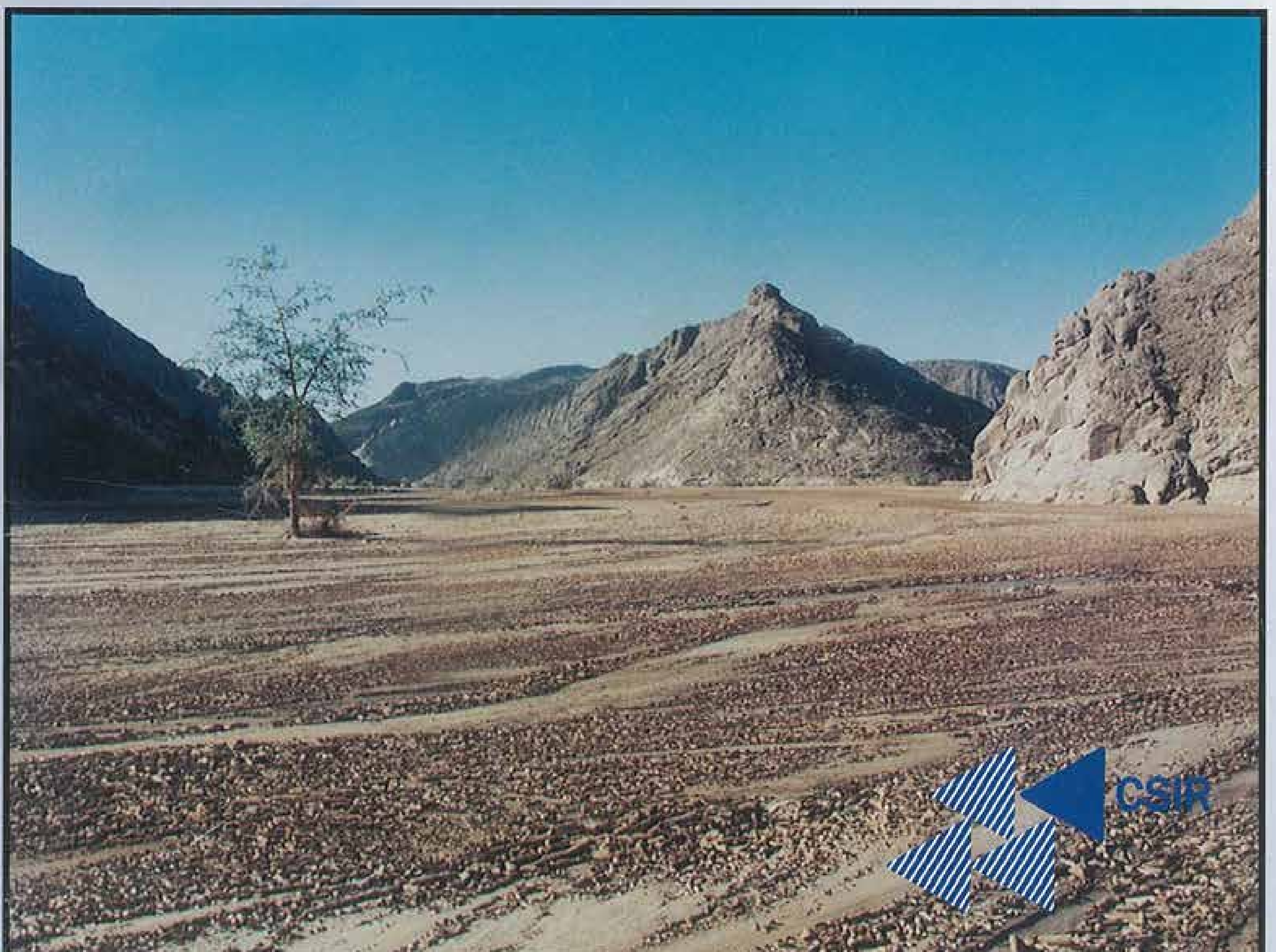
AN ASSESSMENT OF THE POTENTIAL ENVIRONMENTAL IMPACTS OF THE PROPOSED AQUIFER RECHARGE SCHEME ON THE KHAN RIVER, NAMIBIA



Cover Photograph: *The proposed dam site for the KARS Project, viewed from upstream, within the inundation basin. Photograph taken in February 1997, shortly after a small flood had passed down the Khan River. The riverbed is covered with "plates" of dried out silt deposited by the flood waters.*

When used as a reference, this document should be cited as follows:

"CSIR (1997). *An Assessment of the Potential Environmental Impacts of the Proposed Aquifer Recharge Scheme on the Khan River, Namibia.* Final Report by CSIR Division of Water, Environment & Forestry Technology to Rössing Uranium Limited, Swakopmund, Namibia. Report No. ENV/P/C - 97104. xxxvi + 172 pp. + 7 Appendices."

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 (**Figure 1**), 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).

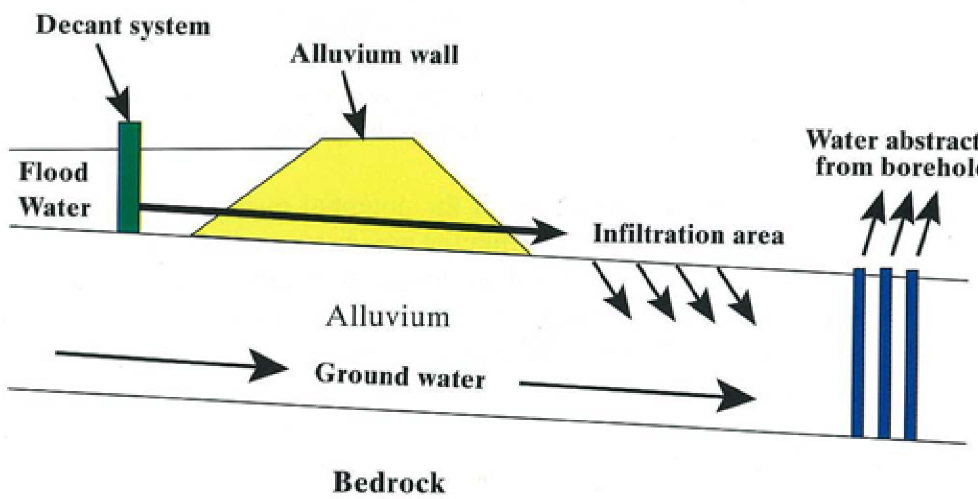


Figure 1: Schematic diagram illustrating the KARS Dam and infiltration concept.

The proposal aims to capture a portion of the occasional Khan River 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 (**Plate 1**). 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.

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.

This 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 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**). 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**.

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 water resource management strategies 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. In the evaluation process, all available data sources were examined, together with anecdotal information obtained from local residents, the Swakopmund Municipality and Government officials.

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 findings reported in the Final Report were presented to all stakeholders at public meetings in Usakos, Arandis and Swakopmund. Interested and Affected Parties (I&APs) were able to comment on the findings and their concerns were then incorporated into the Final Report. Copies of the Final report will be available for public examination. All I&APs who registered their names and addresses during the public meetings will receive a copy of the Final Report Executive Summary. Any decision to proceed or cancel the KARS project rests, ultimately, with the Management of Rössing Uranium Limited, 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:

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- 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 contribution of flows in the Khan River to total flows in the lower Swakop River;
  - The impact on fauna and flora immediately above and below the dam wall, as well as further down the Khan and lower Swakop rivers;
  - 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.

The I&APs recommended that an independent review of the Draft EIA report should be conducted by a credible Namibian authority with specialist knowledge of the local ecology and hydrology. Accordingly, this report was reviewed by Dr M.K. Seely of the Desert Research Foundation of Namibia and Mr P. Tarr of the Namibian Ministry of Environment and Tourism. Their comments and suggestions have also been incorporated into the Final Report.

3.1 Project motivation

The present (1997) total water demand of the Rössing Mine is 2.96 million m^3/year (2.96 Mm^3/year; **Figure 2**); this is expected to increase to 3.22 Mm^3/year in 1998, and then to 4.1 Mm^3/year in the year 2000 when the mine expects to return to full production. Of the current (1997) total water consumption, approximately 0.24 Mm^3/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 Namibian 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.

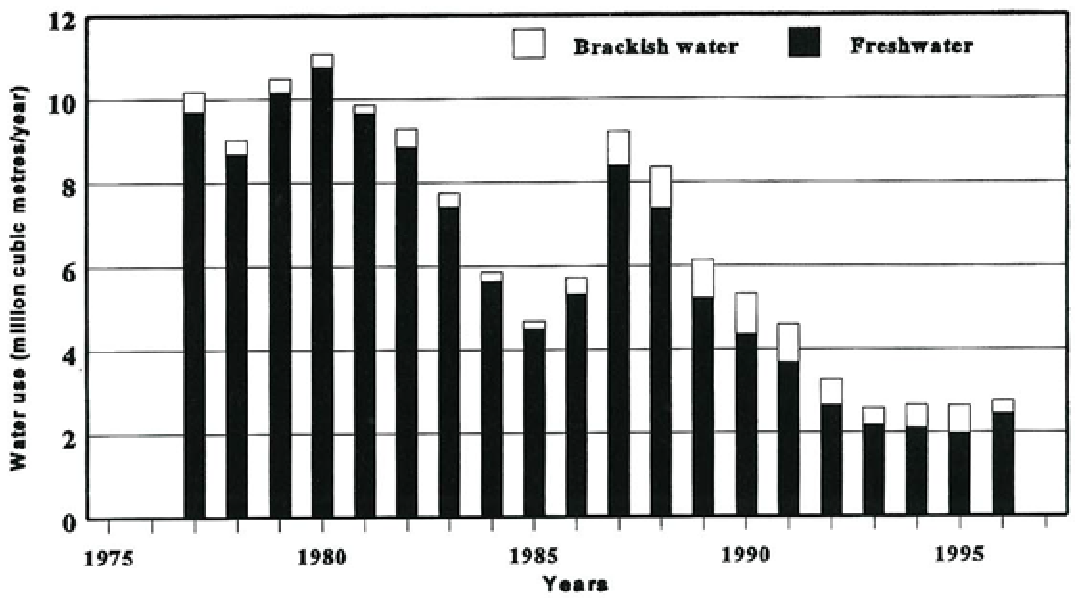

Figure 2: Annual total water consumption at the Rössing Mine since 1977.

It is anticipated that the KARS project would increase the quantity of water that Rössing could abstract from the Khan River aquifer to an average of 3,500 m^3/day (equivalent to 1.28 Mm^3/year). This additional ground water would enable Rössing to maintain its water demand from the CNSWS at current levels, despite the increased quantities of water that will be required when the mine returns to full production in the year 2000. Immediately after a flood event, the abstraction rate could be increased in the short-term, to about 7,000 m^3/day (equivalent to 2.55 Mm^3/year).

For the remaining life of the mine, (currently estimated to be twenty years), Rössing will still need to use substantial volumes of water from the CNSWS since the ground water resources of the Khan River alluvial aquifer cannot supply the total water demand. Furthermore, the salinity of the Khan River ground water is relatively high and, if not desalinated, it can only be used for industrial purposes. 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

Effects on upstream water management

The town of Usakos and surrounding farms obtain their domestic water from boreholes in the bed of the upper Khan River, some 80 kilometres upstream of the

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proposed KARS Dam. These water users have faced chronic water shortages during drought periods. Investigations for alternative water supplies for Usakos have been carried out by the Department of Water Affairs since 1972, when two possible dam sites in the upper Khan River were investigated. However, the Department is not presently considering upgrading the water supply to Usakos from local water resources, (i.e. Khan River ground water), and rather sees further demand at Usakos being met by piping water to the town from other state water supply schemes.

Should the Department decide to build a similar aquifer recharge scheme near Usakos within the 20 year lifespan of the KARS project, it would remove most of the flood waters that currently flow in the Khan River. This 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 water from such a scheme at Usakos would therefore be significantly lower than the proposed KARS Dam at Rössing.

The KARS Dam 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 lower Khan and Swakop rivers. However, because there are insufficient flows in the Khan River to ensure the viability of two such schemes, construction of the KARS Dam at Rössing would preclude potential dam developments upstream at Usakos, for at least the estimated twenty-year lifespan of the KARS Dam.

It is important to point out that the relationship between Usakos and Rössing users of water from the Khan River should be a matter of integrated, long-term coordinated planning of the catchment's water resources and their use.

Size of dam wall required for KARS Dam

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 excavated some 6.5 kilometres from the KARS Dam 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.

Consequences of dam wall failure

Very large, natural 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 would have largely dissipated by the time it reaches the farming zone. The major influence would be the level of the flood when it passes through the KARS Dam spillway at the time of the dambreak.

The socio-economic consequences of failure of the dam are unlikely to be severe due to the absence of people and publicly owned infrastructure until below the confluence of the Khan and Swakop Rivers. 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 metres in depth, and this flow depth will be negligible by the time it reaches Swakopmund. Possible damage to Rössing's boreholes in the Khan River will be similar to that experienced during recent major flood events.

A natural flood of the size indicated above would have a devastating effect on riparian vegetation and wildlife in the lower Khan River. The effects would be somewhat smaller in the lower Swakop River since the river is much wider and has a lower gradient. Nevertheless, such a flood would still have a considerable impact on vegetation, wildlife and stock animals along the lower Swakop River.

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. These cross bunds would be constructed with standard earth-moving equipment from surface alluvium.

A series of natural occurring aquifer compartments could also be enhanced by selectively inserting sections of impervious material onto their upper surfaces, thereby increasing the quantities of water retained upstream of each natural barrier, yet still allowing the base flow to continue flowing downstream.

3.3 Ecological issues

Contribution of the Khan River to total flows in the lower Swakop River

Construction of the Von Bach and Swakoppoort Dams in the upper reaches of the Swakop River has reduced the amount of run-off along the Swakop River (**Table 1**). In consequence, the relative importance of run-off contributed by the Khan River has

increased (**Figure 3**). Modelling results indicate that the mean reduction in the volume of flood flows in the lower Swakop River since the construction of the Von Bach and Swakoppoort dams, is of the order of 23.8 Mm^3/year, approximately 39 %. It is estimated that construction of the KARS Dam will cause a further reduction in flows of 0.35 Mm^3/year (approximately 0.6 %). Similarly, figures for the reduction in sediment yield, after commissioning of the Von Bach and Swakoppoort dams were also 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.

Table 1: Comparison of the percentage of flow contributed by the Khan and Swakop rivers to the total flows in the lower Swakop River, with and without the Von Bach and Swakoppoort dams.

Parameter	Without Dams			With Dams		
	Volume (Mm^3)	Swakop River contribution	Khan River contribution	Volume (Mm^3)	Swakop River contribution	Khan River contribution
Mean	69.9	87.0 %	13.0 %	46.1	80.3 %	19.7 %
Maximum	868.5	71.5 %	28.5 %	635.3	61.0 %	39.0 %

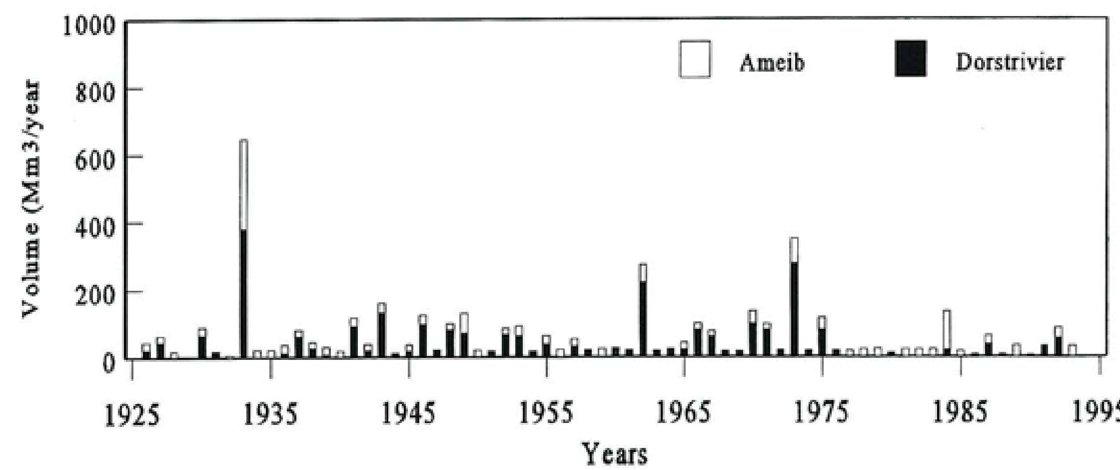

Figure 3: Comparison of the annual flows contributed by the Khan River (Ameib) and Swakop River (Dorstrivier) to total flows in the lower Swakop River.

The reduced flows in the lower Swakop River in particular have promoted the growth of extensive areas of the indigenous shrub *Tamarisk*, as well as the exotic tree *Prosopis* (**Plate 2**). Both of these species have high evapotranspiration rates and their large numbers account for a considerable proportion of the total water lost from the lower Swakop River. Both species are widespread along the lower Khan (**Plate 3**) and Swakop rivers, reaching high numbers in wetland areas on the lower Swakop River.

Plate 1: View of the approximate position of the proposed KARS Dam site, from immediately downstream. Photo taken in October 1996.

Plate 2: View of extensive growths of *Tamarisk* and some *Prosopis* at Palmenhorst, below the confluence of the Khan and Swakop Rivers. (Photo taken in October 1996).

Impacts on fauna and flora

Loss of small floods (< 10 Mm^3) to the lower Khan River will reduce the quantity of water available to shallowly-rooted "riparian" vegetation downstream. This will reduce the vigour, growth and eventually the numbers of larger (perennial) trees and shrubs. Construction of the KARS Dam and the subsequent capture of floods smaller than 10 Mm^3 will impact directly on the riparian habitat of the lower Khan River, through reduced inputs of water, silt and associated nutrients. This will have adverse effects on ecosystem functioning in the medium-term.

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, following the IUCN system of classification, a number of sensitive animal, bird and reptile species do occur along the bed of the Khan River. These species would 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 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 KARS Dam will not significantly alter the long-term distribution patterns of plants or wildlife in the area.

Altered erosion patterns

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.

At the end of its useful life, (expected to be twenty years), the KARS Dam would be decommissioned and the alluvium wall breached. Each natural flood would then erode away the accumulated silt and alluvial material, transporting this to the lower Khan and Swakop rivers and, ultimately, to the Atlantic Ocean. Apart from the case of a large (> 30 Mm^3) flood event, it is considered unlikely that all of the accumulated silt in the KARS Dam basin would be eroded in a single flood event. Rather, it is expected that this process would occur more gradually.

Impacts of 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.

Impacts caused by ground water abstraction

Recharge of the aquifer downstream of the KARS Dam wall will increase the quantity of ground water available for abstraction in this sector. Ideally, abstraction of this ground water should be carefully 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 in the lower Khan River. However, there is no guarantee that sufficient base flows will pass the Rössing wellfield and sustain the riparian vegetation. This aspect should be examined in detail and the potential base flows confirmed before a decision is made to construct the KARS scheme.

The existing ground water monitoring programme should be expanded to include routine evaluation of base flows in the lower Khan and Swakop rivers.

Threat of increased sand dune encroachment

Examination of aerial photographs taken over the last 35 years show that the major sand dunes south of the Swakop River are stationary, though quantities of wind-blown sand are blown across the Swakop River by prevailing winds. Therefore, despite decreased flow volumes in the lower Swakop River at the coast, the sand dunes are unlikely to migrate across the Swakop River and encroach on the town of Swakopmund during the expected life of the KARS Dam.

The positions of the main sand dunes to the south of the Swakop River are shown in **Plate 4**, together with the nearby sand-mining excavations and the Swakopmund beaches.

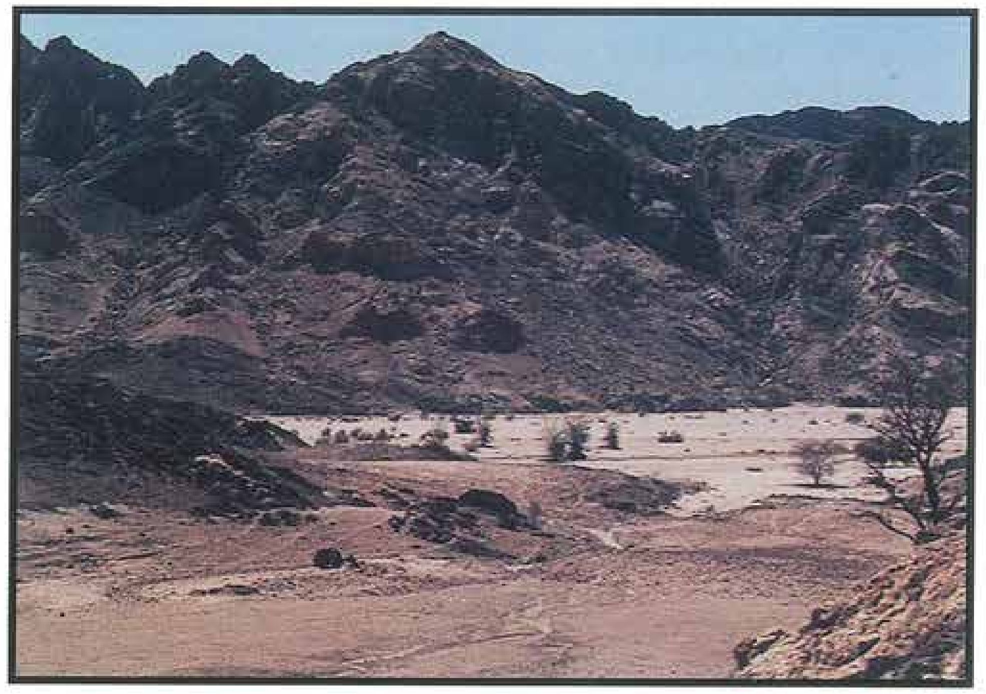

Plate 3: View of the KARS Dam basin, showing riparian vegetation (mostly *Faidherbia albida* and *Salvadora persica*). Photo taken in October 1996.

Plate 4: Aerial view of the lower reaches of the swakop River, showing the dune fields to the south of the river and the locations of sand-mining excavations near the road bridge. (Photo: H. Pepler).

Threat of increased beach erosion

Based on all data since 1925, the modelled average annual sediment contribution to the coast by the Swakop River is approximately 1.3 Mm^3, whilst the average contribution from the Khan River amounts to 0.1 Mm^3. Given the marked reduction in flows and sediment loads since the construction of the Von bach and Swakoppoort dams, the upper Swakop River now appears to contribute considerably less sediment to the lower Swakop River. Therefore, the proportional sediment contribution from the Khan River must have increased. However, there are very few measured data to substantiate these estimates.

The patterns of erosion and deposition along the coastline are affected by the northerly directed longshore drift and "plugs" of sediment brought down the rivers during floods. These events are followed with great interest by the residents of Swakopmund.

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 and 1.4 Mm^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 overall sediment yield to the Namibian coast and will therefore have only a minor, localized influence on the coastal erosion and depositional processes.

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.

Impacts on 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.

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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 at the sand surface or where the water level is close to the surface of the river bed (i.e. forming 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 approximately 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 surface floods that are smaller than about 10 Mm^3. The overall impact of the KARS Dam over its twenty-year lifespan will be to lower the water table in the farming zone by between 0.1 to 0.4 metres as a result of reduced surface recharge. This effect will be in addition to that exerted by reduced flows in the lower Swakop River caused by construction of the Von Bach and Swakoppoort dams.

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 bedrock 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 downstream of the dam, localised changes to ground water in the Khan River could be relatively minor. Ground water flow rates in the Khan River have an average linear velocity of about 1,000 metres per year. Therefore, in the absence of any floods, local changes will not have reached the confluence of the Swakop River (approximately 38 kilometres downstream) by the time that the KARS project has to be decommissioned (20 years).

However, it must be emphasized that the issue of providing sufficient base flow to sustain the riparian vegetation along the lower Khan River needs to be examined in greater detail. The scanty information currently available needs to be supplemented with more detailed studies of the water requirements of riparian vegetation and the impacts that reduced water levels would have on this vegetation.

Using a ground water flow velocity of 1,000 metres/year, the direct effect of the KARS Dam on the ground water baseflow of the Khan River, is unlikely to be observed in the farming zone along the lower Swakop River for at least the next 50 years. In fact, this direct effect will be masked (if not eliminated) by surface recharge events that would occur every time flood waters flow past the KARS Dam.

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. The modelling exercise predicted a further drop in the Swakop River ground water level in the farming zone of the order of 0.1 to 0.4 metres due to the reduced recharge by surface water once KARS is operational. This effect should be interpreted as a worst case scenario.

After decommissioning, and depending on the frequency of floods, surface flood waters will restore ground water conditions in the Khan and Swakop Rivers below the dam to the level it had been before the commissioning of KARS. The current ground water baseflow component (i.e. the minimum flow to be maintained at all times) of 650 m^3/day is likely to decrease irrespective of how well the KARS Dam is managed.

Impacts on ground water quality in the lower Swakop River

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 (**Table 2**):

Table 2: Predicted changes in ground water quality before and after the Von Bach and Swakoppoort dams were in place, and with the KARS Dam in place.

Predicted TDS prior to construction of Swakoppoort and Von Bach dams (1925-1976)	Predicted TDS since commissioning of Swakoppoort and Von Bach dams but before KARS (1976-1998)	Predicted TDS with Swakoppoort, Von Bach and KARS dams in operation (1998-)
6,069 mg/ℓ	9,911 mg/ℓ	11,334 mg/ℓ

The modelling indicates that on average the TDS will increase by about 1,400 mg/ℓ (an increase of approximately 15 %) in the farming zone as a result of the KARS project (**Table 2**). 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 lower 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.

Impacts on sand mining in the lower Swakop River

Using modern luminescence dating techniques, it was established that the bulk of the approximately 600,000 m^3 of sand excavated for building purposes by sand-mining activities over the last few years and affecting a surface area of about 240,000 m^2, is between 340 and 8,700 years old. Based on the ages of the different sediment layers, no evidence could be found that substantial amounts of material suitable for use as building sand are brought down by the small floods (< 10 Mm^3) in the lower Swakop River. It appears that the smaller floods reaching the Swakop Delta cause erosion of sediments rather than deposition.

The modelling exercise has shown that the absolute quantities of sediment which the Khan River contributes to the lower Swakop River, are small. Therefore, any change to 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 along the bed of the Swakop River in the farming zone cause unnecessary water loss through evaporation, further increasing the salt content of local ground water. This, in turn, has adverse effects on downstream farmers.

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 full understanding of the river system is impossible in the absence of detailed knowledge of these processes. However, despite the large number of different studies which have been conducted on the Khan and Swakop rivers, very little quantitative information is available on the long-term hydrological and hydraulic characteristics of these two rivers. As a result, mathematical modelling techniques were the only way in which an overview of the hydrology and geohydrology of the Khan and Swakop rivers could be obtained.

The construction of the KARS Dam and the subsequent capture of the occasional small floods (< 10 Mm^3) will impact directly on the riparian habitat along the lower Khan River. This effect will only be of moderate significance, provided that base flows are sufficient to maintain the vigour of this vegetation. However, if base flows decline to the point where the riparian vegetation dies, the significance will become major for the lower reaches of the Khan River. The adverse impact is expected to be partially off-set by the development over time of some form of replacement riparian vegetation within the dam basin itself.

From the hydrological simulations carried out, the KARS project will trap all small floods (< 10 Mm^3) that occur during its twenty-year lifespan. This will lead to loss of surface recharge in the lower Khan River. In turn, this reduced flow contribution from the Khan River will 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 effect will reduce with time.

The forced recharge of Khan River floodwaters into the aquifer along the mine frontage will improve the quality of ground water available for Rössing. However, this abstraction will reduce ground water flows downstream of the mine. This will have adverse effects on the perennial trees and shrubs along the lower Khan River.

Water table levels in the lower Swakop River are expected to continue dropping and water quality will continue to decline as salt concentrations increase. However, a large proportion of this change has been caused by reduced flood volumes available since construction of the Von Bach and Swakoppoort dams. The KARS project is expected to add to, and accentuate, this trend of change by approximately 15 %.

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. If a decision is taken to proceed with the KARS project, a detailed management and monitoring plan must 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. Large floods usually bring down considerable quantities of alluvial material from the upper and middle reaches of the catchment. There has been only one large flood (in 1985) since the construction of the Von Bach and Swakoppoort dams. Whilst this flood transported a considerable quantity of alluvial material, the other smaller floods have brought down almost no new alluvium. 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 **without implementation of mitigatory**

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actions, are summarized in **Table 3**. The corresponding levels of significance **after implementation of the recommended mitigatory actions** is shown in **Table 4**.

However, despite this conclusion, many people will still have the perception that the KARS Project will have undesirable detrimental effects. In order to minimise the risk that people may attribute any adverse or unwanted effect, whatever their origin, to the KARS project, a comprehensive process of collection, interpretation and communication of information 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. The most important of these 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. Current ground water monitoring programmes in the Khan and Swakop Rivers should be continued.

A serious issue that was revealed during the investigations, although not currently associated with the KARS project, is the uncontrolled mining of sand in the Swakop River bed. 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 Kahn 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.