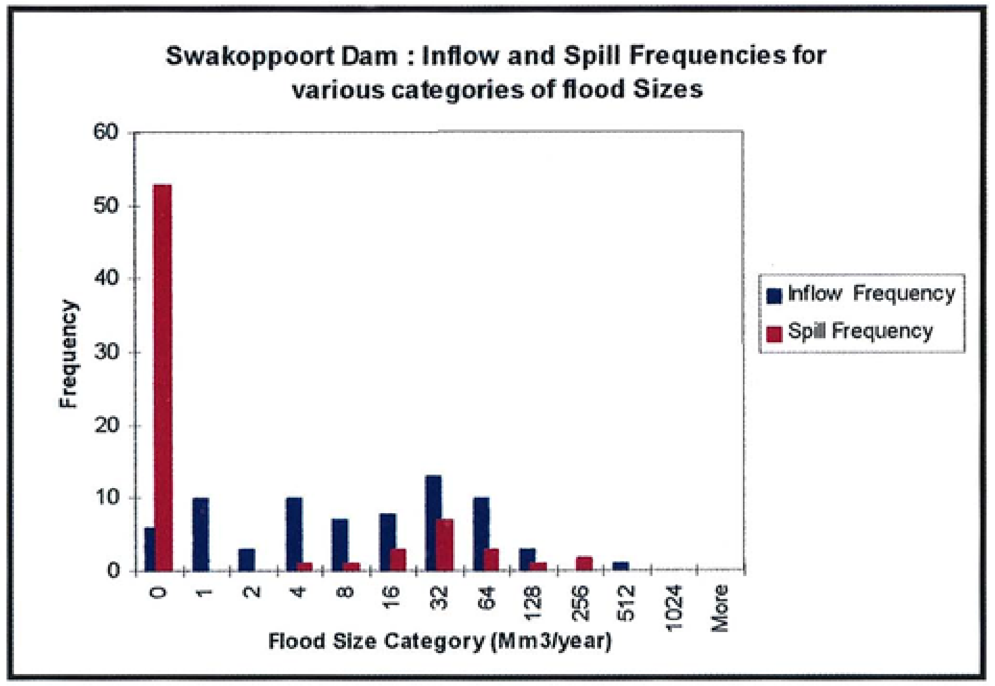

Figure 3 : The Effect of Swakoppoort & Von Bach Dam on Flood Size and Flood Frequency

Most of the seasonal inflows between 10 and 100Mm^3 / year would also resulted in zero spill events, had the dams been in existence over the entire duration of the synthetic record. The evidence of the synthetic record is backed by the actual flow record at Swakoppoort dam from 1976 to 1995. The marked effect of the dam on the flood frequency is clearly evident as none of the inflows to the dam of magnitude in the range 1 to 10 Mm^3 / year have resulted in a zero spill event.

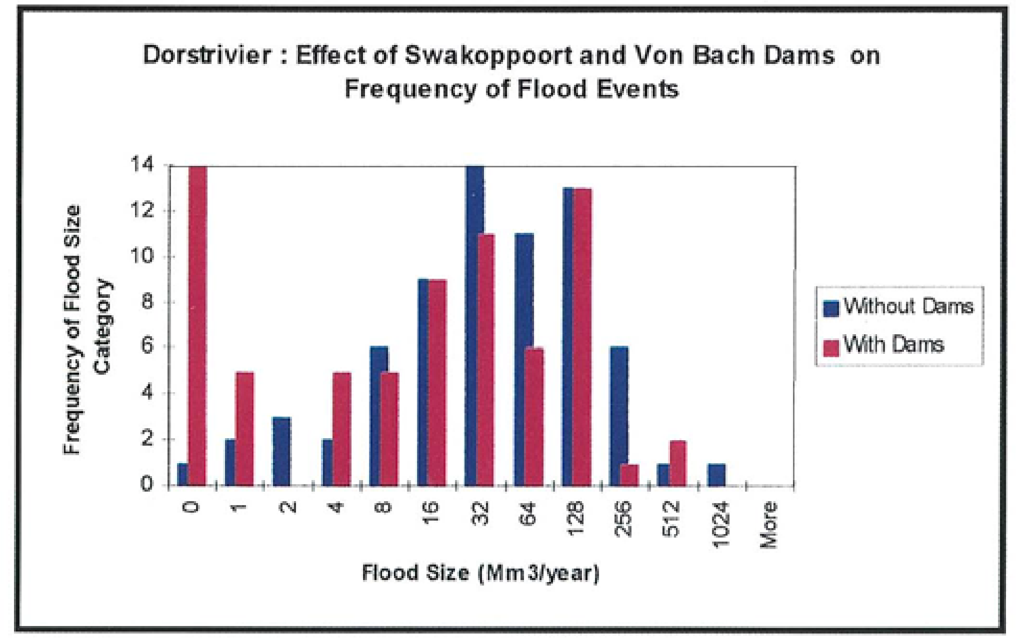

Figure 4 : The effect of Swakoppoort and Von Bach Dam on Flood Volume and Frequency at Dorstrivier

5.2.4 Relative Contributions of the Khan and Swakop Rivers to Flood Volumes in the Lower Swakop River

Figure 5 has been derived by calculating the percentage contribution of the Khan River to the sum of the flows in the Khan and Swakop Rivers at Dorstrivier and Ameib. Both synthetic flow records for the Swakop River, namely with and without the dams have been used in deriving the synthetic record. The histograms illustrate the effect of the construction of the dams on the Swakop River in terms of increasing the relative contribution of the Khan River to the total flow in both rivers (albeit at locations upstream of the confluence). From Figure 5 it is clear that the significance of the Khan River, in terms of flood volumes in the Swakop, must have increased since the construction of the dams. For example, the number of times that the Khan River contributes between 90 and 100% of the total flow in both rivers, increases by approximately an order of magnitude as a result of the dams.

From Figure 5 it is evident that the annual flood volume in the Khan River is generally between 0 and 20% of the total flood volume in both rivers.

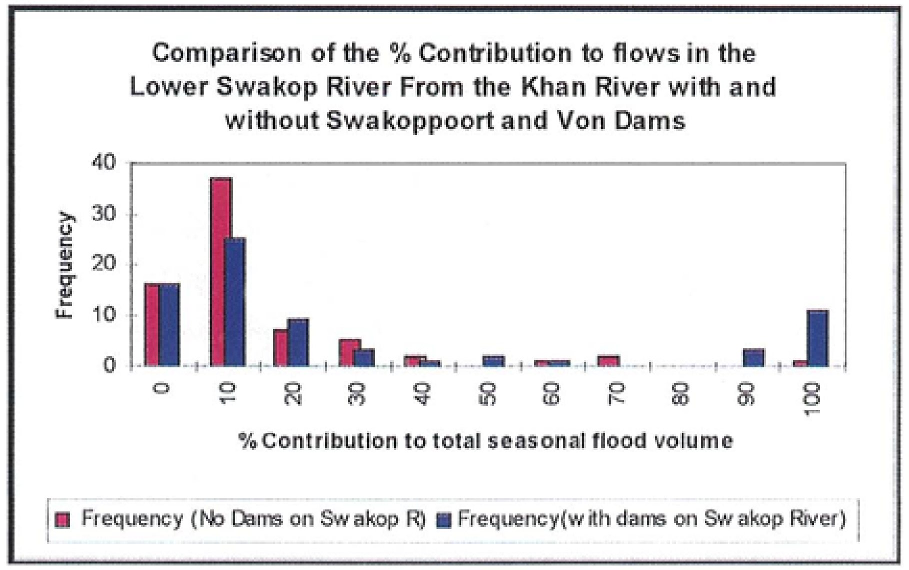

Figure 5 : Relative Contribution of the Khan River to Floods in the Lower Swakop River

The seasonal flood volume in the Khan River at Ameib is plotted as function of the total flood volume in the Khan and Swakop Rivers in Figures 6 and 7. Figure 6 was derived using the synthetic record at Dorstrivier for no dams on the Swakop River and Figure 7 uses the synthetic record assuming both Von Bach and Swakoppoort Dams exist.

From Figure 6, it is clear that the majority of floods contribute less than 10% of the combined flood volume. The effect of Swakoppoort and Von Bach dams is to increase the proportion of floods which contribute more than 10 % of the combined flood volume as can be seen by comparing Figures 6 and 7. The number of times that the Khan contributes 100% of the combined flood volume is significantly increased by the dams on the Swakop River.

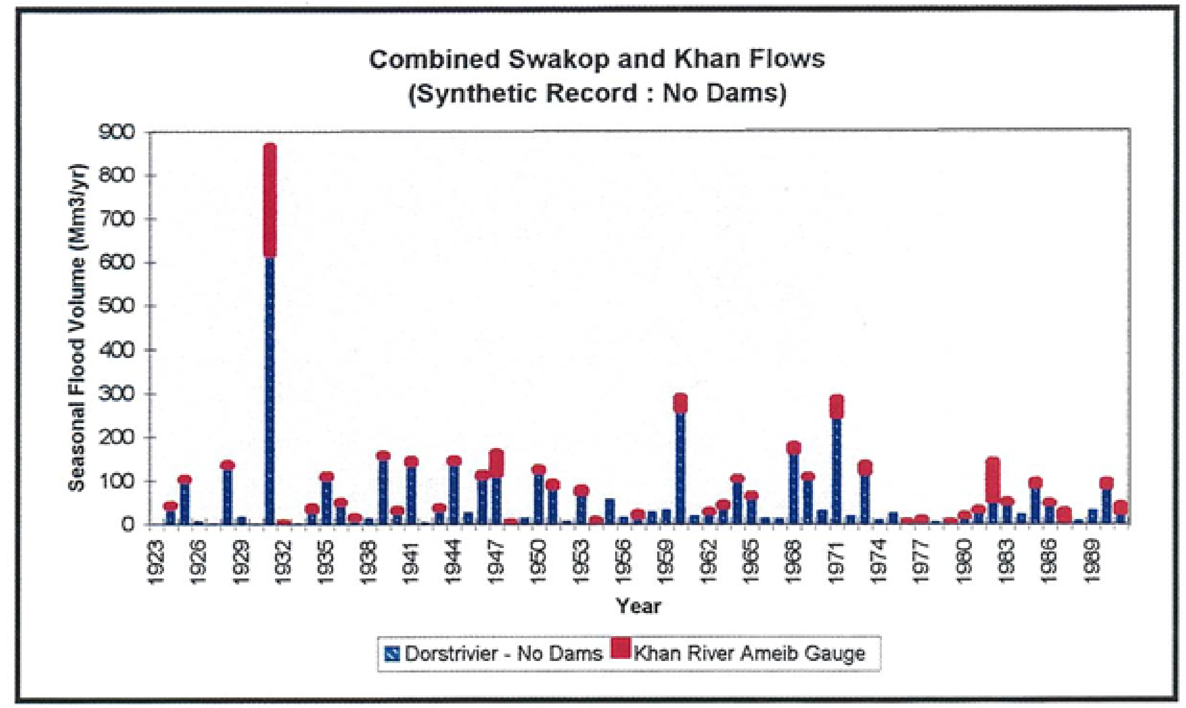

Figure 6: Synthetic Record - Khan and Swakop with No Dams

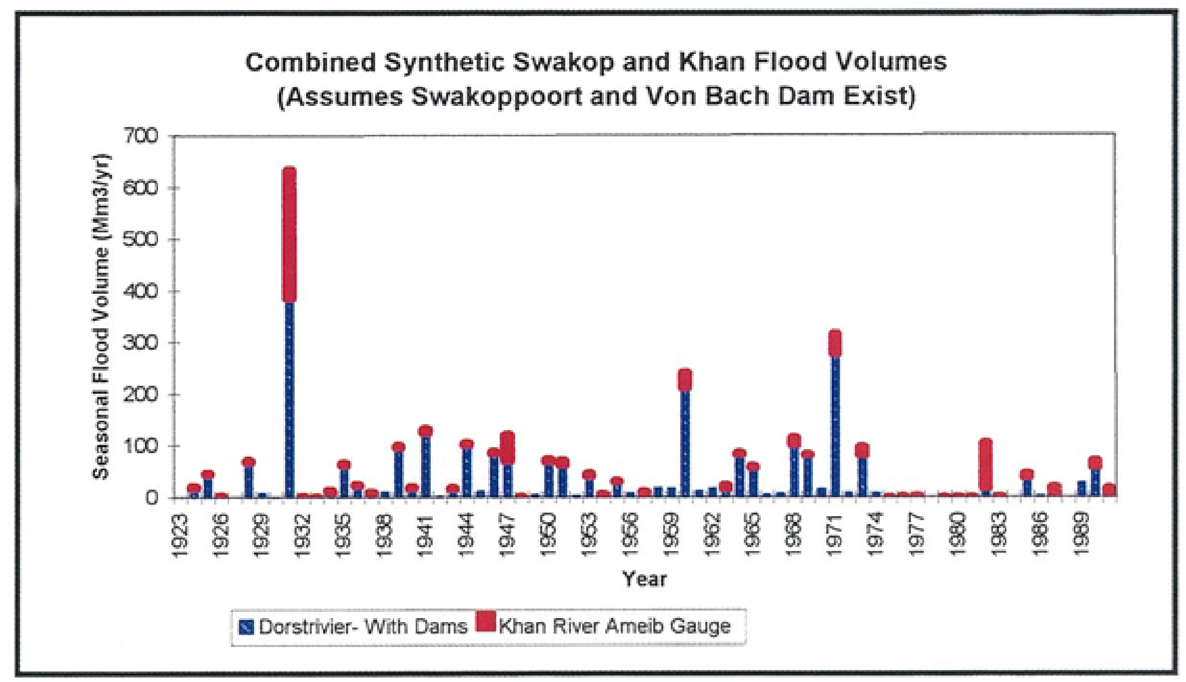

Figure 7 : Synthetic Historic Flood Records - With Von Bach and Swakoppoort Dams

Table 2 summarises statistics derived from the synthetic historic flood records and illustrates the relative contribution of the Swakop and Khan Rivers, based on the synthetic flood records at Dorstrivier and Ameib respectively. Dorstrivier and Ameib are the closest reliable points on the Khan and Swakop Rivers immediately upstream of the Namib desert.

Table 2: Comparison of Flows in the Khan and Swakop Rivers upstream of the Namib Desert

		Synthetic Record (No Dams)		*Synthetic Record (With Dams)*	
	Khan River @ Ameib (Mm³)	*Swakop @ Dorstrivier (Mm³)*	*Khan Contribution to combined flow (% Total)*	*Swakop @ Dorstrivier (Mm³)*	*Khan Contribution to combined flow (% Total)*
Mean	9,1	60,8	13%	37,0	19,7%
Median	1,25	30,07	4,0%	11,0	10,2%
Standard Deviation	32,0	89,7	-	65,0	-
Minimum	0,0	0,0	-	0,0	-
Maximum	247,73	620,76	28,5%	387,6	39,0%

5.3 Transmission Losses

It is generally accepted that from Dorstrivier to the Atlantic and from Amieb to the Swakop confluence, the additional contribution to flood volumes is very small for the Swakop and Khan Rivers respectively. Flood volumes 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 is in turn largely a function of the particle size distribution.
- The average permeability of the alluvium which a function of the degree of saturation of the alluvium and the duration of the flood event. 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.

There is little information available in the literature regarding the time required to saturate the material in the vadose zone. Based on the limited extent to which recharge took place during the 1997 floods and the record of flood duration's and channel widths, it is evident that the average vertical infiltration rate is significantly less than might be expected based on the alluvial aquifer permeability's documented in the literature. A series of finite element analyses were conducted using the programme SEEP/W to analyse the time it would take for fully saturated conditions to develop in the vadose zone after inundation for different depths to the water table. The saturated vertical permeability was assumed to be twenty times less than the saturated horizontal permeability.

5.4 Evaporation Losses

The evaporation map for Namibia was provided by the Department of Water Affairs. This map was used to estimate evaporation rates from wet sand and wetlands.

5.5 Base Flow Rate in the Khan and Swakop Rivers

5.5.1 Aquifer Permeability Storage Characteristics

Pump tests carried out in 1970[6] just upstream of the confluence of the Khan River and Swakop River indicated a hydraulic conductivity of 268 m/day and a storage coefficient of 23%. The permeability of the alluvial aquifer in the lower Swakop River was estimated to be 219 m/day[6] and the storage coefficient 18%.

Storage capacities for the Khan River are given in the references for various sections of the Swakop and Khan Rivers as shown in Table 3.

[6] *Dziembowski, Z M (1970). Aquifer Constants of Alluvial Sediments in the Khan and Swakop Rivers near Rossing.- Geological Survey, Pretoria.*

TABLE 3: STORAGE CAPACITIES : SWAPOK AND KHAN ALLUVIAL AQUIFERS

River Section	*Storage Capacity Mm^3*	*Fraction of Total Capacity*
Swakop River		
Atlantic - Richthofen	17,6	16,8%
Richthofen -Palminhorst	5,7	5,4%
Palminhorst - Riet	14,8	14,1%
Riet - Salem	1,8	1,7%
Salem - Horebisnoord	17,7	16,9%
Horebisnoord - Dorstrivier	*~14*	13,3%
Total Swakop Aquifer (Namib Region)	***71,6***	***68,3%***
Khan River		
Rössing to Confluence	6,5	6,1%
Namibfontein - Rössing	8,4*	8,0%
Usakos - Namibfontein	*~15*	14,3%
Ameib - Usakos	*~3,4*	3,2%
Total khan River (Namib Region)	***33,3***	***31,7%***
Total for Combined Aquifers	***104,9***	***100,0%***

Table 4: Flood Volumes as a Percentage of the Aquifer Storage Volume

	Khan Aquifer	*Swakop Aquifer*		*Combined Aquifers*	
		No Dams	*With Dams*	*No Dams*	*With Dams*
Mean Flood Volume / ***Aquifer Storage Vol.***	27,3%	84,9%	51,7%	66,6%	43,9%
Median Flood Volume / ***Aquifer Storage Vol.***	3,8%	42,0%	15,4%	29,9%	11,7%

From Table 4 it can be deducted that the Khan aquifer is likely to be fully recharged far more rarely than the Swakop aquifer since the median flood volume is a small percentage of the aquifer storage capacity. (i.e. 3,8% versus 15,4% for the Swakop.)

5.5.2 Groundwater Abstractions

Use is made of the alluvial Aquifers of the Khan River at the following locations:

- Spes Bona, located approximately 35 km upstream of Ameib. Annual production figures supplied by the Department of Water Affairs indicate an average abstraction rate of 79 800m^3/annum. The abstraction rate has decreased significantly since 1990 as shown in Figure 8

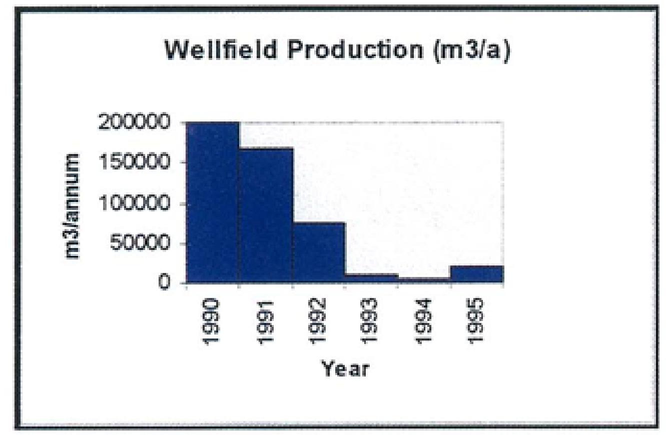

Figure 8: Spes Bona Groundwater Abstractions

- A second well field operates at Usakos, records of production rates indicate an average abstraction of 119 000 m^3/ year but decreasing in recent years as shown in Figure 9, to an abstraction rate of 14 355 m^3 in 1996.

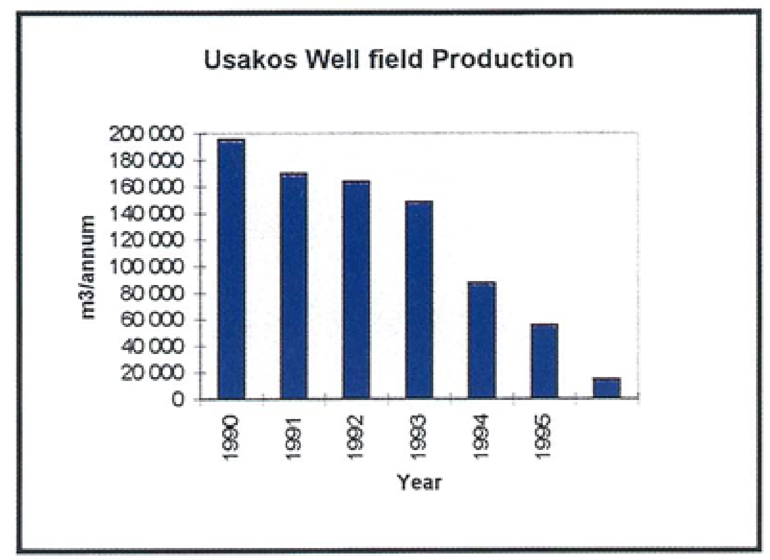

Figure 9: Usakos Well Field Production

- Rössing have abstracted water from the Khan Aquifer since the 1960's. Boreholes 1 to 8 were established between 1973 and 1976. Boreholes 9 and

10 were established in 1993 upstream of Dome Gorge[7]. Rössing are currently allowed to abstract a maximum of 870 000 m^3/ annum based on their permit conditions. In 1995 the DWA recommended a reduction to 600 000 m^3/annum due to the general draw down of the aquifer in the vicinity of the Mine well field. Annual abstraction rates for the mine well field are shown in Figure 10. Monitoring boreholes in the vicinity of the Mine's abstraction wells indicate a general decline in the level of the phreatic surface over the period 1985 to 1996. Prior to extraction, the phreatic surface was within 2 to 6 m of the surface[7].

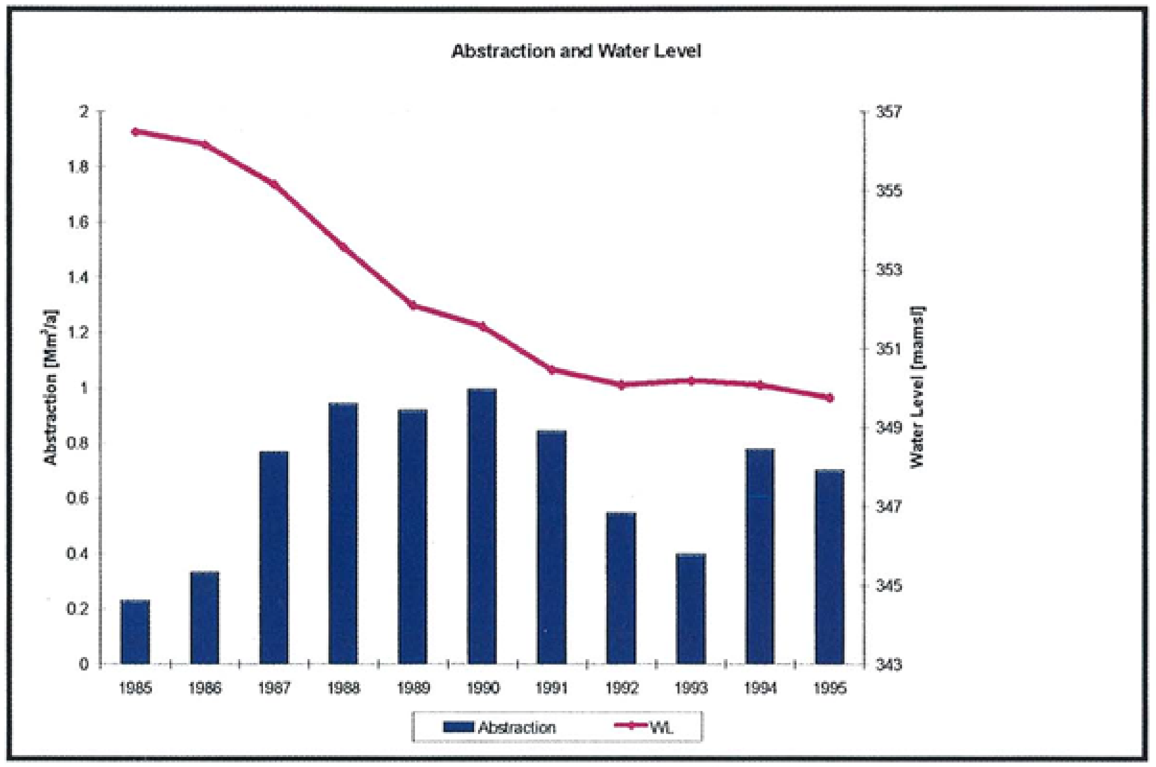

Figure 10 : Rössing Uranium Limited Abstraction Record

Groundwater is abstracted from the Swakop River in the following places :

- Consumption of water in the lower Swakop River is estimated to be in the region of 727 000[8] m^3/annum in a wet season increasing to 821 000 m^3/annum during dry seasons. This water is used almost exclusively for irrigation. Based on

[7] *Rossing Uranium Limited, 1996. The Status of the Khan River Aquifer in 1995/6, Geohydrological Report.*

[8] *Stubenrauch Planning Consultant, June 1992 : Derived from Swakopmund Small Holding Plan, Appendix C.*

agricultural developments that are either planned or in the process of being implemented, the annual abstraction rate by small holdings is likely to increase.

- Historical abstraction records for the well field at Otjimbingwe, located approximately 225 km's upstream of Swakopmund, indicate an average abstraction rate of 170 000m^3/ annum. Figure 11 shows the total annual production rate at Otjimbingwe based on records of 9 boreholes.
- There are no further records of significant groundwater abstraction points along the Swakop River downstream of Swakoppoort Dam.
- It is likely that consumption of groundwater in the lower Swakop River will increase in future as more and more commercial agricultural developments come into existence. There are several plans to develop asparagus farms in the area.

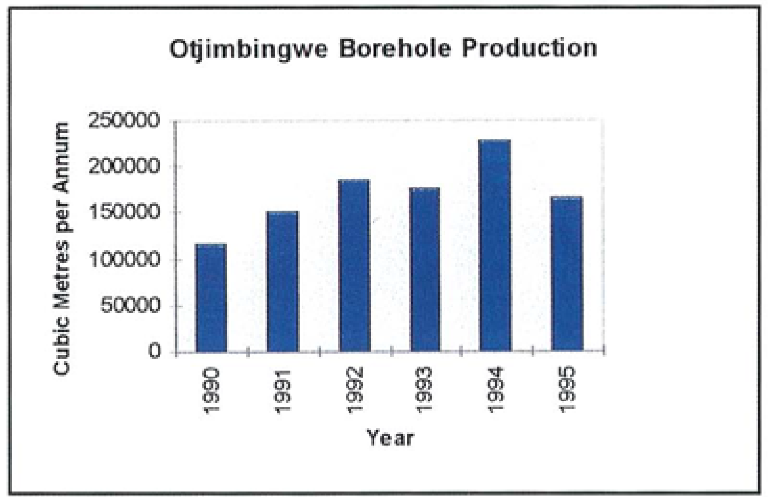

Figure 11 : Otjimbingwe Well Field Production

5.5.3 Evaporation and Evapotranspiration Losses

Evaporation Rates

Measurements have been taken at Gross Barmen for open water, wet sand and potential evapotranspiration. The evaporation rate from wet sand was found to be 70% of the A-pan evaporation rate and the potential evapotranspiration rate, 64% of the A-pan rate. The A-pan evaporation rate in the study area was 3 033 mm/annum.

Evapotranspiration from trees and Shrubs

Trees and shrubs growing in the alluvium are dependent on the groundwater stored in the aquifer for survival. Under circumstances of drought, trees are able to an extent to reduce the uptake of water. There is only minimal data available regarding the quantity of water used by vegetation in the Khan and Swakop Rivers. Factors which are likely to influence the rate of water consumption include :

- the density of the vegetation or bio-mass ;
- climatic factors including temperature, wind speed and humidity;
- the availability and level of groundwater and the moisture content of the vadose zone, and
- the rate of change of the groundwater level.

The surface area of the river bed between Swakoppoort Dam and the mouth of the Swakop River was estimated as 7 144 Ha. The surface area of the Khan River between Ameib and the confluence of the Swakop was estimated as 2 735 Ha. The vegetated area was found by Hellwig to be 38% of the total river bed area. Thus the total volume of water lost to evapotranspiration is estimated to be in the region of 0,38x7144Ha*0,64*1/100=52,7Mm^3 /annum. This rate is considered to be an upper limit and assumes that water is readily available to plants. Large trees and shrubs, whose roots extend to the phreatic surface, are likely to consume more or less a constant amount of water each year.

Anecdotal evidence and a comparison of older and more recent air photo's indicates that the vegetation density in the Swakop River has increased significantly since the 1970's. Furthermore, the presence of exotic trees (e.g. Prosopis) are likely to increase the rate of evapotranspiration further.

Ephemeral Vegetation

Ephemeral vegetation which germinates shortly after a flood, seeds rapidly and then dies back, is expected to use the water held in the upper layers of sand which remains only for a relatively short period of time until the sand dries out due to evapotranspiration and evaporation.

Wetlands

The followings factors contribute to the formation of wetlands which enhance evaporation/ evapotranspiration losses in the Khan River :

- A geological condition located approximately 61 km's 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 m^3/Ha/day[9].

- A similar reed bed is situated on the Swakop River at Riet, located approximately 120 km's upstream of Swakopmund.
- 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[10]

Evaporation from wetlands was believed to contribute significantly to the evaporation losses, at least in the 1960's when the CSIR conducted their study. The total area of wetlands was estimated from the colour air photo's taken in February 1997 as 3 Ha at Nabas and 223 Ha between the small holdings and the sea. The area of wetlands has reduced in recent years and may be compared with that measured by Hellwig in 1958 which was 816 Ha.

Water Loss from Sand Pits and Trenches

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. Thus the volume of water lost per annum through evaporation is less than 0,1Mm^3 which is insignificant at this stage. The loss of water could potentially have an effect on the TDS of groundwater in the immediate vicinity of the sand pits and trenches due to the concentrating effect of evaporation. The effect of sand mining and trenches is not considered to warrant further detailed consideration in the model at this stage since the effect of sand pits is localised. Should the extent of sand pits increase significantly over the forthcoming years, there impact on the TDS of the groundwater in particular, could become significant.

5.5.4 River Bed Gradients

The gradients of the Khan and Swakop Rivers have been estimated from 1:50 000 topographical maps. The gradients vary between 1:130 and 1:540.

[9] Based on Info supplied by Dr P Ashton relating to loss of water in reeds in the Highveld Region.

5.6 Groundwater Quality in the Khan and Swakop Alluvial Channels

5.6.1 Water Quality Trends

The rate of salinification of groundwater (in terms of TDS) is illustrated in Table 5 for the Swakop River.

TABLE 5 : TDS IN THE SWAKOP RIVER

River Reach	*TDS*	*Distance from Swakopmund*	*Increase in TDS/km*
Swakop River			
Atlantic - Richthofen	>10 000	21,5 km's	>100
Richthofen -Palminhorst	5 000 -10 000	25,5 km's	196mg/l/km
Palminhorst - Riet	2 000 -5 000	69	43mg/l/km
Riet - Salem	1 000 -2 000	10	100
Salem - Horebisnoord	<1 000	24	

The quality of the Khan River groundwater is generally considered to be poorer than that of the Swakop River. Reasons given for the poorer quality is the lower flood volume and the higher proportion of the catchment which passes through the Namib Desert. Table 6 illustrates the trend in TDS values for the Khan River.

TABLE 6: WATER QUALITY TREND IN THE KHAN RIVER [10]

River Reach	*TDS*	*Distance from Swakop Confluence (km's)*	*Estimated Increase in TDS/km*
Ameib	N/A	140	
Usakos	N/A	110	
Rössing Mine	3900 - 4200[10]	26 to 36	140 - 150 mg/l/km
Confluence	9246 -13745	0	

The TDS of the Swakop River at Swakopmund was reported as 14 000mg/l.

[10] *CSIR, 1966. Verslag oor opname van die Swakop Rivier Suidwes- Afrika, met spesiale verwysing na die Chemiese Kwaliteit van die Water en Die Faktore wat dit Beinvloed*

5.6.2 TDS Variability

The 1976 report[11] describes water quality tests conducted in the vicinity of Rössing Country Club which indicated a TDS of 14 000 mg/l to 28 000 mg/l. These changes take place over relatively short distances in the aquifer and cannot be accounted for by evapotranspiration. Channelling and layering of waters of different qualities may be responsible for the relatively rapid change in concentrations over short horizontal distances and at different depths within the alluvium.

In 1975/6 ten boreholes drilled in the lower Swakop River indicated that the quality of groundwater in the Swakop River was much the same as it was in the 1960's, however, given the scarcity of water quality monitoring data, it is difficult to draw conclusions regarding long term trends or short term variability in the water quality.

5.6.3 The Salinification Process

Salt loads in the alluvial aquifers arise primarily as a result of weathering and dissolution processes. In the lower catchment, wind blown salts from the Atlantic Ocean are considered to be a significant source of salts. Secondary sources of salt loads include industrial, mining and farming activities.

Changes in the quality of groundwater in the alluvial aquifers, (attributable to the KARS), may be caused by a change in one or more of the following parameters :

- An increase in ratio of the contribution to base flow from the tributaries and the main channel, which will reduce the extent to which the saline water from the side channels is diluted.
- A reduction in either or both the frequency or quantity of recharge from surface flows. The effect of changing either of the above parameters might be to concentrate salts present in the alluvium, particularly if the main mechanism of water loss from the aquifer is evaporation and evapotranspiration.
- A reduction in the level of groundwater which might impact on the vegetation cover and could give rise to a reduction in evapotranspiration losses from trees shrubs along the river bed.

[11] *Rossing Uranium Limited , 1976.Report on Boreholes Drilled and Developed in the Swakop and Khan Rivers.,*

- A reduction in the base flow rate which could give rise to a reduction in the area of wetlands and hence a reduction in the evapotranspiration losses from the wetlands.
- A change in the evapotranspiration flux brought about by either changes in vegetation density, vegetation type, water availability or wetland area.

According to the study conducted in 1966 by the CSIR, the primary reasons sited for the increase in salinity in the downstream direction, was the effect of evaporation from wetlands. These wetlands are formed where the groundwater is forced to the surface due to local geological conditions. The significance of vegetation growth along the river bed outside of the wetlands areas, was considered secondary to losses from the wetlands. Minor tributaries which feed relatively low volumes of highly saline water into the main aquifers, were considered to be generally less significant effect. (CSIR 1966 Report). Exceptions to this have been observed, for example, after the 1934 flood, the salinity of the Swakop River increased dramatically. The increase was ascribed to the elevated salt loads which entered the Swakop River from the Namib desert where heavy rains had fallen and mobilised considerable tonnage's of salts.

Based on evidence from aerial photographs and anecdotal evidence from people who have lived in the area for several decades, significant changes have occurred over the past few decades including :

- A reduction in the total area of wetlands from 816Ha measured by Hellwig to 226 Ha based on air photos taken in February 1997.
- An increase in the vegetation density along the river beds.
- Increased use of the water for irrigation giving rise to increased salinity due to evaporation and evapotranspiration.

The salt load from side channels which feed groundwater into the main channel of the Khan River is believed to be insignificant between Usakos and the confluence primarily due to the low flow rates. There is no information regarding TDS values in the tributary water or the water flux from the side channels, but even if high TDS values in the order of 5000 to 10000 mg/litre are assumed, the contribution to the total TDS load is small.

The tributaries of the Swakop River between Swakoppoort Dam and Dorstrivier are believed to make a significant contribution to the groundwater flow and the total TDS load in the Swakop River. Downstream of Dorstrivier, once the Swakop River enters the Namib desert, the contribution from tributaries and side channels is believed to be much less significant, despite the likely elevated concentrations. However, there is practically no monitoring evidence available to support this argument which is based purely on consideration of the hydrology and evaporation characteristics.

5.7 Sediment Transport

The proportion of sediment in flood waters is a non-linear relationship (flood volume versus sediment volume) as evidenced from the record of sediment volumes deposited in the Swakop River delta after previous floods shown in Table 7.

Table 7: Historical Sediment Volumes

Year of Flood	*Flood Volume (Mm^3)*	*Delta Deposit (Mm^3)*	*Sediment Volume / Flood Volume (%)*
1933/4	500	35	7
1962/3	300	5	1,7
1973/4	190	1	0,5

Furthermore, the mode of sediment transport may change as the flow rate increases. The sediment may in one instance be transported as bed load whereas for a slightly higher flow rate, the water might create enough bed shear stress to lift the sediment into the suspended transport mode, thus allowing a much larger volume of sediment to be transported. Detailed computations of the volume of sediment which would be transported and deposited in the Swakop delta for each flood event are not possible given the limited data available. Simplifying assumptions must be made based on the long term average siltation rates of dams in similar environments in Namibia, and the data provided regarding the volumes of sediment deposited in the Swakop River delta. On the basis of a long term average silt load, it is reasonable to simplify the problem by assuming that the effect of KARS on the sediment carrying capacity of the river can be assumed to be directly proportional to the change in the annual flood volume.

During spill events, dams will tend to retain the larger particle size fraction but pass a significant portion of the silt and clay size fraction. The particle size distribution of the flood waters downstream of the dam is dependent on the stream power and availability of particles. The availability of sediment downstream of the dams is governed by the alluvial material in the river bed, but since the dams tend to spill only the finer fraction of sediment, the percentage of finer material in the sediment downstream of the dam might be expected to increase over time. The availability of sediment of other size fractions downstream of the dam, brought down either prior to the existence of the dam or along tributaries downstream of the dam, also influences the nature of sediments downstream.

Assuming a twenty year life of KARS and a mean seasonal flood volume of 9,1Mm^3, the total volume of sediment transported by Khan waters would be approximately 5,5 Mm^3 over 20 years (based on an average of 3% sediment by volume). The volume of sediment in the top metre of the river bed between the proposed Khan Dam and the Swakop confluence is approximately 6 Mm^3. Thus, assuming that all sediment passing down the Khan River was trapped by KARS (conservative), the maximum extent to which sediment can be removed from the river bed over the life of the dam would correspond to approximately 1m depth of sand. The actual depth of sand is significantly greater than this and it can therefore be concluded that the availability of sediment will not limit the volume of sediment transported.

6. MODEL CONCEPT

Figure 13 presents a conceptual section of the model developed to predict the impacts of the proposed KARS scheme. For the purpose of this model, the Swakop and Khan Rivers have been divided into six and four reaches respectively, as summarised in Table 8.

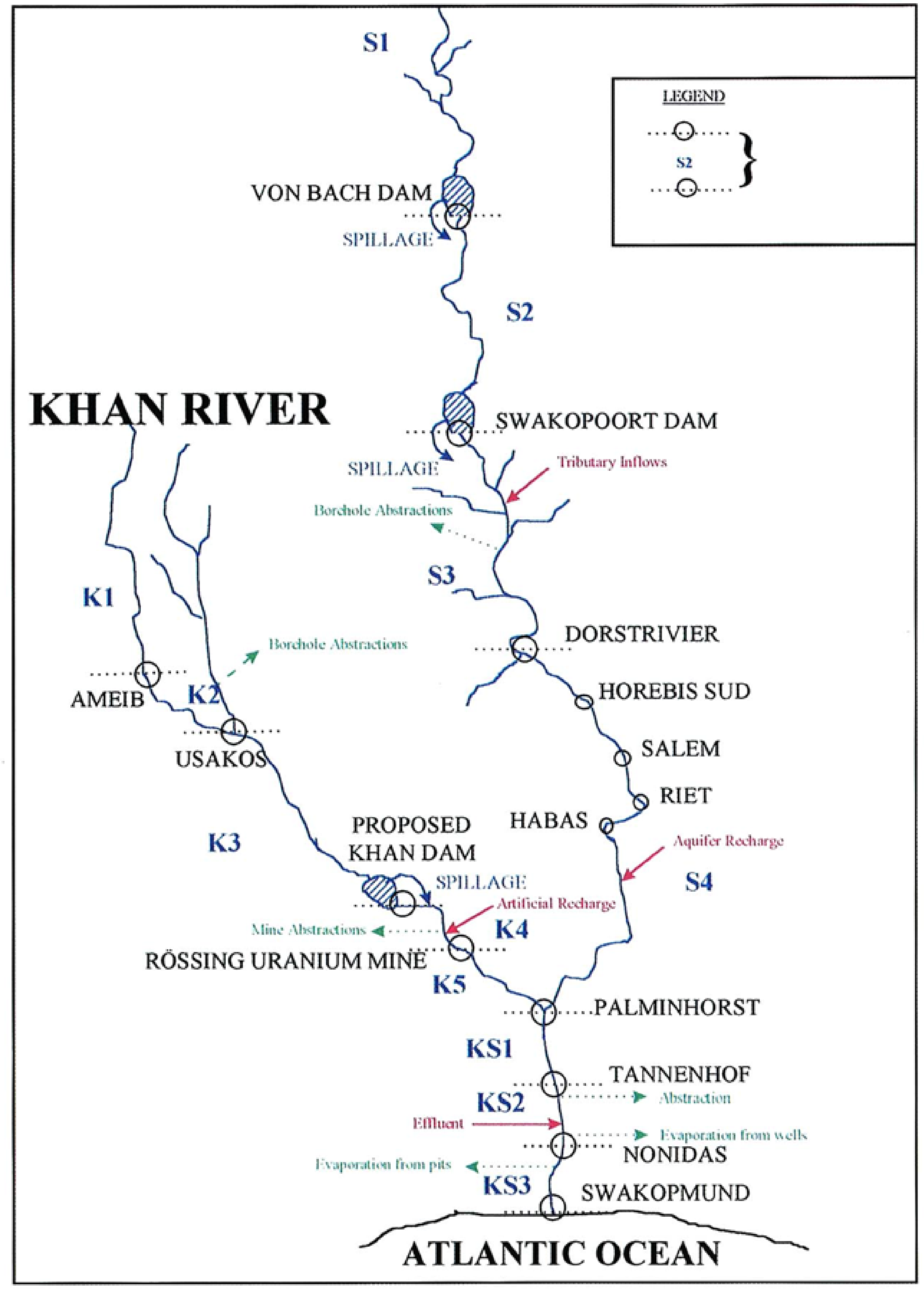

Figure 12 : Conceptual Layout of Swakop-Khan Model

Table 8 : Summary of River Reaches

Reach Start	Reach End	*Length*	***Significant Features associated with the reach***
		Swakop River	
Swakoppoort Dam Spillway	Dorstrivier	117	Good hydrological records available for Swakoppoort dam Zone of accumulation of rainfall. Reasonable synthetic record available at Dorstrivier
Dorstrivier	Khan Confluence	108	Zone of depletion of flood waters.
Khan Confluence	Tannenhof	26	Confluence of the Swakop and Khan Rivers
Tannenhof	Nonidas	11	Farming zone
Nonidas	Mouth	10,5	Sand mining, dunes
		Khan River	
Ameib Gauge Station	Usakos Gauge Station	26	Good hydrological records available for Ameib
Usakos Gauge	Khan Dam Spillway	77	Zone of depletion of flood waters
Khan Dam Spillway	BH6	14,5	Artificial recharge and extraction by Rössing
Bh6	Swakop Confluence	30	Zone immediately downstream of KARS

Four aspects of the Swakop and Khan Rivers systems are represented in the model by the following sub-models :

- 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 groundwater 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.

Figure 13 shows a typical cross section of a reach and illustrates how each of the above components has been represented in the model. Surveys at specific sections of the river have been conducted and would indicate that a triangular or trapezoidal shape could be used to approximate the alluvial aquifer. The triangular cross section significantly simplifies the mathematics and was therefore selected to represent the cross section.

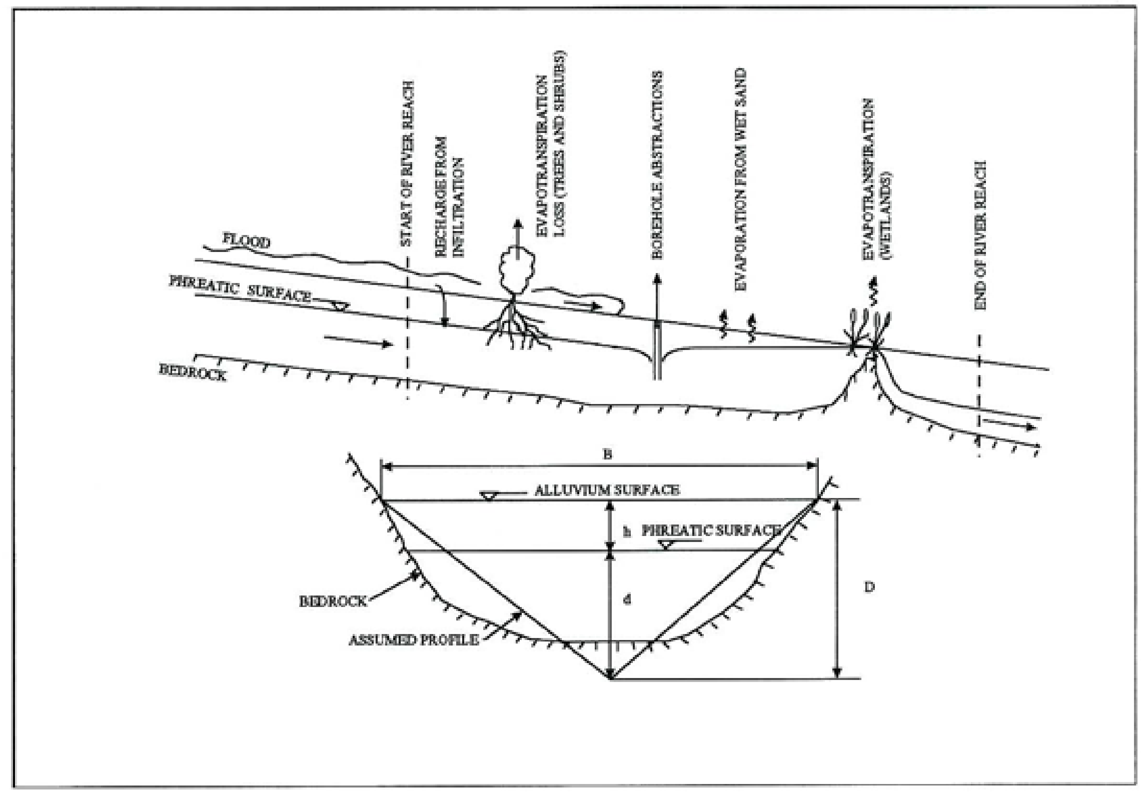

Figure 13 : Conceptual Model of Typical River Reach