiforms are exposed which comprise highly metamorphosed and deformed sedimentary, volcanic and intrusive rocks of the Abbbis Metamorphic Complex of Mokolian age (1,180 - 2,070 Ma). These domes are surrounded by meta-sedimentary rocks of the Neoproterozoic Damara Sequence (750 - 458 Ma).

The Damara Sequence is divided into two groups, the older Nossib Group and the younger Swakop Group. The lowermost part of the Swakop Group (Rössing, Chuos, Arandis, Karibib and Tinkas Formations) is characterized by alternating marbles and schists, with subordinate diorites, whereas the upper Swakop Group (Kuiseb Formation) comprises of a great thickness (> 3,000 metres) of interbedded schist and minor quartzite (Berning, 1986; Schreiber, 1996). These are widely exposed north of the Swakopmund-Usakos road and on the Khomas Highlands.

Granite emplacement, in association with deformational and metamorphic events of the Damara Orogeny, was widespread throughout the area and ranges from early syntectonic dioritic plutons to late, post tectonic alaskites and pegmatites. The Damaran orogenic
movements caused complex folding and metamorphism of earlier sediments (Berning, 1986) to form layered sequences of quartzites, biotite schist, cordierite gneiss and marble. The deeper-lying older rocks were migmatised to form a granitic magma. This formed the pegmatitic granite known as alaskite which contains the primary uranium minerals at Rössing.

The alaskite is present in a range of intrusive bodies, which vary widely in texture, size and emplacement habit (Berning, 1986; Mouillac et al., 1986). The alaskite bodies, which vary in size, texture and manner of emplacement, preferentially intruded the contact between the Khan and Rössing Formations. The Rössing pegmatitic alaskite is one of the youngest intrusives into the central Damara belt; it has been dated by the whole-rock Rb/Sr method and gives a granite emplacement age of 468 ± 8 Ma (Kröner & Hawkesworth, 1977; Hawkesworth et al., 1983).

In the Namib area, zones of uranium mineralization are restricted to a specific structural zone some 50 kilometres wide and extending north-east for a distance of over 100 kilometres (Mouillac et al., 1986). This Central Zone forms the core of the Damara Belt (Jacob et al., 1986). Apart from the Rössing deposit, uraniumiferous alaskite is also known to occur at Goanikontes, the Ida dome area and on the farm Valencia 122 on the Khan River and many other smaller deposits (Mouillac et al., 1986). In addition to these primary deposits, epigenetic sedimentary uranium mineralization is found at Langer Heinrich, on the coastal plains and south of Spitzkoppe, near Usakos. Aerial scintillometer surveys have detected numerous anomalies which are all linked to occurrences of uranium containing orebodies. This mineralization is related to westerly trending rivers which drain the Khomas Hochland and are of late Cretaceous/early Tertiary age.

Local sedimentary rocks and intrusives of the Karoo Sequence were deposited over the older crystalline basement rocks and have been largely eroded away, leaving thin terrestrial superficial deposits, like those outcropping east of Usakos. Numerous north-east and east-northeast trending dolerite dykes of Cretaceous age are now exposed and form prominent features of the landscape.

Large portions of the crystalline basement rocks south of the Swakop River, along the coast and east of the Khan River in the central Namib Desert are covered by Tertiary to Recent superficial deposits of sand, seree, clay and duricrust deposits, such as gypscrete and calcrete (Jacob et al., 1986).

4.1.3.2 Local geological setting and structure

The host formations of the Rössing uraniumiferous pegmatitic granite are the Khan and Rössing Formations. Stratigraphically, these occur in the upper Nossib and lower Swakop Groups respectively. The monotonous succession of gneisses and schists grade upward into the varied lithological sequence of the Rössing Formation. Tight vertical or slightly overturned folds trending north-east south-west are the most striking feature
of the regional geological structure. These deposits occur in a migmatitic zone in which uraniferous alaskite granite/pegmatite and metamorphosed country rock show concordant, discordant and gradational relationships. The orebody is unique in that it is the largest known uranium deposit occurring in granite.

Uranium mineralization is present within Ordovician alaskites, leucogranites and pegmatites originating from a deep-seated source (Berning, 1976). The biotite gneisses of the Etasis Formation and the strata of the Khan and Rössing formations form the favoured host rock to the emplacement of the alaskite, whether radioactive or barren, whereas the felspathic quartzites present at the base of the Etasis Formation and Karibib Formation are essentially free of alaskite units. Xenoliths of country rock, more than 100 metres wide are completely engulfed in the massive alaskite bodies that form the central portion of the ore body.

The main deposit, also known as the SJ anomalies, is located on the south-westerly flank of a large domal structure that is clearly visible on ERTS satellite photographs of western Namibia (Breed et al., 1979). Tight vertical or slightly overturned folds trending north-east/south-west are the most striking feature of the regional structure. Several transverse, vertical, oblique-slip faults occur around the domal structure, while both the alaskites and metasediments show strong jointing, trending in a north-northwesterly direction (Dames & Moore, 1982a; Berning, 1986). A spectacular post-Karoo intrusive dolerite dyke crosses the area from south-west to north-east.

The uranium-bearing alaskites at Rössing are medium- to coarse-grained and vary in colour from grey to shades of pink and white. All of the primary uranium mineralization and the majority of the secondary uranium mineralization occurs within the alaskite. The alaskite is widely distributed beyond the limits of the existing pit, but it is not uniformly uraniferous. Most of it is in fact entirely unmineralised. Uraninite is the dominant primary radioactive mineral, and comprises about 55% of the uranium minerals present in the orebody, whilst betafite contributes less than 5% and secondary minerals account for about 40% (Vernon, 1981).

The primary uranium minerals uraninite and betafite give rise to secondary minerals that are usually bright yellow in colour. These occur either in situ, replacing the original uraninite grains from which they were formed, or along cracks as thin films and occasional discrete crystals. Beta-uranophane is by far the most abundant of the secondary uranium minerals. This mineral is not always confined to the alaskite but is also dispersed into the surrounding country rocks along cracks and fracture lines (Vernon, 1981).

4.1.4 Geomorphology

The Swakop and Khan rivers drain an area that has been subjected to several geomorphological changes. Each of these has had a marked effect on the evolution of the river systems. Epeirogenic movement (uplift) during pre-Tertiary times resulted in
deep incisions of the rivers into the country rocks. However, the depth of the river channel at the road bridge at Swakopmund, is about 20 metres and the base of the channel is 13 metres above present sea level (SWA Administration, 1957). Subsequent subsidence again has resulted in substantial deposition of coarse sediments in the river channels, ultimately resulting in the extensive flat plains along the West Coast along which the Swakop and Khan rivers meandered. Floods in these rivers deposited large volumes of sediments onto the coastal plains. Shallow lagoons and marshes developed on the coastal plains resulting in evaporation and the formation of gypsum and salt layers.

This period was again followed by some uplift, during which the rivers became incised to between 1 and 15 metres below the present surface of the river bed. As the valleys were not incised to the levels of pre-Tertiary times, a large proportion of the salt, produced through evaporation, is still present in the lower parts of the alluvium filling the old river channels.

During Tertiary times, only the Khan River had its river mouth at Swakopmund, whilst the Swakop River reached the sea some 8 kilometres north of Walvis Bay (NIWR, 1966; Ward, 1987). During those times the Swakop River followed the bed of the current Tumas River from Langer Heinrich onwards to the coast.

During modern times, the shape of the estuary is occasionally changed during large floods. A good example is the 1931 and 1934 floods when a large sand bank was deposited in the ocean. Evidence of substantial erosion during some of these floods is also evident from historical records (Stengel, 1964, 1973; Sam Cohen Library, Swakopmund).

4.1.5 Soils

Saline soils are a feature of most deserts (Scholz, 1972) and the Namib Desert is no exception. Rocks are broken down first by physical and chemical weathering processes, after which chemical decomposition processes transform the stone fragments to progressively finer particles. The predominance of chemical weathering processes is accentuated by the dry climate and the occasional deposition of wind-blown salt of marine origin.

The soils in the vicinity of the Rössing Uranium Mine are generally very shallow (< 25 cm) and greyish or ochre in colour, with a large proportion of coarse fragments and occasional calcium carbonate concretions. In areas with surface calcrete or limestone deposits, "Schaumboden" or "foam soils" are frequently found. These are characterized by high soil pH values and the formation of a crusted surface layer. Hard surface crusts, often bound by and overlying a layer of blue-green algae (Cyanobacteria), are found in lower Panner Gorge. These surface crusts can reduce rainfall infiltration rates and accentuate runoff. Wind-blown sand deposits of varying depth are found in sheltered areas in the upper gorges.
Colluvium has been deposited on the shallower slopes of some of the hills, as well as at the base of steeper hills. The colluvium slope wash varies in thickness up to a maximum of about 1.5 metres. The material consists of a mixture of grey-brown silty sand with an open, angular pebble layer and its consistency varies from medium-dense to dense (Robinson & Eivemark, 1987). The average permeability of the colluvium is about $10^{-2}$ cm/s, but the deposits are discontinuous.

Alluvial silty sands and gravels form an almost horizontal fan in the valley bottoms, having been laid down during the infrequent flash floods. The material is laminated, consisting of layers of slightly coarse sand interspersed with layers of angular gravel and pebbles, in a matrix of grey-brown silty coarse sand. In the gorges, the alluvial deposits are estimated to vary in thickness up to about 8 metres. The average permeability of the alluvium is likely to be about $10^{-1}$ cm/s, (P. Marais, personal communication).

Alluvial deposits up to about 20 metres in thickness are also found in the bed of the Khan River, with a composition very similar to those found in the gorges (Marais, 1990). Successive layers of gravels, sands and silts are visible in flood-cut terraces, which vary in width from a few metres to several tens of metres. These stratification patterns indicate successive settling out of transported material with decreasing flood-water velocities. An important distinction of these Khan River bed deposits is the presence of conspicuous laminations of mid-brown or ochre, fine silty clay, reflecting the higher silt loads that are brought down by occasional surface floods (Hydrology Division, 1988; Ashton, 1988b).

### 4.2 General hydrological characteristics

#### 4.2.1 Data availability

This section of the report describes the information available during the period when feasibility studies were conducted and some engineering investigations were underway. It describes the current state of knowledge on the hydrology of the Swakop River catchment. The information obtained from DWA formed the basis for deriving at an appropriate model methodology, the development of the model and eventually the modelling phase. The modelling will be described in more detail in Chapter 5. The information presented in this section is largely contained in reports by Gordon McPhail and Associates (1995) and Metago Environmental Engineers (1997a, 1997b).

#### 4.2.2 Flood Characteristics of the Khan and Swakop Rivers

##### 4.2.2.1 Flood record

The following Khan River flood records were made available:

- Flood records measured at Ameib (station No. 2986MO1A) over the period 1967 to 1994 (MAWRD, 1997). Ameib is located some 185 kilometres from
Swakopmund (measured along the river). This record represents the most reliable flood record and indicates the following information:

- the date of the flood;
- the runoff volume;
- the estimated peak flow rate;
- the peak depth of flow;
- the duration of flow.

- Flood records for the Khan River measured at Usakos (station No. 2987MO1) measured over the period 1951 to 1994. This record is considered not to be as reliable as the Ameib record but is approximately 25 kilometres closer to Swakopmund and the Mine. The proposed dam site is some 100 kilometres downstream of Ameib and 75 kilometres from Usakos.

- A simulated flood record prepared in 1988 by the Department of Water Affairs (DWA, 1988) to predict the flood volumes at Rössing Mine based on a rainfall-runoff model. The simulated flood record was prepared for the period 1925 to 1987. Predicted flood volumes at Ameib compared favourably with the actual record. The simulated flood record is considered to be the best long term prediction of the flood volumes at Ameib. The model assumed a 1% loss per kilometre from Ameib to the Rössing Mine due to aquifer recharge.

The following flood data was made available for the Swakop River:

- A record of floods for the period 1970/1 to 1978/9 at Salt Rock (Station No. 285 MO1). The station's tower was washed away in February/March of 1975 and a new station built in December 1975. Salt rock is located some 10 kilometres upstream of the confluence of the Swakop and Khan Rivers on the Swakop River.

- A seasonal runoff record for the Swakop River at various sites from 1925/6 to 1984/5 including:
  - Von Bach Dam;
  - Swakoppoort Dam;
  - Dorstrivier;
  - Riet;
  - the confluence of the Swakop and Khan Rivers, and
  - Swakopmund.

This represents a combination of simulated run-off and actual data. It is assumed that from Dorstrivier downstream to Swakopmund, only losses occur. A loss factor of 0.1 Mm³/kilometre was taken. For the purpose of the model, this record was considered the most appropriate since it represents the best simulated record for the Swakop River. The time period of one year is also considered suitable for a model of this nature.
The above record is plotted as Figure 4.2 for the confluence of the Swakop and Khan Rivers. From Figure 4.2 it is clear that the proportion of total flow in the Swakop River from the Khan River is relatively small. Figure 4.3 shows the percentage contribution to flow of the Khan River to the total flow in the Swakop River, measured just downstream of the confluence of the Khan and Swakop Rivers. In this figure it is clear that there is an inverse relationship between the total flood size and the proportion of the total flow which the Khan River contributes. The Khan River generally contributes less than 10% of the total flood volume in the Swakop River just downstream of the confluence in the case of floods less than 75 Mm$^3$. With larger floods the contribution of the Khan is generally more than 10% of the total flood volume. The 1934 flood represents a noteworthy exception as the percentage contribution to the total flood volume was in this case considerably higher than might have been expected. This is probably attributable to the fact that the 1934 flood was caused by rainfall over a widespread area of the catchment.

![Flood Volumes in the Swakop and Khan Rivers at the Confluence](image)

**Figure 4.2:** Flood Volumes Khan and Swakop Rivers at the Confluence.

The data in Figure 4.3 has been used to compile a frequency distribution for the contribution of the Khan River to total flow in the Swakop River as shown in Figure 4.4. From the frequency distribution it is clear that the majority of floods contribute less than 10% of the total volume in the Swakop River.
**Figure 4.3:** Historical Percentage Contribution of the Khan River to the Flow in the Swakop River Measured at the Confluence.

**Figure 4.4:** Percentage Contribution of the Khan River to the Total Flow expressed as a Frequency Distribution

**Table 4.1** summarises the relative flow rates in the Khan and Swakop Rivers just downstream of the confluence based on the above data.
Table 4.1: Seasonal Flood Volume Characteristics of the Khan and Swakop Rivers at the Confluence for all Non-zero Flood Seasons.

<table>
<thead>
<tr>
<th></th>
<th>Swakop River upstream of confluence (Mm³)</th>
<th>Khan River (Mm³)</th>
<th>Total Swakop downstream of confluence (Mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Flood Volume</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>Maximum Flood Volume</td>
<td>377.6</td>
<td>134.77</td>
<td>512.4</td>
</tr>
<tr>
<td>Mean Flood Volume</td>
<td>45.6</td>
<td>5.2</td>
<td>50.8</td>
</tr>
<tr>
<td>Median Flood Volume</td>
<td>9.2</td>
<td>0.45</td>
<td>10.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>180.7</td>
<td>66.5</td>
<td>247.0</td>
</tr>
</tbody>
</table>

- A summary of flood volumes at Swakopmund for a range of periods as follows:
  - 1892/3 to 1977/8 - a subjective record of the flow rate recorded as weak, moderate, strong or very strong and a record of how close the flood came to the mouth of the Swakop River prepared by Stengel (1964);
  - 1970/1 to 1983/4 - A record of flood volumes and peak flow rates measured at the railway Bridge in Swakopmund or at Palmenhorst, located just downstream of the confluence of the Khan River; and
  - 1985 flood - A daily record of the peak flow rate and flood volume in the Swakop area.

- A historical inflow record for Von Bach dam from 1923/4 to 1993/4 (DWARD, 1977);

- A generated historic inflow record for Swakoppoort dam from 1923/4 to 1993/4 (DWARD, 1997);

- Actual monthly inflows and spills for the Von Bach and Swakoppoort dams from 1977/8 to 1995/6 and from 1970/1 to 1995/6 for Swakoppoort and Von Bach dam’s respectively (DWA, 1997b);

- Flow records at Dorstrivier (station 2985MO2) for the period 1977/8 to 1993/4. Dorstrivier is located some 160 kilometres along the river from Swakopmund and represents approximately the start of the zone of depletion of flood volumes. The records are considered to be questionable since the station comprises an open section. The station was relocated in 1988. Flows at this station should be used as an indicator station only.

- Flow records for Westfalenhof (station No. 2984M01) for the period 1961/2 to 1994/5.
The following documentation is available which sheds further light on specific flood events in the Khan and Swakop Rivers:

- Flood information notes recorded by the Department of Water Affairs over the period 1989 to 1997. The record has been compiled primarily from information submitted to the DWA by residents along the Swakop and Khan Rivers.

4.2.2.2 Rainfall records

Daily and monthly rainfall records were obtained for the Swakop and Khan catchments.

4.2.2.3 Unit runoff

A copy of the unit runoff map for Namibia was provided by the Department of Water Affairs.

4.2.2.4 Transmission losses

Flood volumes in the Khan and Swakop Rivers reduce as they pass through the Namib desert due to infiltration of the flood waters into the alluvial aquifers. The proportion of each flood which is lost to infiltration along any reach of the river is dependent on:

- The volume available for recharge in the alluvial aquifer.
- The saturated permeability of the alluvium which in turn is largely a function of the particle size distribution.
- The average permeability of the alluvium which is in turn a function of the degree of saturation of the flood and the time over which the flood takes place. The unsaturated permeability can be as much as several orders of magnitude less than the saturated permeability.
- The width of the river channel.
- The depth to the water table which affects the time that the alluvium in the vadose zone will take to achieve a permeability equal to the saturated permeability of the alluvium.

4.2.2.5 Evaporation losses

The evaporation map for Namibia was provided by the Department of Water Affairs (Crerar and Church (1988)).
4.2.3 River gradients

Gradients over different sections in the Swakop and Khan Rivers are shown in Table 4.2. The Swakop River has a very constant gradient over long sections; the average being 1:270. The mean slope of 1:182 for the Khan River is still regarded as a steep slope (DWA, 1988).

Table 4.2: Gradients of different sections of the Khan and Swakop Rivers (NIWR, 1966).

<table>
<thead>
<tr>
<th>Swakop River section</th>
<th>Gradient</th>
<th>Khan River section</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Okahandja - Sneyrivier</td>
<td>1:388</td>
<td>- Usakos</td>
<td>1:216</td>
</tr>
<tr>
<td>Sney River - Dorst River</td>
<td>1:273</td>
<td>Usakos - Rössing</td>
<td>1:157</td>
</tr>
<tr>
<td>Dorst River - Dolerite Hill</td>
<td>1:243</td>
<td>Rössing - Confluence</td>
<td></td>
</tr>
<tr>
<td>Dolerite Hill to Coast</td>
<td>1:222</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The gradients of the Khan and Swakop Rivers have been estimated from 1:50,000 topographical maps. The gradients for the different modelling sections vary between 1:48 and 1:540.

4.2.4 Sediment transport

Very little information on the sediment load of the Swakop and Khan Rivers is available. In a DWA report (1988), variations in silt load between 2 % to 22.8 % per unit volume of water are quoted. The high silt load is due to the high carrying capacity of the river resulting from the steep slope. A sample collected during the January 1997 flood at Rössing indicated a silt content of 14 %, whereas the next flood in February 1997 showed values of between 4 % and 6.5 % (Kehrbeg, 1997). It is a well established fact that, during flood events following shortly on each other, the silt load of the second event is less than in the first flood.

4.3 Geohydrology of the alluvial aquifers of the Khan and Swakop rivers

4.3.1 Previous studies and data availability

Like most of the alluvial aquifers along the Namibian coast, the aquifers of the Swakop and Khan rivers have attracted their share of studies. Probably the most extensive study conducted so far on the Swakop River was that by the CSIR in the 1960's, the results of which were compiled in a report by the National Institute for Water Research (NIWR) of the CSIR (NIWR, 1966). This was followed by numerous reports and publications
by Rössing Uranium Limited (RUL), the CSIR and the Department of Water Affairs of
the then South West African Administration (Hellwig, 1973a, 1973b; 1973c; 1973d;
1976b; 1976c; 1978;1979; 1988). The main conclusions relevant to the present study
are briefly summarised here.

The primary aims of the CSIR investigation during the period 1958 to 1964, and
reported on in 1966 (NIWR, 1966), were to:

- determine the contamination to the ground water stored in the alluvium caused
  by the occasional floods in the river;
- determine the contamination caused by the different brackish water sources along
  the river;
- determine the influence of evaporation in areas where the ground water level
  reaches the surface of the river bed;
- quantify the ground water flow in the alluvium and to investigate the alleged
  large contributions made by tributaries;
- develop methods to protect the fresh water in the Swakop River and its
  tributaries; and
- determine the possible impact of the Von Bach Dam on the Swakop River.

Some of the more important conclusions relevant to the present investigation were:

- the alluvium in the Swakop River can be regarded as a continuous aquifer with
  a perched water level;
- dewatering of the alluvium occurs gradually through drainage towards wet areas
  ("nat kolie") where it evaporates;
- fine sediments and dissolved salts accumulate in the alluvium and the primary
  mechanism responsible for increasing salt concentrations is evaporation;
- leaching of accumulated salt in the alluvium is responsible for mineralisation of
  both flood water and ground water;
- borehole sections across the lower Swakop River often display a "dual channel"
  profile which has implications for the mixing of ground water in the alluvium;
- the total dissolved salt concentration of flood water in the Swakop River is
  inversely proportional to the distance from the coast (Figure 4.5);
• despite the general observation that the surface water from those tributaries which contribute to the total flow in the Swakop River is notably more mineralised than that of the Swakop River at the confluence, these inflows are too small to have a significant adverse impact on the water quality of the Swakop River;

• variations in the chemical character of the flood water along the length of the Swakop River are caused by selective leaching of salt (for example it changes from bicarbonate-rich water in the upper parts of the catchment, to a bicarbonate-chloride water and eventually to a chloride-bicarbonate water at the coast);

• the influence of different geological formations on the surface water quality could not be established satisfactorily;

• The best ground water quality at the different observation points, compares favourably with that of the flood water at the corresponding same positions (Figure 4.5);

• The concentration of salts in ground water increases as one moves towards the coast where it reaches a value of approximately 14,000 mg/l. This is regarded as a normal consequence of a water table aquifer under arid conditions;

• In areas referred to as the "nat kolle" where ground water is forced to the surface due to geological structures cutting across the river bed, water quality can deteriorate by up to 10 times due to evaporation;

• The effect of springs on the ground water quality is clearly visible, but is only a localised effect. The tributaries to the Swakop River also only have a localised effect on the water quality and even the Khan River is regarded as having only a minor effect on the Swakop River ground water quality. At the confluence the Khan River ground water has a higher total salt concentration than that of the Swakop River;

• The salt-rich Tertiary sediments may contribute significantly to the salt load of the Swakop River. This is confirmed by the spring water at the Tanka River downstream of Salem. The largest single factor contributing to the salt load in the Swakop River, however remains the "nat kolle" and areas where the ground water level is less than 1 metre below surface; and

• Based on samples collected after the 1962/1963 flood, the ground water quality along the Swakop River is characterized by three distinct quality zones:

  - Zone I (average TDS ~ 300 mg/l) - Upper part of catchment;
  - Zone II (average TDS ~ 1,400 mg/l; range 800 - 3,000) - central part of catchment (down to Salem); and
  - Zone III (average TDS ~ 5,600 mg/l; range 1,800 - 18,000) - from Salem to the coast at Swakopmund.
Figure 4.5: Changing groundwater and surface water quality in the Swakop River between Okahandja and the coast
From the 1966 study of the Swakop River, it was apparent that evaporation from the river bed had a major adverse influence on water quality. This led to further extensive investigations over a number of years to determine the evaporation from dry alluvial river beds. For this purpose a research station was established at Gross Barmen on the Swakop River near Okahandja during the early 1970's. As a first step, evaporation and evapotranspiration were calculated using meteorological data which was then compared to that measured at Gross Barmen. The surface area of the total length of the Swakop River, including vegetated areas and "nat kolle", was determined to an accuracy of ~ 10%.

The loss of water through evaporation and evapotranspiration from the Swakop River bed between Okahandja and the coast (area 8,300 hectares) was calculated to be 76 x 10^6 m^3/yr using the meterological data for Gross Barmen and applying it over the entire length of the Swakop River. Of this figure, 68% is attributed to evapotranspiration and 19.5% to evaporation from permanently wet areas and the rest from temporary wet areas (NIWR, 1971; Hellwig, 1973c).

Taking into account variable meteorological conditions along the length of the Swakop River it was estimated that the total loss of water from the river must be between 65 x 10^6 m^3/yr and 95 x 10^6 m^3/yr. Hellwig (1974c) also estimated that, by removing phreatophyte vegetation from the river bed, between 16 and 43 x 10^6 m^3/yr could be prevented from being lost to the atmosphere. As part of a series of experiments it was also established that if infiltration can be enhanced by extracting the silt load in, for example, a settling dam, and the water table is more than 60 cm below the surface, evaporation losses are minimal. Evaporation from an open water surface was about 8% more than from a water saturated sand (Hellwig, 1974d).

Another important result from the experiments by Hellwig (1974) was the relationship established between evaporation of water from sand and the concentration of salts dissolved in the water stored in the sand. When water is transported to the sand surface by capillary action, the salts removed from solution accumulated in a thin sand layer near the sand surface (Hellwig, 1979).

Dziembowski (DWA, 1970) reported average permeabilities of 219 metres/day and 286 metres/day and specific yields of 0.18 and 0.23, respectively, for the Swakop and Khan Rivers near Rössing, based on aquifer tests conducted by the DWA and Geological Survey. He also established that the specific capacity of boreholes in the Khan River was almost double those of boreholes in the Swakop River. From these results, it was concluded that for one kilometre of river bed at the test sites, 424,000 m^3 (DWA, 1969) and 341,000 m^3 (Dziembowski, 1970) of ground water was stored in the Swakop and Khan, respectively.

Following a geoelectrical survey done by the Geological Survey, three boreholes (BH01, BH02 and BH03) were drilled in 1974 in the Khan River (Wegerhoff, 1974). Based on the results of a seismic refraction survey, another borehole (BH04) was drilled in the Khan River in 1975. In 1976, RUL drilled two boreholes in the lower Swakop River
near the Country Club, and another two in the Khan River (BH05 and BH06), on the basis of additional seismic refraction surveys (RUL, 1976). Tested yields and quality for the boreholes in the Swakop and the Khan are listed in Table 4.3.

Table 4.3: Water quality and yield from boreholes in Swakop and Khan Rivers (from RUL, 1976).

<table>
<thead>
<tr>
<th>Component</th>
<th>Swakop River</th>
<th>Khan River</th>
</tr>
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<tr>
<td></td>
<td>BH01</td>
<td>BH02</td>
</tr>
<tr>
<td>pH</td>
<td>7.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Conductivity (mS/m)</td>
<td>3,700</td>
<td>2,900</td>
</tr>
<tr>
<td>Total dissolved solids (mg/l)</td>
<td>28,400</td>
<td>21,200</td>
</tr>
<tr>
<td>Yield (m³/day)</td>
<td>2,448</td>
<td>2,087</td>
</tr>
<tr>
<td>Yield (l/s)</td>
<td>~28</td>
<td>~24</td>
</tr>
</tbody>
</table>

It is important to note the significant difference in total dissolved solids concentrations between the Khan and the Swakop rivers.

The Department of Water Affairs has given two possible reasons for sudden rise in salt concentration after the 1934 floods in the Swakop River (DWA, 1976a). These are that large volumes of alluvium in the Swakop River were removed, resulting in generally shallower ground water levels and that large amounts of salt must have been transported to the Swakop River from the Tertiary age coastal plains in the Namib as these also received good rains. Between 1964 and 1976, when 10 additional boreholes were drilled in the Swakop River, no significant change in the chemical character of the water occurred (DWA, 1976a). In this report, the stored reserves in the Khan River between Namibfontein and Rössing were estimated to be between 8.4 and 11.2 Mm³ over a 40 kilometre length of the river. The report further stated that only 70% of these reserves were abstractable and that the annual recharge from flood events for the Khan River between Namibfontein and the confluence with the Swakop River was 2.4 Mm³. This figure was thought to correspond to the long-term safe yield of the aquifer.

Ground water quality determined at different positions in the Khan River between the mine and the confluence with the Swakop River during 1974, showed the following trend:

Opposite the mine: 3,887 mg/l
10km downstream of the mine: 6,424 mg/l
At the Khan/Swakop confluence: 9,858 mg/l.

The 1976 Department of Water Affairs report (DWA, 1976a) estimates water stored in the two rivers to be $6.5 \times 10^6$ m³ for the Khan between Rössing and the Swakop River.
confluence, and $23.3 \times 10^6$ m$^3$ for the Swakop River between the confluence with the Khan River and the coast. Recharge to the Swakop River alluvial aquifer was estimated as 50,000 m$^3$/year/kilometre of river bed, taking into account evaporation losses (DWA, 1978).

In 1982, as part of a seepage control study, pumping tests on two boreholes gave storage coefficient values of 22% and permeabilities of between 80 and 100 metres/day (Dames and Moore, 1982a).

In an attempt to relieve the pressure on the water supply to Rössing from the coastal aquifers, Rössing started to investigate the possibility of artificially recharging the Khan River aquifer by capturing flood waters and then infiltrating these into the alluvium in 1988 (RUL, 1989). The DWA was asked to compile a report on the hydrology of the Khan River and to assess the feasibility of constructing a dam in the Khan River upstream of the then production well field (DWA, 1988). This report concentrated on the rainfall-runoff data for the Khan River and derived at different yields for a proposed dam for various dam capacities. This was followed by an internal report by Marais (1989) proposing a detailed study of the geohydrology of the Khan River and a proposal to construct a dam in the Khan River to enhance ground water recharge.

4.3.2 Current state of knowledge of the water quality conditions of the Swakop River alluvial aquifer

4.3.2.1 The lower Swakop River

For the purposes of the EIA, only the downstream section of the Swakop River and its banks from the confluence with the Khan River is relevant and is referred to as the *lower Swakop River*. However, for the hydrological modelling the entire length of the Swakop River was considered. Relevant geohydrological information required for the modelling will therefore be reported on here.

Geomorphologically, the lower Swakop River can be divided into two sub-areas: (i) between the confluence with the Khan River and the farm Tannenhof where the river is incised 200 metres deep into the folded and metamorphosed rocks of the Damara Sequence; and (ii) the relatively flat topography and river terraces of Quaternary age alongside the river area between Tannenhof and the coast.

In the Lower Swakop River section the river varies in width between 50 metres and 500 metres, with an average of about 400 metres. Vegetation is generally sparse except for wetlands downstream of the confluence with the Khan River, the surrounds of Nonidas and around the railway bridge. In these areas dense vegetation of mainly Tamarisk, suede and reeds is characteristic. Open water appears at Nonidas and the railway bridge.
In the section between the confluence and Tannenhof, 12 farms with an average size of 50 hectares are situated. Early reports (Seydel, 1943; Gebhardt, 1934) refer to fertile farmland in this area, extensive wetlands and brackish ground water. Currently only at Goanikontes some limited farming is continuing. Between Tannenhof and the Rössing Country Club, 25 farms averaging 10 hectares in size are situated mostly on the northern bank of the river. The farms between the confluence with the Khan River and the farm Swakopau in the farm 性善 are shown on Figures 4.6, 4.7 and 4.8.

A recent survey of part of the area during which 15 of the owners were interviewed (Marais, 1997) revealed that approximately 150 people occupy land in the lower Swakop, 34 hectares of land is cultivated (15 hectares lucerne, 6 hectares vegetables, 2 hectares asparagus, 10 hectares under spray/drip irrigation and 24 hectares under flood irrigation) and that the stock consists of chicken (~ 10 000), cattle (~ 300) and small stock (~250). Current (brackish) water consumption is ~ 1,450 m³/day extracted from boreholes, wells and open trenches. Future planning for the area includes extension of the asparagus farming to just over 100 hectares by Rössing Foundation.

4.3.2.2 Data availability

The information on water quality and water supply for Swakopmund and the farming community upstream has been extracted from the following sources:

- Historic information on the water supply to Swakopmund since approximately 1900 from the archives in Swakopmund and from the files of DWA in Windhoek;
- DWA chemical analyses;
- analyses done by CSIR laboratory;
- drilling results from DWA from 1957;
- CSIR 1966 study of the Swakop River (NIWR, 1966);
- Geophysical surveys and drilling at Rössing Country Club;
- Survey of smallholdings during 1997 by Mr P Marais; and
- Water analyses from 1997 sampling of boreholes.

4.3.2.3 Water quality

From the historic records and correspondence between the Departments of Water Affairs and Works, and the Administrator/Secretary of SWA, it is clear that water from the Swakop River, from which Swakopmund originally received its water, has always been of a brackish nature (Boss, 1934; Richter, 1934; DOW, 1952; NiCR, 1957; Wipflinger, 1957, 1958; DWA, 1958).

Isolated analyses of water between 1913 and 1957 indicate a variation in concentration between 2,100 and 4,650 mg/l total dissolved salts (TDS) (DWA, 1958). The improvement of the ground water quality due to flooding events in the Swakop River is highlighted in a letter from the Secretary of Water Affairs to the Secretary of the then
SWA in 1952 (DWA, 1952). However, the same letter emphasises the short duration of the improvement in quality and that it is not wise to rely on flooding events. At Goanikontes the water quality from an irrigation well was at 700 mg/l in September 1948, but increased in salinity to 8 000 mg/l in August 1951. He remarked in his letter that this is typical of the Swakop River and to develop a water supply scheme from the Swakop River is not recommended.

A water quality profile with depth across the Swakop River at Km 2.5 was conducted in 1951 (DWA, 1951). Ten boreholes were used in this profile. The profiles showed a steady increase from about 2,000 mg/l at the water level to > 16,000 mg/l at the bedrock interface. Three additional water quality profiles across the Swakop River were done by DWA in 1957 at Mile 5, Mile 8 and Mile 10. Mile 5 was at the Rosmund Golf Club, Mile 8 is near Nonidas and Mile 10 near the smallholding Rheinland (DWA, 1957). The results for Mile 8 and Mile 10 are diagrammatically illustrated in Figure 4.9. It is important to note that due to geological structures across the river near Mile 8, the ground water level reaches the surface and a large wetland ("nat kol") is present. Evaporation and evapotranspiration from this area increases as a result and so does the salt content of the water. The effect of these wetlands on the ground water quality is dramatically illustrated by this example. At Mile 5 further downstream, the quality is similar to that at Mile 8. The CSIR study in 1966 concluded that the enhanced evaporation and evapotranspiration in those areas where the water level was either at the surface or very close to, was the main reason for the increase in salinity of the water.

A number of observations can be made from these results: (i) the water quality at Mile 10 shows a definite layering with quality decreasing with depth from approximately 1,700 mg/l at the water level to > 10,000 mg/l at the bedrock interface; (ii) by the time the water has passed the wetland and reached Mile 8, the quality layering has disappeared and total dissolved solids are at concentration levels between 15,000 and 23,000 mg/l; and (iii) at Mile 10 the water quality in general is better towards the centre of the river and in the upper layers of the alluvium.

The latter point can be explained by the fact that fresh water infiltrates in areas where surface flow (during flooding events) cuts deepest into the channel, and lateral inflow from the fractured hardrock aquifer occurs at the bottom of the river channel. Water from the hard rock aquifer is generally expected to be of low volume and high salinity although reports of fresh water from these sources have been filed (Mr Putzier, personal communication).

In Figure 4.10 the depth to the water level as well as the water quality at each monitoring position over the section between the confluence with the Khan River and the coast is indicated. A clear correlation between water quality and water table depth emerges, reinforcing the CSIR conclusion that higher salt load are related to shallower water tables.
SMALL HOLDINGS AT SWAKOP RIVER

FIG.: 4.8
### SWAKOP RIVER AT MILE 10

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### SWAKOP RIVER AT MILE 8

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**Figure 4.9:** Water quality across the Swakop river at Mile 8 and Mile 10.
Figure 4.10: Correlation between water table depth and quality of ground water
Figure 4.11: Ground water quality variations with time and depth at Section 23 (NIWR, 1969)
Flooding events seem to improve mainly the upper parts of the alluvial aquifer. In Sections 23, 25, and 26 the CSIR monitored the water quality with depth between 1961 and 1966 (NIWR, 1966). The results for borehole 3 on Section 23 is shown in Figure 4.11. The results show that the water quality improved in the top central areas over the medium term, but reverted to the original status after about 2 years.

The current water quality at the different farms in the lower Swakop River is reflected in Table 4.4. These were collected during December 1996 and January 1997.

4.3.2.4 Water quality near the confluence with the Khan River

By comparing the water quality observed at Sections 22 (Swakop River upstream of confluence), 23 (Khan River upstream of confluence) and 24 (downstream of confluence), some important features emerge (NIWR, 1966). Firstly, the water quality over the largest part of the Swakop River channel (Figure 4.12) has a TDS value of under 2,000 mg/l (Section 22), whereas that of the Khan River (Section 23) is > 10,000 mg/l (Figure 4.13). Secondly, downstream of the confluence, (Sections 24 and to a lesser extent at Section 25) the TDS is still > 10,000 mg/l (Figure 4.14). At Section 25 the river channel is much wider and some improvement in quality can be observed, but overall the TDS is ~ 8,000 mg/l and higher.

It is therefore concluded that the water contributed by the Khan River to the Swakop River, has a much higher salt content and does not contribute to the improvement in the quality of the Swakop River water downstream of the confluence. On the contrary, the negative influence the Khan River has on the water quality of the Swakop River continues for a long distance downstream of the confluence.
Figure 4.12: Water quality in the Swakop River just above the confluence (Section 22) as recorded during the early 1960's (From NIWR, 1966).
Figure 4.13: Water quality in the Khan River just above the confluence (Section 23) as recorded during the early 1960's (From NIWR, 1966).
Figure 4.14: Water quality in the Khan and Swakop Rivers below the confluence Section 24) as recorded during the early 1960's (From NIWR, 1966)
Table 4.4: Ground water quality in the farming zone on the Lower Swakop River (Dec. 96 and Jan. 97).

<table>
<thead>
<tr>
<th>Farm</th>
<th>Date sampled</th>
<th>K</th>
<th>Na</th>
<th>Ca</th>
<th>Mg</th>
<th>NH₄</th>
<th>SO₄</th>
<th>Cl</th>
<th>Alk</th>
<th>NO₃</th>
<th>P</th>
<th>EC mS/m</th>
<th>TDS (calc)</th>
<th>pH (lab)</th>
<th>Hardness</th>
<th>Balance</th>
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<tbody>
<tr>
<td>Unit</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
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<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mS/m</td>
<td>mg/l</td>
<td></td>
<td></td>
<td>%</td>
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<tr>
<td>Blakey</td>
<td>13/02/97</td>
<td>40</td>
<td>1009</td>
<td>368</td>
<td>100</td>
<td>&lt;0.1</td>
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<td>2139</td>
<td>167</td>
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<td>4608</td>
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<td>874</td>
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<td>175</td>
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<td>10880</td>
<td>7.7</td>
<td>3176</td>
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<td>74</td>
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<td>10816</td>
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<td>1760</td>
<td>11264</td>
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<tr>
<td>Erb</td>
<td>14/02/97</td>
<td>95</td>
<td>1932</td>
<td>670</td>
<td>194</td>
<td>&lt;0.1</td>
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<td>3987</td>
<td>203</td>
<td>6.4</td>
<td>&lt;0.1</td>
<td>1285</td>
<td>8224</td>
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<td>2470</td>
<td>0.33</td>
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<td>711</td>
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<td>4346</td>
<td>269</td>
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<td>3257</td>
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<td>&lt;0.1</td>
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<td>2.48</td>
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<tr>
<td>Jooste</td>
<td>14/02/97</td>
<td>50</td>
<td>1458</td>
<td>465</td>
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<td>1753</td>
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<td>de Kock</td>
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<td>0.82</td>
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<td>&lt;0.1</td>
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<td>4.00</td>
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<td>718</td>
<td>3572</td>
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<td>7552</td>
<td>7.3</td>
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<td>2.16</td>
</tr>
<tr>
<td>Rossing Foundation</td>
<td>25/02/97</td>
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<td>1697</td>
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<td>170</td>
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<td>3480</td>
<td>210</td>
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<td>&lt;0.1</td>
<td>1150</td>
<td>7360</td>
<td>7.4</td>
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<td>1.91</td>
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<td></td>
</tr>
<tr>
<td>Geomagnetic S 1</td>
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<td>1835</td>
<td>778</td>
<td>245</td>
<td>0.1</td>
<td>1074</td>
<td>3860</td>
<td>229</td>
<td>0.1</td>
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<td></td>
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<tr>
<td>Geomagnetic S 2</td>
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<td>2473</td>
<td>980</td>
<td>359</td>
<td>0.21</td>
<td>1303</td>
<td>5333</td>
<td>205</td>
<td>0.1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomagnetic Z</td>
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<td>35.5</td>
<td>1550</td>
<td>511</td>
<td>183</td>
<td>302</td>
<td>833</td>
<td>902</td>
<td>902</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paimbhore 1</td>
<td>03/02/97</td>
<td>45.2</td>
<td>1001</td>
<td>390</td>
<td>102</td>
<td>405</td>
<td>1928</td>
<td>211</td>
<td>5.8</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hallamshab 25/02/97</td>
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<td>4.71</td>
<td>390</td>
<td>102</td>
<td>405</td>
<td>1928</td>
<td>211</td>
<td>5.8</td>
<td>405</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3.2.5 Lateral variation in ground water quality across Swakop River aquifer

During 1957 and 1961 ground water quality variations (lateral and vertical) across several sections of the Swakop River were determined (SWA Administration, 1957; NIWR, 1966). The results are schematically illustrated in Table 4.5. In the table the TDS values are grouped into different quality categories. No definite pattern emerges but in general it appears that the water quality in the centre of the alluvial canal is of a better quality. This situation is, however, apart from being time dependent, also dependent on flood size, period between floods, channel width and amount of water abstracted from the aquifer.

Table 4.5: Ground water quality variations across the lower Swakop River.

<table>
<thead>
<tr>
<th>Section</th>
<th>North Bank</th>
<th>Centre</th>
<th>South Bank</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (NIWR, 1961)</td>
<td>&gt; 2,500</td>
<td>&lt; 2,000</td>
<td>&lt; 2,000</td>
<td>Channel in centre; Note 1</td>
</tr>
<tr>
<td>21 (NIWR, 1961)</td>
<td>&gt; 4,000</td>
<td>&lt; 4,000</td>
<td>&gt; 6,500</td>
<td>Channel south bank; Note 1</td>
</tr>
<tr>
<td>22 (NIWR, 1961)</td>
<td>2,500 - 3,000</td>
<td>1,000 - 2,000</td>
<td>1,000 - 2,000</td>
<td>Channel north bank; Note 1</td>
</tr>
<tr>
<td>23 (NIWR, 1961)</td>
<td>&gt; 10,000</td>
<td>&lt; 10,000</td>
<td>&lt; 10,000</td>
<td>Channel south bank; Note 1</td>
</tr>
<tr>
<td>24 (NIWR, 1961)</td>
<td>&gt; 10,000</td>
<td>&lt; 10,000</td>
<td>&lt; 10,000</td>
<td>Channel north bank; Note 1</td>
</tr>
<tr>
<td>25 (NIWR, 1961)</td>
<td>&gt; 8,000</td>
<td>&lt; 3,500</td>
<td>&lt; 20,000</td>
<td>Channel north &amp; south; Note 1</td>
</tr>
<tr>
<td>26 (NIWR, 1961)</td>
<td>10,000 - 21,000</td>
<td>Note 3</td>
<td>18,000 - 24,000</td>
<td>Both channels on north bank; Note 1</td>
</tr>
<tr>
<td>27 (NIWR, 1961)</td>
<td>&gt; 14,000</td>
<td>&lt; 14,000</td>
<td>&lt; 14,000</td>
<td>Channel south bank; Note 1</td>
</tr>
<tr>
<td>Mile 10, 1957</td>
<td>2,000 - 9,000</td>
<td>&lt; 2,000</td>
<td>2,000 - 11,000</td>
<td>Channel centre; Note 2</td>
</tr>
<tr>
<td>Mile 8, 1957</td>
<td>16,000 - 23,000</td>
<td>16,000 - 23,000</td>
<td>23,000</td>
<td>Channel south bank; Note 2</td>
</tr>
<tr>
<td>Mile 5, 1957</td>
<td>12,000 - 18,000</td>
<td>12,000 - 18,000</td>
<td>18,000</td>
<td>Channel north bank; Note 2</td>
</tr>
<tr>
<td>Km 3 (1951)</td>
<td>&lt; 3,000</td>
<td>&lt; 4,000</td>
<td>&lt; 2,000</td>
<td>Note 4</td>
</tr>
<tr>
<td>Km 2.5 (1951)</td>
<td>&lt; 4,000</td>
<td>&lt; 4,000</td>
<td>&lt; 4,000</td>
<td>Note 4</td>
</tr>
</tbody>
</table>

Note 1: ~ 10 Mm³ flood in 1960 and 1961.
Note 2: No floods between 1955 and 1959.
Note 3: Double channel with ridge in between.
Note 4: Deeper than 7 metres quality decreases rapidly. Flood of ~ 100 Mm³ in 1949 and in 1950.
4.3.2.6 Average water quality of the Swakop and Khan Rivers over ~40 years

All available water quality information for the Swakop and Khan Rivers was analyzed. Each river was divided into logical sections, based on geographical or geological features and the minimum, mean and maximum TDS values over the time period 1958 to 1997 was determined. The results are tabulated in Table 4.6 and shown graphically in Figure 4.15.

<p>| Table 4.6: TDS values for different sections of the Khan and Swakop Rivers. |
|-----------------------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|</p>
<table>
<thead>
<tr>
<th>Section</th>
<th>Minimum TDS (mg/l)</th>
<th>Mean TDS (mg/l)</th>
<th>Maximum TDS (mg/l)</th>
<th>Section</th>
<th>Minimum TDS (mg/l)</th>
<th>Mean TDS (mg/l)</th>
<th>Maximum TDS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sneyrivier - Ukuip</td>
<td>127</td>
<td>997</td>
<td>5,586</td>
<td>Spes Bona - Ameib</td>
<td>190</td>
<td>409</td>
<td>550</td>
</tr>
<tr>
<td>Rookuiseb - Hildenhof</td>
<td>466</td>
<td>2,906</td>
<td>6,830</td>
<td>Goabeb - Krantzberg</td>
<td>348</td>
<td>512</td>
<td>754</td>
</tr>
<tr>
<td>Palmenhorst - Birkenfeld</td>
<td>1,186</td>
<td>5,343</td>
<td>11,543</td>
<td>Usakos Suid - Vergenoeg sp.</td>
<td>1,141</td>
<td>3,911</td>
<td>7,141</td>
</tr>
<tr>
<td>Tannenhof - Nonidas</td>
<td>1,400</td>
<td>6,567</td>
<td>19,879</td>
<td>KEM3 - Rössing wellfield</td>
<td>4,343</td>
<td>4,797</td>
<td>5,399</td>
</tr>
<tr>
<td>Nonidas - Mile 5</td>
<td>15,352</td>
<td>23,550</td>
<td>31,458</td>
<td>Rössing wellfield - confluence</td>
<td>2,610</td>
<td>5,931</td>
<td>10,270</td>
</tr>
</tbody>
</table>

The results clearly show an increase in TDS correlated with distance travelled from the head waters to the coast for both of the rivers. It confirms similar results for the Swakop River found by the CSIR (NIWR, 1966). It is important to observe the large variations in quality, indicated by the maximum/minimum bars, that occur over time in the two rivers. In Section 4.3.2.4 above the difference in Khan water compared to that of the Swakop at the confluence was highlighted. However, when taking the long term mean, the water quality of the two rivers up to the confluence is similar. This again highlights the effect of seasonal and flood event influences on the average quality of the ground water in the two systems.

Samples from three newly drilled boreholes (Boreholes 1.10, 1.11 and 1.12) in the Khan River just upstream of the confluence (Rössing, 1996) show that the electrical conductivity in January 1997 (before the floods) was between 800 and 820 mS/m (5,100 and 5,250 mg/l). This is similar to the long term mean value but about half of what it was in the early 1960's.
Figure 4.15: TDS values for different sections of the Khan and Swakop Rivers
4.3.2.7 Ground water abstraction from the Swakop River

The larger ground water abstraction points along the Swakop River at the following places:

- Abstraction, mainly for irrigation purposes in the lower Swakop River is estimated to be in the region of 727,000 m$^3$/year (Strubenrauch Planning Consultant, 1992) in a wet season, increasing to 821,000 m$^3$/year during dry seasons. During the 1997 survey of the farms along the Swakop River, it was established that the present abstraction is of the order of 550,000 m$^3$/year.

- Records for the well field at Otjimbingwe, located approximately 225 kilometres upstream of Swakopmund, indicate an average abstraction rate of 170,000 m$^3$/year. Figure 4.16 shows the total annual production rate at Otjimbingwe based on records of 9 boreholes.

- There are no further records of significant ground water abstraction points along the Swakop River.

![Otjimbingwe Borehole Production](image)

**Figure 4.16:** Otjimbingwe Well Field Production

4.3.2.8 Water levels over time

The only continuous water level monitoring results that could be found were those of two boreholes in the vicinity of Haigamkab which were monitored between 30/12/69 and 15/11/74. During this period, two floods passed through this section of the river. These
boreholes show a continuous decline in the water level, interrupted by recharge events during floods (Figure 4.17). The recharge events are reflected in the sharp rises in water level and then a gradual decline towards the longer term trend and baseflow level.

No other continuous water level records exist and estimates of water level variations can only be made from single values reported during different surveys. These are captured in Figure 4.18. From this figure it is clear that the long term trend is one of declining water levels. A rough estimate of the average annual decline of the water level is 0.07 m/year. By comparing the 1957 levels with current (1997) observations in the sand mining pits, a lowering of at least 1.15 metres in the centre of the river over 40 years is recorded (0.03 m/year).

The generally declining trend of the water level with time, is attributed in part at least to the construction of the Von Bach and Swakoppoort dams, and the increased abstraction of water from the Swakop River at Otjimbingwe.

4.3.2.9 Evaporation and evapotranspiration losses

The followings areas and factors contribute to evaporation/evapotranspiration losses in the Swakop River:

- At Nonidas and the railway bridge outside Swakopmund large areas are covered with reeds and Tamarisk which leads to high evaporation losses.

- A geological structure located approximately 61 kilometres upstream of the Swakop confluence gives rise to a spring and wetland area. The proximity of vegetation has given rise to prolific reed bed growth. The rate of evapotranspiration from the reed beds is estimated to be in the region of 250 m³/ha/day.

- A similar reedbed is situated on the Swakop River at Riet, located approximately 120 kilometres upstream of Swakopmund.

- There are several hot springs in the Swakop River, namely at Klein Barmen, Gross Barmen and Okandu (Gevers, 1936). In certain isolated areas, the springs are considered to recharge the regional water aquifer although the net contribution is believed to be negligible. Several wetland areas occur along the Swakop River, the increase in salinity towards the coast is considered to be largely attributable to the evaporation which takes place in these areas.
Figure 4.17: Continuous water level record from Haiganqab showing effect of recharge events.
Figure 4.18: Water levels in the Lower Swakop River over the period 1957 to 1997.
4.3.3 Current state of knowledge of the geohydrological conditions of the Khan River alluvial aquifer

Following on the proposal by Marais (1989) a series of investigations were started culminating in a large number of reports by Rössing and others (CGS, 1989; Marais, 1990, Corner, 1995; Gordon McPhail and Associates, 1995; Kehrberg 1995; Kehrberg 1996a; 1996b; 1996c; 1996d; 1996e). The most extensive studies of the geohydrology of the Khan River were done by staff from Rössing Uranium Limited. These reports contain the results of geohydrological investigations carried out at the mine since its start up to 1996, and summarize the current state of knowledge on the aquifer. This was followed by a report reviewing all available hydrogeochemical information (Kehrberg, 1997).

4.3.3.1 Aquifer geology and geometry

The bedrock of the Khan River at Rössing Mine consists of meta-sediments of the Nosib and Swakop Group of the Damara Sequence. The rock types are mainly schists of the Kuiseb Formation as well as marble, quartzite and tillite of the Karibib and Chuos Formations. The Khan River course generally follows the strike of the formations, and where it cuts across the strike, hard layers like marble bands can create bedrock barriers that subdivide the alluvial aquifer into "compartments".

The alluvium in the river bed comprises coarse gravel with minor silt layers near the surface. These sediments can be up to 25 metres thick, though they normally average about 18 metres in depth. The sand is composed of quartz, feldspar, mica and rock fragments and varies from medium to very coarse and exhibits poor sorting, often with angular to sub-rounded grains. The gravels vary from pebbles to boulders and can be sub-rounded to rounded. Silt deposits are prominent in recent terraces where they are inter-layered with thin sand and pebble bands. The silt deposits cause a thin layering in the alluvium which leads to a reduced hydraulic conductivity in a vertical direction.

Deposition of silty material by flood waters in the Khan River has a significant impact on aquifer recharge. It appears that the silt load in the rivers draining the escarpment, has increased in recent years due to the deteriorating soil conditions in the catchment areas. This is a reason for concern in terms of the natural and artificial ground water recharge.

Unlike the Omaruru or Kuiseb rivers the Khan River does not form a deep erosional channel or delta. The sediments of the Khan aquifer have an average thickness of less than 20 metres with a grain size much coarser than those of the Kuiseb or Omaruru rivers. This results in a high hydraulic conductivity and consequently, a high throughflow rate and, therefore, fast draining of ground water from the aquifer.
In 1989, Groundwater Consulting Services conducted a detailed auger drilling programme over nearly 13 kilometres of river bed opposite the mine on behalf of RUL to determine the aquifer geometry. Using the 1995 water levels and a storage coefficient of 0.22, it was calculated that the 13 kilometre long aquifer section could store a maximum of approximately $3.73 \times 10^6$ m$^3$ of water. This is 44% less than the volume calculated earlier.

### 4.3.3.2 Aquifer parameters

From pumping tests done over the years by the DWA and Rössing, as well as a water balance, 200 metres/day was determined as being representative of the permeability of the aquifer in the Khan river. This value was used to determine the rate of throughflow across the average cross-sectional area of 1,250 m$^2$ at varying water levels. This is graphically depicted in **Figure 4.19**.

![Graph](image)

**Figure 4.19:** Relation between rate of ground water throughflow and water level below surface.

Using the throughflow, average cross-sectional area of the channel and the gradient of the water level, the permeability is calculated to be 219 metres/day. From this a Darcy velocity of 1.2 metres/day or 438 metres/year, and a true velocity of 5.6 metres/day or 2,000 metres/year is derived.
4.3.3.3 Recharge and 'safe yield' of aquifer

Over the period 1986 to 1994, the average baseflow was only 1,300 m³/day, whilst the abstraction was 1,990 m³/day. The additional 690 m³/day is interpreted as having being drawn from water derived from the natural recharge to the system from surface flood events. Previously this was regarded as part of the safe yield of the aquifer, and for that reason the safe yield of most of Namibia's alluvial aquifers have been over-estimated. The result is rapidly dropping water levels as is evident from the abstraction vs water level over a 10 year period shown in Figure 4.20. It is clear that recharge failed to materialise over this period.

![Graph showing annual ground water abstraction at Rössing vs average water level over the period 1985 to 1995 (From Kehrberg, 1996d)](image)

**Figure 4.20:** Annual ground water abstraction at Rössing vs average water level over the period 1985 to 1995 (From Kehrberg, 1996d)

4.3.3.4 Ground water reserves

Rössing has developed a spreadsheet model to calculate the monthly available water reserves in the alluvial aquifer over a 15 kilometre section of the aquifer opposite the mining area. This model accepts that the aquifer is empty when the water level has dropped to below the 15 metre level set by DWA. Maximum reserves are when the water level is at surface over the entire length of the aquifer. For the model the aquifer
is divided into 5 sub-compartments 3 kilometre length, each with a cross-sectional area of 1,250 m². Water levels measured within each of these sections are taken as being representative of that section, and the volume for that section is calculated. The reserve available for abstraction at any time is taken as the sum of each segment. For aquifer management purposes this determination is done on a monthly basis, and pumping schedules adapted accordingly.

Water levels in relation to the pumping rate since 1991 is shown in Figure 4.21. The flattening off of the water level since the beginning of 1996 when the pumping rate was on average about 20,000 m³/month, was indicative of the sustainable yield of the aquifer at that time. If the pumping rate exceeds the baseflow of the aquifer, water levels decline accordingly.

4.3.3.5 Ground water quality and contamination

Ground water quality at the mine has been analyzed sporadically during the exploration and early phases of the mine. When Rössing started to operate its tailings dams, monitoring of water quality was done more regularly. Several analyses for the period 1967-1974 are available from three wells in the Khan River between Dome Gorge and Panner Gorge. During this period one small and one medium size flood occurred. These can be regarded as base line or pre-mining ground water quality data for this section of the Khan. The 1966, CSIR study of the Swakop River included boreholes in the Khan River at the confluence with the Swakop River (NIWR, 1966). The maximum and minimum concentration (TDS values in mg/l) over the period 1967 to 1974 are given in Table 4.7.
Figure 4.21: Water levels in relation to pumping rates at three production boreholes
### Table 4.7: Water quality variations in boreholes with time.

<table>
<thead>
<tr>
<th>Borehole/element</th>
<th>Old well</th>
<th>New well</th>
<th>Basement rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS Max.</td>
<td>6 424 (1974)</td>
<td>6 280 (1968)</td>
<td>8 550 (07/68)</td>
</tr>
<tr>
<td>TDS Min.</td>
<td>4 465</td>
<td>2 321 (1974)</td>
<td>1 800 (01/76)</td>
</tr>
<tr>
<td>Na Max.</td>
<td>1 465</td>
<td>1465 (1968 &amp; 74)</td>
<td>1 465 (07/68)</td>
</tr>
<tr>
<td>Na Min.</td>
<td>1 169</td>
<td>1 220 (1971)</td>
<td>495 (01/76)</td>
</tr>
<tr>
<td>K Max.</td>
<td>70</td>
<td>76 (1968)</td>
<td>120 (07/68)</td>
</tr>
<tr>
<td>K Min.</td>
<td>60</td>
<td>35 (1974)</td>
<td>12 (01/76)</td>
</tr>
<tr>
<td>SO(_4) Max.</td>
<td>890</td>
<td>900 (1968)</td>
<td>2 280 (07/68)</td>
</tr>
<tr>
<td>SO(_4) Min.</td>
<td>539</td>
<td>390 (1974)</td>
<td>157 (01/76)</td>
</tr>
<tr>
<td>NO(_3) Max.</td>
<td>44</td>
<td>44 (1968)</td>
<td>128 (07/68)</td>
</tr>
<tr>
<td>NO(_3) Min.</td>
<td>0</td>
<td>0 (1968)</td>
<td>4 (01/76)</td>
</tr>
<tr>
<td>F Max.</td>
<td>2.5</td>
<td>1.5 (1968)</td>
<td>3.5 (03/66)</td>
</tr>
<tr>
<td>F Min.</td>
<td>1</td>
<td>1 (1974)</td>
<td>1 (12/71)</td>
</tr>
<tr>
<td>Cl Max.</td>
<td>3 000</td>
<td>3 100 (1968)</td>
<td>3 150 (07/68)</td>
</tr>
<tr>
<td>Cl Min.</td>
<td>2 520</td>
<td>860 (1974)</td>
<td>950 (01/76)</td>
</tr>
<tr>
<td>Tot. alk. Max.</td>
<td>295</td>
<td>343 (1974)</td>
<td>245 (03/66)</td>
</tr>
<tr>
<td>Tot. alk. Min.</td>
<td>215</td>
<td>220 (1968)</td>
<td>62 (01/76)</td>
</tr>
</tbody>
</table>

From this table it is evident that large variations do occur and that no clear pattern in terms of when maximum and minimum values occur, is visible. Water quality in the basement rocks and upstream of the mine also shows large variations in concentration through time. No clear correlation between drought/recharge periods and concentration emerges.

By comparing the water quality in the two Rössing boreholes, BH 1.4 (upstream of Dome Gorge) and BH 1.6 (downstream of Panner Gorge), through time, it is clear that seepage originating at the mine, has at times in the early 1980's, reached the Khan River. Major flood events, and in particular the 1985 flood, shows that during such events, significant dilution occurs and water quality returns to close to ambient levels again. Good examples of this are NO\(_3\), TDS and uranium concentrations at boreholes BH 1.4 and BH 1.6 (Kehrbarg, 1996). Seepage control systems installed during the mid 1980's were effective in controlling the seepage from the mine workings and improvements in quality resulted. This is also confirmed by recent stable isotope studies (Talma & Meyer, 1997).
Nitrate concentrations

High concentrations, as well as large fluctuations, of nitrate concentrations occur in ground water of the Khan River and its tributaries. These variations are seen both upstream and downstream of the mining area. Historical records indicate that these variations can be attributed to a number of causes. These include geological/biological conditions in the catchment, floods in the Khan river and mining. It is, however, difficult to appropriate the contribution in time and concentration to the different sources.

From the published data by Huyser (1982a, 1982b) and Goetze (1982), it is evident that nitrate concentrations in the region of 100 mg/l (and even as high as 522 mg/l) values is common for the Khan River catchment upstream of Rössing. In the international literature several references can be found for the natural accumulation of nitrate in ground water under natural conditions through fixation of nitrogen by specific plant species, notably the Acacia spp. (Tredoux, 1993). Geological formations as such are not considered as the primary origin of nitrates in ground water, but that they exercise a “secondary” control on the concentration (Tredoux, 1993; Heaton, 1985). Permeable formations, such as unconsolidated sands of the Kalahari and alluvial river beds, provide the conditions for the formation and leaching of nitrates.

In BH 1.4, upstream of Dome Gorge, for example a steady increase in NO₃ concentration occurred between 1979 and 1981, followed by a decrease to ambient levels by 1990. A similar situation was seen at BH 1.6. This pattern repeated itself during the period 1990 to 1995, but in the case of BH 1.6, the decline to ambient levels appears to be much slower. At this borehole the sulphate concentrations also increased between 1991 to 1995 in sympathy with the nitrate. The question arises to what extent the Rössing mining activities contribute to the nitrate concentrations in the ground water of the Khan River.

Ground water samples from a number of boreholes were analyzed for their nitrogen isotope concentrations to establish the most likely source of nitrate as part of the KARS EIA project. Although the results were not conclusive, the values suggest that most of the nitrate is derived from the bacterial decay of animal and human wastes, or that the natural nitrate concentration of the water is being reduced by denitrification, thereby causing higher nitrogen isotope concentration (Talma and Meyer, 1997). Based on available information, the high nitrate values appear not to originate at the mine.

TDS ratio

Evaluation of the water quality since 1989 indicated a steady increase in the total salt content (TDS). The TDS ratio between boreholes BH 1.6 and BH 1.4 for example increased from 0.8 to 1.2, with fluctuations of a similar order in between. Several factors could have contributed to this situation. These include seepage from the mining
operations, decreased baseflow due to overabstraction in the well field and thus less dilution and little recharge as a result of no significant flood events. To investigate the possible contribution from seepage, stable isotope analyses (\(^{16}\)O and deuterium) were done on 25 samples from the Khan River and its tributaries. The samples collected in the tributaries (Khan Mine, Panner, Pinnacle and Dome Gorges) all showed evaporated signatures, whereas those in the Khan River did not. From these results it is concluded that there is no evidence that significant amounts (> 10 %) of stable isotope enriched water from the mining operations, contributes to the ground water in the Khan River (Talma & Meyer, 1997).

_Uranium concentrations_

During March 1997 ten water samples, collected from boreholes in the Khan River and gorges leading to the Khan River, as well as samples from tailings seepage were analyzed for uranium concentration and isotope analyses. The objective was two-fold. Firstly, to determine the uranium concentrations in ground water around the mine, and secondly, to establish whether any indication of contamination from uranium has occurred in the past. The radioactivity of each sample was determined by alpha spectrometry according to a technique described by Kronveld & Vogel (1991).

The Central Namib Area is known to have high levels of uranium in the surface layers of the peneplain. This uranium is probably derived from the weathering of uranium bearing rocks in the area. High levels of dissolved uranium in the ground water and in the river beds thus do not necessarily indicate uranium pollution caused by modern mining activity. Uranium derived from freshly ground rock can, however, be distinguished from uranium dissolved during natural weathering of surface rocks meaning the activity ratio of the uranium isotope \(^{238}\)U and its daughter isotope \(^{234}\)U.

Under natural conditions dissolved uranium has an activity ratio, \(^{238}\)U/\(^{234}\)U > 1, while uranium dissolved from freshly broken rock shows a ratio equal to 1 (Kronveld & Vogel, 1991). By determining this activity ratio in the water samples around the mine, should thus show the extent of any uranium pollution from the mining activity (Oshadleus & Vogel, 1997). The sample descriptions and the results of the analyses are listed in Table 4.8. The sampling positions are indicated on Figure 4.22.

As is to be expected, the two samples draining the tailings dam directly have the highest uranium concentrations, viz. 2.7 and 4.1 ppm. The isotope activity ratios also show the signature of freshly leached uranium (value close to 1). The local streams draining into the Khan River have considerably higher concentrations compared to the Khan River water. The high concentrations are as a result of presence of uranium orebodies. Borehole 1.9 is a typical example, where chemical weathering explains the high concentration of 1.2 ppm and the relatively low activity ratio of 1.150 ± 0.013. The latter is nevertheless distinctly different to the ratios obtained for the polluted ground water. The activity ratios in water sampled in the other Gorges are statistically indistinguishable from those in the Khan River (~1.3).
Table 4.8: Uranium activity ratios and concentrations in water samples from Rössing.

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Date sampled</th>
<th>Description</th>
<th>$^{234}\text{U} / ^{238}\text{U}$</th>
<th>U (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRK1</td>
<td>12/03/97</td>
<td>Ground water from tailings</td>
<td>1.001±0.013</td>
<td>2.711±0.090</td>
</tr>
<tr>
<td>Seepage dam</td>
<td>12/03/97</td>
<td>Surface seepage from tailings</td>
<td>0.996±0.006</td>
<td>4.05±0.065</td>
</tr>
<tr>
<td>Pinnacle trench</td>
<td>12/03/97</td>
<td>Ground water in alluvium of Pinnacle Gorge downstream of tailings dam</td>
<td>1.297±0.019</td>
<td>0.835±0.029</td>
</tr>
<tr>
<td>Panner Trench</td>
<td>12/03/97</td>
<td>Ground water in alluvium of Panner Gorge</td>
<td>1.272±0.023</td>
<td>0.333±0.010</td>
</tr>
<tr>
<td>Borehole K</td>
<td>12/03/97</td>
<td>Ground water from Dome Gorge at confluence with Khan</td>
<td>1.296±0.044</td>
<td>0.693±0.051</td>
</tr>
<tr>
<td>Borehole 1.9</td>
<td>11/11/96</td>
<td>Southern tributary of Khan draining known uranium orebody site</td>
<td>1.150±0.013</td>
<td>1.210±0.019</td>
</tr>
<tr>
<td>Transect 0</td>
<td>10/03/97</td>
<td>Khan ground water upstream of mine</td>
<td>1.295±0.021</td>
<td>0.128±0.002</td>
</tr>
<tr>
<td>Transect 5</td>
<td>10/03/97</td>
<td>Khan ground water downstream of mine</td>
<td>1.320±0.031</td>
<td>0.129±0.004</td>
</tr>
<tr>
<td>Haigamkab</td>
<td>10/03/97</td>
<td>Swakop ground water upstream of Khan confluence</td>
<td>1.511±0.089</td>
<td>0.033±0.002</td>
</tr>
<tr>
<td>Palmenhorst</td>
<td>10/03/97</td>
<td>Swakop ground water downstream of Khan confluence</td>
<td>1.408±0.051</td>
<td>0.120±0.005</td>
</tr>
</tbody>
</table>

The uranium content in the Swakop River bed (0.033 ppm), increases downstream of the confluence with the Khan River to 0.120 ppm and the isotope activity ratio decreases accordingly, reflecting the water contribution from Khan to the Swakop.

The conclusion reached by Oschadleus and Vogel (1997). Is that insignificant amounts of uranium polluted water has reached the sampling points in Panner, Pinnacle or Dome Gorges as well as the Khan River. The measure installed to prevent polluted water from the tailings dam to reach the Khan River have, thus far, been successful. There is no evidence of uranium pollution being added to the water environment by Rössing activities, although the background uranium concentrations in the area are, due to geological reasons, higher than normal.

In an analysis of all historic ground water quality information by Kehrberg (1996), it was concluded that in the case of Panner Gorge, that the contribution by lateral inflow towards the Khan River is dominant compared to the effect from abstraction. This was attributed to insufficient seepage control measures. However, the effects of major flood events like the 1985 for example, in general result in marked improvements in water quality. Therefore, the KARS project, during which substantial volumes of good quality
water will be infiltrated into the aquifer downstream of the KARS dam, will have the added advantage of improving the water quality in the mining front.

4.3.4 Ground water utilisation patterns and water level variation with time

Ground water abstraction occurs along various sections of the Khan alluvial aquifers. The more important ones, in terms of volumes abstracted are:

- Rössing Khan Wellfield
  In 1977, Rössing started to abstract water form the Khan River alluvial aquifer. According to DWA permit, conditions a maximum abstraction of 870,000 m³/year is allowed. A subsequent amendment to the permit set a provisional drawdown limit of 15 metres, with the proviso that vegetation monitoring should be done on a regular basis. However, due to declining water levels, DWA recommended in 1995 that only 600,000 m³/year be abstracted. The total annual ground water abstraction is listed in Table 4.9.

Seven production boreholes, BH 1, BH 2, BH 5, Bh 7, BH 8, BH 9 and BH 10, are currently in use. These are spread over approximately 10km of river bed from Panner Gorge to about 4 km upstream of Dome Gorge (Figure 4.22). All boreholes are equipped with electrically driven submersible pumps operating on a 24h/day schedule. Abstraction levels are automatically controlled not to drop below 15 metres below ground surface. Typical long term water level response of three of the boreholes is illustrated in Figure 4.23. The cut back in abstraction rate and the effect it had on the declining water level, is clearly visible at boreholes 6 and 1.6 (Kehrberg, 1996).

- Spes Bona, located approximately 35 kilometres upstream of Amieb. Annual production figures supplied by the Department of Water Affairs indicate an average abstraction rate of 79,800 m³/annum. The abstraction rate has decreased significantly since 1990 as shown in Figure 4.24.

- A third well field operates at Usakos. Records of production rates indicate an average abstraction of 119,000 m³/annum but decreasing in recent years as shown in Figure 4.25, to an abstraction rate of 14,355 m³ in 1996.
Figure 4.23: Long-term water level response of three Rössing production boreholes.
Table 4.9: Total annual ground water abstraction volumes at Rössing.

<table>
<thead>
<tr>
<th>Year</th>
<th>Ground water consumption (x10^6m³)</th>
<th>Year</th>
<th>Ground water consumption (x10^6m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>0.5</td>
<td>1987</td>
<td>0.8</td>
</tr>
<tr>
<td>1978</td>
<td>0.3</td>
<td>1988</td>
<td>1.0</td>
</tr>
<tr>
<td>1979</td>
<td>0.3</td>
<td>1989</td>
<td>0.9</td>
</tr>
<tr>
<td>1980</td>
<td>0.3</td>
<td>1990</td>
<td>1.0</td>
</tr>
<tr>
<td>1981</td>
<td>0.2</td>
<td>1991</td>
<td>0.9</td>
</tr>
<tr>
<td>1982</td>
<td>0.4</td>
<td>1992</td>
<td>0.9</td>
</tr>
<tr>
<td>1983</td>
<td>0.3</td>
<td>1993</td>
<td>0.4</td>
</tr>
<tr>
<td>1984</td>
<td>0.2</td>
<td>1994</td>
<td>0.6</td>
</tr>
<tr>
<td>1985</td>
<td>0.2</td>
<td>1995</td>
<td>0.7</td>
</tr>
<tr>
<td>1986</td>
<td>0.4</td>
<td>1996</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Figure 4.24: Spes Bona Wellfield Production
Figure 4.25: Usakos Well Field Production

4.4 General ecological characteristics

During the first 60 years of the Twentieth Century very little attention was paid to the biology of the Namib Desert and most of the observations relate to those areas to the west and south of the present Rössing Uranium Mine. Since the early 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. The ecological characteristics and any unique features of the habitats or organisms of the region around the Rössing Uranium Mine were largely unknown 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. This was followed in 1990-91 by the compilation of an internal detailed Environmental Impact Statement (EIS) for the Rössing Uranium Mine (Ashton et al., 1991). This EIS used appropriate portions of earlier published information, supplemented with studies made by the State Museum staff and personal observations to compile a description of the environmental conditions that prevail around the Rössing Uranium Mine. The descriptions of the biotic environment listed here are based on the earlier work by Ashton et al. (1991).
4.4.1 Vegetation

4.4.1.1 Regional distribution patterns

The Namib Desert comprises a relatively narrow tract of land, some 2,000 kilometres long and mostly less than 200 kilometres 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).

The Rössing Uranium Mine is located towards the eastern edge of the Central Namib vegetation zone. 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. The extent of each vegetation zones is largely determined by altitude and the regional rainfall patterns (Geiss, 1971; Brown et al., 1985; Huntley, 1985).

Although botanists (e.g. Geiss, 1971) regard the Central Namib 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 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). The plant species recorded at Rössing by Craven (1986) are listed in Appendix 1.

Close to the coast, there is a narrow (approximately 200 metres 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 stapfii and Arthraeura leubnitziae the predominant species. These two species often occur as single specimens, widely spaced on the gravel flats (Craven & Marais, 1986). The extensive gravel and gypsum flats, located further inland but still relatively close to the coast, are in places densely covered with lichens, which are usually attached to small fragments of stone or flakes of gypsum crust. Arthraeura leubnitziae often forms relatively dense stands in the shallow depressions and gullies, as well as on the slopes of low ridges.

The vegetation found in shallow depressions, dry water courses and small river beds becomes progressively denser with increasing distance from the coast (Geiss, 1971). Shrub forms of Acacia reficiens occur within about 30 kilometres of the coast and Asclepias buchenaviana is widespread. White desert grasses are especially plentiful.
after the sporadic rainfalls, with several annual species of *Stipagrostis* the most conspicuous and common (Muller, 1983). Further eastwards, grass plains develop between the true desert and the Escarpment. Large numbers of annual plants appear after rainfalls and completely transform the vegetation of this region (Craven & Marais, 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 in the western portion of this zone at the foot of the escarpment. This vegetation 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 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 and function as linear oases. Species that are more characteristic of the Escarpment Zone 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 most common tree species found along these river beds are: *Acacia erioloba*, *Faidherbia albida*, *Tamarix usneoides*, *Euclea pseudobemus*, *Ziziphus mucronata*, *Salvadora persica* and *Prosopis glandulosa* (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). The size of individual trees and the numbers of trees per unit area is influenced by their position relative to flood pathways and silt deposits. 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, the river beds are also colonized by several species of annual plants whose seeds have been washed down from the Escarpment by floods. These plants are mostly short-lived species and are only plentiful shortly after floods or rainfalls (Craven, 1986).

4.4.1.2 Seasonal changes

Sporadic rainfalls bring about the most obvious seasonal changes in the vegetation. While the effects of these events has already been mentioned above (Section 4.4.1.1), their importance to the vegetation of the Central Namib Desert cannot be over-emphasized.

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

Summer rainfalls on 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 *Faidherbia albida*, have shown that most riverine populations are composed of distinct cohorts. Each cohort consists of trees of virtually equal age (Ward & Breen, 1983; Theron et al., 1985; Hydrology Division, 1988), reflecting 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.

### 4.4.1.3 Aquatic vegetation

The only truly aquatic higher plants recorded from natural surface water sources in the Rössing area are the emergent sedges and reeds, *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 "Pietse-Gat", the only natural pool near the Rössing Uranium Mine (Archibald, 1987). Archibald found 15 species of diatoms, noting that large numbers were present despite the low species diversity. This situation is typical of 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 (Schoeman & Archibald, 1988).

### 4.4.1.4 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.

Rivers have long been known to act as corridors of dispersal for vegetation, particularly in regions of high rainfall. In the arid 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 other mechanisms of seed dispersal and climatic conditions, particularly the availability of rainfall. In the virtual absence of rainfall so characteristic of the Central Namib Desert, populations of invasive species remain confined within the river beds where they compete with indigenous species for the available habitat.

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).

4.4.2 Fauna

4.4.2.1 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. 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. A list of mammals that are known to occur in the Central Namib Desert and which may occur in the Sub-region is given in Appendix 2.

Klipspingners 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 mountain zebra are occasionally seen at wet areas along the Khan River, while Rock dassies (Procavia capensis), Black-backed jackal (Canis mesomelas) and troops of Chacma baboon (Papio ursinus) have been seen in Panner and Pinnacle Gorges (James, 1985).
4.4.2.2 Small mammals

Four species of shrew, eight 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; Appendix 2). 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.

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 Namibia off early sailing ships, but its distribution appears to have been confined to coastal ports (Griffin & Panagis, 1985).

4.4.2.3 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 bird 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 bird 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.

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. A total of 75 species were recorded, of which 21 were associated with artificial waterbodies (Appendix 3). Nine species of bird were thought to be breeding in the area (Colahan, 1987).
4.4.2.4 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 Appendix 4. An additional 7 to 10 species are also expected to occur in the area around the mine and one species new to science has been described from the nearby Husab Mountains (Berger-Dell'mour, 1989).

Greig and Burdett (1976) noted that four genera of tortoises have been recorded from Namibia, but these authors consider that the records of at least one of those genera is open to question. 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.

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).

4.4.2.5 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.

4.4.2.6 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 more than 200 species of endemic tenebrionid beetle
in the Namib Desert Park (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. Seven new insect
species have been described from these collections. 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 is given
in Appendix 5.

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

4.4.2.7 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 5,000 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). Ten new species of spiders have been described from the
Rössing area (Appendix 6).
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.

4.5 Occurrence of building sand in the lower Swakop River bed

4.5.1 Recent geology

Near the coast the Swakop River is incised into marbles of the Damara Sequence. The incision is due to epeirogenic uplift towards the end of the Tertiary about 5 Ma BP (Ward, 1987). The banks of the river show terraces deposited and eroded during the Quaternary (Pleistocene period) between 2 Ma and 10,000 BP. Six terraces have been distinguished by Rust and Wiencke (1976). The top 3 metres of the present river sediment is of Holocene (< 10,000 years BP) age (Woodbourne et al., 1997).

4.5.2 Luminescence and radiocarbon dating

During March 1997 samples of the sediments occurring in the river bed were collected for age dating, in order to assess the nature of sedimentation at the mouth of the Swakop River. Samples were taken from four locations, three of which were in close proximity approximately 2 kilometres from the present coastline. The fourth location is approximately 10 kilometres inland. A total of 6 sediment samples were taken for luminescence dating, and one for radiocarbon dating.

Three major sedimentary units were recognised. The basal unit comprising horizontally or slightly cross-bedded silt with a slight orange colouring deposited on bedrock. This was defined as Member 1. Subsequent scrutiny of the section photographs showed two distinct layers within Member 1. The upper was horizontally bedded while the lower was cross-bedded. These were respectively designated Members 1B and 1A. This distinction could not be made in every exposure that was studied. The intermediate sedimentary unit comprises a coarse cross-bedded deposit that is grey in colour with numerous pebbles in the bedding planes. This was designated Member 2. The uppermost unit is also a pale orange silt that was designated Member 3. The stratigraphy appeared to be consistent over a widespread area at the river mouth, and was also found in exposures several kilometres inland. The relative thickness of the Members varied but at the main point of sampling Member 3 was approximately 40 cm thick, Member 2 was approximately 50 cm thick and Member 1 was approximately 150 cm thick.

The grain size distribution of the these sediments compare with Rust & Wiencke’s (1976) characterisation of sediments from different environmental settings and confirms that the sediments are all fluvial in origin (Woodbourne & Vogel, 1997).

The results from the TL dating are given in Table 4.10.
Table 4.10: Sediment dating results.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Stratigraphic unit</th>
<th>Date (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWM 4</td>
<td>MEMBER 3</td>
<td>&lt;200</td>
</tr>
<tr>
<td>SWM 1</td>
<td>MEMBER 2</td>
<td>340±40</td>
</tr>
<tr>
<td>SWM 2</td>
<td>MEMBER 1B</td>
<td>8 750± 600</td>
</tr>
<tr>
<td>SWM 3</td>
<td>MEMBER 1A</td>
<td>9 300±350</td>
</tr>
<tr>
<td>Pta 7325</td>
<td>MEMBER 2</td>
<td>80±20</td>
</tr>
</tbody>
</table>

4.5.3 Sedimentation regime of the Swakop River

4.5.3.1 Historic evidence of erosion and deposition

Massive amounts of sediment were deposited in the sea and in the river mouth by the 1963 flood and in particular by the 1934 flood. The volume of the 1934 flood deposit is calculated as 40,000,000 m³. This caused a rapid progradation of the beach until it was approximately 1000 m from the 1930 beach, while at the same time a uniform blanket of sediment up to 2.5 metres thick was deposited in the river bed. The 1963 flood deposited 4,500,000 m³ of sediment, prograded the beach by approximately 100 m and deposited approximately 1 metre of sediment in the river bed. It is assumed that the 1893 flood, which carried at least 75 % of the volume of the 1934 flood and 160 % of the volume of the 1963 flood, would also have deposited a large quantity of sediment, but no record of this could be found.

Between 1934 and 1963 the delta that was formed by the 1934 flood was eroded away, and between 1963 and the present the delta that was formed by the 1963 flood has eroded away. This is the result of wave attrition and longshore transport of the sediment. At the same time the flood deposits in the river also eroded away. Flood protection on a borehole constructed in the river bed in 1957 (R. Schneeweiss personal communication) establishes the level of the sediment at the time. This is at or near the present sediment level, which implies that the 1963 deposits have been eroded down to approximately the 1957 levels. It also suggests that the 1934 deposit had eroded to approximately the current level by 1957. Further evidence for this can be found in the design of telegraph poles that were installed in the river bed. The precise date of this construction has not been established but it must predate the 1934 flood since it appears on the 1930 survey of the river bed. The poles have a cylindrical foundation that penetrated the sand to the bedrock. On top of this the telegraph pole was set into a concrete base that was designed to provide flood protection. Presumably when the structure was designed the junction between the flood protection architecture and the cylindrical pylon was at or near the surface of the river sediment. The 1934 flood subsequently deposited sufficient sediment to bury the flood protection to a depth of
approximately 1 metre. The junction is presently about 2.5 metres above the river bed. This confirms that erosion has occurred on a large scale between 1934 and the present notwithstanding the depositional event of the 1963 flood.

The only way in which the sediment could erode is during flooding events. It may be concluded that "large" floods, such as those of 1934 and 1963, deposit sediment in the river bed, and "small" floods, such as the 11 floods that reached the Atlantic Ocean between 1934 and 1963, erode the deposit from the river bed. All the floods deposit their sediment load when they reach the sea and prograde the beach in the short term. In the intermediate term the average rate of wave attrition of the beach exceeds the average rate of progradation from small floods. If this were not the case the beach would progressively prograde.

The extent of erosion in the river bed is of interest. It appears as if the pre-1934 sediment level was very similar to the pre-1963 level (marked by the level of the 1957 borehole). A railway line constructed across the river after the 1930 flood washed away the railway bridge, is also found buried in these deposits at the interface between Members 2 and 3. Altogether these observations suggest that the surface of Member 2 marks a basal erosion level in the river sediments.

4.5.3.2 Dating evidence

The radiocarbon age on sample SWM 7 from the upper surface of Member 2 is 80 ± 20 (Pta 7,325). The equivalent date taking into account $^{14}$C calibration is 1,900 AD. The date is unique in that, for technical reasons, it could not be from a tree that grew for many years, but was rather from a short lived species. Because old material may be found on the landscape it is assumed that the subsequent sedimentary layer, Member 3, was deposited some time after 1900 AD. This suggests that the upper surface of Member 2 was exposed sometime after 1900 AD. A likely scenario is that it was the erosional base that had been reached before the 1934 flood. It may be argued that the sample was not incorporated into the deposit during a flood, but instead it was deposited on the sediment surface at the time. This does not affect the interpretation of the date.

The luminescence date on sample SWM 1 from the base of Member 2 is 340 ± 40 (Pl 0108). The sample is from a relict barkhan dune that invaded the river bed from the south and was trapped and preserved under deposit laid down by a flood at that time. The sediment in mobile barkhan dunes is extensively exposed to sunlight and has a zero luminescence age when deposited so that this date is believed to be an accurate reflection of the date of the flood that buried the dune.

The dates for Member 2 indicate that this layer was deposited between 350 and a little less than 100 years ago. The member has some internal structure that indicates several events contributed to the formation. It is suggested that Member 2 represents a series of exceptionally large floods that occurred in previous centuries. It is also a layer that by virtue of being "untransportable" in small floods represents the basal erosion level that
the river can reach under its present energy regime. A further point that can be made on
the basis of the Member 2 dates is that the 1934 flood, which is the biggest ever recorded
in the Swakop River, contributed very little to the accumulation in this Member. The
floods that in the last 350 years have contributed the bulk of this Member must have
been massive, even in comparison with the 1934 flood, and possibly more numerous.

The luminescence age on sample SWM 4 from Member 3 is less than 200 years (Pl
0110). This sample is also alluvium, and the spread in age determinations between 200
and 350 years on five different age determinations suggests that this sample was not
sufficiently zeroed by sunlight exposure prior to deposition. In general the dating of
alluvium of such young age is considered problematic for luminescence techniques. The
age is therefore considered to be less than 200 years based on the analysis, but it is in
reality less than 100 years on the basis of its stratigraphic relation to SWM 7.

The luminescence date on sediment sample SWM 2 from Member 1B at the top of
Member 1 is 8 750 ± 600 years (Pl 0109) while SWM 3 from Member 1A at the bottom
of Member 1 is 9 300 ± 350 years (Pl 0111) Member 1 is alluvial sediment, presumably
deposited by a "large" flood. It is possible that the grains may have a residual
luminescence age before deposition. As in the case of SWM 4, a large standard deviation
on the date for these layers supports this, but the error that occurs is likely to be less than
a few hundred years and is considered insignificant on a samples of such antiquity. The
true age of deposition for Member 1 may be a little less than 9,000 years.

4.5.4 Conclusions

The sedimentary history of the Swakop River mouth can tentatively be deduced from a
combination of historical records and dating evidence. These suggest that the river has a
relatively high sedimentation and erosion rate. Whether sediments erode or are
deposited is dependent on the size of any particular flood. "Large" floods deposit large
amounts of sediment uniformly over the river channel. "Small" floods erode the
sediments. The dating evidence suggests that a substantial flood occurred approximately
350 years ago. At this time very coarse gravel layers, indicative of substantially higher
ergy levels than the 1934 flood, were deposited. Since that time it has been a barrier
against erosion and the depositional and erosional cycles in the river bed all take place
above this.

4.5.5 Sand mining activities

The mining of building sand from the river bed started around the 1980's by which time
about 6 hectares had already been affected (1980 Orthophotos). This activity has
increased substantially and now also takes place on or near the farms Lilofo, Richthofen
and in the river bed near Nonidas.
Mining takes place in an uncontrolled, unpermitted and unmanaged manner. The top layers of sediment are removed to get rid of roots, and then the next 2.5 to 3 metres is mined as building sand. Excavations usually stop about 0.5 metres above the water table.

4.5.5.1 Present sand mining areas

Swakop Mouth area

Apart from the 1980 orthophoto maps, no surveyed information on the mining activities exists. Areal photography of the mining area was done after the second flood of the 1996/97 season. Based on field observations and areal photography, it was established that a surface area of 11 hectares has been affected and that 230,000 m$^3$ had been mined out. During the relatively small floods of early 1997, approximately 18,000 m$^3$ of sand has been eroded and 56,000 m$^3$ represents the volume that has either been redeposited and/or brought down by the new floods. It was also established that should the ground water level rise above the pit floor, and area of 81,500 m$^2$ will be exposed to evaporation. The area affected by mining has been mapped in March 1997 and the different units identified are shown on Figure 4.26.

Farm area

In the farm area approximately 13 hectares has been affected by sand mining to an average depth of 2.5 metres has occurred. The total volume mined is estimated at 247,000 m$^3$ and should the water level rise to above the pit floor, an area of 51,000 m$^2$ will be exposed to evaporation. Strong erosion has occurred in these areas during the 1997 floods resulting in long and narrow approximately 1 metre deep dongas. In the downstream areas large sections have been filled to nearly its original level by silt and sand deposited by the recent floods (new and eroded material).

4.6 Swakopmund beaches and the dunefields to the south of the Swakop River

To the south of the Swakop River and on the landward side of the road to Walvis Bay, a few hundred metre wide permanent dune field is established. By comparing the 1966 aerial photography, 1982 orthophoto maps and 1997 colour air photos, no detectable movement of the dunes can be recognised over this 30 year period. The extent of the windblown sand, mobilised by the south-westerly winds, can be seen as a clear line on the photos, beyond which no windblown sand occurs. The position of the dunes in relation to the sand mining areas, is shown in Figure 4.27.
Any obstruction, like vegetation, will reduce wind speed and cause windblown sand to be deposited. Situations where up to 2 metres of sand has already accumulated behind vegetation can be seen in the area. The pits formed as a result of sand mining, also form a trap to the windblown sand. This is only occurring on a small scale and it is unlikely that the sand pits will be filled up by sand blown sand. The cliffs on the northern bank of the river also form a natural barrier and will prevent dune sand to progress further north.

It is concluded that any northward migration of the dunes is restricted by mainly topographical features and that floods in the Swakop River are not the main mechanisms to contain the dunes from spreading further north.

The tourist industry plays a very important role in the economy of Swakopmund and other coastal towns. The condition and quality of the beaches are therefore of vital importance to Swakopmund. The largest floods on record were in 1930, 1934 and 1963. The largest of these occurred in 1934 during which 40 Mm³ of sand was deposited in the delta of the river. This caused a rapid progradation of the beach until it was approximately 1,000 metres from the 1930 beach, while at the same time a uniform blanket of sediment up to 2.5 metres thick was deposited in the river bed. The 1963 flood deposited 4,500,000 m³ of sediment, prograded the beach by approximately 100 metres and deposited approximately 1 metre of sediment in the river bed (Stengel, 1964). Between 1934 and 1963 the delta that was formed by the 1934 flood was eroded away, and between 1963 and the present the delta that was formed by the 1963 flood has eroded away. This is the result of the well known wave attrition and longshore transport of the sediment towards the north along the coast (Zwamborn, 1969; Swart & Huizenga, 1976; Swart, 1982; Schonees, 1985; Van Wyk, 1990; Holtzhausen, 1993; Moes, 1993; Moes et al., 1994). All the floods deposit their sediment load when they reach the sea and prograde the beach in the short term. In the intermediate term the average rate of wave attrition of the beach exceeds the average rate of progradation from small floods. If this were not the case the beach would progressively prograde.

From an assessment of old records done by Swart and Huizenga (1976), it is clear that the beaches can change dramatically depending on the availability of sand for deposition and the changing forces of longshore drift. Periods of sediment starvation resulting in significant changes in the appearance of beaches are well known along the Namibian coast. A prime example is the changes currently occurring at Sandwich Harbour south of Walvis Bay where beach barrier bars are migrating landwards at a rate of 50-100 metres/year (Ward & Seeley, 1989; Ward, personal communication, 1997). The erosion currently visible at the beach north of the Mole where an old slipway is exposed, is also attributed to a deficit in sediment available for deposition (Press report in The Windhoek Observer, 10/05/1997; Ward, personal communication, 1997).

4.7 General demographic characteristics

The region forms the central part of the West Coast Recreational Area and most of the
infrastructure is designed to provide access to and between recreational areas, mining operations and the main service and urban centres (Department of Government Affairs, 1987). Access to the area is via the national tarred road which bisect the area from east to west, linking the town of Swakopmund with towns in the interior. A further 40 kilometres of tarred road links Swakopmund with the major port of Walvis Bay to the south. A railway line follows a route parallel to the tarred road, linking Walvis Bay and Swakopmund with the interior of Namibia.

A tarred road links Swakopmund with Henties Bay and the Skeleton Coast National Park to the north, while a similar gravel-surfaced road over the Komas Hochland links the capital city Windhoek to the port at Walvis Bay. In the arid Central Namib Desert tracks are few and far between, but most areas are readily accessible with a four-wheel drive vehicle. The flat sand-floored tributaries of the Khan and Swakop rivers also serve as ideal road ways for these vehicles.

Airports are located at Swakopmund and Rooikop, where scheduled commercial flights link these centres with Windhoek and destinations in South Africa. Smaller airstrips are also located at Arandis and Henties Bay.

Electricity supplies to Swakopmund, Walvis Bay and the Arandis-Rössing complex, as well as minor centres such as Rooibank, Rooikop and Henties Bay, are provided by NAMPOWER via overhead high tension powerlines. The electricity grid is now linked to the Eskom network in South Africa from which additional power can be drawn if needed. A modern telecommunications system links Swakopmund with other towns in the country, while remote areas are served by radio-telephone.

The major urban centre in the region is Swakopmund, located on the Atlantic coast. The town has a State hospital with intensive care unit, private hospital, clinics, primary and secondary schools, library, oceanarium and a police force.

The major sources of income and activities in the regional centres are:

- **Walvis Bay:** Salt, guano and granite exploitation, as well as commercial fishing and canning, plus the related harbour activities associated with export activities. Estimated total population in 1995 was 35,000 (KfW, 1996).

- **Swakopmund:** The economy of Swakopmund centres around the tourist industry and the production of leather goods from the skins of game and domestic animals. Since the development of Rössing in the mid-1970's, the town also provides logistic support services and accommodation for Rössing Uranium Mine. The town is the premier holiday resort in Namibia and provides all amenities for residents (approximately 18,300 (KfW, 1996)) and which can double as a result of an influx of visitors during the holiday season. Other important local industries included beer brewing and the production of a variety of meat and other fresh and processed food products. Outside the town limits of Swakopmund, farmers occupy small-holdings along the lower Swakop River.
• **Henties Bay**: This coastal and retirement resort consists of approximately 1,400 dwellings, and supports some 2,700 permanent residents plus up to 20,000 visitors during the holiday season (KfW, 1996). Amenities include a hotel, time-share apartments, a cultural centre and sports club. Approximately 10,000 holiday makers visit in season, many of whom occupy the nearby caravan park.

• **Wlotzkas Baken**: This small community consists of some 5 permanent residents and a few holiday homes. No infrastructure is available and water is supplied by tanker from Swakopmund. Approximately 500 holiday makers visit the site in season.

• **Arandis**: Located some 65 kilometres inland from Swakopmund, Arandis was originally built to house the families of about half the staff at the nearby Rössing Uranium Mine. It functions as an independent town with its own municipality and town council. Arandis possesses well-developed infrastructure and several small secondary industries, as well as a semi-State hospital, primary and secondary school, sports club and cultural centre. In the recent KfW study (1996), the population of Arandis was estimated to be about 3,800.

4.8 General land use characteristics

4.6.1 **Archaeology**

A small site of archaeological interest, consisting of a chalcedony outcrop which was used for the production of stone tools, is located towards the head of Panner Gorge and some 5 kilometres from the Khan River.

4.6.2 **Land use patterns**

Much of the Namib Desert falls within conservation areas, for example the Namib-Naukluft and Skeleton Coast Parks. The game populations in these conservation areas is highly variable, with the animals migrating into and out of the area in response to seasonal rainfalls. Those areas of the Central Namib Desert which have not been proclaimed as conservation areas usually have no surface water and little or no potable underground water available. Consequently, they are generally of very low agricultural potential and cannot support formal farming activities. In some of the nearby communal areas of Damaraland, land-use is often of very low intensity, with the raising of cattle, goats, sheep, donkeys and some game ranching being the major activities.

Nearer the coast, formal farming is undertaken on several smallholdings in the Lower Swakop River. The major activity is concentrated to supply the needs of Swakopmund and Walvis Bay communities by producing vegetables, asparagus, milk and meat.

Towards the interior portion of the Central Namib Desert, informal farming is conducted
along the courses of most of the rivers due to the presence of fodder plants (mainly *Prosopis glandulosa*, *Acacia albida* and *Acacia erioloba*) and sub-surface water supplies. Perhaps the greatest effect that this informal farming is the competition that domestic stock provide for the food and water resources used by wild animals (Department of Government Affairs, 1987).

In 1977, some small-holdings along the Swakop River were acquired by the State and the land incorporated into the Namib Desert Park. However, informal farming is still continued along the rivers to the north of the Swakop. In addition, several groups of Topnaar Hottentots continue to raise goats, cattle and donkeys along the lower reaches of the Kuiseb River. During periods of drought, the domestic stock greatly reduces the available forage in the areas surrounding the Topnaar villages (Huntley, 1985).

Prior to the start of mining operations at Rössing, several small- to medium-scale prospecting and mining operations were located in the Central Namib region. These endeavours were focused mostly on the recovery of copper, tin and semi-precious stones (former Department of Government Affairs, 1987).

4.6.3 Site area characteristics

The proposed KARS dam site is located close to the north-eastern boundary of the mining grants and claims operated by Rössing Uranium, adjacent to the northern boundary of the Namib-Naukluft National Park. The Khan River joins the Swakop River approximately 35 kilometres downstream of the dam site. A few smallholdings are located at Palmenhorst, a short distance further down the Swakop River. Several smallholdings are located further downstream along the Swakop River, and are most numerous between Goanikontses and Swakopmund. Farms are situated along both sides of the Khan River, upstream of the Rössing mining licence where limited farming takes place.

Apart from the infrastructure associated with the Rössing Uranium Mine, there is no well-developed infrastructure around the dam site. Access is via informal tracks for four-wheel-drive vehicles along the bed of the Khan River and linking with similar gravel-surfaced tracks along some of the gorges. The original access track to the Khan River via Dome Gorge has been modified by the extensions to "Waste Dump 7", and access is now restricted to mine personnel. All access to the Khan River via Panner and Pinnacle Gorges is restricted by fences and locked gates erected by Rössing. Just north of the KARS dam site a broad tributary provides access to the dam site from the north.

Well-developed infrastructure exists at the mine site, with road and rail links as well as the nearby Arandis Airport. A series of water extraction boreholes and monitoring wells is located in the bed of the Khan River. These are not accessible to the public.

There are no resources or amenities other than those provided by the natural environment.
5. EVALUATION OF ISSUES ASSOCIATED WITH THE KARS PROJECT

5.1 Introduction

This Chapter describes and evaluates the impacts expected to occur should the KARS dam be constructed. The issues that will be addressed in this chapter follow from the public meetings held during January 1997 in Swakopmund and Arandis, written and verbal comments received from I&APs, and general impacts associated with projects of this nature. These issues have been categorised into several sections, and within each of these, a number of potential impacts are addressed.

The lay-out of the chapter followed is similar to the one used in the Omdel EIA report (Department of Fisheries & Water, 1991a), whilst the approach used to evaluate the significance of environmental impacts is a combination of the techniques used by Ashton et al. (1991), Department of Fisheries & Water (1991a) and Ashton et al., (1997). The approach used to identify impacts and the criteria used to assess their significance has been described in Chapter 4 of this Report.

Within each of the main sections of this chapter, the impacts are described under a standard set of headings to facilitate comparisons, as follows:

- **Impact statement**
  This comprises a brief statement of the type and form of impact and, where appropriate, identifies the parties likely to be affected.

- **Impact description**
  A description of the effects of the impact and, where possible, the provision of quantitative data on the magnitude of these effects and the groups, communities or individuals affected by the impact.

- **Impact significance**
  An evaluation of the importance (significance) of the impact is given, based on the criteria described in Section 4 and the specific considerations in Sections 3.3 and 3.4 for evaluating ecosystem impacts and socio-economic impacts.

- **Impact mitigation**
  A summary of the management actions required to prevent or reduce the negative effects of a given activity. Where appropriate, suggestions are also given for enhancing any positive benefits of the project action.

- **Research and monitoring needs**
  Suggestions as to which aspects require the collection of additional information or data should the project proceed.
5.2 The modelling approach used in this study

5.2.1 Motivation for model

In order to address several of the issues raised during the public meetings, a detailed investigation of the hydrological behaviour of the Swakop and Khan River systems was required. Given that very few flow data are available for the river reaches in question, it was decided that this would best be achieved by predictive mathematical modelling. A conceptual model was constructed to predict the impacts of the proposed KARS scheme. The different components of the model are shown in Figure 5.1.

![Diagram of river system with various flow and abstraction points.]

**Figure 5.1:** Schematic representation of the conceptual model.

For the purpose of this model, the Swakop and Khan Rivers have been divided into six and four reaches respectively, as summarised in Table 5.1.
5.2.2 Model components

Four aspects of the Swakop and Khan river systems are represented in the model by the following components:

- A hydrological component to model seasonal flood volumes. The hydrological component includes a routine to predict losses due to infiltration along the length of the river.

- A hydrogeological component to predict the behaviour of ground water in the alluvial aquifers of the Swakop and Khan Rivers. The hydrogeological component is primarily concerned with the prediction of the change in the mass balance of water in the alluvial aquifers and changes in the general level of the water table.

- A sediment component to predict changes in the volume of sediments brought down during flood events as a direct result of the changes in the flood volumes.
• A water quality component to assess the potential changes in the TDS of the groundwater which might arise due primarily to changes in the general level of the phreatic surface or due to changes in the relative contributions of groundwater from the Khan and Swakop aquifers.

To evaluate the impact of the proposed dam and recharge scheme on the flood volumes and flood frequencies in the Khan and Swakop Rivers, the following three cases have been modelled:

• Case 1: Assumes that there are no major dams present on either the Swakop or the Khan rivers. This case represents the background case and assists in measuring the impacts of further developments.

• Case 2: This case represents the current situation, i.e. that Swakoppoort and Von Bach dams are constructed and that the KARS scheme is not implemented.

• Case 3: This case requires the prediction of flood volumes after implementation of the KARS.

Comparison of Case 3 with Case 1 enables the total impact of developments on the Khan and Swakop rivers to be assessed while comparison of Case 3 with Case 2 allows the incremental or additional impact associated with the proposed scheme to be assessed.

5.2.2.1 Hydrological Component

The specific objectives of the hydrological model are the following:

• To evaluate the relative contributions of the Swakop and Khan Rivers to the runoff volume;
• To estimate the losses which occur during each flood event due to infiltration of flood waters into the alluvium; and
• The seasonal flood volume is also required to estimate salt loads and sediment volumes brought down during flood events.

Method of Approach

Flood Record

The flood record prepared by Mr B.A. Mian of the Department of Water Affairs for various sites along the Swakop River, over the period 1925/1926 to 1984/1985 were used as the basis for seasonal flood records in the Swakop River. This record represents a combination of synthetic and actual flood records.

The seasonal record from the gauging station at Ameib was used as the basis for the prediction of seasonal flood volumes in the Khan River. Actual flood records are used for the period 1925/1926 to 1984/1985 at Swakoppoort dam, Dorstrivier and Ameib.
For the prediction of floods after 1984/1985 and into the future, the same record is used but with a randomly selected starting year for the 1985/1986 flood. The approach suffers the disadvantage that the actual return period of floods which have taken place over the 59 year record are not taken into consideration, but has the advantage that the periodicity of wet and dry cycles is accounted for. The approach is considered adequate for the purpose of quantifying the impact of the proposed KARS project.

**Losses due to infiltration into the Alluvium**

Contributions to surface runoff into the Swakop and Khan Rivers is assumed negligible after Dorstrivier and Usakos respectively. The loss factor applied to the synthetic record of 0.1 Mm³/kilometre is not applied in the model, but rather the infiltration to the alluvial aquifer is estimated. An equation was derived by fitting a curve to the results of a series of transient finite element analyses carried out to determine the change in the infiltration rate as a function of the time since the start of a flood.

The analyses have shown that the infiltration into the sand is initially slow and then increase with time until the wetting front in the sand has moved down to the water table or permanent phreatic surface. The deeper the phreatic surface, the longer it takes for the alluvium to become saturated throughout the depth. Similarly, if the alluvium is initially dry, the air filled void spaces between particles must first be filled with water before the void space can serve as channels for the flow of infiltrating water. Thus the permeability of the unsaturated alluvium is significantly less than that of the saturated material.

The equation presents an empirical relationship for the effective vertical permeability of the alluvium as a function of the time since the top surface of alluvium became with inundated with water, and the depth to the water table. Once the wetting front has moved down to the water table, the infiltration rate is governed by the saturated vertical permeability of the alluvium. The saturated vertical permeability is less than the saturated horizontal permeability of the alluvium for the following reasons:

- Horizontal layers of finer sand and silt exist due to hydraulic deposition of silt particles during flood events; and
- The horizontal permeability of the finer fractions of the alluvium is generally significantly less than the vertical permeability due to the fact that the silt comprises largely plate-like mica particles which tend be deposited with a horizontal orientation during hydraulic deposition.

The above two factors alone could theoretically result in a vertical permeability in the region of three to four orders of magnitude less than the horizontal permeability, but since the silt and fine sand layers are not generally continuous either in the downstream direction or across the channel, the vertical permeability of the alluvium will not be as low as consideration of the previous two factors might indicate. Instead the saturated vertical permeability might be expected to be in the region of one to two orders of magnitude less than the horizontal permeability.
5.2.2.2 Alluvial Aquifer Component

The hydrogeological component of the model has the following objectives:

- To estimate the effect of the KARS on the quantity of water stored in the alluvial aquifer within each reach and the change in the general level of the water table within each reach. This is important in reaches downstream of the proposed KARS;
- To estimate the change in the relative contributions to ground water flow from the Khan and Swakop rivers downstream of the confluence of the Khan and Swakop rivers; and
- To distinguish the effect of the KARS from other effects which are likely to affect the Swakop River and identify when these effects are likely to be felt. For example, abstraction wells along the Khan and Swakop rivers will have an effect on the ground water flux downstream of these points, but the effect might only be felt decades after the abstraction event. The construction of the proposed aquifer barriers in the vicinity of Rössing Mine could reduce the median or average groundwater flux downstream of the barrier thus eventually affecting the groundwater level downstream of the confluence. This effect might or might not coincide with the effect of the construction of Swakoppoort Dam or the effect of groundwater abstractions at Otjimbingwe.

Method of Approach

The hydrogeological component solves the continuity equation for each reach during each season. Inflows to the aquifer are considered to be as follows:

- Ground water flow into the reach from the top end of the reach;
- Ground water inflows from tributaries alluvial aquifers along the reach; and
- Recharge from the surface of the alluvium during flood events.

Losses from the aquifer reach are assumed to comprise:
- Ground water flow out of the reach at the downstream end of the reach;
- Evapotranspiration from plants growing within the gorge;
- Borehole abstractions;
- Evaporation from man made trenches and sand pits where these have been excavated down to the water table;
- Evaporation/evapotranspiration from areas where the groundwater is forced to the surface as a result of natural barriers; and
- Evaporation from wet sand near the surface of the alluvium after flood events.
Water Loss from Sand Pits and Trenches

Although the total volume of water lost from the sandpits and open trenches located between the confluence of the Khan and Swakop Rivers and the mouth may not be that significant, these trenches and sand pits might have a significant effect on the increasing salinity of the aquifer due to evaporation losses. The trenches are generally excavated to the level of the phreatic surface and expose the groundwater to evaporation over an area equivalent to the base of the trench or pit. The area of open trenches is estimated to be 320 m² between the confluence and Tannenhof and 375 m² between Tannenhof and Nonidas.

The total area affected by sand mining in the lower Swakop River is estimated to be 240,000 m². The wet sand evaporation rate is used in the model to estimate the water loss ascribed to these activities.

5.2.2.3 Sediment transport component

The objectives of the sediment transport component of the model are as follows:

- To determine the impact of the proposed KARS on the total sediment load after the confluence of the Khan and Swakop Rivers over the life of the scheme; and
- To assess the likelihood of a significant change in the make up of sediment downstream of the proposed KARS scheme, in particular, the proportion of silt brought down during flood events.

Key Assumptions

The following key assumptions are relevant to the sediment component of the model:

- The sediment load in any flood season is assumed to be directly proportional to the flood volume;
- Only the silt size fraction is assumed to pass over the Swakoppoort and Khan dam spillways; and
- It is assumed that since only silt is able to pass over the dam spillways, the dams tend to result in an increase in the silt size fraction in the sediment. The proportion of silt in the sediment downstream of the dams is calculated by adding the silt volume which passes over the spillway to the volume of silt which would be suspended in the event of a flood of the same size but without the dam.

Detailed studies of grading distributions in sediment have shown that the particle size distribution is a function of the stream power. The last assumption is considered to be conservative as the model will tend to over predict the increase in the proportion of silt in the floods attributable to the dams.
5.3 Categories of issues

5.3.1 Project viability issues

5.3.1.1 Alternative water supply options to the KARS Project

- **Impact statement**
  There has been relatively widespread public concern that, by pursuing the KARS Project, Rössing Uranium will not contribute to other water resource development options being considered for the Central Namib Area.

- **Impact description**
  Rössing Uranium is one of the largest single water users in the Central Namib Area. If Rössing does not contribute to the planned desalination scheme at Walvis Bay, this scheme may become too expensive for the other water users.

- **Impact significance**
  The planned desalination scheme at Walvis Bay has been designed for the anticipated growth in demand by all water users in the Central Namib Area. Furthermore, the costs of producing and delivering potable water from this scheme have been based on the assumption that all water users will participate proportionately in the scheme. If one or more of the larger water users does not participate, the costs of water will escalate for the remaining users.

- **Impact mitigation**
  Rössing Uranium Management have frequently and openly supported the desalination concept as a strategy for meeting the water demands of the Central Namib Area. In this regard, they are actively co-operating with, and assisting, the authorities in this regard. The KARS Project provides an additional opportunity to obtain industrial grade (brackish) water and thereby reduce the existing pressures on the scarce regional water resources. Rössing Uranium still requires large quantities of potable water which cannot be supplied from the KARS Project.

- **Research and monitoring needs**
  None required.

5.3.1.2 Regional water supply and management

- **Impact statement**
  The ground water resources of the Central Namib Area have been over-exploited to such an extent that they will be unable to sustain the projected demands for the region.
Impact description
Over-exploitation of the Kuiseb and Omaruru aquifers during the last twenty years has seriously depleted these water resources. As one of the major water users in the Central Namib Area, Rössing Uranium has been perceived to contribute to this situation. Given the relatively small size of the proposed KARS Project, it is unlikely that, if implemented, it will significantly reduce the pressure on these existing water resources.

Impact significance
It has been projected that the Kuiseb and Omaruru aquifers will not be able to meet anticipated water demands by the end of the twentieth Century. However, similar to the benefits to be gained from the Omdel aquifer recharge scheme, the KARS Project will help to reduce the existing demand and thereby help to prolong the useful life of these water resources, without giving rise to significant negative impacts downstream.

Impact mitigation
If implemented, the KARS Project should seek to maximize the quantity of brackish water that Rössing Uranium can utilize. This must be achieved without compromising the baseflow of the Khan aquifer or the integrity of the salt and water balances on the mine.

Research and monitoring needs
Namibian water resource managers should continue to monitor all freshwater and brackish water usage in the Central Namib Area. In addition, greater attention should be paid to determining natural rates of recharge and the sustainable yield of all alluvial aquifers in the Central Namib Area.

5.3.1.3 Improved knowledge of aquifer functioning and recharge

Impact statement and description
This project will provide a considerable body of information on the dynamics of the Khan River aquifer. The effectiveness of the retention dam option for aquifer recharge can also be evaluated. The expected environmental impacts of this type of scheme on an ephemeral river in a sensitive ecological region can also be quantified and applied to other schemes in future.

Impact significance
The potential benefits of this knowledge could be of major significance in an arid country like Namibia, since some of the most important water resources in Namibia are alluvial aquifers. The knowledge and experience gained may also benefit other arid countries, both in southern Africa and elsewhere in the world.

Impact mitigation or optimization
Devise a means of monitoring, recording and documenting the progress and
results of this project through all the construction stages and throughout the lifespan of the reservoir. This information should be carefully documented and referenced to permit easy access by Rössing staff and the Namibian Department of Fisheries and Water.

- **Research and monitoring needs**
  As given under benefit optimization.

### 5.3.1.4 Upstream water resource management

- **Impact statement**
  The residents of Usakos will not benefit from the KARS Project.

- **Impact description**
  The residents of Usakos rely heavily on groundwater drawn from alluvial aquifers in the upper reaches of the Khan River; this resource is not sufficient to meet the growing demands. If a dam similar to the KARS Project is constructed at Usakos within the twenty-year lifespan of the KARS Project, it would undermine the viability and objectives of the KARS Project, thereby eliminating any possible benefit to Rössing Uranium.

- **Impact significance**
  The supply of water to the town of Usakos is the responsibility of National Government. The KARS Project will not influence either the quantity or quality of groundwater in the vicinity of Usakos.

- **Impact mitigation**
  It is anticipated that the demand for water in Usakos will have to be met from either local groundwater resources or by an extension to the Karibib pipeline.

- **Research and monitoring needs**
  None required.

### 5.3.2 Technical issues

#### 5.3.2.1 The ideal capacity for the proposed dam

- **Impact statement**
  The general public have expressed concern that the capacity of the proposed dam in the Khan River may not be ideal for the purpose of recharging the Khan aquifer or supplying fresh water to downstream users.

- **Impact description**
  If the proposed dam is too small it would not function efficiently. A large
capacity dam would be able to trap major floods and release this water for the benefit of downstream users. If water is not released downstream than farmers along the lower Swakop River would have to contend with a progressive deterioration in ground water quality.

- Impact significance
  A deterioration in ground water quality along the lower Swakop River, caused by reduced rates of recharge from flood waters, would have adverse economic consequences for irrigation water users.

- Impact mitigation
  The capacity of the dam under consideration was examined against stringent technical and economic criteria. It has emerged from the techno-economic study that the ideal capacity for the dam is limited by capital constraints rather than aquifer capacity. This is because of the differential between the cost of Khan River water and the cost of potable water. These calculations have indicated that a capacity of the order of 9 million cubic metres (9 Mm³) is likely to strike the best balance between capital, life of scheme and net savings. This results in a dam wall of 25 metre maximum height and includes a 5.5 metre allowance for freeboard during flood events. The full supply level which coincides with the level of the main spillway would therefore be at a height of 19.5 metres above the river bed.

  This size of dam would trap almost all of the smaller floods during the early years of its life; medium- and large-sized floods would not be trapped. As silt accumulates within the dam basin, its capacity will also reduce. Thus, its impact on floodwaters along the Khan River will reduce over time.

- Research and monitoring needs
  Volumes of floodwaters that are trapped within the dam basin should be carefully recorded. In addition, those higher flows which are discharged via the spillway system should also be monitored.

5.3.2.2 How can the wider public benefit from the KARS proposal?

- Impact statement
  There is a perception that the wider public in and around Swakopmund will not benefit directly from the KARS Project, and that the only beneficiary from the use of a "public" or "National" resource will be Rössing Uranium.

- Impact description
  The KARS Project has been designed specifically to meet the brackish (non-potable) water needs of Rössium Uranium and thereby reduce the mine's demand for potable water. No specific provision has been made in the KARS Project to meet the water needs of other users.
• **Impact significance**
  Given the very specific chemical characteristics of ground water in the Khan River aquifer, the water has very limited use outside of certain industrial processes. This quality of water is of limited use to other users.

• **Impact mitigation**
  Whilst this aspect has not been specifically studied, it is likely to be feasible provided additional infiltration management was effected at Swakopmund. Rössing would be happy to consider a wider involvement with the KARS scheme provided this involvement were matched by a willingness to contribute to the capital and operating costs.

• **Research and monitoring needs**
  None required.

5.3.2.3 Can the proposed dam withstand major floods?

• **Impact statement**
  Major flood events are considered to be the most likely cause of dam wall failure. Given that the Khan Dam would be constructed of alluvium, the public perceive this to be a serious risk to downstream residents.

• **Impact description**
  A perception exists that the use of alluvium could render the Khan Dam "unsafe" as it would be vulnerable to a major flood. However, it must be recognized that any dam of the size proposed for the Khan Dam would be severely stressed by a major flood. (It is important to note that there are no earthfill materials known to man that could withstand over-topping and erosion due to a major flood. Alluvium therefore represents as good a choice as any material).

• **Impact significance**
  In the event that a major flood did occur, the low capacity of the Khan Dam would not provide a significant barrier to the flood waters. Provided that the spillways both function correctly, the dam is designed to withstand a flow of 1,100 m$^3$/second. This impact is considered to have a low significance.

• **Impact mitigation**
  The Khan Dam has been designed with two spillways as illustrated in the plan in Figure 5.2. No water will flow over the dam wall itself.

  A main spillway on the right flank which will be able to handle up to 1:50 year flood events on its own. This spillway will be blasted and excavated into relatively unweathered rock which will form an erosion resistant sill.
An emergency spillway on the left flank which, when operating together with the main spillway, will cater for floods up to the 1:200 year event. Drilling and geophysical investigations to date indicate that the materials in the proposed spillway section comprise alluvial sands and gravels which have been mildly and variably cemented in places. These materials are likely to be highly erodible. It is therefore currently proposed that operation of the emergency spillway take advantage of the potential for erosion of the spillway section by the flood. To this end it is proposed that a channel section of nominal width be preformed in the spillway section to accommodate initial flow. Thereafter discharge capacity will be naturally generated by the flood as this erodes the preformed channel wider and deeper to meet flood requirements.

Final assessment of the viability and reliability of this proposal as well as the extent of sub-surface blasting to disturb mildly cemented layers will be assessed after excavation of a trial section through the spillway. Flow through the emergency spillway would necessitate reinstatement of the spillway section after the event and this has been accounted for in the economic analyses. During operation of the emergency spillway some of the silt within the dam basin would be removed thereby enhancing the storage capacity of the basin.

- **Research and monitoring needs**
  A careful check should be maintained on the integrity of the Khan Dam during all floods.

### 5.3.2.4 Consequences of dam wall failure

- **Impact statement**
  There is a perception that if the Khan Dam wall fails during a major flood event, the consequences could be disastrous for downstream residents.

- **Impact description**
  Floodwaters released from the Khan Dam as a result of the dam wall failing during a major flood would inundate the full width of the lower Swakop River channel. This could endanger local residents and could destroy existing irrigation activities and livestock.

- **Impact significance**
  The Khan Dam has been designed to trap and contain small- and medium-sized floods only; it is too small to trap and contain a major flood. In such an event, a major flood would be routed past the dam wall over the two spillways. In an extremely large flood occurred, the Khan Dam would not withstand such a situation.

- **Impact mitigation**
  The consequences of failure of the dam wall are unlikely to be severe due to the
absence of people and publically owned infrastructure along the river all the way down to Goanikontes. Assessments of dam break flow characteristics indicate that, if the dam were to break in the course of passing an unusually large flood of 1,100 m³/second, the combined flow depth by the time the flood wave reaches Goanikontes will be less than 1.8 metres and the flow depth will be negligible by the time the flood reaches Swakopmund. Damage to Rössing's boreholes and Khan River water reticulation systems will be similar to that experienced during any major flood event without breach of the dam wall.

- **Research and monitoring needs**
  A careful check should be maintained on the integrity of the Khan Dam wall during all flood events.

### 5.3.2.5 Choice of dam wall design

- **Impact statement**
  Several people perceive that alluvium is an unsuitable material from which to construct a dam wall.

- **Impact description**
  Instead of using alluvium, alternative materials should be evaluated and appropriate sources identified.

- **Impact significance**
  Use of alternative materials will significantly increase the costs associated with the proposed Khan Dam and could also lead to additional adverse impacts on other areas where different materials have to be borrowed. This impact is considered to have the potential for **major** significance.

- **Impact mitigation**
  Following evaluation of a range of alternatives and an extensive investigation of earth and rollfill material suitable for dam construction, it is proposed to construct a zoned earth fill embankment comprising alluvial fill (excavated from the river bed within the dam basin) which will be compacted into the upstream and downstream zones. A core of compacted decomposed gneiss which is of low to medium plasticity and low permeability is to be provided. The core material is to be borrowed some 6.5 kilometres from the dam just off the desert plains; a cross-section through the dam is indicated in **Figure 5.3**. Seepage pressures under the dam and through the abutments will be controlled by means of pressure relief wells as illustrated in **Figure 5.4**.
Water from the pressure relief structures will discharge into drainage media constructed at the downstream toe of the dam as well as at the downstream interface between the core and the downstream zone.

The core material is to be extended upstream along the base of the embankment to form a blanket over the base of the dam at the embankment - alluvium contact. With time it is anticipated that fine silt will accumulate in the basin and that this silt, together with the core blanket, will act as a partial seal to the base of the dam and serve to reduce seepage underflow and seepage pressures. It is important to note that there is no permanent cut-off under the dam. This alternative was eliminated due to potential decommissioning difficulties and also due to difficulty in ensuring a complete seal without which the cut-off would be ineffective.

- **Research and monitoring needs**
  Only required during the period when the dam has trapped flood waters. During decanting operations, a close check should be kept on the degree to which water is able to percolate through the alluvium dam wall.

5.3.2.6 Decanting water and infiltration management

- **Impact statement**
  Decanting clarified water from the Khan Dam and allowing it to flow over the surface of the river bed is perceived to be inefficient and wasteful.

- **Impact description**
  High evaporation rates will lead to large losses of water decanted from the Khan Dam. In addition, this evaporation loss will also lead to a decrease in water quality through an increase in total dissolved salts.

- **Impact significance**
  Floodwaters in the Khan River are typically of a relatively good quality, with low concentrations of total dissolved salts. If the quality of this water is allowed to deteriorate it will reduce its usefulness to other users. This impact is considered to be of minor significance.

- **Impact mitigation**
  The primary objective of the KARS Project is to capture surface run-off and effect controlled infiltration of the water into the alluvial sands forming the base of the river. Since the longer the water is kept at surface the greater will be the evaporative losses, as soon as the water captured in the dam has had an opportunity to clarify water will be decanted from the dam via a decant system and outlet pipe. This water, together with seepage water, will be routed down the river via a system of cross-bunds orientated so as to detain the water and enhance infiltration (Figure 5.5).
TYPICAL SECTION THROUGH KHAN RIVER AT THE PROPOSED RIVER BARRIERS

KHAN AQUIFER RECHARGE SYSTEM

FIGURE 5.5
The bunds are simple-to-construct, low-technology structures that can be breached and re-located as management of infiltration dictates. Silt which is likely to accumulate in the basins formed by the bunds will be excavated and disturbed from time to time to maintain infiltration rates.

The length of the river between the dam and the downstream limit of the mine concession area will be managed in a series of compartments to be formed by enhancing natural geological structures which act as sub-surface flow retarders, where possible, as well as by constructing artificial retarder structures using controlled in-section grouting techniques. The retarders will be located and sized to ensure that base flow passes over or through the structures without the ground water surfacing (Figure 5.6).

Recharge and abstraction from the compartments will be managed so as store as much water as the aquifer will accommodate. Water will be abstracted from the alluvial aquifer by means of boreholes located in the two lower-most compartments which are located within the mine concession area.

- **Research and monitoring needs**
  Different recharge and infiltration mechanisms and management strategies need to be evaluated in order to maximize recharge efficiency.

5.3.2.7 Decommissioning options

- **Impact statement**
  Several problems are associated with the decommissioning of a dam wall and associated structures built in the Khan River. The scale of these problems is determined largely by the type of material used in construction of the dam wall.

- **Impact description**
  The alluvium dam wall will have to be decommissioned once the KARS Project has reached the end of its useful life and the dam capacity has been lost through the accumulation of trapped silt and alluvium. The decommissioning process could cause a marked increase in the load of sediment which is transported downstream to the lower Swakop River. Sub-surface flow retarder structures would form permanent flow barriers which would force sub-surface flow to surface, causing evaporation loss and salinization.

- **Impact significance**
  Because the original dam wall material will be excavated from sites in or near to the bed of the Khan River, it would be possible merely to breach the wall vertically in the centre and allow successive floods to erode away the accumulated silt and alluvium. Whilst the low frequency of floods indicates that it could take a considerable time to remove the wall completely, it would eventually restore the Khan River to its original gradient.
For an alluvium dam wall, it would be necessary to first remove any material (such as waste rock) which was placed to reduce wind and storm erosion. This could be buried in a waste dump designed for rehabilitation. It would be difficult to decommission any concrete inlet or spillway structures; the most feasible option would be to remove the material to a waste dump on the Rössing Mine property for rehabilitation.

The impact of the sub-surface flow retarder structures is likely to be minor since these will have been constructed so as to operate without allowing sub-surface water to reach the surface of the river bed.

- **Impact mitigation**
  It is envisaged that on decommissioning the dam will be breached to allow floods to pass through the basin. For some years following breaching there will be gradual erosion of silts, sand and gravel which will have accumulated within the basin. This silt will be dispersed along the Khan River to the Swakop River and along the lower Swakop River.

Concrete structures in the outlet works and the main spillway will be blasted, removed from the river section and transported to Rössing Mine for disposal together with similar materials.

In respect of the artificial sub-surface flow retarders it is proposed that these blasted and excavated to an extent required to reinstate flow conditions typical of the river section immediately upstream or downstream.

- **Research and monitoring needs**
  None required. Decommissioning of the dam will be the responsibility of Rössing who will make adequate provision for this event within the ambit of their current policy of making provision for mine closure.

5.3.2.8 Silt accumulation reduces project lifespan

- **Impact statement**
  The rapid accumulation of silt within the reservoir basin will reduce the lifespan of the project and reduce its effectiveness as a solution to recharging the Khan River aquifer. The removal or dredging of accumulated silt would greatly increase the costs of the water.

- **Impact description**
  Silt accumulation in the dam will be determined by flood size and flood frequency (Hydrology Division, 1988; Marais, 1990; Department of Fisheries & Water, 1991a). Floods occurring near the beginning of the rainy season tend to carry larger quantities of silt than floods which occur later in the rainy season. Measurements of the silt content of Khan River flood waters show that silt
content varies between about 2 % and 23 %. An average silt content of 5 % is accepted as a fair estimate (Hawkins, Hawkins & Osborn, 1991a). If the long-term mean annual inflow of 3.41 Mm$^3$ is accepted, this will bring in approximately 170,000 m$^3$ of silt per year. A 9 Mm$^3$ capacity reservoir could have a theoretical lifespan which could possibly be greater than the estimated remaining lifespan of the Rössing Uranium Mine.

Silt-laden waters entering an empty reservoir basin will have their velocity reduced and thus a reduced silt carrying capacity. Silt will be deposited mainly in the deeper areas of the dam and both the maximum and average depth of the reservoir will rapidly decrease. Should further flood inflows occur whilst water is still retained in the reservoir, the more classic advancing delta type of silt deposition will occur. There is also the extreme possibility that a major flood carrying 5 % by volume of silt might reach the dam and reduce its capacity by 50 % in one season. Nothing can be done about this possibility.

The progressive shallowing of the reservoir basin will promote higher water temperatures and thus greater evaporative losses. Undisturbed layers of accumulated silt within the reservoir basin will retard infiltration into the aquifer from within the reservoir and will increase the quantity of silt in waters discharged over the spillway. This silt-laden water will reduce the infiltration rates in downstream spreading grounds and require frequent maintenance of the surface to remove silt layers. Any reduction in anticipated infiltration rates in the spreading grounds will increase the length of time which standing water remains in these basins. This will lead to increased algal growth in the water and increased evaporative losses.

The flood trapping efficiency of the dam will decrease at an increasing rate over time as its capacity is decreased by accumulated silt loads within the reservoir basin. There is therefore an unavoidable element of risk in terms of the long-term viability of the project. However, since the projected lifespan of the dam is approximately equal to the lifespan of the mine, a dam on the Khan River would still provide a long term solution to the water supply problems of the Rössing Uranium Mine.

- **Impact significance**
  The impact is considered to be of moderate significance, since alternative, more expensive options may have to be considered. The removal and disposal of silt could result in significant increases in costs and cause additional environmental impacts at whichever site is chosen for silt disposal.

- **Impact mitigation**
  Ideally, the largest dam feasible should be constructed in order to maximize the flood retention capacity and prolong the lifespan of the project. This will reduce the significance of this impact to minor levels. However, whilst the topography of the dam site would allow the construction of a very large dam, the negative
impacts of a dam at this site would increase accordingly. The benefits to be derived from removing accumulated silt are unlikely to outweigh the costs involved.

- **Research and monitoring needs**
  Monitor the volumes of floods and their silt loads reaching the dam and conduct a regular silt survey of the reservoir basin.

  Establish a photographic record using fixed-point photographs to monitor changes in vegetation and general effects of silt accumulation on the dam.

  Monitor the dam operation and efficiency on an ongoing basis.

### 5.3.3 Ecological issues

#### 5.3.3.1 Loss of riparian habitat at and above project site

- **Impact statement**
  The existing perennial riparian vegetation in the bed of the Khan River at the dam site will be lost during dam construction. Above the project site, inundation will also reduce the extent of this very important habitat. The riparian vegetation forms an important refuge and food source for many species of Namib fauna; the intense disturbance at the project site, followed by inundation of upstream vegetation by trapped floods, will eliminate sections of this habitat.

- **Impact description**
  The construction of an alluvial dam in the bed of the Khan River will cover an estimated basal area of between 2.5 and 3 hectares. An estimated additional area of 2 hectares upstream of the dam site will be affected by the excavation of borrow materials. In addition, construction of a spillway will affect an additional area of approximately 1 hectare. As soon as the dam fills, the additional area inundated would depend on the size of the dam wall that is constructed. If a 25 metre high alluvium dam wall is built, the maximum area inundated would be approximately 70 hectares. At full supply capacity, a 25 metre high wall would inundate some 3-4 kilometres of riverbed.

  The area most likely to be immediately affected by inundation following dam construction is obviously the portion of riverbed immediately upstream of the dam wall, since it is probable that smaller floods rather than larger floods will occur. Certain types of habitats could be covered during dam construction or inundated when either dam starts to fill. A plan view of the area inundated at full supply level (for the 25 metre high wall option) is shown in **Figure 5.2**.

  Stands of perennial riparian vegetation, predominantly *Acacia erioloba* and *Faidherbia albida* are confined to scattered groups on alluvial terraces on the
inward sides of meanders in the river. These are interspersed with scattered
groups of shrubs and small trees, predominantly a few Prosopis sp., and
numerous Tamarix usneoides and Euclea pseudoephelbus. A few Salvadora persica
bushes are scattered over the lower rocky slopes of the river banks. Annual plants
also occur on the flood terraces and in the lowest flood channels of the river bed
of the Khan River.

A short distance (approximately 1 kilometre) upstream of the dam site the
vegetation in the riverbed becomes slightly more luxuriant, with several rushes
and sedges, mainly Scirpus spp., Cyperus spp. and Phragmites australis. This
reflects the presence of groundwater close to the surface of the riverbed.

Approximately 15 kilometres upstream of the dam site, the lower extremity of
another aquifer compartment reaches the surface of the river bed as the water
passes over an impermeable band crossing the river. The numerous game tracks
in the area indicate that this site is an important watering point for game animals.

• Impact significance
  Construction of a 25 metre high dam wall will result in the loss of a small area of
  riparian habitat. This is considered to be a minor impact in view of the presence
  of additional riparian habitat along the Khan River, both above and below the
  proposed dam site. However, it is likely that the impacts from the dam could be
  partially off-set by the development over time of some form of replacement
  riparian vegetation. However, whilst this replacement vegetation is likely to
  contain a number of different species, it is unlikely to possess the same
  characteristics as the original habitat.

• Impact mitigation
  (See research and monitoring requirements).

• Research and monitoring needs
  The species diversity and vigour of the riparian vegetation immediately upstream
  of the dam site should continue to be monitored at least on an annual basis.
  Fixed-point photographs should be taken annually to allow a record to be kept of
  the demise of the original flooded vegetation and the colonization by replacement
  species.

5.3.3.2 Loss of rare or endangered species

• Impact statement
  Damage to, and alteration or loss of, habitat may threaten the existence of rare or
  endangered species occurring in the sensitive ecosystems of the sub-region.
  Intense disturbance due to construction activities may discourage or prevent the
  local fauna from utilizing the site area.
Environmental Impact Assessment of the Proposed Khan Aquifer Recharge Scheme

- **Impact description**
  At present, ten species of rare and protected plants occur in the sub-region (Appendix 1). However, all of these species have been recorded from the open stony flats and washes; no protected plant species have been recorded from the bed of the Khan River.

  In contrast, a number of sensitive animal (Appendix 2), bird (Appendix 3) and reptile (Appendix 4) species occur along the bed of the Khan River. These could be adversely affected by construction activities. However, any floods trapped by a dam will create a new, if temporary, source of surface water; this could well attract additional bird and animal species to the vicinity of the dam.

  If the construction site is well managed and restored after completion of the dam, the improvement in habitat could result in some re-colonization of the area.

- **Impact significance**
  In the absence of rare or protected plant species in the areas where construction or inundation could occur, the potential impact on plant species is likely to be minor at most. The impact on bird, animal and reptile species is also likely to be minor.

- **Impact mitigation**
  All construction activities should be controlled to limit the extent of physical disturbance along the bed of the Khan River. All disturbed areas, such as borrow pits, etc., should be restored on completion of the dam wall and spillway.

- **Research and monitoring needs**
  None required.

5.3.3.3 Damage to downstream riparian vegetation

- **Impact statement and description**
  The riparian vegetation downstream of the dam site may be damaged due to a variety of factors and activities. These include drying out due to excessive water abstraction, collection of firewood by construction crews, trampling effects caused by large numbers of people and machinery, and removal to facilitate the movement of construction machinery.

  The loss of this vegetation could also have several secondary effects such as the loss or interruption of a plant and animal dispersion or migration corridor (Section 5.3.3.5) and an increase in downstream erosion rates (Section 5.3.3.7).

- **Impact significance**
  Whilst the sub-region is not in a pristine condition, the linear oasis formed by the Khan River is one of very few such systems in the Namib Desert (Ashton et al.,...
1991). Its significance in the overall ecological functioning of the Namib Desert system therefore increases in importance. The vegetation of the Khan River has the potential to provide habitat for a wide variety of animals, reptiles, amphibians, birds and insects (Appendices 2, 3, 4, 5, 6). All game in the area is protected in terms of the Nature Conservation Ordinance of 1975.

Damage to the riparian habitat would also affect its associated fauna; since the area of greatest impact is limited to the immediate vicinity of the dam site and the downstream spreading grounds, the impact is therefore potentially of moderate significance. Effective implementation of mitigatory actions will reduce the significance of these impacts to minor.

- **Impact mitigation**
  Strict control should be maintained over the construction activities to reduce the area of impacts in the vicinity of the dam wall. All work zones, storage areas and borrow areas, as well as routes followed by construction vehicles and teams should be clearly demarcated.

  No collection of firewood from the riparian vegetation should be allowed. Construction workers should be supplied with fuel (e.g. firewood or gas).

  All borrow sites and vehicle routes downstream of the dam site should be rehabilitated as far as possible by levelling and back-filling. Preferably, no borrow pits should be located outside the reservoir basin.

- **Research and monitoring needs**
  The species diversity and vigour of the riparian vegetation downstream of the Dome Gorge Site should continue to be monitored at least on an annual basis.

5.3.3.4 Increased spread of alien vegetation

- **Impact statement**
  Alien invasive plants are usually pioneering species which thrive on areas of disturbed ground. Construction activities and the movement of numbers of people around the dam site will lead to high levels of localized habitat disturbance. This is likely to facilitate the spread of existing populations of alien invasive plants with the gradual displacement of indigenous species.

- **Impact description**
  At present, the only information available on the distribution of alien invasive plants around Rössing is listed in Craven (1986) and Ashton (1988a, 1988b). Additional information for other rivers in the Namib Desert is contained in Robinson (1976), Tarr and Louit (1985), Boyer and Boyer (1988), Boyer (1989) and Department of Fisheries and Water (1991a). The main species occurring in the Rössing area are listed in Table 5.2. The seeds of all of these species are
transported by water. The construction of a dam across the Khan River will create additional moist habitat that will favour the development of invasive plant populations.

The common reed (*Phragmites australis*) is likely to extend its distribution. The temporary nature of the water body created by a dam will prevent the development of permanent populations of annual invasive species, though these will develop rapidly after water levels recede and remain for periods of up to a few months. Perennial species will colonize the areas which retain moisture longest. Populations of invasive alien plants which develop in the basin of a dam on the Khan River will provide a continual source of seeds for the spread of infestations further down the Khan and Swakop Rivers.

**Table 5.2:** Summary of the management strategies recommended for the eradication of alien invasive plants in Namibia, for possible implementation in the Khan River; Based on information from Craven (1986) and Department of Fisheries & Water (1991a). (The two species shown with an asterisk (*) indicate that their significance is usually very localized).

<table>
<thead>
<tr>
<th>Species</th>
<th>Annual / Perennial</th>
<th>Probable Ecological Effect</th>
<th>Present Method of Eradication</th>
<th>Priority Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Prosopis sp.</em></td>
<td>Perennial</td>
<td>High</td>
<td>Mechanical and Chemical</td>
<td>High</td>
</tr>
<tr>
<td><em>Ricinus communis</em></td>
<td>Perennial</td>
<td>Medium</td>
<td>Mechanical</td>
<td>Medium</td>
</tr>
<tr>
<td><em>Nicotiana glauca</em></td>
<td>Perennial</td>
<td>Medium</td>
<td>Mechanical</td>
<td>Medium*</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>Perennial</td>
<td>Medium</td>
<td>Mechanical and Chemical</td>
<td>Medium*</td>
</tr>
<tr>
<td><em>Salsola kali</em></td>
<td>Annual</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
</tr>
<tr>
<td><em>Datura innoxia</em></td>
<td>Annual</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
</tr>
<tr>
<td><em>Argemone ochroleuca</em></td>
<td>Annual</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
</tr>
</tbody>
</table>

- **Impact significance**

The present levels of alien invasive vegetation in the bed of the Khan River are low to moderate, with the exception of the moist area upstream of the Dome Gorge site. Here, stands of *Phragmites australis* are common. In addition, the small borrow areas where alluvium was obtained for the construction of the earlier alluvium dams now contain dense stands of invasive species, particularly: *Salsola kali, Nicotiana glauca, Ricinus communis* and *Datura innoxia*.

Increased numbers of alien invasive plants could have a moderate to major impact on the indigenous vegetation of the Khan River. The potential significance of this impact is dependent on the efficacy of any control measures which may be used (Table 5.2). The use of any chemical control technique should be very carefully
evaluated since this could have far greater adverse effects than the target invasive plants. In the case of Prosopis sp., the seed pods and foliage provide a useful food source for game animals; an increased abundance of this tree species could have a minor beneficial impact.

- Impact mitigation
  Ideally, alien invasive vegetation should be manually or mechanically removed, preferably before seed has been set, to limit further spread. The current eradication techniques used in Namibia are listed in Table 5.2. Their applicability to the situation that develops following dam construction will have to be assessed after the dam has filled for the first time. It is important to note that the effectiveness of any eradication programme depends on the thoroughness with which it is conducted.

- Research and monitoring needs
  Assess current distribution and species diversity of alien invasive plant species growing in the bed of the Khan River. Monitor changes at annual intervals over the different stages of the project. Consult Departments of Fisheries and Water, and Wildlife Conservation as to the necessity of implementing any control strategies.

5.3.3.5 Loss of dispersion/migration corridor

- Impact statement and description
  Construction of a dam wall across the Khan River will reduce the extent to which the river functions as a dispersion route and migratory pathway for small mammals, amphibians, some large mammals and riparian vegetation.

- Impact significance
  The Khan River is an important linear oasis in the Namib Desert. The river system is the only suitable continuous habitat within a large area which allows the dispersion and migratory movement of small mammals and amphibians, in particular. The river bed also forms a migratory route for certain large mammals and allows the downstream spread and replacement of indigenous and alien riparian vegetation. Loss of this vital function will disrupt the local and possibly even the sub-regional functioning of this system. These impacts could have a moderate significance for the functioning of the ecosystem.

- Impact mitigation
  It is unlikely that management actions can effectively restore the loss of a direct migratory route such as the Khan River, unless alternative nearby pathways exist. Given the locally hilly terrain and absence of surface water in the sub-region, alternate migratory pathways around the Dome Gorge Site are unknown. However, after the dam has been built, re-colonization of the reservoir basin and downstream riparian vegetation will limit the extent of the "blockage" to a few...
hundred metres. If the area remains largely undisturbed, at least some elements of the fauna will be able to cross over the spillway or gently-sloping dam wall; if a waste rock wall is constructed, the slope may be too steep to allow passage of game animals.

Whilst the construction of some form of "pathway" over the dam wall will facilitate this movement, it must be remembered that such a "pathway" could also be used by off-road vehicles with concomitant damage to the dam wall structure. Inevitably, game animals are expected to find their own bypass route around the new dam wall.

- Research and monitoring needs
  None required.

5.3.3.6 Loss of sediments and nutrients to downstream ecosystems

- Impact statement and description
  A dam on the Khan River will trap sediments and their associated nutrients from flood waters. This will change the geomorphological processes presently operating in the bed of the river and will reduce the supply of nutrients and alluvial material to downstream ecosystems.

- Impact significance
  The passage of sediment-laden water down the normally dry rivers of the Namib Desert during flood events represents probably the major mechanism whereby downstream ecosystems receive nutrient inputs. Interception of flood-borne sediments by a dam wall will limit the potential for nutrient recharge to the groundwater. However, it is likely that this impact will only extend down the Khan River as far as its junction with the Swakop River. This could have a moderate impact if the groundwater nutrient supply is insufficient to meet the nutrient requirements of downstream ecosystems.

- Impact mitigation
  See research and monitoring requirements.

- Research and monitoring needs
  The lack of quantitative information on the relative quantities of nutrients transported by surface floods and groundwater in the Khan River prevents proper evaluation of the potential significance of this impact. Clearly, the relative quantities of nutrients transported by surface floods and groundwater is dependent on the size of particular floods. It is recommended that this impact should be accepted as inevitable.
5.3.3.7 Elevated erosion rates below dam wall

- **Impact statement**
  Any water passing over the spillway of a dam on the Khan River will have an elevated capacity to pick up and suspend downstream sediments because its original sediment load will have been depleted by deposition in the reservoir basin.

- **Impact description**
  The enhanced sediment-carrying capacity of water discharged from a dam results in increased erosion of riverbed sediments from the river reach below the dam wall, until an equilibrium between aggradation and degradation is reached. The quantitative assessment of this impact is extremely difficult but it can be described in qualitative terms. Basically, the "sediment hungry" water scours away accumulated sediments downstream of the dam wall or spillway until the depth and rate of flow is insufficient to lift and transport sediment particles.

- **Impact significance**
  This impact is potentially of moderate significance in the area immediately downstream of the dam wall where water flows are highest and sediment loads lowest. The sediment load carried by the Khan River during floods varies between 3 % and 22 %; a fair estimate of the average sediment carrying capacity of flood water is 5 % (Marais, 1990). This value can be used to estimate the approximate volume of sediment likely to be eroded by water discharged via the spillway.

  As the Khan River flow equilibrates and sediment-carrying capacity is restored with increasing distance from the dam wall, the significance of this impact will decline to become minor.

- **Impact mitigation**
  Protection of the area immediately below the dam spillway with rock-filled gabions would reduce the impact of fast-flowing water in the vicinity of the dam wall. However, this technique is expensive and the only sources of easily exploitable rock would be waste rock from waste dump 7 or rock blasted out to construct a spillway. At the dam site, dissipation of the energy of waters spilling over the spillway would require localized riverbed protection.

  The low walls of downstream spreading grounds will also help to retard the flow of water discharged over the spillway. However, if the flow is sufficiently high, the spreading ground walls can be allowed to wash away, increasing the sediment load carried by the water and decreasing its erosion potential.

- **Research and monitoring needs**
  The sediment-carrying capacity of sediment-poor water should be estimated for different possible discharge flow scenarios.
5.3.3.8 Disturbance due to elevated noise and dust levels

- **Impact statement and description**
  Increased levels of dust and noise can be expected to occur during the construction of the dam wall, spillway, outlet structures and the walls of downstream spreading grounds. Noise levels will be particularly high when blasting of rock formations is required to properly shape the spillway. These impacts will disturb small and large mammals and, possibly, birdlife.

- **Impact significance**
  Since this impact is expected to be confined mainly to the construction period, its significance is expected to be minor. High levels of airborne dust can be expected after construction if the exposed alluvium material of the dam wall is not covered with a protective layer of waste rock or a geo-textile fabric to reduce wind erosion.

- **Impact mitigation**
  Construction activities should be completed as soon as possible to reduce the length of time that the disturbance occurs. Where possible, exposed areas of alluvium (e.g. the faces of the dam wall) should be covered to reduce wind erosion. Rain falling on the construction site will form a thin crust on the soil surface which will limit the extent of wind erosion in borrow areas. However, given the scarcity and localized nature of rainfall at Rössing, it may be necessary to provide some form of cover for those borrow areas located away from the riverbed. Floodwaters carry sufficient quantities of silt to cover any borrow areas located in the bed of the Khan River.

- **Research and monitoring needs**
  None required.

5.3.3.9 Development of new riparian habitats along shoreline

- **Impact statement and description**
  New riparian habitat could be created along the shoreline of the reservoir created by a dam at the Dome Gorge Site. Fast-growing indigenous and alien tree species, as well as a variety of reeds and sedges, could proliferate in response to the higher water table and nutrient-rich silt deposited upstream of the dam wall.

- **Impact significance**
  This benefit has the potential for moderate significance to the fauna and flora of the Khan River ecosystem. The benefit may, however, be reduced if alien invasive species such as *Prosopis* sp. predominate and prevent the development of indigenous tree species such as *Acacia albida*.

RÖSSING URANIUM LIMITED
- **Impact optimization**
  Where possible, the development of alien invasive species of vegetation should be prevented.

- **Research and monitoring needs**
  Regular annual checks of the vegetation that develops around the shoreline of the reservoir basin should be conducted. A control programme should be considered if large numbers of alien invasive species are encountered.

5.3.3.10 Reservoir effect on local microclimate

- **Impact statement and description**
  The introduction of a body of open water in an arid area such as the Namib Desert could cause a localized change in the microclimate along the Khan River.

- **Impact significance**
  In view of the expected low frequency of floods in the Khan River and the intention to empty the reservoir relatively rapidly, the significance of this impact is considered to be minor to negligible.

- **Impact mitigation**
  None required.

- **Research and monitoring needs**
  None required.

5.3.4 Health and safety issues

5.3.4.1 Contamination of groundwater by radionuclides

- **Impact statement**
  There is continued public concern that groundwater emanating from, or flowing past, the Rössing Uranium Mine could be contaminated by radionuclides (Ashton et al., 1991). The concern centres on the perception that such contamination will render the water unfit for use by downstream water users, including the natural ecosystems, and also have adverse effects on the health or survival of these users.

- **Impact description**
  If groundwater is contaminated by excessively high levels of radionuclides it is unfit for human use and could cause damage to elements of the natural fauna and flora, such as riparian vegetation, which make use of groundwater. The natural background radiation levels in the area around the Rössing Uranium Mine are considered to be relatively high, due to the presence of localized radiation anomalies in the area around the Rössing orebody.
The radionuclide levels present in groundwater compartments around the Rössing Uranium Mine are monitored at several points on a regular basis. The location of some of these monitoring boreholes is shown in Figure 4.22 in relation to the various components of the Rössing Uranium Mine infrastructure; the results of analyses since 1989 are shown in Table 4.8. Boreholes N6, L19 and X16 are not influenced by seepage from the mine and reflect the natural background variability of radionuclide concentrations derived from local geological formations. The water chemistry of samples from borehole N12 indicates that it is affected by seepage; nevertheless, the radionuclide levels in this borehole are well within accepted levels. Similarly, boreholes 1.4 and 1.6 in the bed of the Khan River do not show any signs of seepage contamination and also have very low levels of radionuclides. The year-to-year variation for each borehole, as shown in Table 4.8 is also within acceptable levels.

- Impact significance
  The data shown in Table 4.8 for radionuclide concentrations in monitoring boreholes reflect the variability of the natural background levels of radionuclides derived from the regional geological formations. The low levels of radionuclides in the monitoring borehole samples indicates that the impact of radionuclide contamination of groundwater is minor.

  However, if waste rock is used to construct a dam wall at the dam site, additional quantities of radionuclides could be leached from the rock into the groundwater. This type of contamination cannot yet be quantified with accuracy. However, given the alkaline nature of the Rössing orebody and the acid extraction process required to recover uranium from the alaskites, it is highly unlikely that the normally alkaline flood waters will leach any radionuclides from waste rock. Thus, radionuclide concentrations are unlikely to increase above their current levels. This impact is considered to be of minor significance.

- Impact mitigation
  The use of waste rock for dam wall construction should be avoided, despite the fact that the possible level of radionuclide contamination cannot be estimated with accuracy and is likely to be insignificant. The use of riverbed alluvium from the Khan River is unlikely to increase radionuclide levels in groundwater and the impact would therefore be insignificant.

  Nevertheless, routine monitoring of radionuclide levels in the monitoring boreholes should continue. In addition, any additional boreholes drilled in the bed of the Khan River downstream of a dam should be regularly sampled and checked for their radionuclide content.

- Research and monitoring needs
  See details of recommended mitigatory actions.
5.3.4.2 Contamination of groundwater

- **Impact statement**
  Contamination of the Khan River groundwater by nitrate derived from the quantities and types of explosives used at the Rössing Uranium Mine could reduce the groundwater’s fitness for use by downstream users.

- **Impact description**
  There are many different views on the acceptable levels of nitrate and nitrite in drinking water. For example, accepted American (USA) practice will allow up to 45 mg NO₃-N plus NO₂-N/l whilst the South African standard (SABS 241) stipulates 10 mg NO₃-N plus NO₂-N/l. Medical evidence indicates that high concentrations (greater than 25 mg/l) of nitrate and nitrite in water used continually for drinking purposes can cause methylhaemoglobinemia in infants under the age of 6-12 months (Kempster, Hattingh & van Vlier, 1980). There is no such effect on adult humans.

- **Impact significance**
  The explosive used at Rössing is Heavy Ammonium Nitrate Fuel Oil (Heavy ANFO) which comprises two components: an oxidizer in the form of ammonium nitrate and a dense fuel, trade named HIF (High Energy Fuel).

  Based on an average of 0.3 kg of explosive for every tonne of material blasted, this would require approximately 42 tonnes of explosive per day. During a blast, most of the nitrate would be burnt off and only very small amounts of residue would adhere to the rock. Inevitably, waste rock removed from the open pit would contain quantities of nitrate though the quantity involved cannot be estimated with accuracy.

  The natural background levels of nitrate in groundwater around the Rössing Uranium Mine are very variable, ranging from zero (i.e. non-detectable) to 312 mg/l, with a mean value of 20.8 mg/l. In addition, high background levels of fluoride, sulphate and chloride raise the total salt content of the ground water and render it brackish and unfit for human consumption. Therefore, since it is highly unlikely that humans would drink groundwater from the Khan River, the significance of high nitrate levels is minimal.

- **Impact mitigation**
  Whilst the impact of nitrate contamination of groundwater from the explosives used at the Rössing Mine is considered to be minor, it could cause public concern. The most suitable means of eliminating this impact is through the continued use of the existing cut-off trenches which intercept any seepage from the mine site.

- **Research and monitoring needs**
  No special measures required. The routine monitoring of groundwater chemistry should continue.
5.3.4 Socio-economic issues

5.3.4.1 Aesthetic impacts of borrow areas etc.

- **Impact statement**
  If borrow areas and waste rock piles located near the dam site are not adequately rehabilitated after construction, there will be an adverse impact on the aesthetic appearance of the dam site. Similarly, the aesthetic appearance of borrow pits located away from the dam site could be adversely impacted if they are not properly rehabilitated.

- **Impact description**
  The aesthetic appearance of the Khan River could be adversely affected by the presence of large areas of open-cast alluvium diggings during spillway construction. This will detract from the present beauty of the area.

- **Impact significance**
  This impact has a potentially moderate significance. Location of borrow pits within the reservoir basin will lead to a minor increase in reservoir capacity; implementation of this and other appropriate rehabilitation measures will reduce this significance to minor levels.

- **Impact mitigation**
  All borrow areas should either be located within the reservoir basin or rehabilitated by in-filling and landscaping. Waste rock cover should not be used in exposed areas or those that are visible from public access routes.

- **Research and monitoring needs**
  Maintain a routine check of rehabilitated areas to ensure that the layer of covering material remains in place. Add additional cover material if the fill is exposed by wind or water action.

5.3.4.2 Increased litter and waste around construction site

- **Impact statement and description**
  The increased numbers of people in the area and the construction activities could result in the accumulation and dispersion of litter and other garbage in the site area and the work force camp area. This could cause damage to the flora and fauna as well as a decrease in the aesthetic appeal of the area. The greatest damage is caused by waste oil and plastics, as well as flammable materials.

- **Impact significance**
  This impact will be of minor significance provided that the mitigatory measures are applied.
• **Impact mitigation**
  Plan and implement an efficient waste collection and disposal system, as well as a clean-up campaign after construction is completed. Ensure that all waste materials are disposed of in appropriate systems. Prevent the risk of fires spreading from incineration systems.

  Transport any waste oil to the Rössing Uranium Mine workshops for recycling.

• **Research and monitoring needs**
  Maintain a regular check on the presence of waste material in and around the construction site and work force camp.

5.3.4.3 Disturbance of local archaeological sites

• **Impact statement**
  Construction activities and the movements of large numbers of workers around a construction site could result in damage to or loss of archaeological sites. The research, educational and historical value of such sites could be lost.

• **Impact description**
  The only known archaeological site of possible interest is a small chalcedony outcrop used in the manufacture of stone implements and located some 10 kilometres away from the proposed dam site. There are no known archaeological sites in the immediate vicinity of the dam site. There would therefore appear to be little chance of this impact occurring.

• **Impact significance**
  The impact significance must be negligible in view of the apparent absence of archaeological sites near the dam site.

• **Impact mitigation**
  None required.

• **Research and monitoring needs**
  None required.

5.3.4.4 Severance of public access to the bed of the Khan River

• **Impact statement and description**
  Construction of a dam wall and the subsequent inundation of the dam basin will reduce the previous accessibility of the area to members of the public. Fencing off the dam site will exclude public access. Potentially affected parties are members of the Namib Off-road Club and other individuals who may drive up the bed of the Khan River on an *ad hoc* basis.
Impact significance
It may be possible to allow public access over a 25 metre high dam wall via a firm "pathway" at the side of the dam wall (e.g. over the spillway) if this can be built during construction. In this case, it would also be necessary to provide access around the upstream flooded area to prevent vehicles bogging down in silt deposits. The steep topography of the terrain, coupled with the proximity of the Rössing property and protected areas within the Namib Naukluft Park, precludes the development of alternate routes outside the bounds of the bed of the Khan River.

The direct significance of this impact is considered to be minor. However, the secondary significance of this impact lies in the choice of alternative route(s) that the affected parties might use. The use of other, perhaps more sensitive, areas as alternate routes could have far greater impacts than the severance of public access caused by the dam wall alone.

Impact mitigation
No mitigation required other than the prevention of impacts resulting from people visiting the area. A possible option in this regard is the erection of a fence to limit public access to vulnerable portions of the dam wall and downstream spreading grounds.

The option of creating a safe "pathway" over the spillway region of the dam wall should be examined to test its feasibility.

Research and monitoring needs
None required.

5.3.4.5 Risk of increased beach erosion at Swakopmund

Impact statement and description
There is a perception that, if the Khan Dam is built and is able to trap and retain small- to medium-sized floods, this will greatly reduce the quantity of sediments discharged from the mouth of the Swakop River into the shore zone of the Atlantic Ocean. It is perceived that sediments discharged by the Swakop River are vital to sustaining the beaches in Swakopmund.

Impact significance
The contribution of sediments from the Khan River is less than ten percent of the sediment load contributed by the upper Swakop River. If this is reduced, it will have a minor negative effect on sediment loads discharged into the sea.

Erosion and deposition patterns along the coastline are affected by the northerly directed longshore drift and, to a minor extent, by material brought down by local rivers during floods. The erosion pattern at Swakopmund beaches is similar to
that at Sandwich Harbour to the south of Walvis Bay. Indications from coastal studies conducted elsewhere along the coastline are that coastal erosion rates have increased substantially in recent years. Sediments brought down the Khan and Swakop rivers and discharged into the sea generally have a very short-lived effect before they are dispersed by wind and wave action. Therefore, the effect of a reduction in the sediment load brought down by the Khan River is expected to be very minor to negligible.

- **Impact mitigation**
  Given the minor significance attached to sediment loads contributed by the Khan River, no mitigatory actions are recommended.

- **Research and monitoring needs**
  A watch should be kept of rates of beach erosion and deposition at beaches along the Namibian coastline to determine if there is a regular pattern.

  At Swakopmund, annual elevation surveys should be carried out of the beaches along a number of transects or profiles. If possible, a close check should be kept on rates of sediment transport along the coastline.

5.3.4.6 Intermittution of sand-mining activities

- **Impact statement and description**
  There is a perception that the sediments brought down by the Khan and Swakop Rivers replace the building sand that is removed during sand mining activities near the mouth of the Swakop River. Any reduction in the loads of sediment brought down by the Khan and Swakop rivers will adversely affect the replacement of this building sand.

- **Impact significance**
  Thermoluminescence dating techniques have revealed that the extensive sand deposits which have been mined in recent years are between 340 and 8,700 years old. No evidence could be found to support the contention that small- and medium-sized floods have brought down comparable material in recent years. Instead, these smaller floods cause erosion of the existing deposits and merely re-distribute the material which is already in place. Therefore, any alteration of the current flooding regime in the Khan and lower Swakop rivers will have a negligible effect on the material available for sand mining.

- **Impact mitigation**
  The current, somewhat haphazard methods of sand mining could be better organized so that the available sand resources could be utilized efficiently. This could also help to reduce water lost through evaporation and thereby help to reduce increased salinization of the ground water.
Research and monitoring needs
Annual evaluation of the areas affected by sand mining and the quantities of sand removed. In addition, a coherent management plan should be developed to facilitate sustainable utilization of the sand resources.

An annual elevation survey of the river bed profile at the three sand mining sites should be carried out to determine the rates of sand deposition and/or erosion.

5.3.4.7 Risk of dune encroachment into Swakopmund

Impact statement and description
There is a perception that those Swakop River floods which are able to reach the sea also scour out wind-blown sand dunes (from the south of the Swakop River) and prevent these from encroaching into the town of Swakopmund.

Impact significance
Examination of serial photographs taken over the last thirty-five years have revealed that the sand dunes located on the south bank of the Swakop River have been stationary during this period and have not migrated into or across the Swakop River. Therefore, any reduction in flood volumes in the lower Swakop River is unlikely to have any noticeable effect on the position or movement of these sand dunes, and they are unlikely to migrate across the Swakop River into Swakopmund.

Impact mitigation
None required.

Research and monitoring needs
Regular annual checks should be maintained on the sand dunes to determine whether or not they display any tendency to begin mobilizing. If the dunes start to mobilize the situation should be re-evaluated.

5.3.4.8 Water quality deterioration in the lower Swakop River

Impact statement and description
Farmers located along the lower reaches of the Swakop River already experience difficulties due to lowering of water levels and a deterioration in the quality of water drawn from the bed of the Swakop River. There is a widespread belief that the proposed Khan Dam will cause a severe deterioration in water quality and cause a further drop in water levels, rendering the water unfit for irrigation or stock-watering. In turn, this could result in these farming activities becoming uneconomic and causing the cessation of all farming activities.
• **Impact significance**

Modelling results have indicated that the current lowering of the water table and deterioration in water quality in the lower Swakop River is due largely to reduced surface water flows in the Swakop River as a result of the operation of the Von Bach and Swakoppoort Dams. Reduced surface water flows have caused recharge rates to decline, whilst evaporation at so-called "nat kolle" have contributed significantly to a deterioration in water quality.

The surface (flood) water flows in the Khan River have helped to alleviate some of these problems. However, since the contribution from the Khan River is relatively small compared with that from the Swakop River, this effect is relatively small. If small- and medium-sized floods in the Khan River are trapped and prevented from reaching the Swakop River, it is anticipated that, under worst case conditions, this could cause a further drop in ground water levels of some 10 to 40 centimetres, together with an increase in total dissolved salts of some 1,400 milligrammes per litre. This could potentially have moderate-to-serious impacts on irrigation farmers.

Given the slow flow rate of ground water in the Khan River (some 400 to 500 metres per year), any ground water effect arising from the proposed Khan Dam will not reach the lower Swakop River during the expected life of the Khan Dam. By the time that the Khan Dam would be decommissioned, any surface water flood flows would rapidly recharge the alluvium and improve ground water quality.

The bed of the Swakop River is above sea level and no sea water would intrude into the Swakop River aquifer as a result of declining water levels.

• **Impact mitigation**

There is apparently a pattern of water quality improvement towards the centre of the Swakop River aquifer. Water drawn from this area would be of a better quality than that drawn from the banks of the Swakop River as most farmers do at present. However, this could pose potential risk of loss of borehole equipment if the Swakop River comes down in flood. Therefore, any move to site boreholes near the centre of the Swakop River would have to be carefully considered. In addition, permission would have to be sought from the relevant authorities before this practice was attempted.

If approved, "communal" boreholes or wells could be constructed in the centre of the Swakop River. This would improve the efficiency of use of financial resources and would also allow careful construction to withstand floods.

Small-sized floods could be trapped and the ground water recharged if a small-scale aquifer recharge scheme were to be implemented in the lower reaches of the Swakop River. This would lead to a rapid improvement in water quality and would prevent any unnecessary loss of flood waters to the sea.
• **Research and monitoring needs**
  The existing Rössing Mine ground water monitoring programme should be continued. In addition, new monitoring boreholes should be developed in the farming area along the lower Swakop River. These should be used to establish any patterns of water quality change across the Swakop River, as well as any changes which take place along the length of the river. The positions of these boreholes should be decided on in consultation with the farmers. These boreholes should also be sited so that they are not affected by current ground water abstraction patterns. A regular check must be kept on water levels and water quality at all boreholes.

5.6 **Socio-economic benefits**

5.6.1 **Improved management and monitoring of area**

• **Impact statement and description**
  The area affected by the aquifer recharge scheme should be managed and monitored on a continuous basis. The current water chemistry, water level and vegetation monitoring programmes should be continued and supplemented with additional monitoring of the reservoir basin, aquifer dynamics and the diversity of bird and animal life inhabiting the area around the reservoir basin.

• **Impact significance**
  The significance of this benefit will depend on the extent of additional monitoring and management actions that are initiated. The benefit is potentially of moderate to major significance as there are few protected riverine areas in the Central Namib region. These river systems are critical for the maintenance of the delicately balanced ecological processes which function in the Namib Desert; their conservation is therefore of prime importance.

• **Impact optimization**
  Allocate appropriate resources to continue and extend the existing monitoring programmes on affected areas along the Khan River. Draw up a combined monitoring programme schedule to incorporate the additional monitoring requirements.

• **Research and monitoring needs**
  As described under benefit optimization.

5.6.2 **Improved knowledge of aquifer functioning**

• **Impact statement and description**
  There will be an improvement in the knowledge and understanding of aquifer dynamics and recharge processes within the Khan River aquifer. This will also
allow evaluation of the efficacy of the aquifer recharge scheme and its potential for application in other arid areas, as well as the extent and significance of its environmental impacts.

- **Impact significance**
The benefits to be gained by this knowledge are potentially of major importance in an arid country like Namibia.

- **Impact optimization**
Monitor, record and document the progress achieved and the resulting impacts during each stage of the project. Document and store all information in an easily retrievable form.

- **Research and monitoring needs**
As described under benefit optimization.

---

### 5.6.3 Conservation of existing water resources

- **Impact statement and description**
If this project is successful, the existing groundwater reserves in the Khan River aquifer will provide an effective supplementary source of water to the Rössing Uranium Mine. This aquifer recharge scheme will supply sufficient brack water to meet the dust suppression and process water demands of the Rössing Uranium Mine and reduce the mine's dependence on freshwater supplies.

- **Impact significance**
Despite the relatively small quantities of water involved, the benefits to be derived from the Khan River aquifer recharge scheme will be of major significance to the Central Namib region. The eventual significance will depend on the care with which the recharge scheme is operated and maintained.

- **Impact optimization**
A balance must be maintained between water abstraction from, and water recharge to, the Khan River aquifer. The operational management of the dam and infiltration basins must be well-planned, implemented and monitored. In addition, the contribution of Khan River water to the overall water balance within the Rössing Uranium Mine plant should be monitored on an on-going basis.

- **Research and monitoring needs**
As described under benefit optimization.
5.6.4 Improved recreational opportunities

- **Impact statement and description**
  The area around the new dam site is expected to sustain increased riparian vegetation and attract increased numbers of birds and animals to this habitat. This could provide an opportunity either to create a public access picnicking area or to proclaim a controlled access conservation area.

- **Impact significance**
  The benefit is considered to be of minor to negligible significance, depending on the decision to allow public access and the type and level of facilities provided.

- **Impact optimization**
  The dam site should be restored to as near a natural state as possible after construction is completed. Consideration should be given to allowing limited public access to the dam site and, if public access is granted, appropriate access roads should be provided as well as sanitation and suitable facilities to minimize fire hazards and littering.

- **Research and monitoring needs**
  None required.

5.7 Economic benefits

- **Impact statement and description**
  The proposed Khan Dam facilitates the use of brackish water at a location where significant economic benefit to Rössing and local, regional and National Government coffers. The water requires minimal treatment to render it fit for use, unlike present resources which comprise potable water which, in time, would comprise a base volume of desalinated sea water.

- **Impact significance**
  Since treated water is sold on a full-cost recovery basis at minimal mark-up, any brackish untreated water used to replace the treated water would result in a real financial saving to Rössing and coastal residents would also benefit financially by virtue of a reduced rate of commissioning of desalination modules.

  The effective use of water (per cubic metre) from the KARS Project will be of the order of N$ 0.41/cubic metre for a 20-year scheme. Over this period an average volume of 1,500 cubic metres per day would have been abstracted from the Khan River over and above currently sustainable abstraction rates.

- **Impact optimization**
  The KARS Project should be implemented along with all relevant mitigatory actions as soon as practicable to maximize the benefits.
5.8 Summary of issues and anticipated impacts

The expected impacts of dam construction in the Khan River are summarized in Table 5.3. This table also summarizes the duration, scale, degree of reversibility, potential for mitigation and overall significance of the expected impacts.

The major ecological impacts centre on the loss of riparian and other vegetation at and above the dam site due to inundation and siltation (Table 5.3). The loss of a portion of the dispersion/migration corridor formed by the riparian ecosystem and interference with the dynamics of the Khan River aquifer system could also have serious implications for the Khan River ecosystem. If mitigatory actions are implemented, the other impacts are likely to have minor significance.

The major socio-economic impacts associated with the construction of a dam wall across the Khan River centres on the adverse effects on downstream users along the lower Swakop (Table 5.3). The potential for mitigatory management actions on the socio-economic impacts are also summarized in Table 5.3.

The major benefits associated with the construction of a dam wall across the Khan River centre on the acquisition of improved knowledge of aquifer dynamics, the maintenance of water levels for downstream riparian vegetation and the economic advantages to be gained by extending the life of other ground water resources in the region (Table 5.3). Minor additional benefits are gained by the development of new riparian habitats along the shoreline of the new reservoir. Appropriate optimization actions, including suitable monitoring programmes, enhance the perceived benefits (Table 5.3).

An additional benefit, which cannot at this time be properly quantified, is the strong likelihood that the aquifer recharge scheme will improve the quality of the groundwater in the Khan River aquifer. Whilst this observation is based on the lower total salt content of flood waters compared to existing groundwater in the Khan River aquifer, the degree of improvement in groundwater quality can not be predicted accurately.

The overall conclusions and recommendations as to the KARS Project and an overview of appropriate mitigatory or optimization actions that are required to minimize impacts and optimize benefits are given in Chapter 6 of this Report.
Table 5.3: Summary of Key Issues and the importance/significance of the anticipated impacts

<table>
<thead>
<tr>
<th>Environmental Component or Activity</th>
<th>Impact Type</th>
<th>Sign</th>
<th>Scale</th>
<th>Duration</th>
<th>Severity</th>
<th>Certainty</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water flows</td>
<td>Direct</td>
<td>Negative</td>
<td>Regional</td>
<td>Medium</td>
<td>Moderate</td>
<td>Definite</td>
<td>Medium</td>
</tr>
<tr>
<td>Ground water flows</td>
<td>Direct</td>
<td>Positive</td>
<td>Local</td>
<td>Medium</td>
<td>Moderate</td>
<td>Definite</td>
<td>Medium</td>
</tr>
<tr>
<td>Water levels</td>
<td>Direct</td>
<td>Positive (Khan)</td>
<td>Local</td>
<td>Medium</td>
<td>Moderate (Khan)</td>
<td>Definite</td>
<td>High (Khan)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Negative (Swakop)</td>
<td></td>
<td></td>
<td>Low (Swakop)</td>
<td></td>
<td>Low (Swakop)</td>
</tr>
<tr>
<td>Sediment loads</td>
<td>Direct</td>
<td>Negative</td>
<td>Regional</td>
<td>Medium</td>
<td>Moderate</td>
<td>Definite</td>
<td>Medium</td>
</tr>
<tr>
<td>Ground water quality</td>
<td>Direct</td>
<td>Positive</td>
<td>Local</td>
<td>Medium</td>
<td>Moderate</td>
<td>Probable</td>
<td>Medium</td>
</tr>
<tr>
<td>Riparian vegetation</td>
<td>Direct</td>
<td>Negative</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Possible</td>
<td>Low/medium</td>
</tr>
<tr>
<td>Birds</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Possible</td>
<td>Low/medium</td>
</tr>
<tr>
<td>Mammals</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Possible</td>
<td>Low/medium</td>
</tr>
<tr>
<td>Reptiles and amphibians</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Possible</td>
<td>Low/medium</td>
</tr>
<tr>
<td>Archaeological sites</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Definite</td>
<td>Zero</td>
</tr>
<tr>
<td>Ecological integrity</td>
<td>Direct</td>
<td>Negative</td>
<td>Regional</td>
<td>Medium</td>
<td>Moderate</td>
<td>Probable</td>
<td>Medium</td>
</tr>
<tr>
<td>Dune encroachment</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low/zero</td>
<td>Probable</td>
<td>Zero</td>
</tr>
<tr>
<td>Replacement of sand</td>
<td>Direct</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low/zero</td>
<td>Definite</td>
<td>Zero</td>
</tr>
<tr>
<td>Beach/coastal erosion</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low/zero</td>
<td>Probable</td>
<td>Zero</td>
</tr>
<tr>
<td>Aesthetic values</td>
<td>Direct</td>
<td>Negative</td>
<td>Local</td>
<td>Medium</td>
<td>Moderate</td>
<td>Probable</td>
<td>Medium</td>
</tr>
<tr>
<td>Off-road vehicle travel</td>
<td>Direct</td>
<td>Positive</td>
<td>Local</td>
<td>Medium</td>
<td>Low</td>
<td>Definite</td>
<td>Low</td>
</tr>
<tr>
<td>Radio-activity</td>
<td>Indirect</td>
<td>Zero</td>
<td>Local</td>
<td>Medium</td>
<td>Low/zero</td>
<td>Possible</td>
<td>Low</td>
</tr>
<tr>
<td>River water utilisation</td>
<td>Direct</td>
<td>Positive</td>
<td>Regional</td>
<td>Medium</td>
<td>Moderate</td>
<td>Definite</td>
<td>Medium</td>
</tr>
</tbody>
</table>
6. SUMMARY OF IMPACTS, MITIGATORY ACTIONS AND FURTHER RECOMMENDATIONS

In this Chapter we provide a brief, summarized overview of the impacts identified during the Project, together with suggestions for provisional mitigatory actions. In addition, since communication issues are critical to the success of this process, we make suggestions as to where and how the communication process can help to improve the general public’s perceptions of the motives of the project proponents as well as the environmental evaluation process.

Full details of the anticipated environmental impacts have been listed previously under the relevant issues of concern. The reader is referred to the appropriate sections of Chapter 5 of this Report for these details.

6.1 Key impacts and issues of concern

A graphical summary of all the major environmental impacts and their geographical locations identified during the project are listed in Table 6.1. In this table the degree of the impact, whether negative or positive and the degree of confidence in the judgement of the impact being experienced, is identified.

Key impacts that were identified during the project, together with the duration, scale, degree of reversibility and potential for mitigation are summarized in Tables 6.2 and 6.3.

6.2 Proposed mitigatory actions and recommendations

Should Rössing Management eventually decide to continue with implementation of the KARS project, it will be necessary to implement a series of selected mitigatory actions. These mitigatory actions should be designed in such a way as to minimise adverse impacts and maximise the potential benefits associated with the KARS project. In accordance with RTZ and Rössing operational policies of employing best practices during all operations, all mitigatory actions will be designed in such a way that they constitute best contemporary practice. It is important to remember that all actions have an element risk and uncertainty attached to them; no actions or recommendations can be 100% certain to succeed. However, every reasonable precaution and design technique will be taken to minimize risks within the constraints of available proven technology.

It is important that all mitigatory actions which are intended to alleviate potential adverse impacts on individuals and communities, should be designed in conjunction with the affected individuals and communities, as well as Rössing staff and, if required, staff from the Department of Water Affairs. If these individuals and communities are not involved in this process, it is unlikely that the proposed mitigatory actions will ever be successful. Clearly, even if the KARS Project does not proceed, the mitigatory actions listed below would assist in improving the overall water management of the region.
### Figure 6.1: Graphical summary of the key issues associated with the proposed KARS project and their level of significance.

**Legend:**
- Area 1 = Usakos to dam site; Area 2 = dam site; Area 3 = dam site to mine frontage; Area 4 = mine frontage to confluence with Swakop River; Area 5 = Swakop River upstream of confluence; Area 6 = Swakop-Khan confluence to Goanikontes; Area 7 = Goanikontes to coastline; Area 8 = coastline.
- Blank = No effect or no discernible impact; Yellow = Minor negative impact; Red = Moderate negative impact; Green = Minor positive impact; Blue = Moderate positive impact; "?" = Uncertain of impact, probably low. Numerals in blocks indicate level of certainty, e.g. "80%" = 80% certain that effect will occur.

<table>
<thead>
<tr>
<th>Environmental component</th>
<th>Geographical area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water flows</td>
<td>1    2    3    4</td>
</tr>
<tr>
<td>Ground water flows</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Water levels</td>
<td>80   80   40    80</td>
</tr>
<tr>
<td>Sediment loads</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Ground water quality</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Riparian vegetation</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Birds</td>
<td>?</td>
</tr>
<tr>
<td>Mammals</td>
<td>?</td>
</tr>
<tr>
<td>Reptiles / amphibians</td>
<td>?</td>
</tr>
<tr>
<td>Archaeological sites</td>
<td></td>
</tr>
<tr>
<td>Ecological integrity</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Dune encroachment</td>
<td></td>
</tr>
<tr>
<td>Replacement of sand</td>
<td></td>
</tr>
<tr>
<td>Beach/coastal erosion</td>
<td></td>
</tr>
<tr>
<td>Aesthetic values</td>
<td>80</td>
</tr>
<tr>
<td>Off-road vehicle travel</td>
<td>80   80   80    80</td>
</tr>
<tr>
<td>Radio-activity</td>
<td></td>
</tr>
<tr>
<td>River water utilization</td>
<td>40   40   40    40</td>
</tr>
</tbody>
</table>
TABLE 6.2: Summary table showing the duration, scale, degree of reversibility, potential for mitigation and significance of the ecological impacts associated with dam construction at the Khan Dam Site.

<table>
<thead>
<tr>
<th>ECOLOGICAL IMPACT</th>
<th>DURATION</th>
<th>SCALE</th>
<th>REVERSIBILITY</th>
<th>POTENTIAL FOR MITIGATION</th>
<th>IMPACT SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short (S) Medium (M) Long (L)</td>
<td>Local (L) Sub-Regional (SR) Regional (R)</td>
<td>Reversible (R) Non-Reversible (NR)</td>
<td>Low (L) Medium (M) High (H)</td>
<td>Assumes recommended mitigation actions are implemented</td>
</tr>
<tr>
<td>Riparian habitat at and above construction site is lost or removed during construction</td>
<td>L</td>
<td>&quot;L</td>
<td>NR</td>
<td>L</td>
<td>Moderate</td>
</tr>
<tr>
<td>Rare or endangered species are lost from dam basin</td>
<td>L</td>
<td>L &amp; SR</td>
<td>?</td>
<td>?</td>
<td>M</td>
</tr>
<tr>
<td>Downstream riparian vegetation is damaged</td>
<td>S M L</td>
<td>SR</td>
<td>R</td>
<td>M</td>
<td>Minor</td>
</tr>
<tr>
<td>Increased spread of alien vegetation</td>
<td>L</td>
<td>SR</td>
<td>R</td>
<td></td>
<td>H</td>
</tr>
<tr>
<td>Loss of dispersion/migration corridor</td>
<td>S M L</td>
<td>L &amp; SR</td>
<td>?</td>
<td>?</td>
<td>L</td>
</tr>
<tr>
<td>Loss of sediments and nutrients to downstream ecosystems after dam construction</td>
<td>L</td>
<td>SR</td>
<td>Partially R</td>
<td>M</td>
<td>Minor</td>
</tr>
<tr>
<td>Erosion rates below dam wall are elevated when water spills over spillway or spreading grounds</td>
<td>L</td>
<td>L &amp; SR</td>
<td>Partially R</td>
<td>M</td>
<td>Minor</td>
</tr>
<tr>
<td>Fauna are disturbed by elevated noise and dust levels during construction</td>
<td>S</td>
<td>L</td>
<td>R</td>
<td></td>
<td>H</td>
</tr>
<tr>
<td>Dam construction interferes with the dynamics of the Khan River aquifer system</td>
<td>L</td>
<td>L &amp; SR</td>
<td>Partially R</td>
<td>M</td>
<td>Minor</td>
</tr>
<tr>
<td>Groundwater quality in the lower Swakop River deteriorates</td>
<td>M &amp; L</td>
<td>SR</td>
<td>Partially R</td>
<td></td>
<td>L</td>
</tr>
<tr>
<td>Groundwater quality in the Khan River improves as a result of recharge</td>
<td>M &amp; L</td>
<td>SR</td>
<td>Partially R</td>
<td></td>
<td>L</td>
</tr>
<tr>
<td>When full, the reservoir has an effect on the local microclimate</td>
<td>L</td>
<td>L</td>
<td>?</td>
<td>?</td>
<td>L</td>
</tr>
</tbody>
</table>
**TABLE 6.3:** Summary table showing the duration, scale, degree of reversibility, potential for mitigation and significance of socio-economic impacts associated with dam construction at the Khan Dam Site

<table>
<thead>
<tr>
<th>SOCIO-ECONOMIC IMPACT</th>
<th>DURATION</th>
<th>SCALE</th>
<th>REVERSIBILITY</th>
<th>POTENTIAL FOR MITIGATION</th>
<th>IMPACT SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast of future water demands are uncertain or inaccurate</td>
<td>Short (S)</td>
<td>Medium (M)</td>
<td>Local (L)</td>
<td>Sub-Regional (SR)</td>
<td>Reversible (R)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Regional (R)</td>
<td>Non-Reversible (NR)</td>
</tr>
<tr>
<td>Silt accumulation reduces dam lifespan and limits success of aquifer recharge project</td>
<td>L</td>
<td>SR &amp; R</td>
<td></td>
<td></td>
<td>Partially Reversible</td>
</tr>
<tr>
<td>Borrow areas and construction site are aesthetically unattractive</td>
<td>S &amp; M</td>
<td>L</td>
<td></td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Increased litter and waste around the construction site and camp</td>
<td>S</td>
<td>L &amp; SR</td>
<td></td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Local archaeological sites are disturbed</td>
<td>L</td>
<td>L</td>
<td></td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Public access to the full length of the Khan River bed is severed</td>
<td>L</td>
<td>L &amp; SR</td>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Drop in water levels affects farmers in lower Swakop River</td>
<td>L</td>
<td>SR</td>
<td></td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Deterioration in water quality affects downstream farmers along the lower Swakop River</td>
<td>L</td>
<td>SR</td>
<td></td>
<td>NR</td>
<td></td>
</tr>
</tbody>
</table>
In this regard, it will be important to ensure that all interested and affected parties are kept informed of progress in this regard.

6.2.1 Develop an Environmental Management Plan

All mitigatory actions should be developed within the context of an environmental management plan. This plan should be drawn up to ensure that all monitoring and mitigatory actions are closely co-ordinated at all times, and that they reflect the consensus decisions reached with those individuals and communities who may be affected by the KARS Project and resultant mitigatory actions. Therefore, the environmental management plan should focus on those areas which require attention and/or action and should be developed in collaboration with the individuals concerned.

The environmental management plan must contain sufficient information on the anticipated impacts that the reasons for mitigatory action are clear. In addition, the plan must contain a list of firm and unambiguous practical suggestions for action, list the parties and individuals who shall be responsible for implementing these actions, a firm timetable within which the actions must be carried out, a description of the methods which shall be used to monitor and evaluate the success of these actions, and a schedule of reporting back to the interested and affected parties, as well as appropriate authorities.

This plan should be drawn up during the early stages of detailed planning for the KARS Project, and should form an integral part of the Project. Potential mitigatory measures which could be considered are set out below.

6.2.2 Additional aquifer recharge in the lower Swakop River

The principles of aquifer recharge considered for the KARS project could also be applied in the Lower Swakop River to overcome the progressive decline in water levels and deteriorating water quality. This action will, in addition, help to make maximum use of the available fresh water resources. Precise details of this action would need to be decided in conjunction with the potentially affected landowners and taking into account the best available geohydrological information.

6.2.3 Ground water quality - lower Swakop River

Here, too, it is feasible to improve ground water quality abstracted by landowners through a combination of aquifer recharge actions (listed above) and the judicious emplacement of abstraction points in the river bed. In addition, this would also apply to the choice of abstraction methods (wells, open cut trenches and boreholes). Once again, this will require a thorough understanding of the geohydrological conditions which prevail in the area. Within this context there are several opportunities whereby neighbouring land owners can jointly achieve improved water availability and access to better quality water through careful of emplacement of communal abstraction points and abstraction regimes.
Here, too, economies of scale are possible.

6.2.4 Coastal and beach erosion

No specific mitigatory actions are feasible or necessary within the context of the KARS project. Coastal and beach erosion processes are naturally variable, and are not dependent on the supply of water or sediment from the Swakop/Khan River system. The scale of these coastal processes is outside the scope of this river system.

6.2.5 Riparian vegetation

Careful control of downstream ground water levels will ensure that the riparian vegetation does not experience adverse impacts as a result of the KARS Project.

6.2.6 Water use in the lower Swakop River

Once again, the principles of aquifer recharge listed above, and concerted efforts to minimize the effects of poor water quality, will enable water use patterns that maximise the benefits of the fresh water resources of the Swakop/Khan system. This will also help to alleviate current and future pressures on other aquifer system in the Central Namib Area.

6.2.7 Sand mining

The current practices employed in sand mining activities in the lower Swakop River are having a significant adverse impact on the lower Swakop River aquifer. However, through careful management and planning this situation can not only be improved, but could also lead to an improvement in operating practices and the aesthetic values of this important tourist area. More importantly, if sand mining practices are planned in conjunction with aquifer management practices, it would result in considerable benefits to both the sand miners and to water users. In this regard, it would be feasible to restructure the sand mining processes to minimize their negative effects on water levels and water quality, whilst using spoil material to enhance recharge.

6.2.8 Erosion at the KARS dam site spillway

Careful design of the KARS Project, employing scale modelling techniques, would assist in minimizing the probability and scale of adverse effects caused by erosion downstream of the spillway.

6.2.9 Recreational access in the Khan Riveran
The anticipated problems of public access through and around the KARS Dam site can be incorporated into the planning of the dam structure and recharge bunds. In this way, other than those times when water is flowing or standing in the system, access can be provided through carefully demarcated routes, thereby enabling recreational users of the Khan River continued access and use of the river system.

During periods when surface water is present in the system, selected alternative routes can be identified for recreational traffic. This should take into account the fact that it would not be desirable to allow unrestricted access to the Rössing Mine site or to the Namib Naukluft Park. Thus, recreational traffic would be required to exit the Khan River system at selected points and re-enter the system at other points upstream of the KARS Dam site.

6.3 The communication process

The Swakop - Khan River system is an episodic or ephemeral river system and, as such, is very sensitive to any upstream modification or interference. Any proposed development project in the catchment of the Khan and/or Swakop rivers therefore needs to be thoroughly and carefully investigated prior to implementation. Moreover, it is imperative that all interested parties, including both residents who may be directly affected, and NGOs and conservationists who may be indirectly affected, be given the opportunity to fully participate in all phases of these investigations. Failure on the public relations front, as well as poor levels of consultation and involvement, could jeopardise even technically sound development projects.

Several NGOs in Namibia have expressed strong interest in natural resource conservation in the Swakop and other river catchments. One of their prime concerns has centred on the issue of possible cumulative impacts, where the proposed KARS aquifer recharge scheme is considered to add more pressure onto an ecological system which is perceived to be already under considerable strain from existing and proposed future developments. These organizations are able to leverage considerable pressure to support their causes. In such situations, this could lead to pressure being brought to bear at a political and an economic level. In addition, many local residents have shown high levels of suspicion towards the proposed aquifer recharge scheme.

In recent months, many newspaper articles concerning the public’s perceptions of the proposed aquifer recharge scheme have appeared in the Namibian media. Whilst some of these articles are both factually correct and objective in their assessments, many articles have been factually incorrect or have drawn incomplete or incorrect conclusions from the available information. In turn, this has led to a situation where many residents are mis-informed as to the background to the proposed project, the anticipated scale of activities and the scope and level of detail of attendant environmental investigations.

Clearly, the media have an important role to play in fully informing the public in Namibia about topical issues; this they certainly have achieved. However, their main concern seems to centre on perceptions that the proposed aquifer recharge scheme may represent
a so-called "foot in the door" which could well lead to even greater or larger schemes being implemented in the future. Given the anticipated size of the present KARS proposal (a 9 Mm³ capacity dam), and the regional shortage of water in the Central Namib Area, there may be good reason for at least some of their concern in this regard. Accordingly, it is vitally important that the Department of Water Affairs seek to communicate widely the exact scale of the present proposals, as well as the wider strategic importance of optimizing the region's scarce water resources.

The end result of the present situation is that the proposed KARS aquifer recharge scheme appears to have earned a poor reputation in the minds of many members of the general public. This has also led to accusations, which range from incompetence through to outright bias, being levelled by these members of the public at those specialists involved in the environmental assessments. Many people perceive this adverse situation to be true, or at the very least accentuated, by the fact that the environmental studies appear to be under the financial control of a Client who is also the proponent of the water abstraction scheme.

This is an unhealthy situation which cannot improve the image of the project or the professional staff involved. However, this is not a simple matter which can be resolved easily or quickly. It is essential for the environmental team to work closely with the engineering team and consult frequently with the Client so that all aspects of design and construction can be included in the environmental evaluation. Nevertheless, some measure of "independence" needs to be widely perceived so that greater public trust can be placed in the findings and recommendations of the environmental studies.

Accordingly, it is becoming increasingly obvious that the general public need to be more fully and factually informed about the structure and findings of the project. Frequent public meetings and press releases could help to achieve this. Similarly, a philosophy of open and frank public communication must be followed at all times, together with a policy of public participation and involvement.

Throughout southern Africa, there is widespread public concern for the safety, security, affordability and integrity of regional and local water resources. Though often ill-informed, considerable public debate has been focused on a number of closely-related issues in recent years. These issues have included:

- the need to centralize strategic (national, inter-basin and sub-continent) water resource management decision-making whilst de-centralizing day-to-day operational management actions,
- evaluating the suitability and affordability of alternative water resource exploitation scenarios against short-, medium- and long-term projections of economic and population growth and the resulting increasing demand for water,
- selecting and securing the technical and economic means whereby rural and urban communities can be supplied with wholesome water supplies at an affordable cost,
the question of "ownership" of ground and surface water resources, and the attendent “right” to exploit these resources,

selecting those management approaches which will help to retain the essential aesthetic values associated with water systems,

The proposed KARS aquifer recharge scheme on the Khan River has presented the Namibian authorities with the opportunity to expand their current communication processes and initiate a comprehensive long-term communication process with all their citizens. Ideally, this process should not be confined to the proposed water abstraction scheme but should be extended to include all aspects of shared water resource use and similar issues.

In such a process, each community can help jointly to address the issues of public perceptions and fears around water resource management. The ultimate outcome of such an information-sharing process is a better-informed and more supportive public, who better understand the issues at stake and are better able to contribute meaningfully to the democratic decision-making process.
7. PRELIMINARY ESTIMATE OF MONITORING REQUIREMENTS

It is anticipated that all monitoring associated with the construction of the KARS aquifer recharge scheme will be considered to form part of the overall recommendations of the project. The monitoring programme should strive to ensure that any impacts on the Khan River (litter collection, garbage disposal, sewage disposal, rehabilitation of borrow pits and earth-works, etc.), which may be associated with the construction phase of the project, are kept to an absolute minimum.

Monitoring of the relevant ecological and social aspects of the Khan and Swakop rivers in Namibia presents a complex problem. In this type of situation, it is extremely difficult, if not impossible, to require or force a project proponent to undertake any form of additional environmental monitoring which may require resources (money and manpower) to be expended at locations distant from the project is undertaken.

The impacts from the proposed aquifer recharge scheme will be most easily visible in the lower reaches of the Swakop River. These impacts are likely to occur several months to several years after the project has been commissioned. This situation will require that any monitoring efforts must be carefully and closely co-ordinated in order to ensure that the greatest value is obtained from the data and information collected.

Similarly, there must be clear and shared agreement on the following:

• which agencies are to be involved and take responsibility for the monitoring programme and any subsequent management actions that may be required;
• what information is to be collected and by whom is it collected;
• how and where will the data be collected;
• how will the data will be transformed and integrated into useful management information;
• how and where will the data be stored;
• who will have access to this information; and
• in what form and by what means will information be distributed to interested and affected parties.

Only once these decisions have been taken, and the necessary resources of money, equipment and man-power have been made available, does it become a relatively straight-forward matter to design an appropriate and cost-effective monitoring programme. If these decisions are not resolved at an early stage, then any monitoring programme will lack cohesion and will lose a large measure of its potential value.
through being fragmented and incomplete.

Given that there is, as yet, no decision to proceed with the proposed KARS aquifer recharge scheme, there is little point in defining all the details of an appropriate monitoring programme. Nevertheless, there are a number of general issues and principles which can be dealt with at this early stage and statements can be made as to several specific components which should form a central part of any monitoring programme which may be launched in the future. The major environmental (ecological and social) components which should form part of any monitoring programme include the following issues.

7.1 Climate and water flow data

Climate data should continue to be monitored at existing weather stations along the Khan and Swakop rivers. Ideally, each weather station should be capable of recording maximum and minimum temperatures, relative humidity, daily rainfalls, wind speed and hours of sunlight. Data to be available within 6-8 weeks of collection.

River flows should continue to be monitored in both the Khan and Swakop rivers. These flow gauging stations should ideally be capable of continuous flow gauging with data storage on chart or tape. Data must be available for analysis no later than 6-8 weeks after collection. Each flow gauging station should be calibrated (or recalibrated) regularly, and particular attention should be paid to their ability to accurately record low flows.

Flows into the lower Swakop River should be monitored. Inflows are currently calculated from flows measured at upstream stations; whilst this provides a reasonable level of accuracy, it is not ideal. Data should be stored on chart and tape and should be made available for analysis within 8 weeks of collection. Gauging stations should have their calibrations checked regularly.

Estimates of ground water levels and flow rates within the Khan and Swakop rivers provide extremely useful information as to what changes can be expected to occur. This monitoring needs to be closely co-ordinated and conducted regularly if it is to be of any use in evaluating the consequences of management actions.

7.2 Sediment transport

Sediment transport is a critically important mechanism upon which many of the ecological functions of the Khan and Swakop rivers. In the past, attempts to obtain accurate data on the quantities of sediment transported by flood waters in the Khan River revealed values of between 2% and 23% of the flood water volume. This variation indicates clearly the problems of accurate sampling and the variability of suspended sediments in flood waters. In future, accurate measurements of suspended sediment loads will enable better estimates to be made of the likely life of the KARS
Accurate measurements of sediment load and rates of transport require specific field sampling apparatus and trained personnel; the measurements themselves are both tedious and time-consuming. Nevertheless, they provide extremely useful information which improves not only our understanding of river functioning, but also of the rate of sediment accumulation.

7.3 Standard water quality parameters

The normal range of water quality parameters (major cations and anions, pH, conductivity, nutrients (nitrogen and phosphorus), should be monitored routinely at boreholes and at the flow-gauging stations to evaluate ground water quality in the Khan and Swakop rivers. Given the number of people who rely on the river for all their water requirements, routine water quality monitoring will provide an assessment of the fitness-for-use of the lower Swakop River.

7.4 Radio-isotopes

In addition, given the public concern around the issue of radio-isotopes and radioactivity in general, it will be very important to continue with routine measurements of selected radio-isotopes in ground water. These measurements should be carried out by Rössing staff, but there should also be independent verification by an external organization. This will help to resolve the concern that Rössing may not be reporting enough information.

7.5 Riparian vegetation

The current vegetation monitoring programme should be continued at its current level of intensity and frequency of sampling. This will allow firstly, comparisons to be made against the vegetation condition which has prevailed since the start of the monitoring programme and, secondly, will allow evaluation of any effects which the proposed Khan Dam and the aquifer recharge scheme may have on downstream vegetation.

Fixed-point photography should be used to provide a basis for visual comparisons with earlier stages. Great care should be taken in any decision to use direct measurements of moisture stress in the riparian trees. The preferred techniques of moisture stress measurement require several measurements to be made using living tree material. This can result in the removal of considerable quantities of small branches and leaves. Since most of the riparian trees do not have dense foliage, this can lead to a relatively rapid loss of foliage and can cause a rapid increase in moisture stress levels within individual trees.
7.6 Human and socio-economic impacts

Clearly, if the proposed KARS aquifer recharge scheme is expected to have even minor adverse ecological impacts, it is likely also to have adverse impacts on people. Accordingly, these should be identified and monitored to assess the reliability and scale of predictions, as well as to provide a focus for possible remedial actions such as compensation.

The most important issue is to identify those individuals along the lower Swakop River who are likely to be adversely impacted or might benefit from the scheme. Given the anticipated spatial scale and location of the expected impacts, this will involve a relatively small number of people in a restricted area. Regular ground surveys should be undertaken to develop a clear picture of the scale and duration of any impacts, as they occur. These should then be evaluated, together with representatives of the affected communities, against criteria drawn up previously, regarding remedial management actions and even financial compensation. It is unwise to attempt to deal with these issues after impacts start to be experienced.

Issues which should be monitored include the extent of change in water table and the degree of change in water quality that has taken place over time, the financial and economic value of these changes, the extent to which these uses are (or may be) impaired or altered, the availability and suitability of possible alternative resources, and the effectiveness of procedures for allocating resources to communities or compensating them for losses experienced.

7.7 Data storage and handling

If at all possible, all data relating to the Khan and Swakop river system should be kept at a central facility, even if the data are collected by different agencies. This will facilitate curation of the data and will allow rapid comparisons to be made of data from different sectors and of different aspects of the system. All data tapes and files should be backed up with the backup copies kept in a fire-proof facility.

Monitoring data should be reported regularly, in accordance with any statutory requirements laid down in terms of water abstraction permits issued by the Department of Water Affairs.

In addition, it would be very useful to Rössing if summarized monitoring data could be made available to the general public. Whilst this is not presently required in terms of any Namibian legislation, this would help to alleviate some of the public's suspicion that information is being concealed from them. Preferably, the Department of Water Affairs should be involved in the dissemination of such information to the general public, together with a clear statement as to whether or not the data indicate that Rössing are complying with the terms of their water abstraction permit and effluent control permits.
8. SOURCES OF INFORMATION

The following individuals and information sources were consulted during the course of this project.

8.1 Personal Communications

Mr G von Langenhove, Department of Water Affairs
Owners of smallholdings, Swakopmund
Mr Piet Hamman, Swakopmund, and member of the 1958-162 CSIR team who studied the Swakop River hydrology
Dr John Ward, Chief Geologist, NAMDEB. Coastal zone dynamics and geology expert
Mr J S Schoonees, CSIR Stellenbosch. Coastal engineer, Beach erosion along Namibia West Coast.
Dr Dave Scott, Hydrologist, CSIR Stellenbosch. Water consumption of riparian vegetation along West Coast rivers
Dr John Vogel, Isotope Specialist, Environmentek, CSIR. Dune geomorphology, uranium in water.

8.2 Published References


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CSIR (1976). Swakopmund Beach Improvements. Confidential; report to the South west African Administration, Coastal Engineering and Hydraulics Division, National Institute for Oceanology, CSIR. Report no C/SEA 7602.

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Department of Fisheries and Water (1991a). *Final Environmental Impact Report for the Proposed Omdel Dam on the Omururu River*. Report to the Namibian Department of Fisheries and Water, Windhoek, by the Environmental Evaluation Unit, University of
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ENVIRONMENTAL IMPACT ASSESSMENT OF THE PROPOSED KHAN AQUIFER RECHARGE SCHEME

Sam Cohen Library, Swakopmund. Cross sections of Swakop River at Kilometre 2.5 and Kilometre 3. Author unknown, Date: 1951.


SWA Administration (1957?). Cross sections of the Swakop River channel at the estuary of the Swakop River. From design report of two new tube wells for Swakopmund Water Supply.


Van Zijl, J.S.V. (1967). ‘N Kort oorsig oor die voorkoms van grondwater in die rivierbeddings van SWA. Confidential report to the Water Planning Commission, South West African Administration by the National Physical Research Laboratory, CSIR, Pretoria. 10pp + 1map.


APPENDIX 1

List of plant species recorded in the vicinity of the Rössing Uranium Mine, Namibia. (Species which are protected in Namibia are preceded by * ; Data from Craven, 1986).

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPHIOGLOSSACEAE</td>
<td>Cheno</td>
</tr>
<tr>
<td>Ophioglossum polyphyllum A. Braun</td>
<td>S. kafi L., ssp. australica</td>
</tr>
<tr>
<td>URTICACEAE</td>
<td>S. cf. nolothoms Aellen</td>
</tr>
<tr>
<td>Forskloea candida L. fil.</td>
<td>Suaeda pliosa Aellen</td>
</tr>
<tr>
<td>F. hereroensis Schinz</td>
<td>AMARANTHACEAE</td>
</tr>
<tr>
<td>LORANTHACEAE</td>
<td>Arthraera lewinii (O. Kuntze) Schinz</td>
</tr>
<tr>
<td>Tapinanthus oleifolius (Wendl.) Danse</td>
<td>Calicaroba capitata (Moq.) Hooker fil.</td>
</tr>
<tr>
<td>Vicia rotundifolia L. fil.</td>
<td>Hermbstaedtia spathulifolia (Engler) Baker</td>
</tr>
<tr>
<td>POLYGONACEAE</td>
<td>Sericoconoa heterocliton Lopr.</td>
</tr>
<tr>
<td>Polygonum plebeium R.Br.</td>
<td>HYDNORACEAE</td>
</tr>
<tr>
<td>NYCTAGINACEAE</td>
<td>Hydnora africana Thunb.</td>
</tr>
<tr>
<td>Boerhavia hereroensis Heim.</td>
<td>PAPAVERACEAE</td>
</tr>
<tr>
<td>Convolvulus squarrosus (Heim.) Standley</td>
<td>Argemone ochroleuca Sweet</td>
</tr>
<tr>
<td>MOLLUGINACEAE</td>
<td>CAPARACEAE</td>
</tr>
<tr>
<td>Gisekia africana (Lour.) O. Kuntze</td>
<td>Rocioa albitrunca (Burch.) Gilg &amp; Benedict</td>
</tr>
<tr>
<td>Limonium argente-carinatum Wawra &amp; Peyr.</td>
<td>B. foetida Schinz</td>
</tr>
<tr>
<td>Mollugo cerviana (L.) Ser. ex DC.</td>
<td>Cleome foliosa Hook. f. var. foliosa</td>
</tr>
<tr>
<td>AIZOACEAE</td>
<td>C. suffruticosa Schijz</td>
</tr>
<tr>
<td>Aizoantheum dinteri (Schinz) Friedr.</td>
<td>Maerua schinzii Pax</td>
</tr>
<tr>
<td>A. membranaceum Dinter ex Friedr.</td>
<td>MORINGACEAE</td>
</tr>
<tr>
<td>Galenia africana L.</td>
<td>* Moringa ovatifolia Dinter &amp; Berger</td>
</tr>
<tr>
<td>G. dinteri Schellenb.</td>
<td>CRASSULACEAE</td>
</tr>
<tr>
<td>* Lithops ruzchiorum (Dinter &amp; Schwantes) N.E. Br.</td>
<td>Cotyledon orbiculata L.</td>
</tr>
<tr>
<td>Mesembryanthemum gunericanum Pax</td>
<td>VAHLIACEAE</td>
</tr>
<tr>
<td>Psilocaulon kunzei (Schinz) Dinter &amp; Schwantes</td>
<td>Vahlia capensis (L. fil.) Thunb.</td>
</tr>
<tr>
<td>P. salicioides (Pax) Schwantes</td>
<td>MIMOSACEAE</td>
</tr>
<tr>
<td>Sesuvium sessiloides (Frenz.) Verde.</td>
<td>Acacia albida Del.</td>
</tr>
<tr>
<td>Triandema triqueta Willd. ssp. parryi (Sonder) Jeffrey</td>
<td>A. erioloba E. Meyer</td>
</tr>
<tr>
<td>TETRAGONIACEAE</td>
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<td>PORTULACEAE</td>
<td>(Burch.) Bren.</td>
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<td>* Anacampseros albissima Marloth</td>
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<td>A. pechuelii (O. Kuntze) Torre &amp; Hille.</td>
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### APPENDIX 1 - (Continued)

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<td><em>Heranania affinis</em> K. Schum.</td>
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<td><em>H. amabilis</em> Marl. ex K. Schum.</td>
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<td><em>Adenia pechuelii</em> (Engler) Harms</td>
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<td>Pelargonium ovatense Knuth</td>
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<td><em>Tamarix usnooides</em> E. Meyer ex Bunge</td>
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<td><em>S. salmoniflorum</em> Moffett</td>
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<td><strong>ZYGOPHYLLACEAE</strong></td>
<td><em>Kissena capensis</em> Endl.</td>
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<td><em>Corallocarpus dissectus</em> Cogn.</td>
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<td>E. virosa Wild.</td>
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<td>&amp; Bentham</td>
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<td><em>C. tenuepistola</em> Engler</td>
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<td><em>H. gardoni</em> (Maston) Sweet</td>
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<td><strong>CELASTRACEAE</strong></td>
<td><em>Sarcostemma viminale</em> (L.) R.Br.</td>
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<td>Maytenus heterophylla (Ecklen &amp; Zeyher) N. Robson</td>
<td><em>Trichosanthes olavatvum</em> (Wild.) H. Huber</td>
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<td><strong>SALVADORACEAE</strong></td>
<td><strong>RUBIACEAE</strong></td>
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<td>Salvadoras persica L.</td>
<td><em>Kohautia ramostissima</em> Bremek</td>
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<td><strong>TILLIACEAE</strong></td>
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| Grewia tenax (Forsk.) Fiori | }
## APPENDIX 1 - (Continued)

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<th>Scientific Name</th>
<th>Scientific Name</th>
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<td>Ipomoea adenoides Schinz</td>
<td>Berkheya spinosissima (Thunb.) Willd.</td>
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<td>HYDROPHYLACEAE</td>
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<td>Calastephane mariuthiana O. Hoffm.</td>
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<td>C. schenckii Schinz</td>
<td>Felicia anthemoides (Hern.) Mendonca</td>
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<td>HELIOTROPIACEAE</td>
<td>Gazania jurineaefolia DC. ssp. scaber (DC.) Roessler</td>
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<td>Cordia gharaf (Forsk.) Ehrenb. ex Ascherson</td>
<td>Geigeria ornativa O. Hoffm.</td>
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<td>H. tubulosum E. Meyer ex DC.</td>
<td>Kleina longiflora DC.</td>
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<td>BORAGINACEAE</td>
<td>Nolletia gariepina (DC.) Mattf.</td>
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<td>Oateospermum microcarpum (Harvey) T. Norl.</td>
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<td>Senecio alliarfolius O. Hoffm.</td>
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<td>S. engleranus O. Hoffm.</td>
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<td>S. mariothianus O. Hoffm.</td>
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<td>A. imbricata Schinz</td>
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<td>A. inflata Schinz</td>
<td>Launaea intybuscna (Jacq.) Beauverd</td>
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<td>Aiptsolum lineare Marloth &amp; Engler</td>
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<td>Ruppia maritima L.</td>
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<td>S. hereroensis (Engler) Skan ³</td>
<td>* Aloe asperfolia A. Berger</td>
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<td>S. maxii Hjern</td>
<td>* A. dichotoma Masson</td>
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<td>Blepharis bossii Oberm.</td>
<td>D. platyphyllum Baker</td>
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<td>B. grossa (Nees) T. Anderson</td>
<td>Eriopuspermum rautanenii Schinz</td>
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<td>B. obnirata C.B. Clarke</td>
<td>E. tortuosum Dammer</td>
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<td>Monechma arenicola (Engler) C.B. Clarke</td>
<td>Ornithogalum stapfitti Schinz</td>
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<td>Ornithogalum cf. tubiflorum</td>
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<td>Petalidium canescens (Engler) C.B. Clarke</td>
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<td>Trachychaia laxa (N.E. Br.) Oberm. var. laxa</td>
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<td>Ruella diversifolia S. Moore</td>
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<td>PEDALIACEAE</td>
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<td>Cynodon dactylon (L.) Pers.</td>
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<td>E. scaber Leh.</td>
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<td>Eragrostis nindeensis Fic. &amp; Hjern</td>
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<td>Paspalum vaginatum Swartz</td>
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## APPENDIX 1 - (Continued)

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<td><em>S. schaeferi</em> (Mez) De Winter</td>
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<td><em>S. uniptumis</em> (Licht. ex Roemer &amp; Schultes)</td>
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<td>De Winter var. <em>intermedia</em> (Schweickerdt)</td>
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APPENDIX 2

List of mammals occurring in the Central Namib Desert, which may occur in the study area. (Data obtained from James, 1985 and Department of Fisheries & Water, 1991).

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<th>Scientific Name</th>
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<tbody>
<tr>
<td>Smith’s rock elephant-shrew</td>
<td><em>Elephantulus rupesstris</em></td>
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<td>Bushveld elephant-shrew</td>
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<td>Reddish-grey musk shrew</td>
<td><em>Crocidura cyanea</em></td>
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<td>Grant's golden mole</td>
<td><em>Eremtala grobbi</em></td>
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<td>Straw-coloured fruit bat</td>
<td><em>Eidolon helvum</em></td>
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<td>Egyptian slit-faced bat</td>
<td><em>Nycteris thebaica</em></td>
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<td>Darling’s horseshoe bat</td>
<td><em>Rhinolophus darlingi</em></td>
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<tr>
<td>Flat-headed free-tailed bat</td>
<td><em>Sauromys petrophilus</em></td>
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<tr>
<td>Long-tailed serotine bat</td>
<td><em>Eptesicus hottentottus</em></td>
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<td>Somali serotine bat</td>
<td><em>Eptesicus somalicus</em></td>
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<tr>
<td>Schreiber’s long-fingered bat</td>
<td><em>Miniopterus schreibersii</em></td>
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<td>Namib long-eared bat</td>
<td><em>Laephotes namibensis</em></td>
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<tr>
<td>Chacma baboon</td>
<td><em>Papio ursinus</em></td>
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<tr>
<td>Cat-eared fox</td>
<td><em>Otocyon megalotis</em></td>
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<td>Cape fox</td>
<td><em>Vulpes chama</em></td>
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<td>Black-backed jackal</td>
<td><em>Canis mesomelas</em></td>
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<td>Striped polecat</td>
<td><em>Ictonyx striatus</em></td>
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<td>Honey badger</td>
<td><em>Mellivora capensis</em></td>
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<td>Small-spotted genet</td>
<td><em>Genetta genetta</em></td>
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<td><em>Galerella sanguinea</em></td>
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<td>Dwarf mongoose</td>
<td><em>Helogale parvula</em></td>
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<td><em>Proteles cristatus</em></td>
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<td><em>Hyaena brunnea</em></td>
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<td>Spotted hyaena</td>
<td><em>Crocuta crocuta</em></td>
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<td><em>Felis lybica</em></td>
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<td><em>Felis nigripes</em></td>
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<td>Canecal</td>
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<td>Rock Dassie</td>
<td><em>Procavia capensis</em></td>
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<td>Hartmann’s mountain zebra</td>
<td><em>Equus zebra hartmannae</em></td>
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<td>Warthog</td>
<td><em>Phacochoerus aethiopicus</em></td>
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<td>Steenbok</td>
<td><em>Raphicerus campestris</em></td>
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<td>Klipspringer</td>
<td><em>Oreotragus oreotragus</em></td>
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<td>Springbuck</td>
<td><em>Antidorcas marsupialis</em></td>
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<tr>
<td>Gemsbok</td>
<td><em>Oryx gazella</em></td>
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<tr>
<td>Kudu</td>
<td><em>Tragelaphus strepsiceros</em></td>
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<tr>
<td>Cape hare</td>
<td><em>Lepus capensis</em></td>
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<td>Porcupine</td>
<td><em>Hystrix africaeaustralis</em></td>
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<td>Dassie rat</td>
<td><em>Petromus typicus</em></td>
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APPENDIX 2 - (Continued)

List of small and large mammals occurring in the Central Namib Desert, which may occur in the study area. (Data obtained from James, 1985 and Department of Fisheries & Water, 1991).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
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<tr>
<td>Ground squirrel</td>
<td>Xerus inauris</td>
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<td>Springhare</td>
<td>Pedetes capensis</td>
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<td>Rock dormouse</td>
<td>Graphiurus platyops</td>
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<tr>
<td>Namaqua rock dormouse</td>
<td>Aethomys namaquensis</td>
</tr>
<tr>
<td>Tree rat</td>
<td>Thallomys paedaculus</td>
</tr>
<tr>
<td>Striped mouse</td>
<td>Rhabdomys pumilio</td>
</tr>
<tr>
<td>Pygmy rock mouse</td>
<td>Petromuscus collinus</td>
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<tr>
<td>Short-tailed gerbil</td>
<td>Desmodillus auricularis</td>
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<tr>
<td>Hairy-footed gerbil</td>
<td>Gerbillurus paeba</td>
</tr>
<tr>
<td>Brush-tailed hairy-footed gerbil</td>
<td>Gerbillurus vallinus</td>
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<tr>
<td>Setzer's hairy-footed gerbil</td>
<td>Gerbillurus setzeri</td>
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<tr>
<td>Dune hairy-footed gerbil</td>
<td>Gerbillurus tytonis</td>
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<tr>
<td>House mouse</td>
<td>Mus musculus</td>
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<td>Brown rat</td>
<td>Rattus rattus</td>
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APPENDIX 3


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<th>Common Name</th>
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<td>Ostrich</td>
<td>Breeding resident</td>
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<td>Podiceps nigricollis</td>
<td>Blacknecked Grebe</td>
<td>Occasional visitor</td>
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<tr>
<td>Tachybaptus ruficollis</td>
<td>Dabchick</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Pelecanus onocrotalus</td>
<td>White Pelican</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Phalacrocorax africanus</td>
<td>Reed Cormorant</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>Ardea cinerea</td>
<td>Grey Heron</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>A. melanocephala</td>
<td>Blackheaded Heron</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>Tadorna cana (B)</td>
<td>South African Shelduck</td>
<td>Breeding resident</td>
</tr>
<tr>
<td>Anas capensis (B)</td>
<td>Cape Teal</td>
<td>Breeding visitor</td>
</tr>
<tr>
<td>A. erythrorhyncha</td>
<td>Redbilled Teal</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>A. smithii</td>
<td>Cape Shoveller</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Oxyura maccoa</td>
<td>Maccoa Duck</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Melierax canorus</td>
<td>Pale Chanting Goshawk</td>
<td>Uncommon resident</td>
</tr>
<tr>
<td>Falco tinunculus</td>
<td>Rock Kestrel</td>
<td>Common</td>
</tr>
<tr>
<td>Numida meleagris</td>
<td>Helmeted Guineafowl</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Gallinula chloropus</td>
<td>African Moorhen</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Fulica cristata</td>
<td>Redknobbed Coot</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Eupodotis rueppelli</td>
<td>Rüppell's Koorhaan</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Charadrius pecuarius</td>
<td>Kittlitz's Plover</td>
<td>Regular resident</td>
</tr>
<tr>
<td>C. tricoloris</td>
<td>Threebanded Plover</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Vanellus armatus</td>
<td>Blacksmith Plover</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Tringa hypoleucos</td>
<td>Common Sandpiper</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>T. glareola</td>
<td>Wood Sandpiper</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>T. stagnatilis</td>
<td>Marsh Sandpiper</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Calidris minuta</td>
<td>Little Stint</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Philomachus pugnax</td>
<td>Ruff</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Recurvirostra avosetta</td>
<td>Avocet</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Himantopus himantopus</td>
<td>Blackwinged Stilt</td>
<td>Resident (?Breeding)</td>
</tr>
<tr>
<td>Burhinus capensis</td>
<td>Spotted Dikkop</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Rhinoptilus africanus</td>
<td>Doublebanded Courser</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>Pterocles namaqua</td>
<td>Namaqua Sandgrouse</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>P. bicinctus</td>
<td>Doublebanded Sandgrouse</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Columba guinea</td>
<td>Rock Pigeon</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Streptopelia senegalensis</td>
<td>Laughing Dove</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Oena capensis</td>
<td>Namaqua Dove</td>
<td>Common resident</td>
</tr>
<tr>
<td>Corythaioides concolor</td>
<td>Grey Lourie</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>Merops hirundineus</td>
<td>Swallowtailed Bee-eater</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>Apus apus/A. barbatus</td>
<td>European/Black Swift</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>A. bradfieldi</td>
<td>Bradfield's Swift</td>
<td>Rare visitor</td>
</tr>
<tr>
<td>A. affinis</td>
<td>Little Swift</td>
<td>Common resident</td>
</tr>
<tr>
<td>Colius collis</td>
<td>Whitebacked Mousebird</td>
<td>Regular visitor</td>
</tr>
<tr>
<td>Mitrafa curvirostris</td>
<td>Longbilled Lark</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Alauda starki</td>
<td>Stark's Lark</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Ammomanes grayi</td>
<td>Gray's Lark</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td>Eremopterix verticalis (B)</td>
<td>Grey-backed Finchbrake</td>
<td>Breeding visitor</td>
</tr>
<tr>
<td>Hirundo rustica</td>
<td>European Swallow</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>H. fulgula (B)</td>
<td>Rock Martin</td>
<td>Breeding visitor</td>
</tr>
<tr>
<td>Riparia paludicola</td>
<td>Brownthroated Martin</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td>Corvus capensis</td>
<td>Black Crow</td>
<td>Occasional visitor</td>
</tr>
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</table>
## APPENDIX 3 - (Continued)

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Comments</th>
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<tbody>
<tr>
<td><em>Corvus albus</em></td>
<td>Pied Crow</td>
<td>Regular visitor</td>
</tr>
<tr>
<td><em>Pycnonotus nigricans</em></td>
<td>Redeyed Bulbul</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td><em>Oenanthe monticola</em></td>
<td>Mountain Chat</td>
<td>Resident</td>
</tr>
<tr>
<td><em>O. pileata</em></td>
<td>Capped Wheatear</td>
<td>Rare visitor</td>
</tr>
<tr>
<td><em>Cercomela familiaris</em></td>
<td>Familiar Chat</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>C. tractrac</em></td>
<td>Tractrac Chat</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>C. schlegelii</em></td>
<td>Karoo Chat</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>Parisoma subcaeruleum</em></td>
<td>Titbabbler</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td><em>Acrocephalus baeticatus</em></td>
<td>African Marsh Warbler</td>
<td>Regular visitor</td>
</tr>
<tr>
<td><em>Sylvietta refescens</em></td>
<td>Longbilled Crombec</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td><em>Eremomela icteropygialis</em></td>
<td>Yellowbellied Eremomela</td>
<td>Regular visitor</td>
</tr>
<tr>
<td><em>E. gregalis</em> (B)</td>
<td>Karoo Eremomela</td>
<td>Breeding resident</td>
</tr>
<tr>
<td><em>Malcorus pectoralis</em></td>
<td>Rufouseated Warbler</td>
<td>Rare visitor</td>
</tr>
<tr>
<td><em>Melanornis infuscatus</em> (B)</td>
<td>Chat Flycatcher</td>
<td>Breeding resident</td>
</tr>
<tr>
<td><em>Motacilla capensis</em></td>
<td>Cape Wagtail</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>Lamprokollum collaris</em></td>
<td>Fiscal Shrike</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>Nilaus afer</em></td>
<td>Brubru Shrike</td>
<td>Rare visitor</td>
</tr>
<tr>
<td><em>Telephorus zeylonus</em></td>
<td>Bokmakierie Shrike</td>
<td>Irregular visitor</td>
</tr>
<tr>
<td><em>Onychognathus nabolourop</em></td>
<td>Palewinged Starling</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>Nectarinia fusca</em> (B)</td>
<td>Dusky Sunbird</td>
<td>Breeding resident</td>
</tr>
<tr>
<td><em>Passer domesticus</em></td>
<td>House Sparrow</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>P. melanurus</em></td>
<td>Cape Sparrow</td>
<td>Common resident</td>
</tr>
<tr>
<td><em>Ploceus velatus</em></td>
<td>Masked Weaver</td>
<td>Occasional visitor</td>
</tr>
<tr>
<td><em>Amadina erythrocephala</em></td>
<td>Redheaded Finch</td>
<td>Single specimen</td>
</tr>
<tr>
<td><em>Serinus albogularis</em></td>
<td>Whitethroated Canary</td>
<td>Regular visitor</td>
</tr>
<tr>
<td><em>Emberiza impetuani</em></td>
<td>Larklike Bunting</td>
<td>Common winter visitor</td>
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</table>
APPENDIX 4

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).

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pachydactylus puncticatus</td>
<td>Geckoes</td>
<td>12 species found, 1 more expected</td>
</tr>
<tr>
<td>Pachydactylus bicolor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachydactylus bibronii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachydactylus laevigatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachydactylus werneri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachydactylus kochii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ptenopus garrulus maculatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narudasia festiva</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chondrodactylus angulifer nanibensis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhoptropus afer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhoptropus b. Bradfieldi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhoptropus barbari</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agama anchiatae</td>
<td>Agamas</td>
<td>2 species found</td>
</tr>
<tr>
<td>Agama p. planticeps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chamaeleo namaquensis</td>
<td>Chamaeleons</td>
<td>1 species found</td>
</tr>
<tr>
<td>Merolea suborbitalis</td>
<td>True Lizards</td>
<td>5 species found</td>
</tr>
<tr>
<td>Mesalina v. undata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesalina sp. nov.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesalina breviceps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesalina namaquensis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mabuya hoeschii</td>
<td>Skinks</td>
<td>6 species found</td>
</tr>
<tr>
<td>Mabuya occidentalis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mabuya spilogaster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mabuya v. variegata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mabuya acutilabris</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mabuya s. sulicata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cordylusaurus subiessellatus</td>
<td>Plated Lizards</td>
<td>1 species found</td>
</tr>
<tr>
<td>Leptotyphlops occidentalis</td>
<td>Snakes</td>
<td>7 species found, 3 more expected</td>
</tr>
<tr>
<td>Bitis caudalis</td>
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<tr>
<td>Psammophis leightonii nanibensis</td>
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<td></td>
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<tr>
<td>Psammophis trigrammus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typhlops lalandi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipsina multimaculata</td>
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<td></td>
</tr>
<tr>
<td>Lamphrophis f. fuliginosus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xenopus l. loevis</td>
<td>Frogs and Toads</td>
<td>2 species found, 2 more expected</td>
</tr>
<tr>
<td>Bufo vertebralis hoeschii</td>
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<td></td>
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</tbody>
</table>
APPENDIX 5

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).

<table>
<thead>
<tr>
<th>Insect Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Thysanura - Family Lepismatidae</td>
<td></td>
</tr>
<tr>
<td><em>Clenolepisma namibensis</em></td>
<td>Irish, 1987</td>
</tr>
<tr>
<td><em>Thermobia nebulosa nebulosa</em></td>
<td>Irish, 1989</td>
</tr>
<tr>
<td>Order Coleoptera - Family Buprestidae</td>
<td></td>
</tr>
<tr>
<td><em>Acmaeodora decemguttata namibensis</em></td>
<td>Holm, 1986b</td>
</tr>
<tr>
<td><em>Acmaeodora liessnerae</em></td>
<td>Holm, 1986b</td>
</tr>
<tr>
<td><em>Notomorphoides irishi</em></td>
<td>Holm, 1986a</td>
</tr>
<tr>
<td>- Family Malachiidae</td>
<td></td>
</tr>
<tr>
<td><em>Hedybius irishi</em></td>
<td>Wittmer, 1988</td>
</tr>
<tr>
<td><em>Metaphilhedorus swakopmundensis</em></td>
<td>Wittmer, 1990</td>
</tr>
<tr>
<td>- Family Dermestidae</td>
<td></td>
</tr>
<tr>
<td><em>Attagenus</em> sp. nov.</td>
<td>Kalik, (in preparation)</td>
</tr>
<tr>
<td>- Family Ptinidae</td>
<td></td>
</tr>
<tr>
<td><em>Damarus</em> sp. nov.</td>
<td>Irish, (in Preparation)</td>
</tr>
<tr>
<td>- Family Tenebrionidae</td>
<td></td>
</tr>
<tr>
<td><em>Pachyteles</em> sp. nov.</td>
<td>Penrith, (in preparation)</td>
</tr>
</tbody>
</table>
APPENDIX 6

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).

<table>
<thead>
<tr>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Family Ammoxenidae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Rastellus narubis</em></td>
<td>Platnick &amp; Griffin, 1990</td>
</tr>
<tr>
<td><em>Rastellus struthio</em></td>
<td>Platnick &amp; Griffin, 1990</td>
</tr>
<tr>
<td><strong>Family Migidae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Moggridgea eremicola</em></td>
<td>Griswold, 1987</td>
</tr>
<tr>
<td><strong>Family Eresidae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Seothyra griffinae</em></td>
<td>Dippenaar-Schoeman, 1991</td>
</tr>
<tr>
<td><em>Seothyra longipedata</em></td>
<td>Dippenaar-Schoeman, 1991</td>
</tr>
<tr>
<td><em>Seothyra annetae</em></td>
<td>Dippenaar-Schoeman, 1991</td>
</tr>
<tr>
<td><strong>Family Zodariidae</strong></td>
<td></td>
</tr>
<tr>
<td><em>Cryoctea namibensis</em></td>
<td>Platnick &amp; Griffin, 1988</td>
</tr>
<tr>
<td><em>Heraclida griffinae</em></td>
<td>Jocqué, 1987</td>
</tr>
<tr>
<td><em>Diores namibia</em></td>
<td>Jocqué, 1990</td>
</tr>
<tr>
<td><em>Diores damara</em></td>
<td>Jocqué, 1990</td>
</tr>
</tbody>
</table>