sedimentation of the coarse fraction of the sediment within the dams. This affects the recharge, evaporation and the permeability characteristics of alluvial aquifers downstream of the dams.

- A reduction in vegetation density and the extent of wetlands due to reduced aquifer water levels.
- Reduced sediment load and sediment carrying capacity of the Swakop River due to reduced stream power, lower peak flows and volumes.
- A reduction in the aquifer base flow rate caused by constructing the dam foundation on firm bedrock and thereby reducing seepage losses.

- Borehole abstractions along the Khan and Swakop Rivers at places such as Otjimbingwe, Rössing and Usakos reduce the groundwater levels and possibly the aquifer through-flow rate.
- The construction of open trenches by farmers along the lower Swakop River increases the salinity of water as a result of evaporation from the trenches.
- Sand mining operations, particularly where such mining takes place to within a metre of the water table, enhance evaporation of the aquifer water and thereby increase salinity.
- Sand pits in the river channel change the hydraulic properties such as the channel roughness.
- The proliferation of exotic (e.g. *Prosopis* trees) and indigenous (e.g. *Tamarisk*) invasive vegetation in the river beds increases evapotranspiration losses and hence the TDS of the groundwater.
- Climatic change and long-term climatic trends are evident from flood records, regional groundwater levels in various parts of the country and changes in vegetation cover.

4.2.2 Transmission losses along the rivers

It is generally accepted that very little additional flood flows are contributed by local runoff between Ameib and the Khan-Swakop confluence, and between Dorstrivier and the Atlantic Ocean, for the Khan and Swakop rivers, respectively. Obvious exceptions to this generalization occur whenever localized, short-duration thunderstorms fall in the area downstream of Ameib and Dorstrivier.

Flood volumes in the Khan and Swakop Rivers decline as they pass through the Namib Desert due to infiltration of the flood waters into the alluvial aquifers and to evaporation and evapotranspiration. Earlier studies estimated that transmission losses could amount to up to 1 % per kilometre of river bed. However, this simplistic approach is often highly inaccurate since the proportion of each flood which is lost to infiltration along any reach of these rivers is dependent on:

- The volume available for recharge in the alluvial aquifer.
- The saturated permeability of the alluvium which, in turn, is largely a function of the particle size distribution.
- The average permeability of the alluvium which is in turn a function of the degree of saturation of the flood and the time over which the flood takes place. 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.

Very little information is available in the literature regarding the time required to saturate the material in the vadose zone. Based on the limited recharge which took place during the 1997 floods, and the record of this flood's duration and channel width, it was clear that the actual vertical infiltration which took place was significantly less than might have been expected from information on aquifer permeabilities available in the literature. Based on the best available information and field observations, the saturated *vertical* permeability has been assumed to be twenty times less than the saturated *horizontal* permeability.

Based on an evaluation of a combination of simulated run-off and actual data, for the period prior to the completion of the Swakoppoort Dam, for the Swakop River from Dorstrivier downstream to Swakopmund, a loss factor of 0.1 Mm^3/kilometre was taken to be representative for the purposes of this study.

4.2.3 River gradients

Gradients over different sections in the Swakop and Khan Rivers have been estimated from 1:50,000 topographical maps and are shown in **Table 4.1**. The Swakop River has a very constant, slightly convex gradient over long sections; the average slope being 1:270. The mean gradient of 1:182 for the Khan River is regarded as steep (DWA, 1988) and suggests that, with all other factors being equal, a particular flood in the Khan River would travel downstream at a slightly faster rate, (and possibly also with smaller transmission losses), than an equivalent sized flood in the Swakop River.

Table 4.1: Average gradients for different sections of the Khan and Swakop rivers (data drawn from 1:50,000 topographical maps).

Swakop River section	Gradient	Khan River section	Gradient
Okahandja - Sneyrivier	1:388	Ameib - Usakos	1:216
Sneyrivier - Dorstrivier	1:273	Usakos - Rössing	1:157
Dorstrivier - Dolerite Hill	1:243	Rössing - Confluence	1:170
Dolerite Hill to Coast	1:222	-	-

4.2.4 *Sediment transport*

Very little information is available on the sediment load of the Swakop and Khan Rivers. A Department of Water Affairs report (DWA, 1988), quotes variations in silt load between 2 % and 22.8 % per unit volume of water. The high silt load is due to the high carrying capacity of the river resulting from the relatively steep slope.

Three samples collected during the January 1997 Khan River flood at Rössing indicated an average silt content of 14 %, whereas the next flood in February 1997 showed values of between 4 % and 6.5 % (Kehrberg, 1997). It is a well-established fact that, during flood events following shortly on each other, the silt load of the second event is less than that of the first flood.

4.2.5 *The impact of existing dams on the Swakop River*

In order to evaluate the magnitude and timing of any impacts caused by the Von Bach and Swakoppoort dams on flows in the lower Swakop River, a synthetic data record was compiled. The record spans the period 1925 to 1993 and was compiled from the DWA record developed by Mian (1925-1984), actual spillway records from Von Bach Dam (1970-1984) and Swakoppoort Dam (1977-1984), and synthetic records (1985-1993) compiled for the Central Area Water Master Plan (CAWMP). These data were used to construct a synthetic record, with and without the Swakoppoort and Von Bach dams, for the period covered by the historical records.

The synthetic annual flood volume records for the Swakop River have been prepared for two locations, namely immediately downstream of Swakoppoort Dam and at Dorstrivier. In each case, two scenarios were used:

- No dams present on the Swakop River, (i.e. natural conditions), and
- Both dams in existence since the start of the record in 1925.

The synthetic records for each scenario are listed in **Appendix 1** of this Report. These records assume that the annual flood volume at Swakoppoort would have equalled the annual inflow volume had the dam not been built.

The combined hydrological and geohydrological model developed by Metago Environmental Engineers was used to evaluate the impact of existing dams on flows in the Swakop River. Full details of the model structure, the data sources used and the modelling outputs generated are contained in **Appendix 1** of this Report.

In the modelling exercise, a time period of one year was also considered suitable for a model of this nature. However, this eliminates the possibility of predicting the size and duration of individual flood events. Instead, the total volume of all floods is simulated each year.

The overall effect of the Von Bach and Swakoppoort dams on the annual flood volumes immediately downstream of Swakoppoort Dam and at Dorstrivier are shown in **Figures 4.1 and 4.2**, respectively. Each diagram shows the annual flood volumes between 1925 and 1993, with and without the Von Bach and Swakoppoort dams.

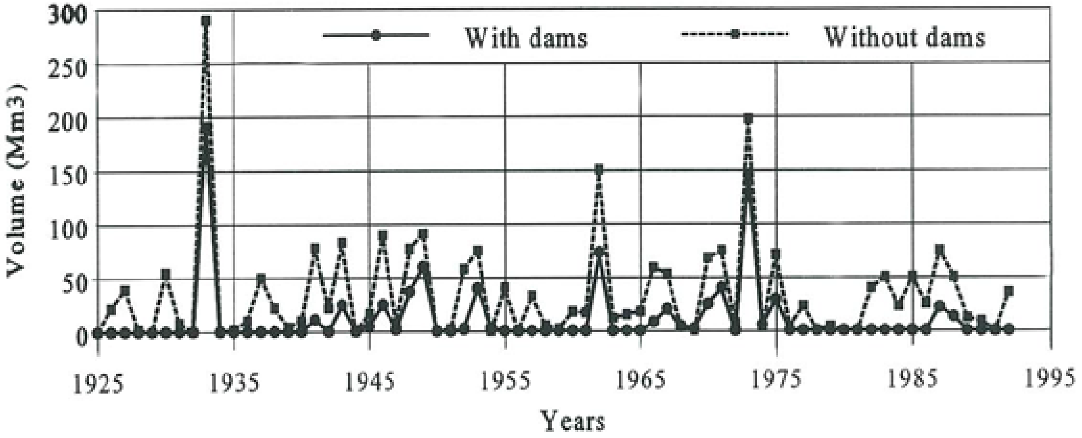


Figure 4.1: Comparison of synthetic flood volumes (Mm^3/year) for the Swakop River at Swakoppoort, with and without the Von Bach and Swakoppoort dams.

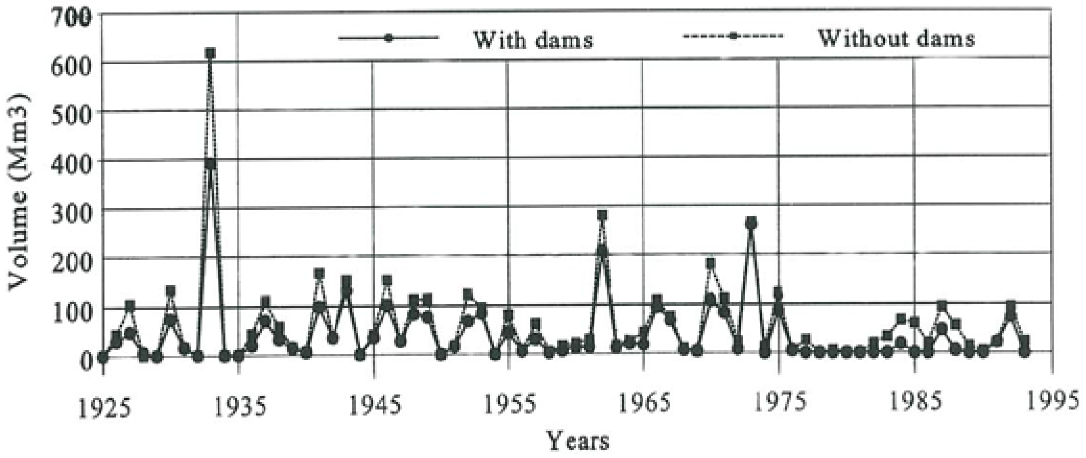


Figure 4.2: Comparison of synthetic flood volumes (Mm^3/year) for the Swakop River at Dorstrivier, with and without the Von Bach and Swakoppoort dams.

The available records for Swakoppoort Dam indicate that this dam has only spilled twice since it was built in 1976/1977, namely during the 1987/1988 and 1988/1989 summer seasons. Averaging out the inflow and spill volumes since 1977, the average annual inflow to Swakoppoort Dam has been 13.09 Mm^3/year whilst the average loss via the spillway amounted to 2.07 Mm^3/year during the same period.

The effect of the two dams on annual flood volumes and relative sizes of floods is shown in **Table 4.2.**

Table 4.2: Comparison of synthetic annual flows at Swakoppoort and at Dorstrivier on the Swakop River, with and without the Von Bach and Swakoppoort Dams.

Parameter	With Dams	Without Dams	% Reduction
Immediately downstream of Swakoppoort Dam site			
Mean	10.7	33.3	67.9 %
Median	0	15.2	100.0 %
Coeff. of Var.	31.0	56.1	44.7 %
Minimum	0	0	0.0 %
Maximum	198.2	431.4	54.1 %
Dorstrivier			
Mean	37.0	60.8	39.1 %
Median	11.1	30.1	63.1 %
Coeff. of Var.	65.0	89.7	27.5 %
Minimum	0	0	0.0 %
Maximum	387	620.8	37.7 %

The effect of the two dams on the frequency of flood events at Swakoppoort and Dorstrivier in the Swakop River was examined by compiling histograms for the frequency of flood events within selected size classes of flood. Once again, the synthetic data records with and without dams were used for this exercise. The results for Swakoppoort and Dorstrivier are shown in **Figures 4.3 and 4.4**, respectively.

From **Figure 4.3**, it can be seen that the dams have a marked effect on the frequency of flood downstream of Swakoppoort; almost none of the inflows in the flood size range of 1 to 10 Mm^3/year have resulted in spills from the Swakoppoort Dam.

Similarly, from **Figure 4.4**, it can be seen that the dams have greatly increased the frequency of "zero flow" events and small floods at Dorstrivier, whilst reducing the frequency of larger flood volumes. These synthetic data support the limited available information and observations that the Von Bach and Swakoppoort dams have reduced both the size and the frequency of floods in the lower Swakop River.

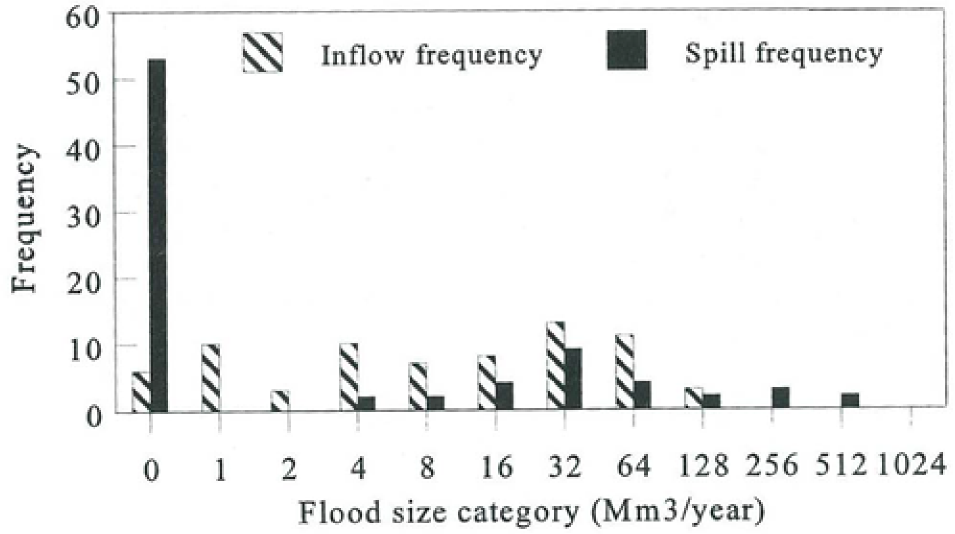


Figure 4.3: The effect of Von Bach and Swakoppoort dams on the frequency on inflows and "spills" at Swakoppoort, for a range of flood size classes.

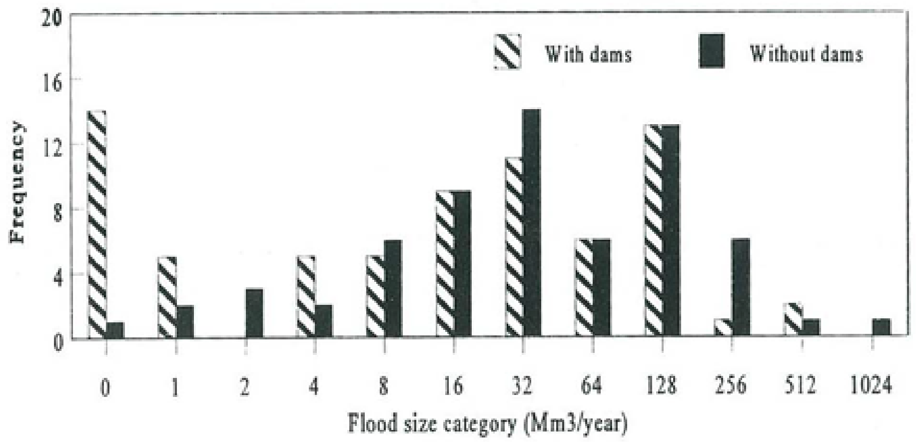


Figure 4.4: The effect of Von Bach and Swakoppoort dams on the frequency of floods at Dorstrivier, for a range of flood size classes.

4.2.6 *Relative contribution of the Khan and Swakop rivers to flood volumes in the lower Swakop River*

Given the obvious effects that the Von Bach and Swakoppoort dams have had on the frequency and size of floods in the lower Swakop River, it becomes important to evaluate the relative contribution of flood flows from the Khan River to flows in the lower Swakop River.

This was achieved by combining the synthetic flood records for Ameib on the Khan River and Dorstrivier on the Swakop River, and calculating the percentage contribution from the Khan River to the sum of the two flows. The resulting frequency histogram which compares the percentage contribution of the Khan River, with and without the Von Bach and Swakoppoort dams, is shown in **Figure 4.5**. It is clear that the significance of the contribution by Khan River flood flows must have increased since the construction of the Von Bach and Swakoppoort dams. Overall, the annual flood volume in the Khan River contributes approximately 20 % of the combined flood volume in the lower Swakop River.

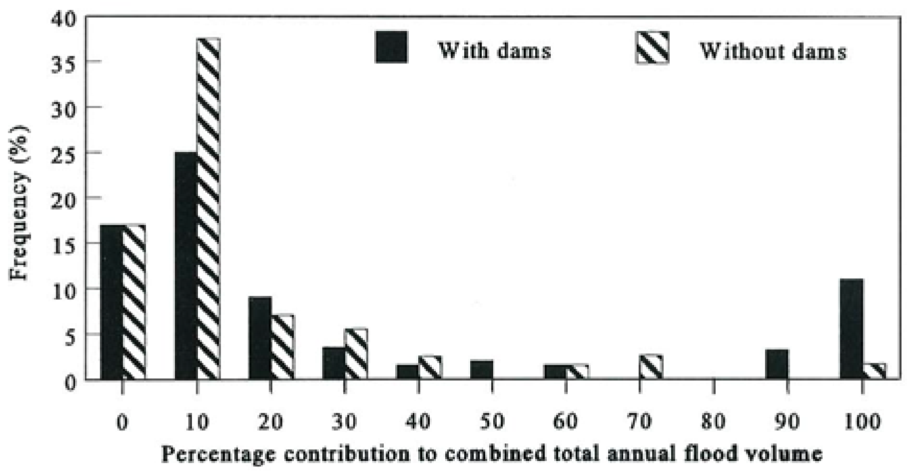


Figure 4.5: Comparison of the percentage contribution of Khan River flood flows to combined flows in the lower Swakop River, with and without the Von Bach and Swakoppoort dams in place.

Figure 4.5 also indicates that the number of times that the Khan River contributes between 90 % and 100 % of the combined flow in the lower Swakop River has increased by a factor of approximately ten. In addition, the number of times that the Khan River contributes only a small percentage (less than 10 %) to the combined flow in the lower Swakop River has decreased. Overall, therefore, the contribution of flood flows in the Khan River to combined flows in the lower Swakop River has increased in both size and importance.

These features can also be seen in **Figures 4.6 and 4.7**, which compare the combined flows from Ameib and Dorstrivier for the period 1925 to 1993, with and without dams, respectively. The importance of flood flows contributed by the Khan River to the combined flood flows in the lower Swakop River increased dramatically from 1977 when the Swakoppoort Dam was completed.

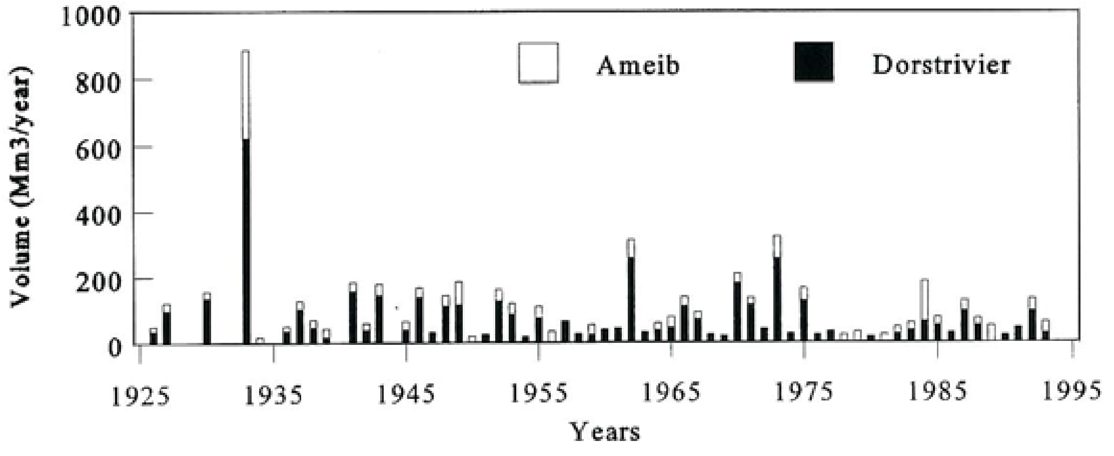


Figure 4.6: A comparison of the combined synthetic flows at Ameib and Dorstrivier for the period 1925 to 1993, without the Von Bach and Swakoppoort dams.

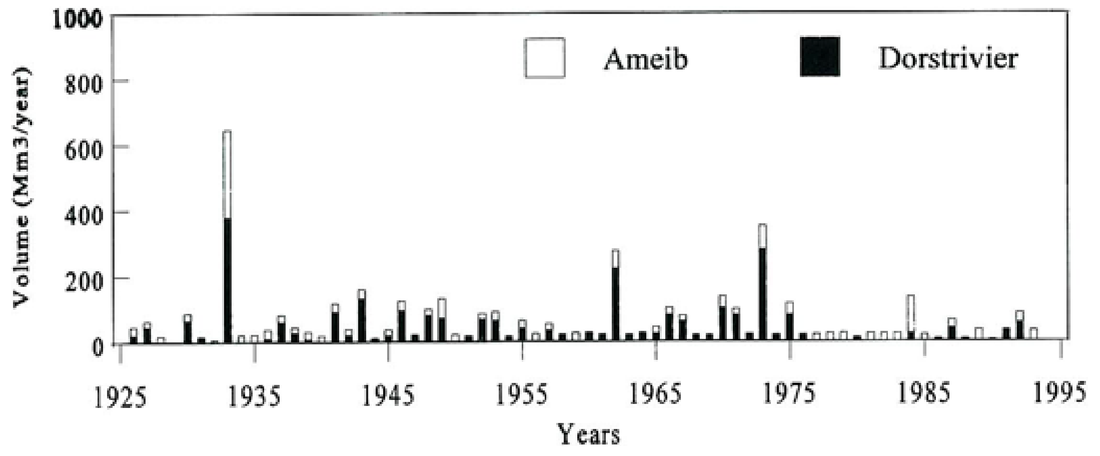


Figure 4.7: A comparison of the combined synthetic flows at Ameib and Dorstrivier for the period 1925 to 1993, with the Von Bach and Swakoppoort dams in place.

Table 4.3 summarizes statistics derived from the synthetic flood records at Ameib and Dorstrivier and highlights the relative contribution of the Khan and Swakop rivers, respectively. This table illustrates that the presence of the dams has increased the size and the significance of the flood flows contributed by the Khan River.

Table 4.3: Comparison of the statistical characteristics of flood flows in the Khan River at Ameib with flood flows in the Swakop River at Dorstrivier, with and without the Von Bach and Swakoppoort dams.

Parameter	Khan River at Ameib (Mm^3/year)	Without Dams		With Dams	
		Swakop River at Dorstrivier (Mm^3/year)	Khan contribution to combined flow (%)	Swakop River at Dorstrivier (Mm^3/year)	Khan contribution to combined flow (%)
Mean	9.1	60.8	13.0 %	37.0	19.7 %
Median	1.25	30.07	4.0 %	11.0	10.2 %
Std Dev.	32.0	89.7	-	65.0	-
Minimum	0	0	-	0.0	-
Maximum	247.73	620.76	28.5 %	387.6	39.0 %

4.3 Geohydrology of the alluvial aquifers of the Khan and Swakop rivers

4.3.1 General description of the aquifers

Like most of the alluvial aquifers along the Namibian coast, the aquifers of the Swakop and Khan rivers have been well studied. The most extensive study was conducted by the CSIR on the Swakop River (NIWR, 1966). This was followed by numerous reports and publications emanating from investigations by Rössing Uranium Limited (RUL), the CSIR and the Department of Water Affairs of the then South West African Administration (Hellwig, 1971; 1973a; 1973b; 1973c; 1973d; 1974; 1978; 1979; NIWR, 1970; RUL, 1976; 1989; 1990; DWA 1976a; 1976b; 1976c; 1978; 1979; 1988).

Despite the fact that most of these studies were carried out prior to construction of the Von Bach and Swakoppoort dams, they do provide essential information on the characteristics of the two aquifers. Those characteristics which are relevant to the KARS project can be summarized as follows:

- Both aquifers occur in alluvium at the base of deeply incised river valleys and gorges. In places, the alluvium attains a thickness of up to 30 metres, consisting of unconsolidated material with grain sizes varying from silt to course fragments of a few millimetres in diameter. The varying composition of the aquifer material has a significant effect on hydraulic parameters.

- The alluvial aquifers are recharged during flood events. The amount of recharge depends on several factors including flood size, flood frequency, silt load, and surface condition of the river bed.

- Impermeable geological structures cut across the river valleys in several places. This causes a water level rise and results in decanting or spring conditions, leading to the formation of wetlands. High evaporation and evapotranspiration rates are associated with these wetlands, resulting in an accumulation of salts and declining water quality.

- Fine sediments and dissolved salts accumulate in the alluvium; the primary mechanism responsible for increasing salt concentrations is evaporation.

- Leaching of accumulated salt from the alluvium is responsible for mineralisation of both flood water and ground water.

- In cross section, the profile of the river channel can vary from a dual channel, (often the case in the Swakop River), a "box" profile, a V-profile or combinations thereof. The shape of the channel often affects the ground water quality and in the case of the dual channel it often restricts the mixing of ground water in the alluvium.

- The total dissolved salt (TDS) concentration of flood water in the Swakop River is inversely proportional to the distance from the coast (**Figure 4.8**). At the coast it reaches a value of approximately 14,000 mg/ℓ. This is regarded as a normal consequence of the evaporative concentration of a water table aquifer under arid conditions.

- Despite the general observation that the surface water from those tributaries which contribute to the total flow in the Swakop River is notably more mineralised than that of the Swakop River at the confluence, these inflows are too small to have a significant adverse impact on the water quality of the Swakop River. A similar situation is expected for the Khan tributaries, although this has not been studied in detail.

- Although the salt-rich Tertiary age sediments can contribute significantly to the salt load of these aquifers, the largest single factor contributing to the salt load remains those areas where the ground water level is less than one metre below surface and large scale evaporation occurs.

- Large variations in ground water quality can occur both vertically and laterally in the Swakop River.

- From samples collected after the 1962/1963 flood in the Swakop River, the ground water quality along the river showed three distinct quality zones:
  - Zone I (average TDS ~ 300 mg/ℓ) - upper part of catchment;
  - Zone II (average TDS ~ 1,400 mg/ℓ; range 800 - 3,000) - central part of catchment (down to Salem); and
  - Zone III (average TDS ~ 5,600 mg/ℓ; range 1,800 -18,000) - from Salem to the coast at Swakopmund.

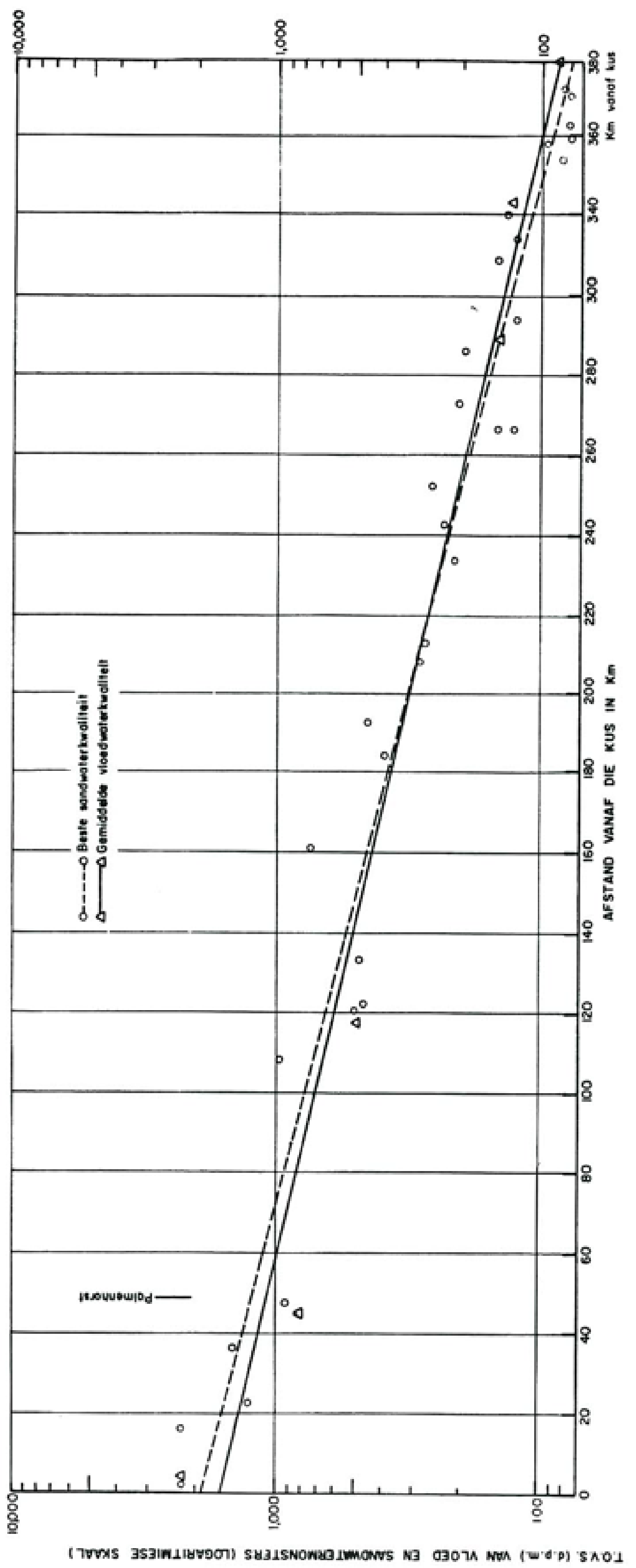


Figure 4.8: Changing ground water and surface water quality in the swakop River between Okahandja and the coast.

4.3.2 The Khan River alluvial aquifer

A series of investigations which relate to geohydrological aspects of the Khan River aquifer were commissioned by Rössing (GCS, 1989; Corner, 1995; Gordon McPhail and Associates, 1995). The most extensive studies of the geohydrology of the Khan River were conducted by Rössing staff (Marais, 1990a, 1990b; Kehrberg 1995, 1996a, 1996b, 1996c, 1996d, 1996e). These reports contain the results of geohydrological investigations carried out at the Rössing Mine between 1976 and 1996, and summarize the current state of knowledge on this part of the aquifer. A final report (Kehrberg, 1997) reviewed all available hydrogeochemical information.

4.3.2.1 Aquifer geology and geometry

The bedrock of the Khan River at Rössing Mine consists of meta-sediments of the Nosib and Swakop Group of the Damara Sequence. The rock types are mainly schists of the Kuiseb Formation as well as marble, quartzite and tillite of the Karibib and Chuos Formations. The Khan River course generally follows the strike of the formations, and where it cuts across the strike, hard layers of marble create bedrock barriers that subdivide the alluvial aquifer into "compartments".

The alluvium in the river bed comprises coarse gravel with minor silt layers near the surface. These sediments can be up to 25 metres thick, though they normally average about 18 metres in depth. The sand is composed of quartz, feldspar, mica and rock fragments and varies from medium to very coarse and exhibits poor sorting, often with angular to sub-rounded grains. The gravels vary from pebbles to boulders and are sub-rounded to rounded. Silt deposits are prominent in recent terraces where they are inter-layered with thin sand and pebble bands. The silt deposits cause a thin layering in the alluvium which reduces vertical hydraulic conductivity.

Deposition of silty material by Khan River flood waters significantly reduces aquifer recharge. It appears that the silt load in the rivers draining the escarpment, has increased in recent years due to deteriorating soil conditions in the catchment. This is a reason for concern in terms of the natural and artificial ground water recharge.

Unlike the Omaruru or Kuiseb rivers, the Khan River does not form a deep erosional channel or delta. The sediments of the Khan aquifer have a grain size much coarser than those of the Kuiseb or Omaruru rivers. This results in a high hydraulic conductivity and consequently, a high throughflow rate and, therefore, fast draining of ground water from the aquifer.

4.3.2.2 Aquifer parameters

Dziembowski (DWA,1970) reported average permeabilities of 219 metres/day and 286 metres/day and specific yields of 0.18 and 0.23, respectively, for the Swakop and

Khan Rivers near Rössing, based on aquifer tests conducted by the DWA and Geological Survey. He also established that the specific capacity of boreholes in the Khan River was almost double those of boreholes in the Swakop River.

From pumping tests done over the years by DWA and Rössing, as well as water balance studies, a permeability of 200 metres/day was considered to be representative of the Khan River aquifer. This value was used to determine the rate of throughflow across the average cross-sectional area of 1,250 m^2 at varying water levels. This is graphically depicted in **Figure 4.9**.

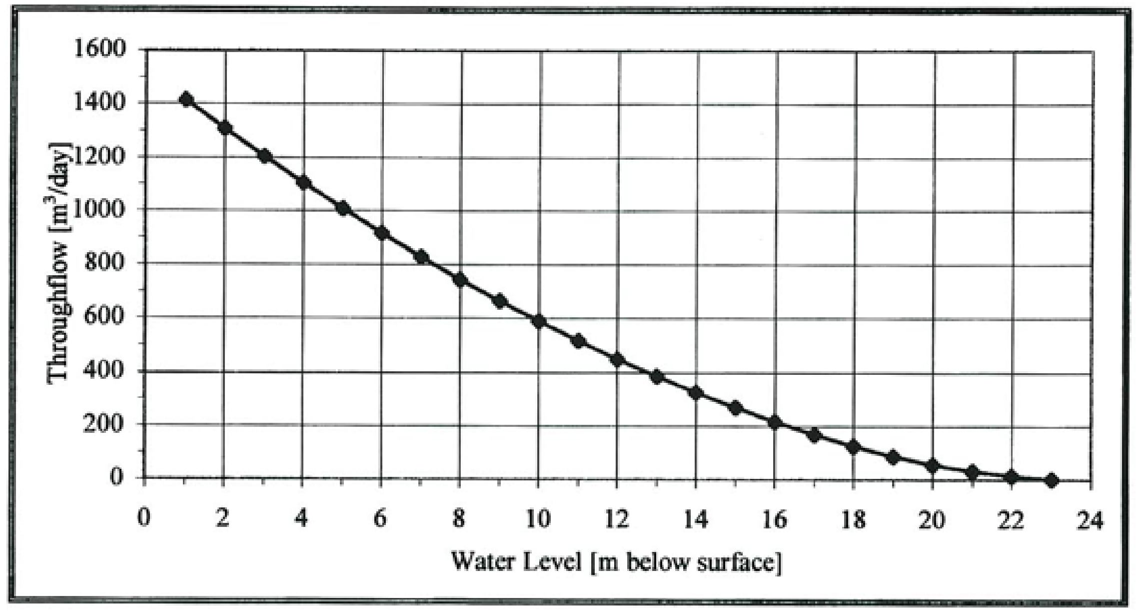


Figure 4.9: Relation between rate of ground water throughflow and water level below the riverbed surface.

Using the values for throughflow, average cross-sectional area of the channel and the gradient of the water level, the permeability is calculated to be 219 metres/day. From this a Darcy velocity of 1.2 metres/day or 438 metres/year, and a true velocity of approximately 5.5 metres/day or 2,000 metres/year, using a porosity of 20%, was derived.

4.3.2.3 Ground water resources, water levels and utilization

From the results reported by DWA (1970), it was concluded that for one kilometre of river bed at test sites in the Swakop and Khan rivers, 424,000 m^3 and 341,000 m^3 of ground water was stored in the beds of the Swakop and Khan rivers, respectively.

In an internal report (DWA, 1976a), the stored reserves in the Khan River between Namibfontein and Rössing were estimated to be between 8.4 and 11.2 Mm^3 over the 40 kilometre length of the river. Between Rössing and the confluence with the Swakop River they estimated that 6.5 x 10^6 m^3 of water was stored in the alluvial aquifer. The report further stated that only 70 % of these reserves were abstractable and that the annual recharge from flood events in the Khan River between Namibfontein and the confluence with the Swakop River was 2.4 Mm^3. This figure was thought to correspond to the long-term safe yield of the aquifer.

Between 1986 and 1994, the Khan River average baseflow was 1,300 m^3/day, whilst the Rössing abstraction was 1,990 m^3/day. The additional 690 m^3/day is interpreted as having being drawn from water derived from natural recharge to the system from surface flood events. Previously this was regarded as part of the safe yield of the aquifer, and for that reason the safe yield of most of Namibia's alluvial aquifers have been over-estimated. The overall result is rapidly dropping water levels; this is evident from the graph of abstraction versus water level over a 10 year period shown in **Figure 4.10**. It is clear that significant recharge did not occur during this period.

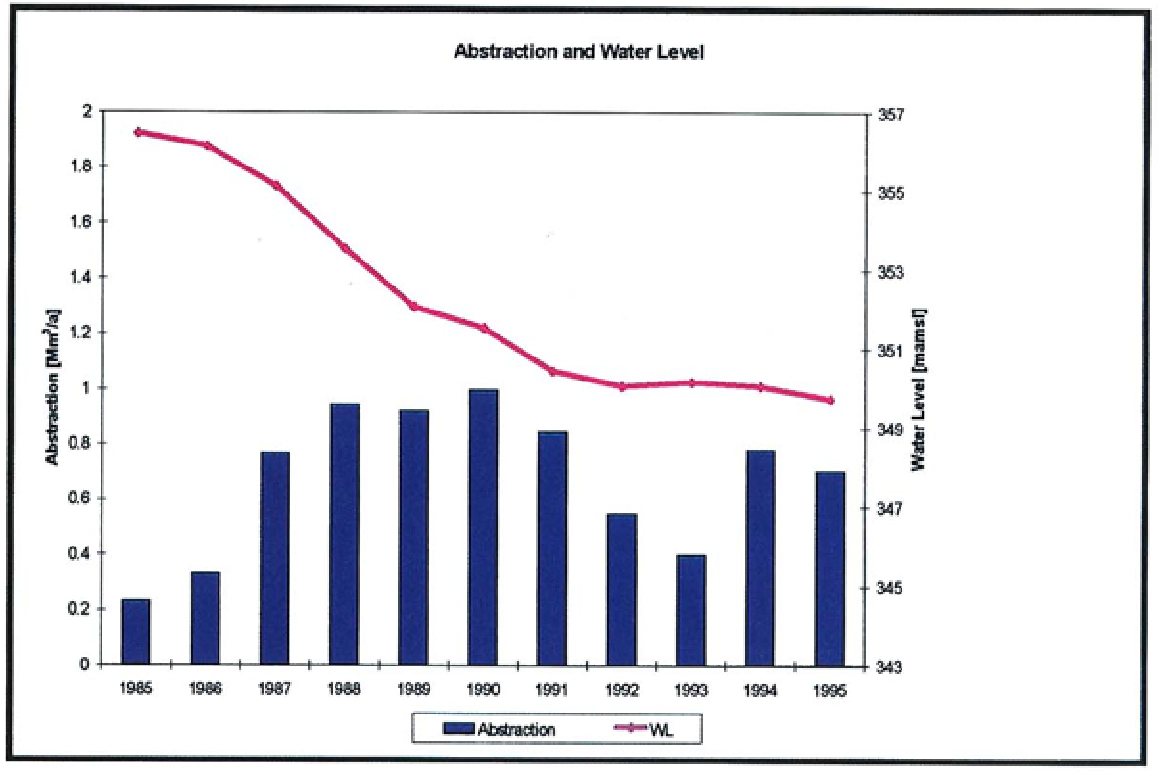


Figure 4.10: Annual ground water abstraction at Rössing versus average water level over the period 1985 to 1995 (data from Kehrberg, 1996d).

Water levels in relation to the pumping rate since 1985 are shown in **Figure 4.11**. The flattening off of the water level since about 1992 when the pumping rate was on average about 42,000 m^3/month, was indicative of the sustainable yield of the aquifer over that time period. If pumping rates exceed the baseflow of the aquifer, water levels decline accordingly.

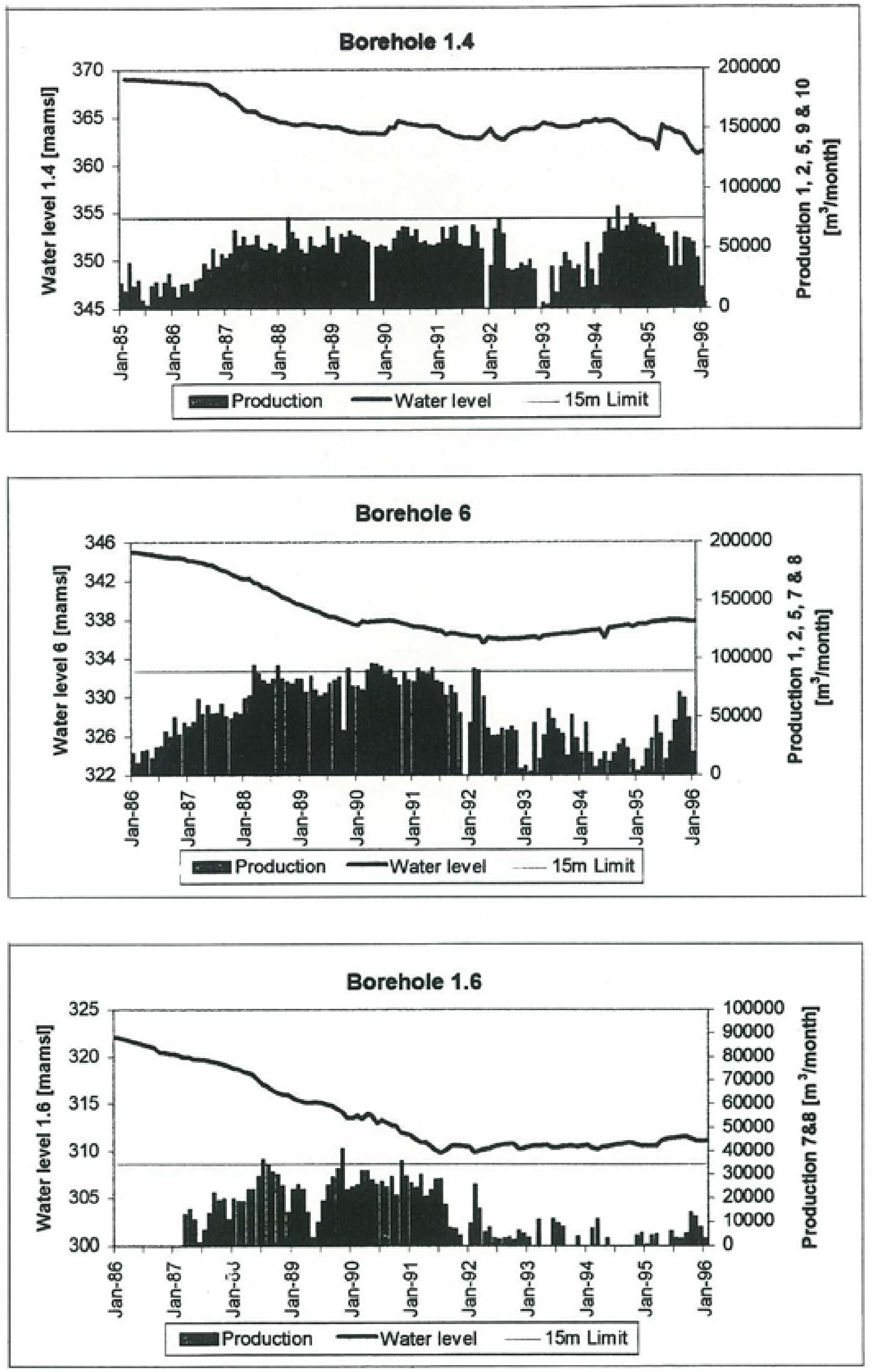


Figure 4.11: Long-term water level response in monitoring boreholes in relation to pumping rates of production boreholes.

Ground water abstraction occurs along various sections of the Khan River alluvial aquifers. The more important ones, in terms of volumes abstracted, are:

- Rössing Khan wellfield. In 1977, Rössing started to abstract water from the Khan River alluvial aquifer. The abstraction permit No. 2932, valid until 1988, allowed the mine to abstract 3,000 m^3/day (1.095 Mm^3/year). A subsequent amendment to the permit set a provisional drawdown limit of 15 metres below surface, with the proviso that vegetation should be monitored regularly. However, due to declining Khan River ground water levels in 1995, DWA recommended that abstraction should be reduced to 0.60 Mm^3/year. The total annual ground water abstraction is listed in **Table 4.4**.

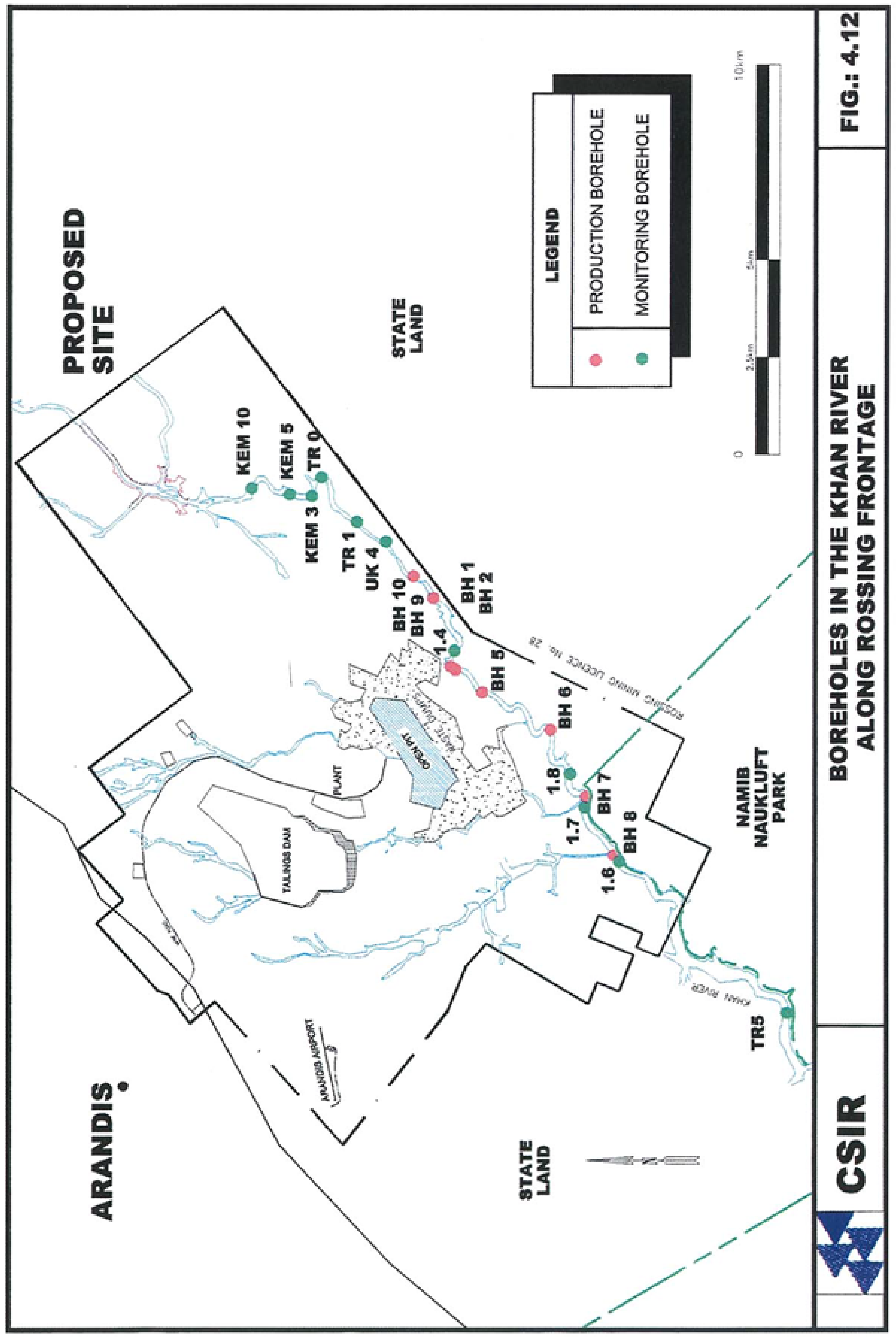
  Seven production boreholes, BH 1, BH 2, BH 5, Bh 7, BH 8, BH 9 and BH 10, are currently in use over some 10 kilometres of river bed from Panner Gorge to about 4 kilometres upstream of Dome Gorge (**Figure 4.12**). All boreholes have electrically driven submersible pumps operating on a 24 hour/day schedule. Abstraction levels are controlled by periodic measurements of water levels and by operating different boreholes accordingly. Typical long-term water level responses of three of the boreholes are illustrated in **Figure 4.11**. The cut-back in abstraction rate, and the positive effect it had on the declining water level, is clearly visible at boreholes 6 and 1.6 (Kehrberg, 1996d).

- The Spes Bona wellfield, located approximately 35 kilometres upstream of Ameib. Annual production figures supplied by DWA indicate an average abstraction rate of 79,800 m^3/annum. The abstraction rate has decreased significantly since 1990 (**Figure 4.13**).

- A third well field operates at Usakos. Records of production rates indicate an average abstraction of 119,000 m^3/annum, decreasing in recent years as shown in **Figure 4.14**, to an abstraction rate of 14,355 m^3 in 1996.

Table 4.4: Total annual ground water abstraction volumes at Rössing Mine.

Year	Ground water abstraction (10^6 m^3)	Year	Ground water abstraction (10^6 m^3)	Year	Ground water abstraction (10^6 m^3)
1977	0.5	1984	0.2	1991	0.9
1978	0.3	1985	0.2	1992	0.9
1979	0.3	1986	0.4	1993	0.4
1980	0.3	1987	0.8	1994	0.6
1981	0.2	1988	1.0	1995	0.7
1982	0.4	1989	0.9	1996	0.3
1983	0.3	1990	0.9		



BOREHOLES IN THE KHAN RIVER ALONG ROSSING FRONTAGE

FIG.: 4.12

CSIR

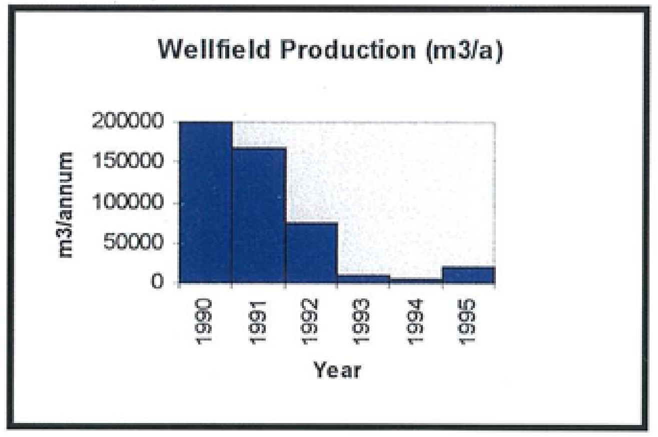


Figure 4.13: Spes Bona wellfield production.

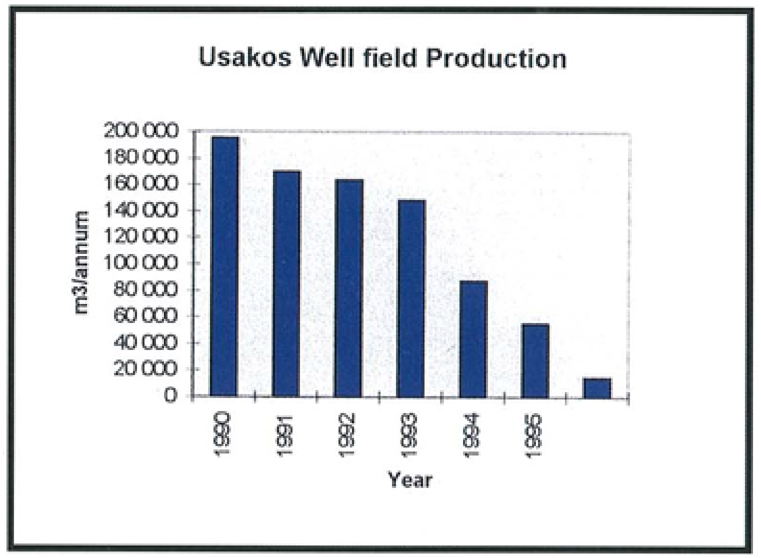


Figure 4.14: Usakos wellfield production.

4.3.2.4 Ground water quality

Boreholes in the Khan River drilled by the Geological Survey and Rössing staff during the period 1974 to 1976 (RUL, 1976) had tested yields and quality as shown in **Table 4.5**.

Ground water quality determined at different positions in the Khan River between the mine and the confluence with the Swakop River during 1974, showed the following:

- Opposite the mine: 3,887 mg/ℓ
- 10 km downstream of the mine: 6,424 mg/ℓ
- At the Khan/Swakop confluence: 9,858 mg/ℓ.

Table 4.5: Water quality and yield from boreholes in the Khan river (data drawn from Wegerhoff, 1974 and RUL, 1976).

Component	BH01	BH02	BH05	BH06
pH	7.2	7.7	7.5	7.4
Conductivity (mS/m)	3,700	2,900	640	645
Total dissolved solids (mg/ℓ)	28,400	21,200	4,290	3,800
Yield (m^3/day) (ℓ/s)	2,448 ~ 28	2,087 ~ 24	2,165 ~ 25	2,092 ~ 24

Based on all the available water quality information, the Khan River was divided into logical sections based on geographical or geological features and the minimum, mean and maximum TDS values over the period 1958 to 1997 was determined (**Table 4.6**).

Table 4.6: TDS values for different sections of the Khan River.

Section	Minimum TDS (mg/ℓ)	Mean TDS (mg/ℓ)	Maximum TDS (mg/ℓ)
Spes Bona - Ameib	190	409	550
Goabeb - Krantzberg	348	512	754
Usakos Suid - Vergenoeg	1,141	3,911	7,141
KEM3 - Rössing wellfield	4,343	4,797	5,399
Rössing wellfield - confluence	2,610	5,931	10,270

There is a clear increase in TDS correlated with distance travelled from the head waters to the confluence, confirming similar results found for the Swakop River (NIWR, 1966).

Water samples from three newly drilled boreholes (Boreholes 1.10, 1.11 and 1.12) in the Khan River just upstream of the confluence (RUL, 1997) show that the electrical conductivity in January 1997 (before the floods) was between 800 and 820 mS/m (equivalent to 5,100 and 5,250 mg/ℓ, respectively). This is similar to the long-term mean value but about half of what it was in the early 1960's.

Ground water quality at the mine was analyzed sporadically during the exploration and early phases of the mine, and more regularly when Rössing started to operate its tailings dam. Several analyses for the period 1967-1974 are available from three wells in the Khan River between Dome Gorge and Panner Gorge. During this period one small- and one medium-sized flood occurred. These can be regarded as base line or pre-mining ground water quality data for this section of the Khan River. The 1966 CSIR study of the Swakop River included boreholes in the Khan River at the confluence with the Swakop River (NIWR, 1966). The maximum and minimum TDS concentrations (values in mg/ℓ) for the period 1967 to 1974 are given in **Table 4.7**.

Table 4.7: Water quality variations in boreholes with time.

Borehole/ element		Old well	New well	Borehole Tapping basement rocks
TDS	Max.	6,424 (1974)	6,280 (1968)	8,550 (07/68)
	Min.	4,465	2,321 (1974)	1,800 (01/76)
Na	Max.	1,465	1,465 (1968 & 1974)	1,465 ((07/68)
	Min.	1,169	1,220 (1971)	495 (01/76)
K	Max.	70	76 (1968)	120 (07/68)
	Min.	60	35 (1974)	12 (0176)
SO_4	Max.	890	900 (1968)	2,280 (07/68)
	Min.	539	390 (1974)	157 (01/76)
NO_3	Max.	44	44 (1968)	128 (07/68)
	Min.	0	0 (1968)	4 (01/76)
F	Max.	2.5	1.5 (1968)	3.5 (03/66)
	Min.	1	1 (1974)	1 (12/71)
Cl	Max.	3,000	3,100 (1968)	3,150 (07/68)
	Min.	2,520	860 (1974)	950 (01/76)
Tot. alk.	Max.	295	343 (1974)	245 (03/66)
	Min.	215	220 (1968)	62 (01/76)

Table 4.7 shows that large natural variations do occur and that no clear pattern is visible in terms of when maximum and minimum values occur. Water quality in the basement rocks and upstream of the mine also shows large variations in concentration through time. No clear correlation emerges between drought/recharge periods and concentration.