Model Parameter	***Units***	***Distribution Type Applied***	***Source of Data***	***Level of Confidence associated with parameter values***	***Qualitative Assessment of the overall Sensitivity of parameter to model results***
Proportion of silt size fraction in sediment	% by volume	uniform	Limited Laboratory tests conducted by Rössing, Swakoppoort Dam siltation Records & discussions with DWA representatives	poor for individual floods but good for a long term average	low
Void Ratio (e) for Deposited Sediment	N/A	uniform	Documented results for similar materials	good	low
Vegetation Characteristics					
MAXIMUM Total Evapotranspiration rate	Mm^3/annum	uniform	Hellwig's research on evapotranspiration rates, Rössing's research of the vegetation density in the Khan and Swakop Rivers	poor	high
% of Maximum (calibration)	%	none	Calibration factor		low
Wetlands					
Evaporation Rate from wetlands	m/annum	uniform	CSIR information	poor	low
Area of wetlands	m^2	uniform	Rössing's information based on digitized air photos	good for time of photographs, poor for other times	low
Borehole Abstractions					
Annual Borehole Abstraction Rate	Mm^3/annum	uniform	Information supplied by various sources including DWA, Rössing and Swakopmund Town Council	fair	low
Minimum allowable/ achievable draw down	% of max capacity	none		poor	moderate
Tributary Characteristics					
Total Catchment area of Tributaries	m^2	none	1: 50 000 maps	good	low

Model Parameter	***Units***	***Distribution Type Applied***	***Source of Data***	***Level of Confidence associated with parameter values***	***Qualitative Assessment of the overall Sensitivity of parameter to model results***
MAP	m/annum	uniform	Climate Maps	good	low
% MAP Entering Tributaries as Groundwater Flow	%	uniform	Guess	very poor	low
Trench/ Sand Pit Characteristics					
Total Area of trenches exposed to water table/annum	m^2	uniform	Rössing's research	good for current situation, otherwise unknown	low
Evaporation Characteristics					
Mean annual Evaporation	m/annum	none	Evaporation map of Namibia	good	low
Reduction Factor for pit evaporation	N/A	uniform	Judgment	poor	low
Depth sand wet sand which can dry over one year	m	uniform	Judgment	poor	moderate
Depression Storage					
Depth of water lost due to ponding and evaporation from surface	m	uniform	Judgment	fair	moderate
Structural Characteristics					
khan Dam Fetch	m	none	Conceptual design layouts	very good	low
Khan Dam Capacity	Mm^3	none	Conceptual design layouts	good	moderate
Barrier Effective permeability reduction factor	n/a	uniform	Expected or intended values	good	high
Recharge field length	m	none		good	moderate
Swakoppoort Dam Capacity	Mm^3	none	DWA information	very good	moderate
Sand Mining annual excavation rate	m^3/ annum	none	Rössing's Research	good	low
Water Quality Parameters					

Model Parameter	*Units*	*Distribution Type Applied*	*Source of Data*	*Level of Confidence associated with parameter values*	*Qualitative Assessment of the overall Sensitivity of parameter to model results*
Flood Water TDS	mg/litre	uniform	1966 CSIR report	poor	low
Initial aquifer water TDS (1925)	mg/litre	uniform	Judgment and CSIR report	unknown	low
Base inflow TDS (uppermost reaches)	mg/litre	uniform	Judgment and CSIR report	unknown	low
Tributary TDS	mg/litre	uniform	Judgment and CSIR report	generally unknown	low
Average annual TDS concentration effluent	mg/litre	uniform	Rössing's research	poor	low
Average annual effluent flux	Mm³	uniform	Judgment	poor	low

The TDS in each aquifer reach is strongly influenced by the evapotranspiration rate. Since the evapotranspiration rate is one of the more difficult parameter values to estimate, the evapotranspiration rate has been used as a means to calibrate the model. There is very little data available regarding the TDS of tributary aquifers. This is particularly important in the reach between Swakoppoort dam and Dorstrivier.

Error! Reference source not found. shows the predicted flood volume at Swakopmund and observed flood record (based on Stengel's records for Swakopmund). Although many of the flood predictions compare favourably with Stengel's flood records, it is clear that there is a significant error in certain years. Attempts to improve the calibration of the model by adjusting infiltration parameters have proved unsuccessful and do not result in an overall improvement in the predictions. Since the synthetic flood record is based on a combination of a rainfall /runoff model and Stengel's record, it is likely that the rainfall runoff model predictions, particularly those affecting the seasonal flood records at Dorstriviër, largely account for the error. Since the synthetic flood record at Dorstriviër appears at times to be greater and at other times less than the actual flow at Dorstriviër, the error is not considered to result in a significant effect on the predictions and conclusions drawn from this model.

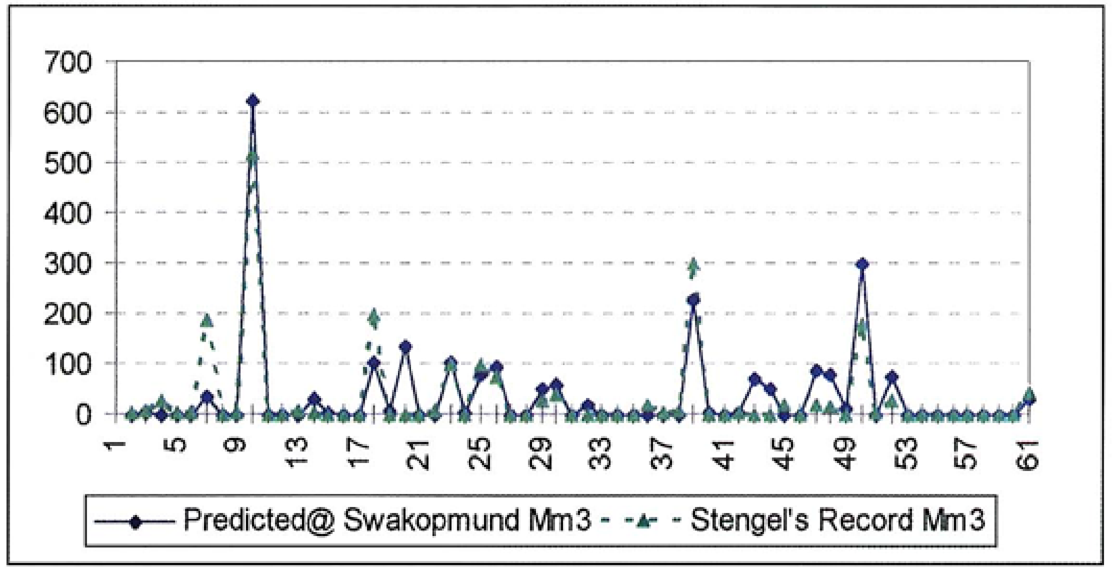

Figure 16 :Comparison of Predicted and Recorded Flood Volumes : Swakopmund

9. MODEL RESULTS

9.1 Cases Simulated

Three cases have been simulated as follows :

- Case 1: This case represents the situation prior to any significant development along the Khan or Swakop Rivers. The simulation has been carried out with the assumption that there are no dams or well fields along the Khan or Swakop Rivers.
- Case 2 : This case represents the situation assuming that the KARS scheme is never constructed but that the existing infrastructure is present.
- Case 3 : This case represents the situation with the existing infrastructure plus the proposed KARS scheme including the aquifer barriers downstream of the mine front aquifer reach.

9.2 Effect of Developments on Flood Frequency

The effect of the developments on flood frequencies at the farms zones, as predicted by the simulation model, are summarised in Table 11.

Table 11: Effect on Flood Frequency

Frequency Interval	*Case 1*	*Case 2*	*Case 3*
$f(V=0\ \text{Mm}^3/\text{annum})$	17±6,9	22±7,5	24±7,7
$f(0\leq V<10\text{Mm}^3/\text{annum})$	20±7	20,9±5,1	19.9±5,7
$f(10\leq V<100\text{Mm}^3/\text{annum})$	25±6	23,2±5,5	22,6±5,2
$f(100\leq V\text{Mm}^3/\text{annum})$	7±0,7	3,0±0,3	2,9±0,3

9.3 The Relative Contributions to Inflows and Outflows from the Alluvial Aquifer

Figures 18 and 19 illustrate the annual contributions to inflows and outflows in each reach. From these figures it is clear that overall, recharge of the aquifer by flood waters is the most significant contributor to inflow, and evapotranspiration due to trees and shrubs is the most significant natural outflow. Evaporation from wetlands, borehole abstractions, sand mining etc. have a less significant overall effect. In specific reaches however, base inflow or outflow may be a more significant factor than recharge or evapotranspiration.

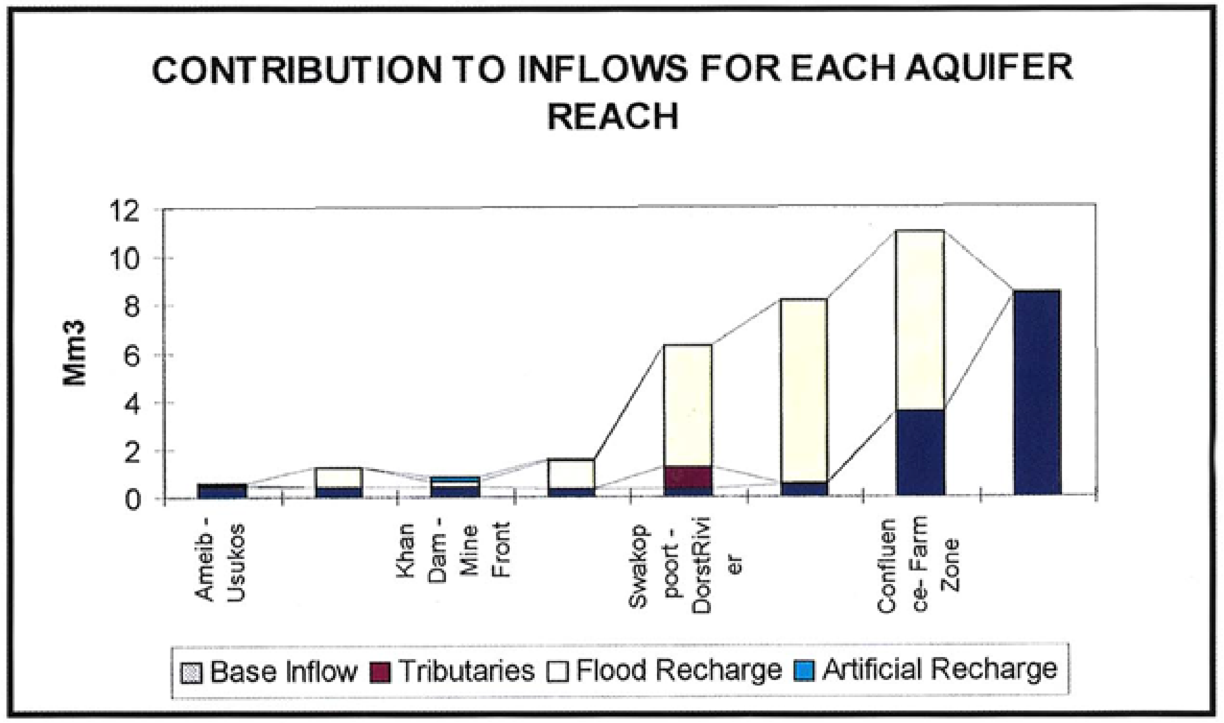

Figure 17: Typical Contribution to Inflows

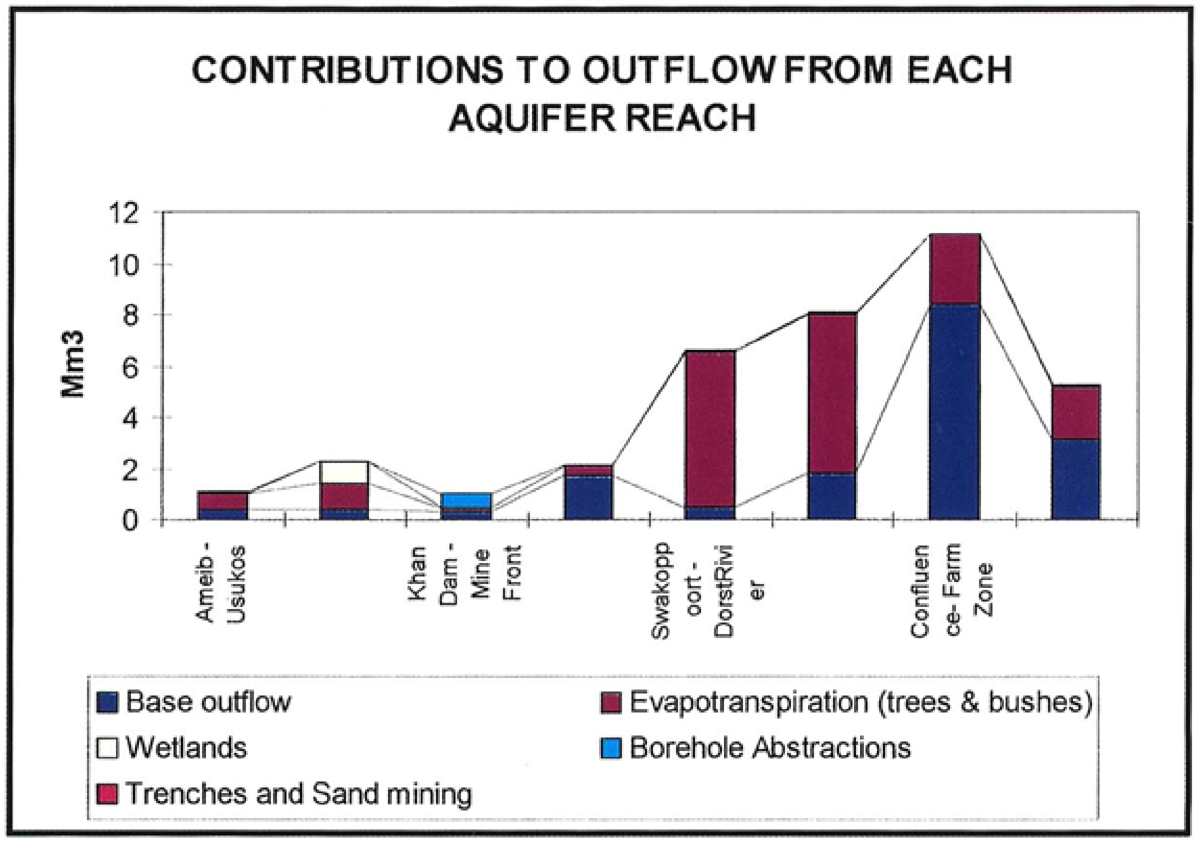

Figure 18 : Typical Contributions to Outflows

The relative significance of base flow, evapotranspiration and recharge are illustrated by the results of simulations conducted for Case 1 as summarised in Table 12, which gives the mean annual contributions at the farming zone. It should be noted that within the farming zone, recharge by flood water is a more important contributor to inflows than base inflow. Likewise, the total quantity of groundwater lost from the aquifer through evapotranspiration exceeds the base outflow from the lower end of the aquifer.

Table 12 : Comparison of Inflows and Outflows at the Farming Zone

Inflow (Mm^3 /annum)		*Outflow (Mm^3 /annum)*	
Base Inflow	1,25±0,13	Base Outflow	1,25 ±0,13
Recharge (floods)	1,75 ±0,42	Evapotranspiration	1,54±0,29
		Others	0,21

9.4 Flood Hydrology

Comparison of the results of case 2 with the results of case 1 reveals a reduction of on average 16 ±12,7 Mm^3/annum as a result of the construction of Von Bach and

Swakoppoort Dams. This corresponds to a 37% reduction in flood volumes. This reduction is illustrated on the trend diagram shown as Figure 20.

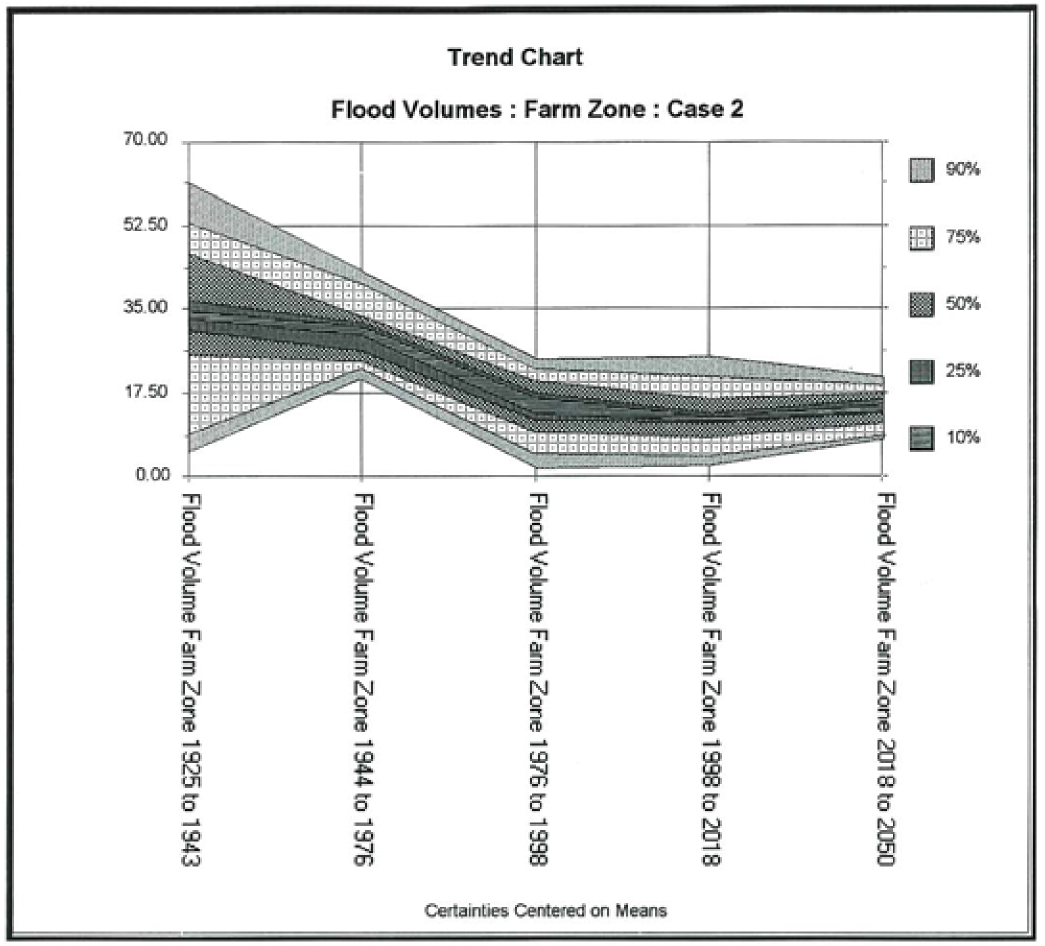

Figure 19 : Trend Diagram : Flood Volumes

Comparison of the results of case 2 with case 3 predicts a reduction in the mean seasonal flood volume of 0,30 ± 0,38 Mm^3 . This represents a 2,3% reduction in the mean seasonal flood volume from the current value which is attributable to KARS.

9.5 Sediment Load

The results of the simulations for sediment loads are summarised in Table 13 below.

Table 13: Sediment Load Simulation Results

Mean ±Standard Deviation	*Sediment Load (Swakop Delta)*	*Proportion of Sediment from Khan River*
Case 1	1,79±0,56	17,11±7,4%

Case 2	1,09±0,30	25,7±9,9%
Case 3	1,01±0,30	23,7±9,6%

Comparison of the results of case 2 with case 1 reveals that Swakoppoort and Von Bach dams are likely to have resulted in a reduction in the sediment load of 0,7 Mm^3/annum on average. This corresponds to a 39,1% reduction in the total sediment volume. KARS is expected to cause a further reduction of 4,5% over the life of the scheme.

The results of case 3 show that development of KARS is likely to increase the silt size fraction of the sediment downstream of the Khan Dam. The silt content of the sediment in the Swakop River is however not expected to increase by more than 6% measured at the Swakop delta. On closure of the Khan dam, the silt content is expected to revert to approximately the pre- Khan dam level.

9.6 Water Table Depths in the Farming Zone

Observations of boreholes levels in the farming zone of the Swakop River have revealed a drop in the level of the water table from 1970 to the present of approximately 3,0m. The model predicts a drop in the average level of the water table in the farming zone of 2,81 m over the same period. Since the Von Bach and Swakoppoort dams were constructed during this period, the drop could be ascribed to the development of these dams. However, the results of case 1 predict that even without the development of these dams, a drop in the water table of approximately 2,56± 0,51m would probably have been observed. This drop is ascribed to the relatively dry period between 1976 and 1985 compared to the previous wetter period between 1944 and 1976.

In order to check this conclusion, the simulation was repeated but the starting date for the synthetic flood record was chosen at random from 1925 onwards. This analysis removes any bias in the results which might have been caused by climatic variations over the period of concern. The results for case 1 revealed that as might be expected, there is no significant change in the depth to the water table for case 1 over the same periods.

Case 2 showed a drop of 0,76±1,49m after construction of Von Bach and Swakoppoort Dams. It is therefore reasoned that 0,76±1,49 m of the observed drop in the level of the water table may be attributed to Von Bach and Swakoppoort Dams and the remainder to climatic factors.

The results of case 3 predicted a further drop in the mean depth to the water table of 0,10 to 0,4 m. This prediction was obtained using a randomly generated start point for the synthetic flood record thus eliminating any bias due to climatic factors. The significance of this change on borehole users in the farming zone falls outside the scope of this investigation but needs to be evaluated.

The average percentage fullness of the aquifer over different reaches is summarised in Table 14 for each case.

Table 14: Effect of Developments on Aquifer Fullness

	Case 1	***Case 2***	***Case 3***
	Khan River		
Ameib - Usakos	94,9	94,6	94,8
Usakos - Khan Dam	81,4	81,2	81,3
Khan Dam - Mine Front	77,4	77,0	***35,4***
Mine Front - Confluence	79,0	78,8	***62,1***
	Swakop River		
Swakoppoort - Dorstrivier	75,7	***45,4***	***45,8***
Dorstrivier - Confluence	81,9	***74,5***	***74,3***
Confluence - Farm Zone	75,7	***71,8***	***70,2***
Farm Zone	52,8	***43,5***	***42,2***

9.7 Water Quality

9.7.1 Dilution Effect of the Khan River

The model predicts that the Khan alluvial aquifer provides some dilution capacity to the water in the aquifer downstream of the confluence. The predicted TDS in the aquifers upstream of the confluence are summarised below

Table 15 : Comparison of Case 2 and Case 3 TDS Predictions at the

	Case 2	*Case 3*
Khan Aquifer TDS	1619 ± 273	1541 ± 291
Swakop Aquifer TDS (midway between Dorstrivier and confluence)	3587 ± 1224	
Swakop aquifer - after confluence	2114 ± 323	2116 ± 321

9.7.2 Mine Front Aquifer

The model predicts a reduction in the average TDS in the mine front aquifer due to the additional recharge of the aquifer by KARS. The predicted TDS in the mine front aquifer changed from an average of 2 585 ± 103 to 1 604 ± 122 mg/litre for case 2 and case 3 respectively. The reduction in TDS values is ascribed to the increased ratio between recharge and evapotranspiration as a result of the scheme.

9.7.3 Farm Zone

The simulations conducted using actual flood records between 1925 and 1985 and a randomly selected start point thereafter, predicted an increase in the TDS as summarised in Table 16.

Table 16 : Predicted TDS values : With Climatic Bias

Farm Zone TDS	*Case 1*	*Case 2*	*Case 3*
Mean ± St. dev.	6069 ± 1106mg/l	9911 ± 3750 mg/l	11 334 ± 3565 mg/l

The simulation conducted without climatic bias predicted an insignificant difference in the average TDS values in the farm zone but an increase in the variability of the TDS as a result of the implementation of KARS. The simulations conducted without climatic bias indicated an increase in the TDS in the farm zone attributable to KARS of less than 1% from case 2 to case 3. Swakoppoort and Von Bach Dams are believed to have resulted in a significant increase in TDS values in the farm zone of up to 51%.

10. CONCLUSIONS

The following conclusions may be drawn from this study :

- The model developed to date is believed to represent the physical operation of the Khan and Swakop River and alluvial aquifer system with a reasonable degree of reliability. Although idealised cross sections and long sections have been applied to model the river systems, the model provides the most reliable available basis on which to predict trends in the aquifers caused by developments on both river systems. The resolution of the model is however not sufficiently fine to predict absolute changes at specific locations within each reach. The prediction of water qualities is at this stage considered to be less reliable and the model should be used with caution for the prediction of water qualities in the alluvial aquifers.
- The model predicts with a high degree of reliability that the reduction in flood volumes downstream of the confluence, as a direct result of the KARS scheme is of the order of 2 %. This is considered insignificant in terms of the behaviour of the sand dunes and the potential for the sand dunes at Swakopmund to migrate across the river. The model has however shown that the impact of the Von Bach and Swakoppoort Dams is significant and is likely to have resulted in a 37% reduction the mean annual flood volume.
- The reduced flood volume is expected to give rise to a proportional reduction in the total sediment load measured at the farm zone of less than 1% due to KARS, from the current value. This reduction is not considered significant in terms of the role that floods play in replenishing beach sand or re-filling of pits excavated for sand mining.
- The sediment load could become slightly finer with time as the dams upstream of the farm zone tend to pass only the finer silt size fraction of sediment during spill events. The increase in the proportion of the silt size fraction of sediment is unlikely to increase by more than 4% over the current value. This change in sediment composition is not likely to have any significant effect on the behaviour of the aquifer downstream of KARS.

- The observed drop in the level of the water table from that of pre-1970 is considered to be attributable to both the impact of Von Bach and Swakoppoort Dams and reduced flood frequencies experienced over this period, as a result of climatic factors. Von Bach and Swakoppoort dams are believed to be responsible for approximately 1m of the observed 3m drop. The KARS project is likely to result in a further drop of between 0,1 and 0,4 m in the average level. Expressed differently, KARS is expected to reduce the % fullness of the farm zone aquifer from 43,4% to 42,2%. This may be compared with the effect of Swakoppoort and Von Bach Dams which are estimated to have caused a reduction in the average percentage fullness of the farm zone aquifer from 52,8% to 43,5% before and after the dam construction.
- The timing of the effect is expected to be relatively rapid given that the bulk of the inflow to the aquifer reach is through recharge from flood events rather than base flow.
- KARS is likely to give rise to a reduction in the TDS in the mine front aquifer. The variability in the TDS is not likely to change significantly from the current level of variability.
- It is unlikely that KARS will have any significant effect on the TDS of the aquifer water within the farm zone. The effect of climatic change on the TDS values must be taken into consideration as this tends to be more significant than the effect of the dams.
- Based on the model results, the effect of Von Bach and Swakoppoort Dams would be observed shortly after the construction of the dams since the main contributor to inflows to each reach is recharge from flood waters. The reduction in the base flow component as a result of the dams is not a significant factor in determining water levels in the aquifers in the lower Swakop River. Likewise the effect of the proposed KARS scheme will be observable shortly after implementation of the scheme.
- A reduction in the evapotranspiration losses from trees along both the Khan and Swakop Rivers is likely to give rise to a significant increase in the volume of water in the farming zone and an improvement in the groundwater quality. The model indicates that a reduction of 20% of the evaporation losses, which might be achieved by removing exotic species, is expected to give rise to an increase of 1,20m (median value) in the level of the water table in the farming zone, and a reduction of as much as 30% in the TDS value. The extent to which the evapotranspiration losses can be reduced by such a programme needs to be investigated further.

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Metago Environmental Engineers cc