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 3.1: Definitions used in the assessment and evaluation of impacts.

Category	Description or Definition
Type	A brief written statement, stating which environmental aspect is impacted by a particular project activity or consequence of project activities.
Sign	Denotes the perceived effect of the impact on the affected area.
• *Positive (+)*	Beneficial impact.
• *Negative (-)*	Deleterious impact.
Scale	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.
• *Site*	A dam basin; realigned road; environs of a dam wall, water purification plant.
• *Local*	The home range of resident organisms that will be impacted (i.e. within about a 2 kilometre radius of the project site).
• *Regional*	The bio-climatic / vegetation / agro-economic region of the West Coast area.
• *National*	Namibia.
Duration	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.
• *Short-term*	0 - 1 years (construction phase only).
• *Medium-term*	1 - 5 years (early operations phase).
• *Long-term*	5 - 20 years (late operations phase).
• *Very long-term*	> 20 years (post-decommissioning or closure phase).
Severity	The intensity of the impact:
• *Very high*	Complete disruption of process, death or loss of all affected organisms.
• *High*	Substantial process disruption, death or loss of many affected organisms.
• *Moderate*	Real, measurable impact, which does not alter process or demography.
• *Low*	Small change, often only just measurable.
• *No effect*	No measurable or observable effect.
• *Unknown*	Insufficient information available with which to make a judgement.
Certainty	A measure of how sure we are that the impacts will occur or that the proposed mitigatory actions will be effective.
• *Definite*	> 90 %.
• *Probable*	70 - 90 %
• *Possible*	30 - 70 %
• *Unsure*	< 30 %
Significance	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.
• *High*	Probably a fatal flaw; could (or should) block the project.
• *Medium*	Requires detailed study and often substantial mitigatory actions.
• *Low*	Real, but not sufficient to alter the project or require detailed study.
• *Zero*	No noticeable or measurable effects, or very minor effects with no significance.

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, if they are not alien species, 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 seen 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 The modelling approach used in this study

3.6.1 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 3.1**.

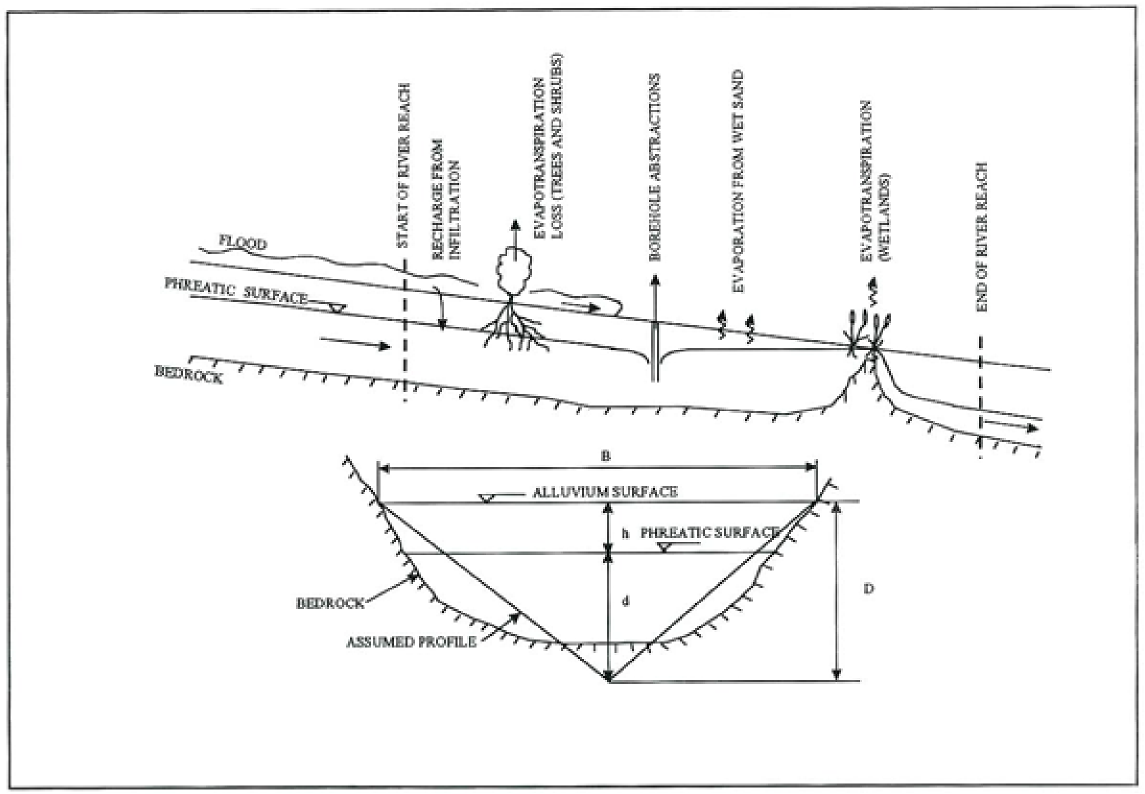

Figure 3.1: Schematic representation of the conceptual model.

For the purpose of this model, the Swakop and Khan Rivers have been divided into six and four reaches respectively, as summarised in **Table 3.2**.

Table 3.2: Summary of river reaches along the Khan and Swakop rivers.

Reach Start	Reach End	Distance	Significant features associated with the reach
Swakop River			
Swakoppoort Spillway	Dorstrivier		Good hydrological records available for Swakoppoort dam Zone of accumulation of rainfall. Reasonable synthetic record available at Dorstrivier
Dorstrivier	Khan Confluence		Zone of depletion of flood waters
Khan Confluence	Tannenhof		Confluence of the Swakop and Khan Rivers
Tannenhof	Nonidas		Farming zone
Nonidas	Mouth		Sand mining, dunes
Khan River			
Ameib Gauge	Usakos Gauge		Good hydrological records available for Ameib
Usakos Gauge	KARS Dam Spillway		Zone of depletion of flood waters
KARS Dam Spillway	BH 6		Artificial recharge and extraction by Rössing
BH 6	Swakop Confluence		Zone immediately downstream of KARS

3.6.2 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 ground water which might arise due primarily to changes in the general level of the phreatic surface or due to changes in the relative contributions of ground water 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, with Swakoppoort and Von Bach dams also in operation.

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.

3.6.2.1 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 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 Mm^3/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.

3.6.2.2 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 average ground water flux downstream of the barrier thus eventually affecting the ground water level downstream of the confluence. This effect could coincide with, and accentuate, the effect of the construction of Swakoppoort Dam and the effect of ground water 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 tributary 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 ground water 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 ground water to evaporation over an area equivalent to the base of the trench or pit. The area of open trenches is estimated to be 320 m^2 between the confluence and Tannenhof and 375 m^2 between Tannenhof and Nonidas.

The total area affected by sand mining in the lower Swakop River is estimated to be 240,000 m^2. The wet sand evaporation rate is used in the model to estimate the water loss ascribed to these activities.

3.6.2.3 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.

3.7 Overall 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. The available information was then combined with mathematical modelling approaches to develop baselines for the hydrological and geohydrological character of the two rivers.

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**.

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.

- **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 km^2) 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-Swakopmund 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 Mine is situated to the north of the Khan River, approximately 25 kilometres upstream of the confluence with the Swakop River, within the Khan River catchment.

4.1.2 Topography

The Rössing 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 185.1 km^2 (a mining licence area of 64.5 km^2 and an accessory works and lease area of 120.6 km^2); approximately 91 % of the total area is on the north bank of the Khan River.

Broad peneplains with low relief characterise the northern 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. The terrain rapidly becomes hilly and more rugged closer to the Khan River, with jagged-crested, steep-sided hills rising some 120 to 200 metres above the river bed. The drainage lines coalesce and deepen to form gorges. Four of these gorges drain the mine property and discharge into the Khan River. Additional gorges drain into the Khan River from the south and the north banks before it eventually joins the Swakop River some 20 kilometres downstream of the mine property. The KARS dam site is located on the Khan River some 20 kilometres upstream of the Rössing Mine. The general topographic features of this site are very similar to those around the Rössing Mine frontage on the Khan River.

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 Climatic characteristics

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. However, since the primary focus of this study relates to water, only precipitation and evaporation characteristics are described here.

4.1.3.1 Precipitation

Annual rainfalls in the catchment of the Khan River decrease from east to west, varying 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 Mine indicate that the mine receives on average some 30-35 mm per year. The close proximity of the KARS Dam site to the Rössing Mine suggests that the dam site would be likely to receive very similar amounts of rainfall.

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 & Midgley, 1979; 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.

The frequent drought conditions experienced throughout southern Africa have given rise to perceptions that global climate change or other continental-scale phenomena have progressively reduced rainfalls in the West Coast region of Namibia. However, there are insufficient rainfall data available to substantiate such a trend. Nevertheless, the nett effect of any reduction **or** increase in rainfalls over the region would be an increase in the importance of flood flows contributed by the Khan River to the lower Swakop River because there are no impoundments or water supply reservoirs which would retard flows in the Khan River.

4.1.3.2 Evaporation

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, while net evaporation (after subtraction of rainfall and conversion to an open water surface) amounts to 2,170 mm (Hydrology Division, 1988). Once again, the close proximity of the KARS Dam site to the Rössing Mine suggests that it would experience very similar rates of evaporation.

4.1.4 Regional geology

The Rössing and other nearby uranium deposits lie within the Central Zone of the Damara Belt that occupies much of northern and western Namibia, (Mouillac *et al.*, 1986). The geology of this area has attracted considerable attention and has been described in detail by several authors (e.g. Jacob *et al.*, 1986; Schreiber, 1996).

Several basement domes and antiforms are exposed along the Swakop and Khan Rivers. These comprise highly metamorphosed and deformed sedimentary, volcanic and intrusive rocks of the Abbabis Metamorphic Complex, surrounded by groups of meta-sedimentary rocks. Widespread granite emplacement throughout the area and 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.

Local sedimentary rocks and intrusives of the Karoo Sequence were deposited over the older crystalline basement rocks. These 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, scree, clay and duricrust deposits, such as gypscrete and calcrete (Jacob *et al.*, 1986).

Extensive erosion of Tertiary deposits resulted in substantial conglomerate terraces, often located some 30 to 70 metres above the present river beds. These deposits form the Oswater Conglomerate Formation (Ward, 1987), and are common along the Khan, Swakop and Kuiseb River systems. Oswater outcrops are usually massive, and up to 40 metres thick. Clasts can reach a few hundred millimetres in size, are generally well-rounded and consist of metaquartzites and vein quartz. They are cemented together by calcium carbonate imbedded in an arenaceous matrix of quartz grains.

The importance of the Oswater Formation to the KARS project lies in the fact that Oswater deposits were encountered during the geotechnical investigations of the spillway sections at the proposed dam site.

The general geological characteristics of the area around the KARS Dam site are similar to those around the Rössing Mine, with the exception that no significant sites of uranium mineralization occur near the KARS Dam site.

4.1.5 Geomorphology

The Swakop and Khan rivers drain an area that has been subjected to several geomorphological changes, each of which has had marked effects on the evolution of the river systems.

Uplift during pre-Tertiary times resulted in deep incisions of the rivers into the country rocks. Subsequent subsidence 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 followed by further 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 modern times, the shape of the Swakop River mouth is occasionally changed during large floods. Good examples are 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).

4.1.6 *Soils*

Soils in the vicinity of the Rössing Mine and the KARS dam site are generally shallow (< 25 cm) and greyish or ochre in colour, with a large proportion of coarse fragments and occasional calcium carbonate concretions. These are characterized by high soil pH values and the formation of a crusted surface layer. These surface crusts reduce rainfall infiltration rates and accentuate runoff. Wind-blown sand deposits of varying depth are found in sheltered areas in the upper gorges.

Alluvial deposits up to about 20 metres in thickness occur in the bed of the Khan River. 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 are caused by the 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, 1988).

4.2 General hydrological characteristics

The hydrological characteristics of the Khan and Swakop Rivers are controlled by the physical characteristics of their respective catchments, prevailing climatic conditions, and anthropogenic activities in the catchment area. In the very arid conditions of western Namibia, river flows are predominantly episodic and are driven by discrete though erratic rainfall events. Since most rainfall events occur as summer thunderstorms, river flows are predominantly of the short-lived, flash-flood type typical of desert regions. The combination of erratic and unpredictable surface flows with very high evaporation rates has prevented the construction of water-supply dams on the middle and lower reaches of the Khan and Swakop rivers.

There is a chronic shortage of measured data on the hydrological characteristics of the Khan and Swakop rivers. Therefore, a combination of measured and modelled (synthetic) data, combined with well-known principles of arid-zone hydrology, was used by the Project Team to describe the main hydrological features of the Khan and Swakop rivers. The full report on the hydrological and geohydrological modelling conducted for the Khan and Swakop rivers, carried out by Metago Environmental Engineers, is presented as an Appendix to this Report (**Appendix 1**).

Most of the available hydrological data and information were obtained from earlier feasibility studies conducted by DWA and from engineering investigations conducted for Rössing Uranium. The detailed information obtained from DWA formed the basis for deriving an appropriate modelling methodology, as well as development and execution of the model (summarized in **Chapter 3** of this Report).

4.2.1 *Existing developments in the catchment*

It is important to be able to distinguish the potential effects of the KARS Project from the impacts of other developments and changes which have occurred primarily during this Century. Furthermore, since the full impact of a particular development may only be felt at a point downstream, several years or even decades after the development, the timing of the impact should also be assessed. The existing developments in the Khan-Swakop catchment, and their associated effects, include:

- On the Swakop River, the Von Bach and Swakoppoort dams were built in 1970 and 1976, respectively. These dams have caused:
    - A reduction in the *volumes of floods* measured downstream of Swakoppoort Dam, resulting in less water being available to recharge the Swakop River alluvial aquifer.
    - A change in the *shape of the flood hydrographs* for the Swakop River downstream of the dams. The dams retard flood waters, thereby lengthening the duration of the flood hydrograph, reducing the peak flow rate and lengthening the period of flow. The implications of these changes in the hydrograph shape include:
        - * a reduction in the sediment carrying capacity of the flood waters downstream of the dam as a result of the reduced peak flow rates;
        - * a reduction in the extent to which riverbed vegetation is cleared during major flood events along the path of the flood; and
        - * an increase in the proportion of the available flood volume which infiltrates into the alluvial materials and contributes to recharge of the alluvial aquifer. This increased recharge rate accelerates the reduction in flood volumes further downstream.
    - The dams reduce the *frequency of flood events* measured downstream of the spillway. This has several important potential impacts which can be summarized as follows:
        - * The alluvial aquifers have a limited or finite storage capacity and they need to be re-filled or recharged at relatively frequent intervals. If they are not filled, they tend to loose their water, primarily to evapotranspiration. This gives rise to increased salinity over the period between successive recharge events.
        - * Riverbed vegetation in the path of the flood is cleared less frequently by flood waters. Thus, the vegetation tends to become more firmly and densely established and more resistant to removal by smaller floods, thereby consuming greater quantities of water through evapotranspiration. These increased evapotranspiration water losses increases the rate of salinization of the aquifer.
    - An increase in the silt size fraction of the sediment load in the flood waters for some distance downstream of Swakoppoort Dam due to