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 cases have been modelled :

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

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

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

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

Each of the model components is described in greater detail in the following section.

7. MODEL DESCRIPTION

7.1 Hydrological Component

7.1.1 Specific Objectives of the Hydrological Model

The specific objectives of the hydrological model are as follows:

- To evaluate the relative contributions of the Swakop and Khan Rivers to the runoff volume, and how these may be expected to change.
- To estimate the losses which occur during each flood event due to infiltration of flood waters into the alluvium.

The seasonal flood volume is also required to estimate salt loads and sediment volumes brought down during flood events.

7.1.2 Method of Approach

Flood Record

The synthetic flood records documented in Appendix C to this report, representing the seasonal flood volumes in the Swakop River for the cases with and without the Swakoppoort and Von Bach Dams, were used to simulate the sequence and magnitude of flows downstream in the Swakop River. The seasonal record from the gauging station at Ameib was used as the basis for the calculation of seasonal flood volumes further downstream in the Khan River. In order to predict the future (post synthetic record) impact of the existing dams and the KARS, the same sequence of floods is used but a random starting point or year, was used as the runoff volume for 1995/6, thus taking cognisance of the periodicity of runoff events.

The approach which makes use of historic synthetic flood records suffers the disadvantage that the actual return period of floods which have taken place over the 75 year record, are not taken into consideration, however, this approach has the advantage that the periodicity of wet and dry cycles are accounted for. The approach is considered adequate for the purpose of quantifying the impact of the proposed KARS.

Climatic Change

Various sources of evidence tend to indicate that at least over the period 1925 to 1996, there has been a general decrease in runoff over the catchment. However, no attempt is made to predict the future climatic change with this model. In order to separate the effect of climatic change from the effect of for example, the construction of Von Bach and Swakoppoort Dams, the model can be run using the same sequence of flood events but using randomly selected start year for the floods. In this way the effect of historic climatic change is eliminated. By comparison of the results of the simulations using historic synthetic record with the randomly selected start point, the impact of climatic change on the on key variables, can be separated or distinguished from that of other developments.

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 infiltration to the alluvial aquifer is estimated from Equation (1). This 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 greater the depth to the phreatic surface, the longer it takes for wetting front to reach the phreatic surface. 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. Equation (1) presents an empirical relationship for the effective vertical permeability of the alluvium as a function of the time (measured from the start of flooding) 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.
- The horizontal permeability of the finer fractions of the alluvium is generally significantly more than the vertical permeability due to the fact that the silt particles comprise largely plate-like mica particles which tend to be deposited with a horizontal orientation during hydraulic deposition.

These factors alone could theoretically result in a vertical permeability in the region of three to four orders of magnitude less than the saturated horizontal permeability measured on a small scale sample at the start of the wetting process. 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 measured on the scale of the river bed, is not likely to 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.

Equation 1 :Effective vertical unit flux

Equation 1

$$q_{effective} = \left.\begin{array}{l} \int_{t=0}^{t=t_{sat}} a.dt + K_{v_{sat}}(t_{infilt} - t_{sat}) \\ = a.t\Big|_{t=0}^{t=t_{sat}} + K_{v_{sat}}(t_{infilt} - t_{sat}) \end{array}\right\} \text{for } t_{infilt} > t_{sat}$$

$$\left.\begin{array}{l} = \int_{t=0}^{t=t_{infilt}} a.t \\ = a.t\Big|_{t=0}^{t=t_{sat}} \end{array}\right\} \text{for } t_{infilt} < t_{sat}$$

Where :

$q_{effective}$	= effective unit infiltration (m^3/m^2)
$K_{v_{sat}}$	= saturated vertical permeability (m/day)
t_{infilt}	= flood duration for which the velocity is greater than v_{crit}
t_{sat}	= the time required for the wetting front to reach the water table
n	= empirical constant determined from the finite element analyses

The time for the wetting front to reach the water table is assumed to be inversely proportional to the depth of the water table as shown in Equation 2. The constants *a* and *b* in Equation 2 have been found by fitting a curve to the results of the transient finite element analyses.

Equation 2: Time to develop saturated conditions as a function of the depth of the water table

$$t_{sat} = a\,e^{bh}$$

Where :

a = an empirical constant determined by fitting a curve to transient finite element analysis results. (estimated to be ~ 1,39 from the results of finite element analyses)

b = as above (estimated to be ~ 0,36 based on the results of finite element analyses)

h = depth to the water table from river bed level (m)

A further factor which is known to affect the infiltration rate is the velocity of flood waters over the alluvium. Crerar et al[12] presented results of infiltration experiments using a flume and found that infiltration became negligible once the water velocity dropped sufficiently to allow the silt size particles to settle. This velocity was found to be approximately 0,34 m/s.

In the model, the floods are assumed to occur as a single flood in each season with a triangular shaped hydrograph as shown in Figure 14. The area under the graph of surface flux versus time is equal to the total seasonal flood volume. For a portion of the hydrograph at the start and end of the flood, the velocity of flow will be below that required to keep the silt in suspension. The duration of the flood over which infiltration is assumed to take place, t_{infilt} is thus calculated from Equation 3.

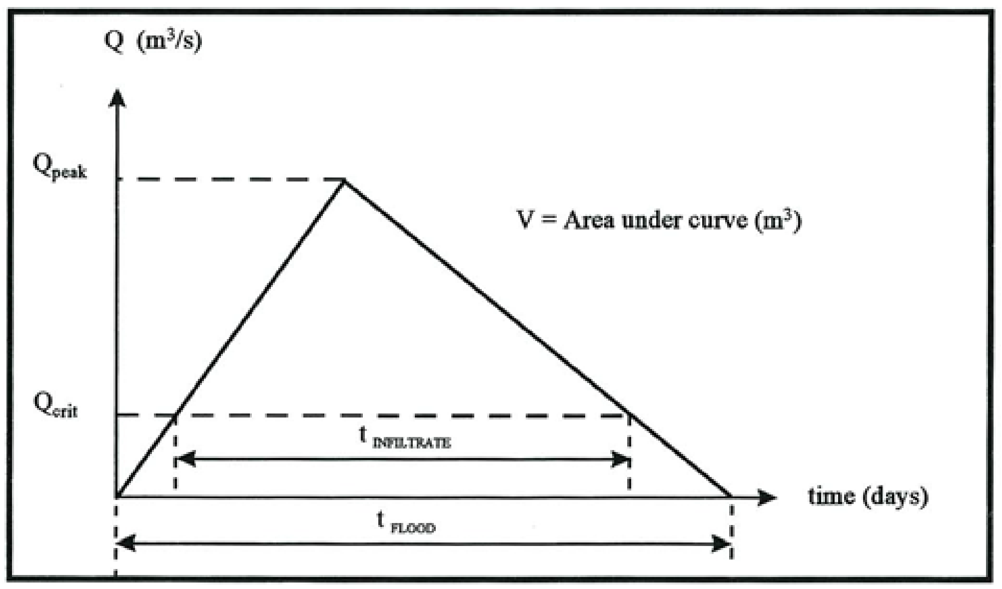

Figure 14 : Simplified Hydrograph Assumed in the Model

[12] *Crerar et al, 1986. "An unexpected factor affecting recharge from ephemeral River Flows in SWA / Namibia"*

Equation 3

$$t_{infilt} = t_{flood}\,\frac{\left[2.Q/t_{flood} - v_{min}.B.\dfrac{(v_{min}.n.)^{3/2}}{i^{3/4}}\right]}{2.Q/t_{flood}}$$

Where :

t_{flood} = Seasonal flood time which is assigned a probability distribution and positively correlated to seasonal flood volume (days)

B = Average breadth of the river channel (m)

v_{min} = Minimum stream velocity to just maintain the silt load in suspension (m/s)

i = Hydraulic gradient (m/m)

The seasonal flood records for the Swakop River do not give an indication of the duration of the flood events. Since the infiltration is a function of the duration of the flood event it is necessary to make certain assumptions regarding the flood duration. Flood duration's are reported for the Ameib gauging station between 1967/8 and 1993/4. For the purpose of this model, the flood duration has been assumed to be correlated to the seasonal flood volume. Probability distributions have been assigned to the flood duration based on the historical records at Ameib since this is the only gauging station with this information. The mean, standard deviation, maximum and minimum flood duration's, have been calculated from the Ameib record for several categories of flood sizes. A beta distribution has then been assigned to each flood size category. Given the lack of flood duration-flood volume data available for the Swakop River, the same distributions were applied to the Swakop River.

In addition to the above factors, the width of the flooded area and depth of flow influence the rate of infiltration. Although the Ameib gauging station records the peak depth of flow, no reliable data is available for the Swakop River. The depth of flow is generally between 0,05 for small floods increasing to 3 m for large floods.

The breadth of flow is expected to be correlated to the size of the flood up to the point where the flood size is large enough to cover the entire channel width. For the purpose of this simplified model, the breadth of the channel was assumed to be a constant proportion of the channel width for each reach.

7.2 Alluvial Aquifer Component

7.2.1 Specific Objectives of the Hydrogeological 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 groundwater flow from the Khan and Swakop Rivers downstream of the confluence of the Khan and Swakop Rivers.
- 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 groundwater flux downstream of these points, but the effect might only be felt decades after the abstraction event. The construction of the proposed aquifer barriers in the vicinity of Rössing Mine could reduce the median or average groundwater flux downstream of the barrier thus eventually affecting the groundwater level downstream of the confluence. This effect might or might not coincide with the effect of the construction of Swakoppoort Dam or the effect of groundwater abstractions at Otjimbingwe.

7.2.2 Method of Approach

The hydrogeological component solves the continuity equation given as Equation 4 for each reach after each season.

Equation 4 : Continuity Equation

$$\Delta S = \sum inflow - \sum outflow$$

Inflows to the aquifer are considered to be as follows :

- Groundwater flow into the reach from the top end of the reach.

- Groundwater inflows from tributary alluvial aquifers along the reach.
- Recharge from the surface of the alluvium during flood events.

Losses or outflows from the aquifer reach are assumed to comprise :

- Groundwater flow out of the reach at the downstream end of the reach.
- Evapotranspiration from plants growing within the gorge.
- Borehole abstractions.
- Evaporation from man made trenches and sand pits where these have been excavated down to the water table.
- Evaporation/ evapotranspiration from areas where the groundwater is forced to the surface as a result of natural barriers.
- Evaporation from wet sand near the surface of the alluvium after flood events.

The approach to modelling each of the above aspects is discussed in further detail below :

Groundwater base flow

The inflow to each reach is calculated from the outflow from the upstream reach. The outflow from each reach is calculated as shown in Equation 5 using the notation shown in Figure 14 :

Equation 5 : Base Outflow from the Aquifer Reach

$$Outflow = \overbrace{\phi_{i,t}}^{AquiferOutflow} = K_{Hsat}.365.\frac{1}{2}.B.\frac{(D-h)^2}{D}.i$$

Where :

K_{Hsat}	=	Saturated horizontal permeability of the alluvium (m/day)
B	=	Average breadth of the river bed (m)
D	=	Average maximum depth of alluvium (m)
h	=	Depth to the phreatic surface from the river bed (m)
i	=	Hydraulic gradient

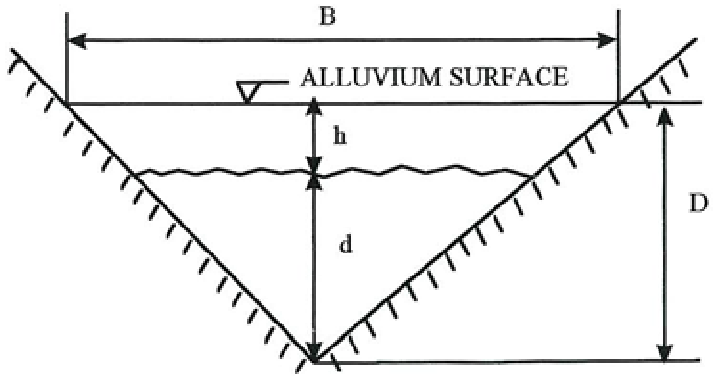

Figure 15: Illustration of Parameters for Outflow Equation

Volume of Water Stored in the Aquifer

The volume of water contained in the aquifer reach is calculated from Equation 6 for each reach, which is derived from consideration of the assumed section geometry and D'Arcy's law for flow in soils.

Equation 6 : Aquifer Storage Volume

$$Storage = \chi_{i,t} = S.L.\frac{1}{2}.B.(D-h)^2\frac{(D-h)^2}{D}$$

Where :

S = Storativity of the alluvium

The percentage fullness of the aquifer reach may be estimated from Equation 7.

Equation 7: Aquifer Fullness

$$\%\ Full = \frac{(D-d)^2}{D^2}$$

The general depth to the water table is calculated from Equation 8.

Equation 8 : General Depth to the Water Table

$$h = D - \sqrt{\%\ full/100}\ .D$$

Contribution to Groundwater Flow from the Tributaries

The contribution to the groundwater flux in the Swakop River is considered to be significant upstream of Dorstrivier. There is however no information available regarding contribution from tributaries. For the purpose of this model, the seasonal tributary contribution to the Swakop River has been assumed to be a function of the mean annual runoff over the tributary catchment and the size of the tributary

catchment relative to the size of the catchment upstream of the reach boundary. The relevant equations given as Equation 9.

Equation 9 : Groundwater Tributary Flux

$$Tributary\ Flux = \overbrace{\phi_{i,t}}^{Tributaries} = \sum_{i=1}^{i=n}\frac{A_{Tributaries_i}.MAR_i}{A_{upper\ reaches_i}.MAR_i}.\overbrace{\phi_{i,t}}^{Groundwater\ Inflow}$$

Where :

MAR_i	=	Mean annual runoff
$A_{Tributaries_i}$	=	Catchment area of tributaries within the reach under consideration for the zone between each MAR contour.
$A_{upper\ reaches\ i}$	=	Total catchment area of the upper reach falling within each MAR contour
$\overbrace{\phi_{i,t}}^{Groundwater\ Inflow}$	=	Groundwater inflow at upstream end of reach *i* during year *t* (Mm^3/annum)

Recharge from Floods

The seasonal recharge to the alluvial aquifers is calculated from Equation 10 as the difference between the volume of water infiltrated into the alluvium in a year and the volume of water evaporated from the wet sand just below the surface.

Equation 10 : Groundwater Recharge

$$Recharge = Infiltration - evaporation\ from\ wet\ sand$$

The method of estimation of the infiltration volume was described previously. Should the infiltration volume in a particular year be less than the potential evaporation from the wet sand then the recharge volume for that year is assumed to be zero.

Evaporation and evapotranspiration losses

The approach to modelling the evapotranspiration loss is based on observations documented by Hellwig (1971)[13]. The model contains a routine to represent water loss from vegetation. Large trees are assumed to transpire at a constant annual rate. Losses due to ephemeral vegetation and evaporation from wet sand after flood

[13] *Hellwig 1971, "The Loss of Water by Evaporation and Evapotranspiration from the Swakop River Bed". Report No. 6321/9901, National Institute for Water Research, CSIR, Windhoek.*

events, is taken into account by allowing a depth of wet sand to dry out each year up to a certain maximum depth.

As the depth to the phreatic surface increases, the evapotranspiration rate may be expected to decrease since fewer trees would have access to groundwater. The evapotranspiration rate from trees is thus modelled as a function of the depth to the water table by the following function shown as Equation 11:

Equation 11: Evapotranspiration loss from trees and shrubs

$$Evapotranspiration = \left[\frac{d}{D}\right]^n R$$

The surface area assigned to each river reach was based on consideration of the proportional length of the reach and the average width of the river bed as measured from the colour air photos.

No account has been taken of the change in the extent of vegetation cover since construction of the major dams on the Swakop River during the 1970's.

The estimate of the evaporation loss from wetlands is calculated using the Hellwig data. The size of the wetlands has been kept constant throughout the analyses as it is not relevant to the incremental impact of KARS.

The evaporation rate from wet sand after a flood event is calculated from Equation 12.

Equation 12

$$\overbrace{\phi_{i,t}}^{wet\ sand} = B.L.n.d_{wet\ sand\ evap}$$

Where :

$\overbrace{\phi_{i,t}}^{wet\ sand}$	=	Total evaporative flux from reach *i* for year *t* from the wet sand
L	=	Length of the Reach measured along the centre line of the gorge
n	=	porosity of the alluvium
$d_{wet\ sand\ evap}$	=	depth to which sand may be dried out below surface due to evapotranspiration from plants with shallow roots and direct evaporation from wet sand

As the sand dries out the evaporation flux decreases. Based on observations of the river bed, it is unlikely that the evaporation rate from wet sand below approximately 0,5 to 1,5 m is significant. The evaporation rate from wet sand of 0,70 X 3 033 mm/annum is considered an upper limit. The model allows a maximum depth of evaporation from the wet sand of between 0,5 and 1,5 m. The maximum depth of evaporation is assigned a uniform distribution between an upper and lower bound limit. Should the depth of infiltration be less than the maximum depth of evaporation in any year, the evaporation volume for that year is set to the infiltration volume.

Borehole Abstractions

For the purpose of projecting the borehole abstraction rates for future years, the average demand for borehole water has been set to the average historical abstraction rate. The model does not allow water to be extracted from boreholes if the general level of water in the aquifer is drawn down below a specified minimum level. The minimum level to which the aquifer can be drawn down may specified as input data. A maximum draw down to a level of 30% of the total depth of the aquifer has generally been assumed.

7.3 Sediment Transport

7.3.1 Specific Objectives of the 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 downstream of the confluence of the Khan and Swakop Rivers over the life of the scheme.
- 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.

7.3.2 Key Assumptions

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

- The sediment load in any flood season is assumed to be directly proportional to the flood volume.
- The high level of uncertainty associated with the proportion of sediment transported by the seasonal flood volume is taken into account by assuming that the seasonal sediment proportion is a random variable. The proportion of silt transported by each seasonal flood volume is randomly selected for each year of the simulation. The model does not correlate the sediment fraction with the seasonal flood volume.
- Only the silt size fraction is assumed to pass over the Swakoppoort and Khan dam spillways.
- The availability of sediment in the channel downstream of KARS is assumed to be large in comparison with the capacity of the river to transport sediment over the life of the dam.
- Since it is assumed that only silt is able to pass over the dam spillways, the dams tend to result in an increase in the proportion of the silt size 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 therefore 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.

7.3.3 Method of Approach

A uniform probability distribution has been applied to sediment load. The total sediment load leaving each reach is calculated from Equation 13 at the end of each flood season :

Equation 13 : Seasonal Sediment Volume

$$\text{Sediment Volume} = v_{sediment} = V_{i,t}.\Theta_{sediment} \quad (Mm^3)$$

where :

$V_{i,t}$ = Seasonal flood volume predicted at the reach *i*

$\Theta_{sediment}$ = Probabilistic volumetric sediment content of the flood waters (m^3 sediment / m^3 flood)

A uniform distribution is assumed for the proportion of silt in the sediment. The suspended volume of silt passing any point in a river reach is calculated from Equation 14.

Equation 14 : Seasonal Sediment Volume

$$\text{Silt Volume} = v_{silt} = V_{i,t}.\Theta_{sediment}\,\Theta_{silt} \quad Mm^3$$

where :

Θ_{silt} = Probabilistic volumetric sediment content of the flood waters (m^3 sediment / m^3 flood)

The coarse fraction of sediment is assumed to settle out in the Khan dam until such time as the dam is completely silted up. The capacity of the dam is recalculated on an annual basis and reduced by the volume of sediment entering the dam. The reduction in the capacity of the Khan dam is calculated as follows:

Equation 15 : Loss of Storage Capacity Due to Siltation

$$\Delta V_{dam} = \frac{V_{i,t}.\Theta_{sediment}}{1+e}$$

Where :

e = assumed void ratio of the alluvium

The volume of silt passing the spillway is calculated for each season from Equation 16.

Equation 16 : Seasonal Silt Volume Passing the Spillway

$$v_{silt} = \frac{V_{spill}}{V_{inf\,low}}.\Theta_{sediment}.\Theta_{silt}$$

Where :

V_{spill} = Volume of water passing over the dam spillway in a season

V_{inflow} = Volume of water entering a dam in a season

The total sediment load just upstream of the confluence is calculated in the same manner as before, thus

Equation 17 : Seasonal Sediment Volume at the Confluence

$$\text{Sediment Volume} = v_{sediment} = V_{confluence} \cdot \theta_{sediment} \qquad (Mm^3)$$

Where :

$V_{confluence}$ = Seasonal flood volume predicted at the confluence

$\theta_{sediment}$ = Volumetric sediment content of the flood waters

The volume of suspended silt in the sediment is calculated from Equation 18

Equation 18 : Seasonal Silt Volume at the Confluence

$$\text{Silt Volume} = v_{silt} = \theta_{sediment} \cdot \theta_{silt} \frac{V_{spill}}{V_{dam}} \qquad (Mm^3)$$

Where :

V_{spill} = Portion of the seasonal flood volume which is spilled

V_{dam} = Seasonal flood volume arriving at the dam site

θ_{silt} = Volumetric sediment content of the flood waters

The sediment load at the confluence is calculated as the sum of the seasonal sediment load from each river.

7.4 Aquifer Water Quality

7.4.1 Objective of the water quality Component

The objective of the water quality model is to assess the impact of the proposed KARS scheme on the general aquifer water quality (in terms of TDS) in the reaches downstream of the Khan Dam.

7.4.2 Assumptions

Complete mixing of water is assumed to take place within each reach and within each season. The model thus represents an average water quality in each reach. In reality, water quality measurements might differ significantly from the modelled values

due to kinematic effects, the presence of fresh and salt water lenses, channelling and differences in the densities of fresh and salty waters. The prediction of effect of KARS on the water quality in individual boreholes is clearly beyond the scope of this model. However, the results of the model can be used to infer an improvement or degradation in the water quality in certain reaches and groups of boreholes.

7.4.3 Method of Approach

The TDS in each aquifer reach is calculated using a salt balance or mass flux equation shown as Equation 19.

In this expression, the mean TDS over the aquifer reach is calculated for each year of simulation by taking cognisance of the following factors:

- The quality and quantity of flood waters which contribute to recharge.
- The quality and quantity of groundwater entering the reach at the upstream end of the aquifer.
- The quality and quantity of groundwater entering the reach from the tributaries.
- The water losses from the aquifer which increase the TDS of the groundwater including :
  - ◊ evapotranspiration and evaporation from the moist sand in the upper zone of alluvium after flood events and tend to concentrate the salts in the upper zone of sand;
  - ◊ evapotranspiration from trees which abstract water from the groundwater;
  - ◊ evaporation losses from wetlands, and
  - ◊ evaporation from sand mining pits and open trenches.
- Additional salt loads associated with effluent discharges from industrial, farming and mining operations may also be included in the model.

Equation 19 : Average Seasonal Aquifer TDS

$$[C_{i,t+1}] = \frac{\left[C_{i,t} \cdot \chi_{i,t} + \overbrace{\Phi_{i,t} \cdot C_{i,t}}^{Inflow} + \overbrace{\Phi_{i,t} \cdot C_{i,t}}^{Infiltration} + \overbrace{\Phi_{i,t} \cdot C_{i,t}}^{Tributary\ Aquifers} - \sum \overbrace{\Phi_{i,t} \cdot C_{i,t}}^{Borehole\ Abstractions} - \overbrace{\Phi_{i,t-1} \cdot C_{i,t-1}}^{Aquifer\ Outflow} + \sum \overbrace{\Phi_{i,t-1} \cdot C_{i,t-1}}^{Effluents} \right]}{\left[\chi_{i,t} + \overbrace{\Phi_{i,t}}^{Inflow} + \overbrace{\Phi_{i,t}}^{Infiltration} + \overbrace{\Phi_{i,t}}^{Tributary\ Aquifers} - \overbrace{\Phi_{i,t}}^{Borehole\ Abstractions} - \overbrace{\Phi_{i,t-1}}^{Aquifer\ Outflow} - \sum \overbrace{\Phi_{i,t}}^{Evapotranspiration} - \sum \overbrace{\Phi_{i,t}}^{Evaporation} - \sum \overbrace{\Phi_{i,t}}^{effluent} \right]}$$

where :

$\phi_{i,t}$ = Water flux for reach *i* over the year *t*.

$C_{i,t}$ = Average TDS of the respective component for reach *i* and year *t*.

$\chi_{i,t}$ = Volume of water stored in the aquifer reach *i* at the start of the year *t*.

The parameter values assigned to the water flux in the above expression are discussed in the previous sections. Data regarding the concentrations of many of the above input parameters required in Equation 19 is very limited and requires that subjective estimates of these values be made. To account for the uncertainty and natural variability associated with each of the input parameters, probability distributions have been assigned to concentrations based on the little data that is available and a subjective assessment of the likely range of TDS values for each parameter.

8. MODEL CALIBRATION

Verification of the model involves ensuring that the following questions are adequately addressed :

1. Does the conceptual model include all the physical processes which significantly affect the results ?
2. Do the mathematical equations and conditions in the model adequately represent our understanding of the physical processes simulated ?
3. Are the mathematical equations correctly programmed ?
4. Is the degree of uncertainty or natural variability adequately taken into consideration in the model ?
5. How well do monitoring results compare with the model predictions ?

Question 5 above represents the acid -test for the model. However, in the absence of adequate monitoring data, verification is of necessity limited to the evaluation of the questions 1 to 4 above. This is particularly true of the geohydrological, water quality and sediment load models. The historical flood record data provided by Stengel's record at Swakopmund (albeit of limited accuracy) provides the only long term data for verification and calibration of the model against historical records. The extent to which each section of the model has been verified is thus largely dependent on the availability of suitable monitoring data.

Verification of the model is further complicated by the extent to which each sub-model is dependent on the other sub-models. The extent of interdependency is illustrated in Table 9 which demonstrates how particular results are dependent on each sub-model.

Table 9 : Relative Importance of Calibration and Verification of each Sub-Model

	Swakop- Khan Sub -models			
Dependency of result on Sub-model	***Hydrological Model***	***Geohydrological Model***	***Sediment Load Model***	***Water Quality Model***
Flood Volume Predictions for each Reach	very high	high	low	none
Depth to the Water Table	high	very high	none	none
TDS of groundwater in each reach	high	very high	none	very high
TDS of flood waters	very high	high	none	very high
Sediment load passing reach boundaries /annum	very high	high	very high	none
Proportion of silt in sediment	very high	none	very high	none
Relative importance of verification and calibration of each sub-model	***Most Important***	***Important***	***Least Significant***	***Less Significant***

From Table 9 it is clear that the hydrological and geohydrological models influence most of the results, while the sediment load and water quality sub-models affect only certain results. Thus, verification and correct calibration of the hydrological and geohydrological models is most important, and verification and calibration of the water quality model and sediment load model is of secondary importance.

The data required by the model for calibration was derived from various sources including previous reports and investigations, air photos and topographical maps. Where there is uncertainty regarding parameter values, the uncertainty and variability in the parameter value was taken into account by assigning a distribution to the parameter value. The choice of distribution type and values was based on our understanding of the natural variability of the system and the uncertainty associated with the parameter values.

The simulation was conducted over the period for which data is available, namely 1925 to 1995 in order to validate the model. Flood hydrology data, water table depth records and aquifer and flood water TDS records were used to assess the validity of the model.

A summary of the parameter values applied in the model is given in Appendix D. Table 10 presents a list of data required by the model and summarises the manner in which the data was acquired. The level of confidence associated with each parameter value is also indicated in qualitative terms as good, fair or poor.

Table 10 : Model 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*
Aquifer Characteristics					
Effective Length of reach	m	none	Air Photos 1:50 0000 and 1:250 000 maps	v high	high
Effective Breadth of Reach	m	none	Air Photos	v high	high
Maximum Depth of reach	m	none	CSIR report 1966, Rössing Information, judgment	fair	high
Average hydraulic gradient	m/m	none	Assumed equal to bed gradient- maps	fair	high
Aquifer horizontal permeability	m/day	none	Various Reports	high	high
Aquifer (saturated) vertical permeability	m/day	none	Field investigation	fair	moderate
Exponent constant for T_{sat}	N/A	none	Calibration factor - likely range determined from SEEP/W analyses	poor	moderate
Initial depth to phreatic surface	m	uniform	Judgment	unknown	low
Effective Storativity of reach	N/A	uniform	Various Reports	good	moderate
River Characteristics					
Effective channel width	m	uniform	Factor of the bed width	fair	low
Manning Roughness coefficient	N/A	uniform	Hydraulic References	good	low
Effective channel length	m	none	Factor of the river length	fair	low
Channel Slope	m/m	none	Topographical maps	good	high
Depression Storage Loss	m	uniform	Guess	fair	moderate
Sediment Characteristics					
Proportion of sediment in flood	m^3/m^3	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