4.3.3 The Swakop River alluvial aquifer

4.3.3.1 The lower Swakop River

The 1966 study of the Swakop River from Okahandja to the coast was the most extensive study ever conducted on this river (NIWR, 1966). For the purposes of this EIA, the downstream section of the Swakop River and its banks from the confluence with the Khan River is referred to as the *lower Swakop River* and is described in more detail in this section. However, for the hydrological modelling the entire length of the Swakop River was considered.

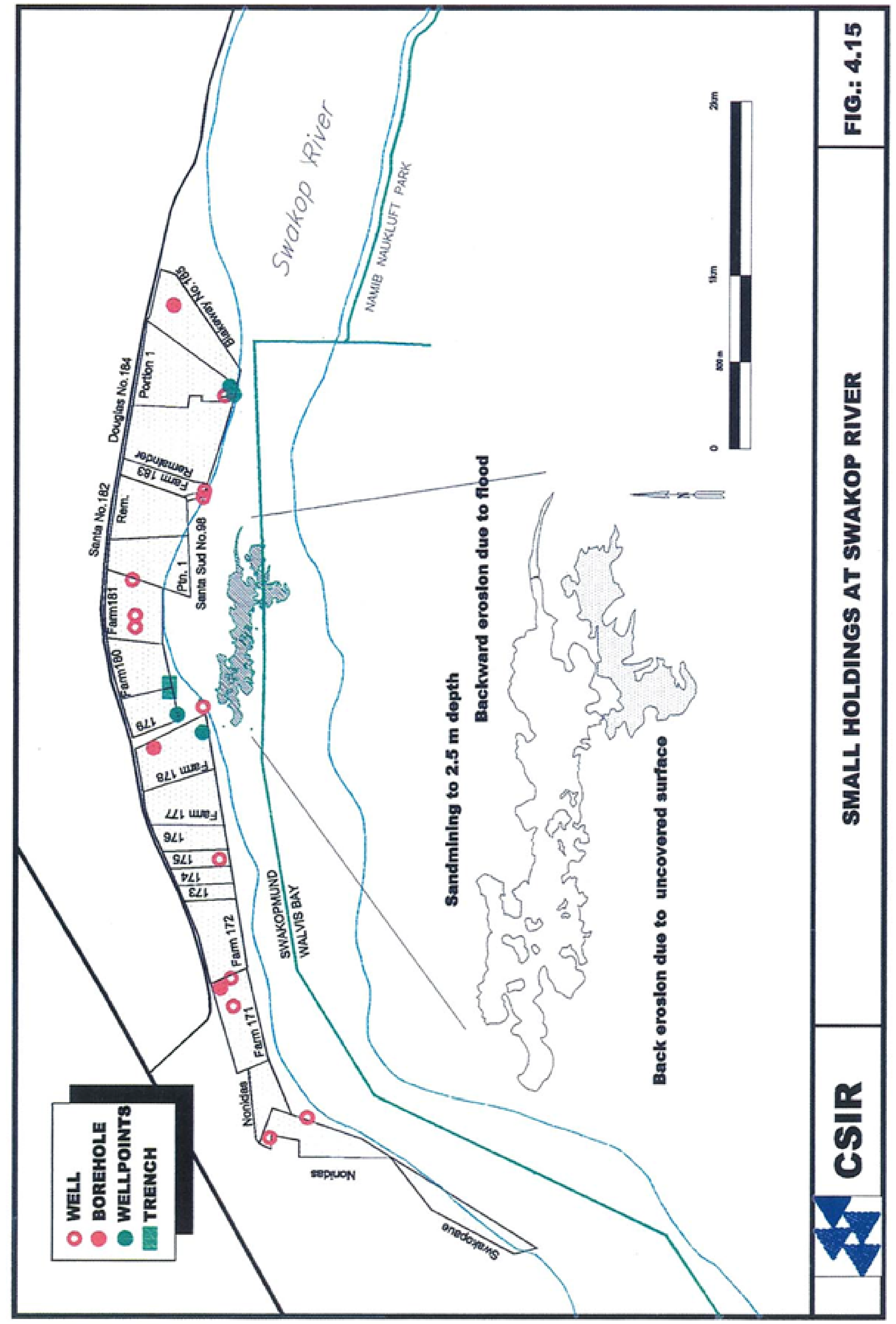
Geomorphologically, the lower Swakop River can be divided into two sub-areas: (i) between the confluence with the Khan River and the farm Tannenhof where the river is incised 200 metres deep into the folded and metamorphosed rocks of the Damara Sequence; and (ii) the relatively flat topography and river terraces of Quaternary age alongside the river area between Tannenhof and the coast.

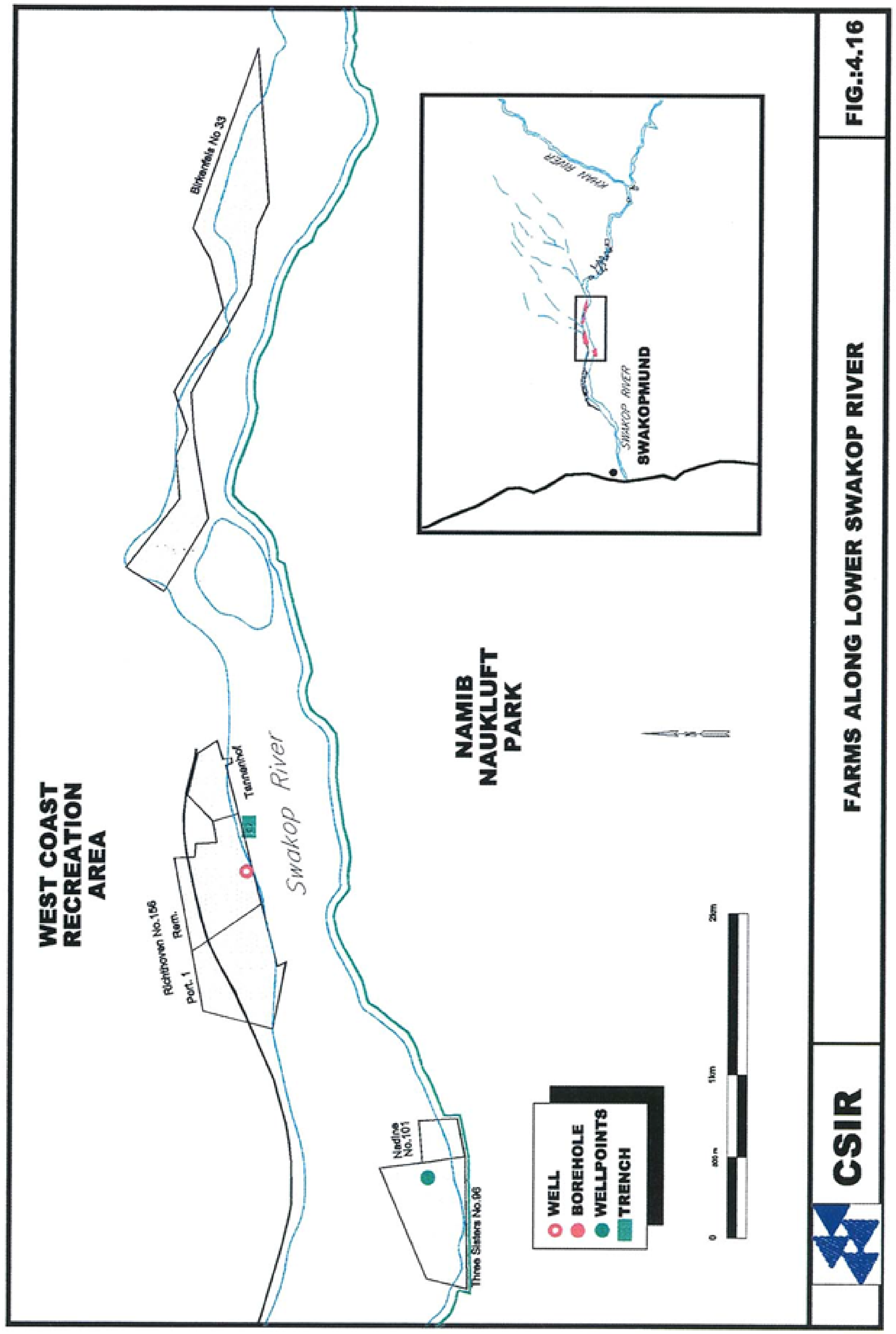
In the lower Swakop River section the river varies in width between 50 metres and 500 metres, with an average of about 400 metres. Vegetation is generally sparse except for wetlands downstream of the confluence with the Khan River, the surrounds of Nonidas and around the railway bridge. In these wetland areas dense vegetation clumps are comprised mainly of *Tamarisk*, *Cyperus* and *Phragmites*. Open water appears at Nonidas and the railway bridge.

Twelve farms with an average size of 50 hectares are situated in the section between the Khan-Swakop confluence and the farm Tannenhof. Early reports (Gebhardt, 1934; Seydel, 1943) refer to fertile farmland in this area, with extensive wetlands and brackish ground water. Currently, limited farming continues at Goanikontes. Between Tannenhof and the Rössing Country Club, 25 farms averaging 10 hectares in size are situated mostly on the northern bank of the river. The farms between the confluence with the Khan River and the farm Swakopaue near Nonidas are shown on **Figures 4.15, 4.16 and 4.17**. Full details of the agricultural activities and the problems experienced by farmers due to declining water levels and deteriorating water quality are contained in the Specialist Report by Du Plessis which is appended to this Report (**Appendix 2**).

4.3.3.2 Aquifer parameters

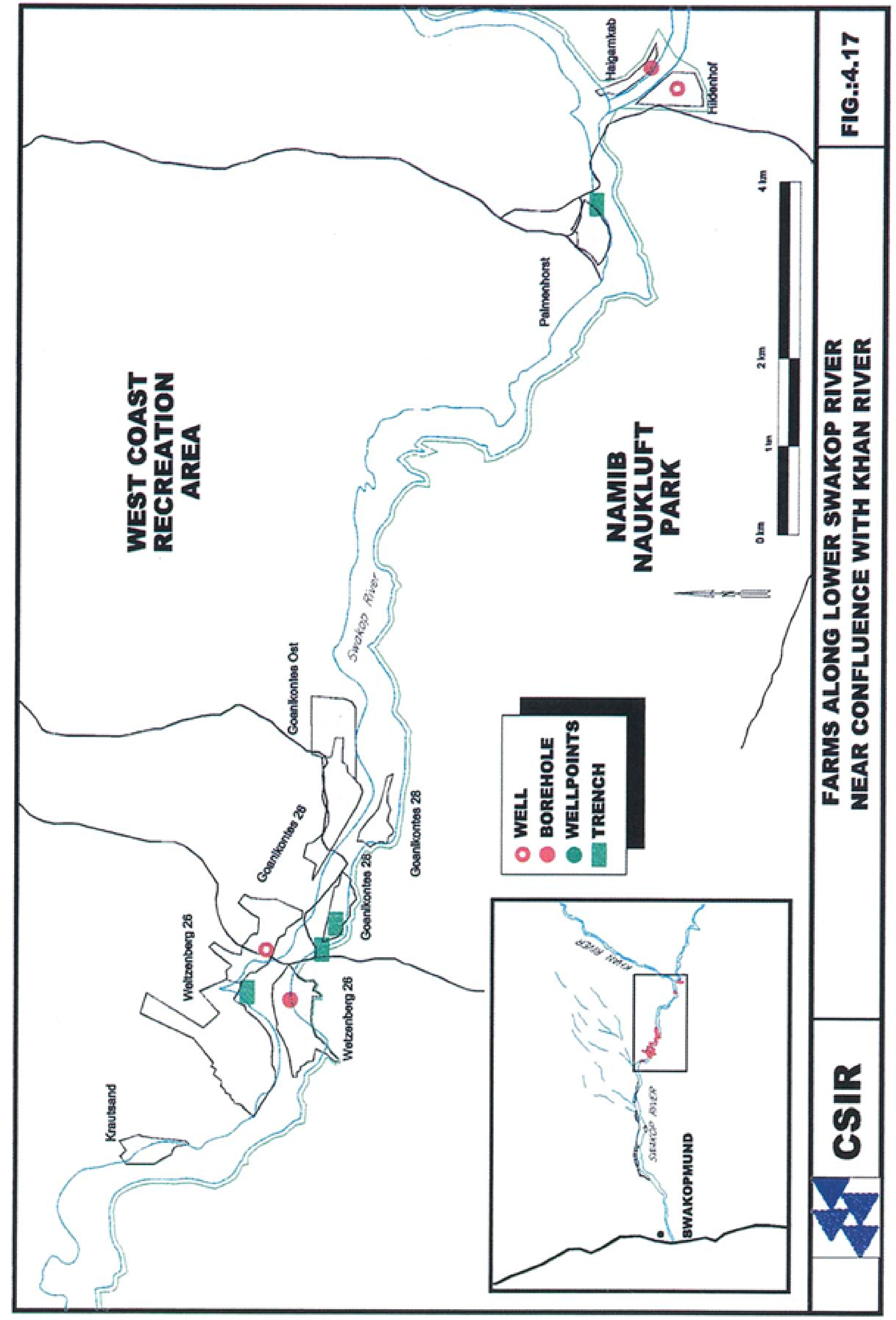
Aquifer tests performed by the South African Geological Survey in 1970 (DWA, 1970) just upstream of the confluence with the Khan River indicated a hydraulic conductivity of 268 metres/day and a storage coefficient of 23%. The permeability of the aquifer in the lower Swakop River was reported as 219 metres/day with a storage coefficient of 18 % (DWA, 1970).





FARMS ALONG LOWER SWAKOP RIVER

ENVIRONMENTAL IMPACT ASSESSMENT OF THE PROPOSED KHAN AQUIFER RECHARGE SCHEME



FARMS ALONG LOWER SWAKOP RIVER NEAR CONFLUENCE WITH KHAN RIVER

4.3.3.3 Ground water levels and recharge

Continuous water level monitoring was done of two boreholes in the vicinity of the farm Haigamkap over the period 30/12/69 to 15/11/74, when two floods passed through this section of the Swakop River. These boreholes show a continuous decline in the water level, interrupted by recharge events during floods (**Figure 4.18**). The recharge events are reflected in the sharp rises in water level and then a gradual decline towards the longer term trend and baseflow level.

Other estimates of water level variations can only be made from individual water level observations reported during different surveys (**Figure 4.19**). From these data it is clear that the long term trend is one of declining water levels and the average annual decline of the water level is estimated at 0.07 metres/year. By comparing the 1957 levels with current (1997) observations in the sand mining pits, the water level in the centre of the river has dropped by at least 1.15 metres over a 40 year period (0.03 m/year).

The generally declining trend of the water level with time is attributed, at least in part, to the construction of the Von Bach and Swakoppoort dams and, on a local scale, to increased abstraction of water from the Swakop River at Otjimbingwe.

Average recharge to the Swakop River alluvial aquifer was estimated as 50,000 m^3/year/kilometre of river bed, taking into account evaporation losses (DWA, 1978).

4.3.3.4 Ground water resources and utilization

In 1976, the DWA estimated that 23.3 x 10^6 m^3 of water was stored in the Swakop River alluvial aquifer between the confluence of the Khan River and the coast (DWA, 1976a).

Records for the larger ground water abstraction points along the Swakop River are available only for the following places:

- Abstraction, mainly for irrigation purposes in the lower Swakop River, was estimated (Hawkins, Hawkins & Osborn, 1993) to be in the region of 727,000 m^3/year in a wet season, increasing to 821,000 m^3/year during dry seasons. During the 1997 survey of the farms along the Swakop River, it was estimated that the present abstraction is of the order of 550,000 m^3/year.

- Records for the well field at Otjimbingwe, located approximately 225 kilometres upstream of Swakopmund, indicate an average abstraction rate of 170,000 m^3/year. **Figure 4.20** shows the total annual production rate at Otjimbingwe, based on records for the nine boreholes of the State Water Scheme.

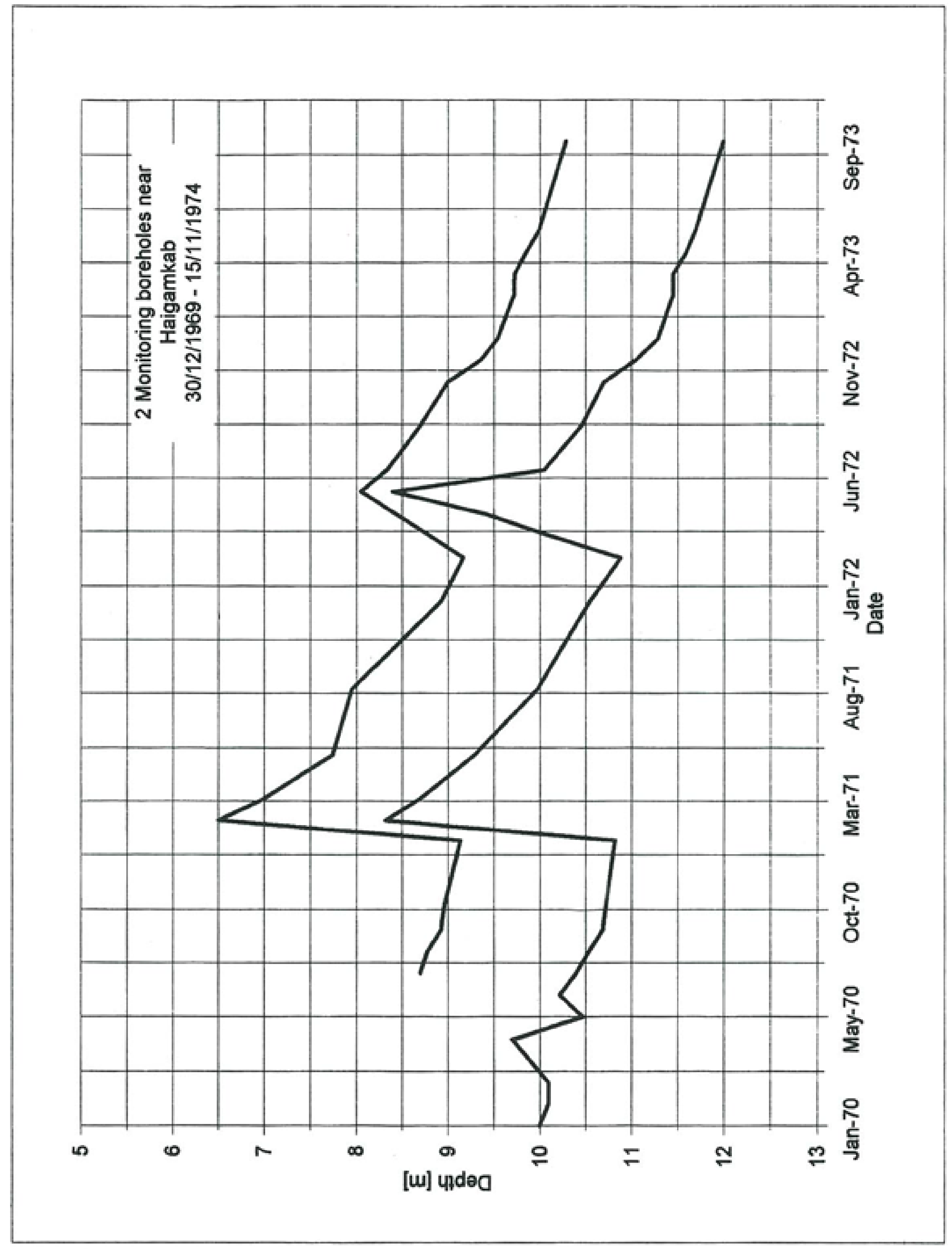


Figure 4.18: Continuous water level record from Haigamkab showing the effect of recharge events.

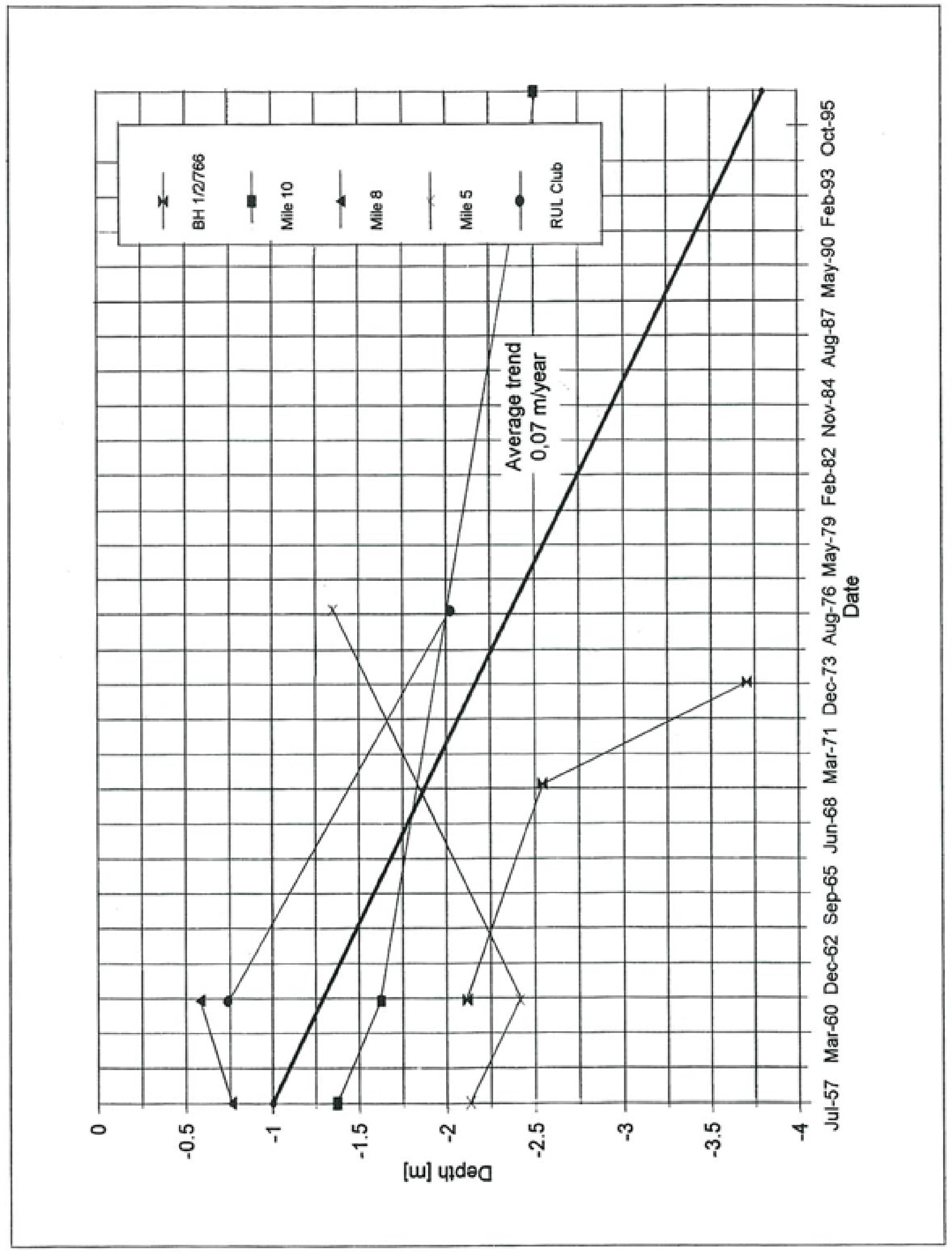


Figure 4.19: Water levels in the lower Swakop River over the period 1957 to 1997.

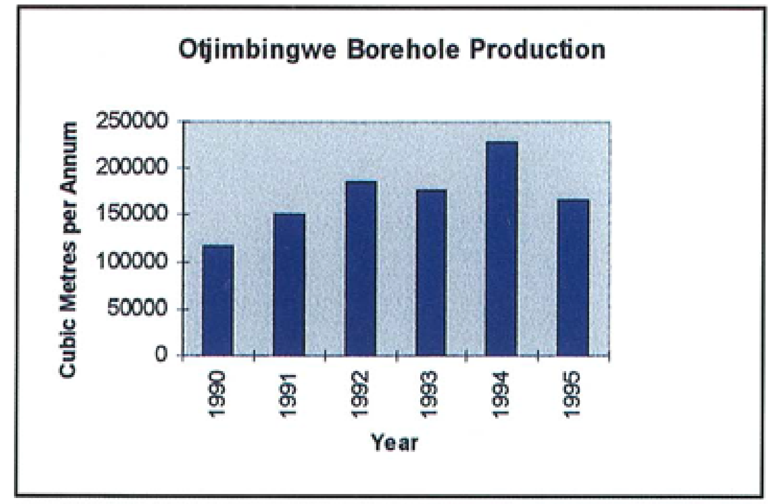


Figure 4.20: Otjimbingwe wellfield production.

4.3.3.5 Ground water quality

The information on water quality and water supply for Swakopmund and the farming community in the lower Swakop River has been extracted from the following sources:

- Historic information on the water supply to Swakopmund since approximately 1900 from the archives in Swakopmund and from the DWA files in Windhoek;
- DWA routine chemical analyses;
- Analyses carried out by the CSIR analytical laboratories;
- Drilling results for 1957 from DWA;
- The 1966 CSIR study of the Swakop River (NIWR, 1966)
- Geophysical surveys and drilling at Rössing Country Club;
- Survey of smallholdings during 1997 by Mr P Marais; and
- Water analyses from 1997 sampling of boreholes.

From historic records and correspondence between the Departments of Water Affairs and Works, and the Administrator/Secretary of SWA, it is clear that water from the Swakop River, from which Swakopmund originally received all its water, has always been of a brackish nature (Boss, 1934; Richter, 1934; DOW, 1952; NICR, 1957; Wipplinger, 1957, 1958; DWA, 1958).

Isolated analyses of water between 1913 and 1957 indicate a variation in concentration between 2,100 and 4,650 mg/ℓ total dissolved salts (TDS) (DWA, 1958), with periodic improvement due to flooding events. At Goanikontes the salinity of the water from an irrigation well was 700 mg/ℓ in September 1948, but increased to 8,000 mg/ℓ in August 1951.

A water quality profile with depth across the Swakop River at Km 2.5 based on ten boreholes was conducted in 1951 (DWA, 1951). The profiles showed a steady increase from about 2,000 mg/ℓ at the water level to > 16,000 mg/ℓ at the bedrock interface. Three additional water quality profiles across the Swakop River were conducted by DWA in 1957 at Mile 5, Mile 8 and Mile 10. The results for Mile 8 and Mile 10 are diagrammatically illustrated in **Figure 4.21**.

It is important to note that due to geological structures across the river near Mile 8, the ground water level rises to the surface and forma a large wetland. High evaporation and evapotranspiration from this area increases the salt content of the water. The effect of these wetlands on the ground water quality is dramatically illustrated by this example. Further downstream at Mile 5, the quality is similar to that at Mile 8. The 1966 CSIR study (NIWR, 1966) concluded that enhanced evaporation and evapotranspiration in those areas where the water level was either at the surface or very close to it, was the main reason for the increase in salinity of the water.

A number of observations can be made from these results: (i) the water quality at Mile 10 shows a definite layering with quality decreasing with depth from approximately 1,700 mg/ℓ at the water level to > 10,000 mg/ℓ at the bedrock interface; (ii) by the time the water has passed the wetland and reached Mile 8, the quality layering effect has disappeared and total dissolved solids levels are between 15,000 and 23,000 mg/ℓ; and (iii) at Mile 10 the best water quality is found towards the centre of the river and in the upper layers of the alluvium.

The latter point can be explained by the fact that fresh water infiltrates in areas where surface flow (during flooding events) cuts deepest into the channel, and lateral inflow from the fractured hardrock aquifer occurs at the bottom of the river channel. Water from the hard rock aquifer is generally expected to be of low volume and high salinity although reports of fresh water from these sources have been filed (Mr Putzier, personal communication).

The depth to the water level as well as the water quality at each monitoring position over the section between the confluence with the Khan River and the coast is indicated in **Figure 4.22**. A clear correlation between water quality and water table depth emerges, reinforcing the earlier CSIR conclusion (NIWR, 1966) that higher salt loads are related to shallower water tables.

Flooding events improve water quality in the upper parts of the alluvial aquifer. The CSIR results for borehole 3 on Section 25 (NIWR, 1966) are shown in **Figure 4.23**. These results show that water quality improved in the top central areas over the medium-term, but reverted to the original status after about 2 years.

The current water quality at the different farms in the lower Swakop River is reflected in **Table 4.8**. These samples were collected during February and March 1997.

ENVIRONMENTAL IMPACT ASSESSMENT OF THE PROPOSED KHAN AQUIFER RECHARGE SCHEME

SWAKOP RIVER AT MILE 10

1	2	3	4	5	6	7	8	9	10	11	12	13
unsaturated zone												
2008	1841	1879	1734	1726	1652	1794	1746	1812	2164	3560	3926	9072
2929	1810	1867	1762	1620	1624	1792	1746	1922	2728	3430	3379	
2603	4790	2028	1728	1844	1666	1796	1658	1720	2166	6310	4600	
2455	2178	2096	1724	1886	1616	1756	1744	1702	3454	4070	10326	
2474	2034	4053	1786	2974	2292	1786	2360	2078	5549	9842		
5211	5012	6193	1954	2726	2484	3046	3188	3763	8749			
6412	5607	4198	2978	3744	3140	3412	2505	3430	9628			
4748	4631	4352	2818	4598	3212	2614		6290	11100			
3097	8647	4272	3340	4126	3986	4088		7131				
9810	10539	5695	3644	8024	3240							
	11639		5172	9280	5318							
			6976		6368							

SWAKOP RIVER AT MILE 8

1	2	3	4	5	6
unsaturated zone					
20090	17734	20575	20446	22804	22675
18926	16301	19549	22037	22468	22241
18148	16256	19650	21564	22943	
19061	17002	20169	22037	23642	22743
14963	17432	20088	19302		23027
14630	15597	19603	18793	22260	22008
15280	19948	19500	19500	22234	22120
16253	20296	19738	17978	21940	
19235	18694	19793	18545	22121	
		21575			
		18109			

	TDS [mg/L]
	0 - 2000
	2000 - 5000
	5000 - 1000
	> 10 000

Figure 4.21: Water quality across the lower Swakop River at Mile 8 and at Mile 10.

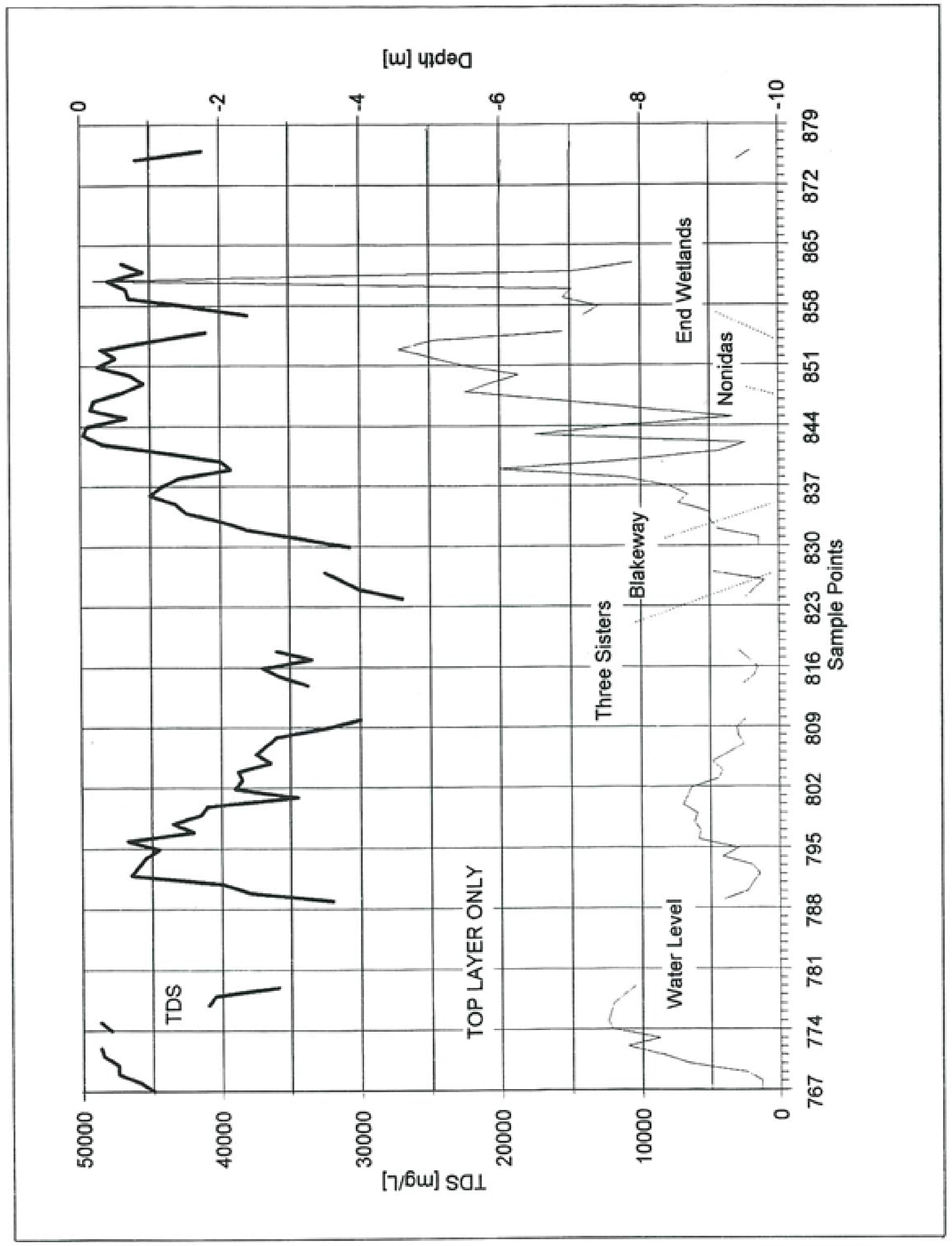


Figure 4.22: Correlation between water table depth and quality of ground water.

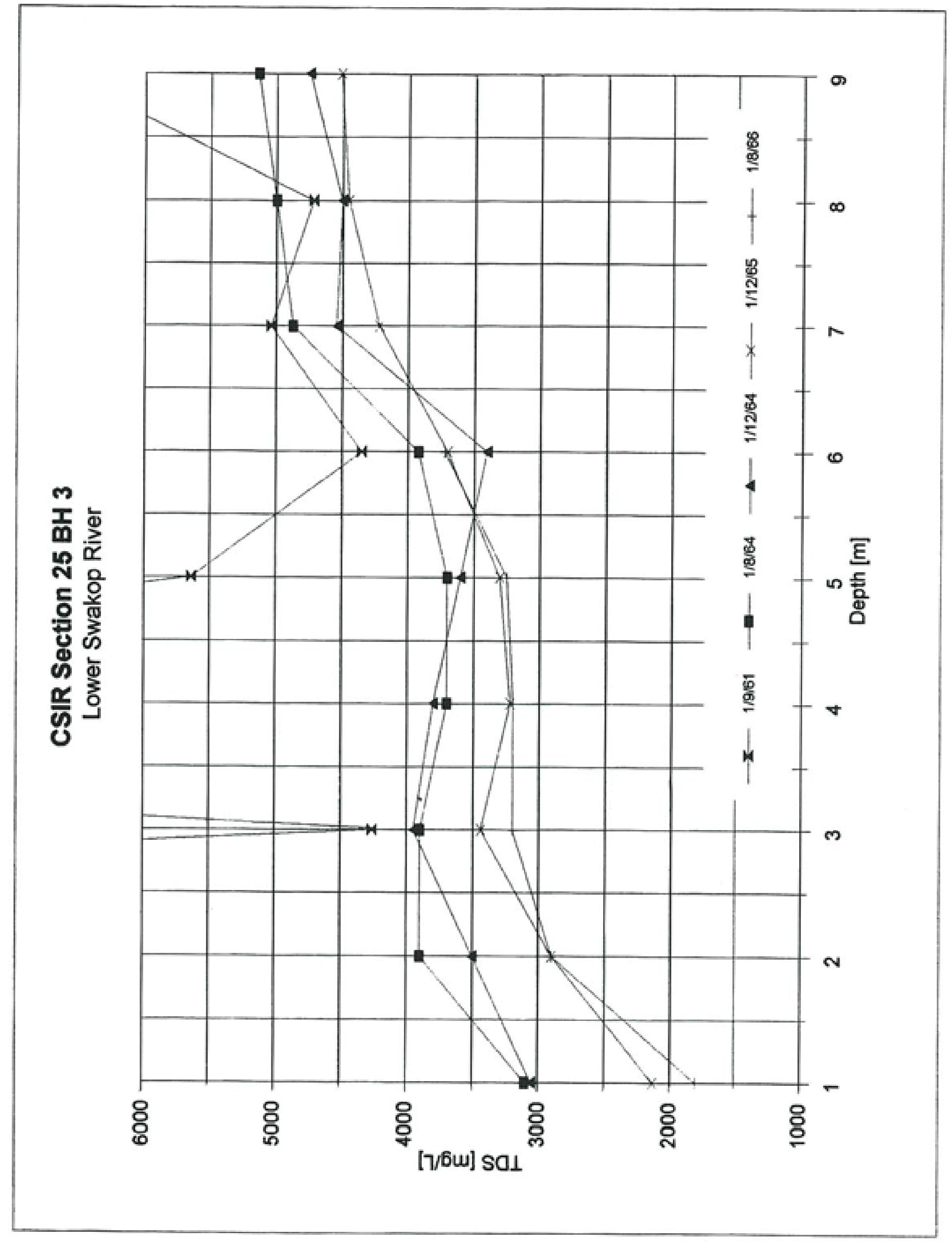


Figure 4.23: Ground water quality variations with time and depth at Section 25 (NIWR, 1966).

Table 4.8: Ground water quality in the farming zone on the lower Swakop River (samples collected February and March 1997).

Farm	Date	K	Na	Ca	Mg	NH_4	SO_4	Cl	Alk	NO_3	P	EC	TDS	pH	Hardness	Balance
	Units ->	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mS/m	mg/ℓ		mg/ℓ	%
Blakeway	13/02/97	40	1009	368	100	<0.1	344	2139	167	7.2	<0.1	720	4608	7.9	1330	0.19
Pampel	13/02/97	75	2737	874	241	<0.1	957	5665	175	20.4	<0.1	1700	10880	7.7	3176	0.14
Hoppe	10/02/97	74	2680	857	257	<0.1	964	5712	202	15.6	<0.1	1690	10816	7.8	3199	2.18
Hoppe well	10/02/97	87	2769	910	276	<0.1	1194	5826	246	3.1	<0.1	1760	11264	7.5	3412	1.81
Erb	14/02/97	95	1932	670	194	<0.1	835	3987	203	6.4	<0.1	1285	8224	7.4	2470	0.33
Horse farm	10/02/97	64	2152	711	190	<0.1	822	4346	269	8.3	<0.1	1370	8768	7.4	2559	0.48
Plot 181	10/02/97	49	1568	512	144	<0.1	636	3257	173	13.3	<0.1	1040	6656	7.7	1872	2.48
Jooste	14/02/97	50	1458	465	144	<0.1	663	2970	222	5.7	<0.1	995	6368	7.8	1753	2.72
Plot 180	10/02/97	57	1811	588	165	<0.1	748	3806	203	7.2	<0.1	1200	7680	7.8	2148	3.55
de Kock	11/02/97	43	1233	473	126	<0.1	539	2582	231	10.7	<0.1	875	5600	7.8	1699	0.82
Stiemert	10/02/97	58	1842	466	152	<0.1	720	3626	166	11.4	<0.1	1145	7397	7.7	1790	3.44
Nonidas	10/02/97	83	2745	788	228	<0.1	1098	5604	274	5.1	<0.1	1690	10816	7.7	2907	4.00
Van Heerden	24/02/97	58	1811	594	167	<0.1	718	3572	222	12.3	<0.1	1180	7552	7.3	2172	2.16
Rössing Fndt.	25/02/97	56.2	1697	559	170	<0.1	647	3480	210	12.7	<0.1	1150	7360	7.4	2095	0.35
Three Sisters	05/03/97	35.4	831	332	90	<0.1	413	1667	192	6.5	<0.1	600	3840	7.5	1201	1.91
Goanikontes 1	02/03/97	60.6	1835	778	245	<0.1	1074	3860	229	0.1	<0.1	1280	2951	7.9	8192	3.32
Goanikontes 2	02/03/97	79.6	2473	980	339	0.21	1303	5333	205	<0.1	<0.1	1700	3846	7.7	10880	2.66
Goanikontes	25/02/97	87	2300	980	344	0.14	1238	5000	255	2.1	<0.1	1600	3865	7.7	10240	4.31
Palmenhorst	03/02/97	55.5	1550	531	183	<0.1	883	2902	258	9.0	<0.1	1030	6592	7.6	2081	4.11
Haigamkab	25/02/97	45.2	1001	390	102	<0.1	495	1928	211	5.8	<0.1	720	4608	7.7	1395	4.71

Comparing the water quality observed during the 1966 CSIR investigation in the Swakop River upstream of confluence, to that downstream of confluence, a five-fold increase in TDS was observed (from > 2,000 mg/ℓ to > 10,000 mg/ℓ). This deterioration in quality was attributed to the contribution originating from the Khan River. Where the river channel is much wider some improvement in quality could be observed, but overall the TDS was still ~ 8,000 mg/ℓ or higher.

Two possible reasons have been given for the sudden rise in salt concentration after the 1934 floods in the Swakop River (DWA, 1976a). These are: firstly, that large volumes of alluvium in the Swakop River were removed, resulting in generally shallower ground water levels and, secondly, that large amounts of salt must have been transported to the Swakop River from the Tertiary age coastal plains in the Namib as these also received good rains. Between 1964 and 1976, when 10 additional boreholes were drilled in the Swakop River, no significant change in the chemical character of the water occurred (DWA, 1976a).

It is therefore concluded that the water contributed by the Khan River to the Swakop River, has a much higher salt content and does not improve the quality of the Swakop River water downstream of the confluence. On the contrary, the negative influence the Khan River has on the water quality of the Swakop River continues for a long distance downstream of the confluence.

Several ground water quality variations (lateral and vertical) across several sections of the Swakop River were determined in 1957 and 1961 (SWA Administration, 1957; NIWR, 1966). The results are shown in **Table 4.9** where the TDS values are grouped into different quality categories. Whilst no definite pattern emerges but in general it appears that the water quality in the centre of the alluvial channel is of a better quality. However, apart from being time dependent, this situation is also dependent on flood size, period between floods, channel width and amount of water abstracted from the aquifer. No information on the present situation is available as this study has not been repeated since.

Available water quality information for the Swakop River was collected and analyzed. The river was divided into logical sections, based on geographical or geological features and the minium, mean and maximum TDS values over the time period 1958 to 1997 was determined. It must be remembered that some of the information used dates from before the construction of the dams on the Swakop River. The results are tabulated in **Table 4.10**.

Table 4. 9: Ground water quality variations across the lower Swakop River.

Section	North Bank	Centre	South Bank	Comments
20 (NIWR, 1961)	> 2,500	< 2,000	< 2,000	Channel in centre; Note 1
21 (NIWR, 1961)	~ 4,000	~ 4,000	> 6,500	Channel south bank; Note 1
22 (NIWR, 1961)	2,500 - 3,000	1,000 - 2,000	1,000 - 2,000	Channel north bank; Note 1
23 (NIWR, 1961)	> 10,000	>10,000	> 10,000	Channel north bank; Note 1
24 (NIWR, 1961)	> 10,000	> 10,000	> 10,000	Channel south bank; Note 1
25 (NIWR, 1961)	> 8,000	~ 3,500 - 4,500*	> 20,000	Channel north & south; Note 1
26 (NIWR, 1961)	10,000 - 21,000	Note 3	18,000 - 24,000	Both channels on north bank; Note 1
27 (NIWR, (1961)	~ 14,000	~ 14,000	~ 14,000	Channel south bank; Note 1
Mile 10, 1957	2,000 - 9,000	< 2,000	2,000 - 11,000	Channel centre; Note 2
Mile 8, 1957	16,000 - 23,000	16,000 - 23,000	16,000 - 23,000	Channel south bank; Note 2
Mile 5, 1957	12,000 - 18,000	12,000 - 18,000	12,000 - 18,000	Channel north bank; Note 2
Km 3 (1951)	< 3,000	< 4,000	< 2,000	Note 4
Km 2.5 (1951)	< 4,000	< 4,000	< 4,000	Note 4

Note 1: ~ 10 Mm^3 flood in 1960 and 1961.
Note 2: No floods between 1955 and 1959.
Note 3: Double channel with ridge in between.
Note 4: Deeper than 7 metres quality decreases rapidly. Flood of ~ 100 Mm^3 in 1949 and in 1950.

Table 4.10: TDS values for different sections of the Swakop River.

Section	Minimum TDS (mg/ℓ)	Mean TDS (mg/ℓ)	Maximum TDS (mg/ℓ)
Sneyrivier -Ukuip	127	997	5,586
Rooikuiseb - Hildenhof	466	2,906	6,830
Palmenhorst - Birkenfels	1,186	5,343	11,543
Tannenhof - Nonidas	1,400	6,567	19,879
Nonidas - Mile 5	15,352	23,550	31,458

In comparison, the water quality contributed by the Khan River, determined at three newly drilled boreholes (Boreholes 1.10, 1.11 and 1.12) in the Khan River just upstream of the confluence, show salinity values in January 1997 (before the floods) between 5,100 and 5,250 mg/ℓ (Kehrberg, 1996b).

4.3.4 *Evaporation and evapotranspiration losses from the alluvial aquifers*

The 1966 CSIR study of the Swakop River demonstrated that evaporation from the river bed had a major adverse influence on water quality. Taking into account variable meteorological conditions, leading to high rates of evaporation and evapotranspiration along the length of the Swakop River between Okahandja and the coast, it was estimated that the total loss of water from the river must be between 65 x 10^6 m^3/year and 95 x 10^6 m^3/year. Of this figure, 68 % of the water lost is attributed to evapotranspiration, 19.5 % to evaporation from permanently wet areas and the remainder is lost from temporary wet areas (NIWR, 1971; Hellwig, 1973c).

Hellwig (1973c) also estimated that, by removing phreatophyte vegetation from the river bed, between 16 and 43 x 10^6 m^3/year could be prevented from being lost to the atmosphere. It was also established that if infiltration can be enhanced by extracting the silt load in, for example, a settling dam, and the water table is more than 60 cm below the surface, evaporation losses are minimal. Evaporation from an open water surface was about 8 % more than from a water saturated sand (Hellwig, 1974). When water is transported to the sand surface by capillary action, the salts removed from solution accumulated in a thin sand layer near the sand surface (Hellwig, 1979).

The followings areas and factors contribute to evaporation and evapotranspiration losses in the Swakop River:

- At Nonidas and the railway bridge outside Swakopmund large areas are covered with reeds and *Tamarisk* which leads to high evaporation losses.
- A geological structure in the Khan River at Vergenoeg, located approximately 61 kilometres upstream of the Swakop-Khan confluence, gives rise to a spring and wetland area. This shallow water level has given rise to prolific reedbed growth. The evapotranspiration rate from the reedbeds is estimated to be some 250 m^3/ha/day.
- A similar reedbed is situated on the Swakop River at Riet, located approximately 120 kilometres upstream of Swakopmund.

4.3.5 *Ground water contamination*

Water quality observations over time at the Rössing borehole BH 1.6 (located downstream of Panner Gorge), showed that seepage originating at the mine has reached the Khan River at times in the early 1980's. Major flood events, (particularly the 1985 flood), show that during such events, significant dilution occurs and water quality returns to close to ambient levels again. Good examples of this are NO_3, TDS and uranium concentrations at boreholes BH 1.4 and BH 1.6 (Kehrberg, 1996b). Seepage control systems installed during the mid 1980's were effective in controlling seepage from the mine workings and improvements in quality resulted. This is also confirmed by recent stable isotope studies (Talma & Meyer, 1997).

Nitrate concentrations

High nitrate concentrations, as well as large fluctuations in nitrate concentrations, occur in the ground water of the Khan River and its tributaries, upstream and downstream of the mining area. Historical records indicate that these variations can be attributed to a number of causes, including geological and biological conditions in the catchment, floods in the Khan River and mining. However, it is difficult to determine which sources were responsible for specific nitrate contributions.

Nitrate concentrations of around 100 mg/ℓ (and even as high as 522 mg/ℓ) are common for the Khan River catchment upstream of Rössing (Huyser, 1982a; 1982b; Goetze, 1982). Natural accumulation of nitrate in ground water through fixation of nitrogen by specific plant species, notably the *Acacia* spp. is well known (Tredoux, 1993). Geological formations are normally not considered as the primary origin of nitrates in ground water, but they do exercise a "secondary" control on the concentration (Heaton, 1985; Tredoux, 1993). Permeable formations, such as unconsolidated Kalahari sands and alluvial river beds, provide conditions for the formation and leaching of nitrates.

At BH 1.4 upstream of Dome Gorge, nitrate concentrations increased steadily between 1979 and 1981, followed by a decrease to ambient levels by 1990. A similar situation was seen further downstream at BH 1.6. This pattern was repeated during 1990 to 1995, but in the case of BH 1.6, the decline to ambient levels was much slower. At this borehole the sulphate concentrations also increased between 1991 to 1995 in parallel with the nitrate. The question arises to what extent the mining activities at Rössing may have contributed to the nitrate concentrations in the ground water of the Khan River.

To answer this question, ground water samples from a number of boreholes were analyzed for their nitrogen isotope concentrations to establish the most likely source of nitrate as part of the KARS EIA project. Although the results were not fully conclusive, the values suggest that most of the nitrate is derived from bacterial decay of animal and human wastes, or that the natural nitrate concentration of the water is being reduced by denitrification, thereby causing higher nitrogen isotope concentrations (Talma & Meyer, 1997). Based on available information, the high nitrate values do not appear to originate from the Rössing Mine. The report by Talma and Meyer (1997) is appended to this report as **Appendix 3**.

TDS ratio

Evaluation of the available water quality data indicated a steady increase in the total salt content (TDS) since 1989. Several factors could have contributed to this situation. These include seepage from the mining operations, decreased baseflow due to over-abstraction in the wellfield (and thus less dilution), and reduced recharge because no significant flood events have occurred since 1989.

To evaluate whether or not seepage from the Rössing Mine property had contributed to water quality in the Khan River, stable isotope analyses (^{18}O and deuterium) were conducted on 25 samples from the Khan River and its major tributaries. The samples collected in the tributaries (Khan Mine, Panner, Pinnacle and Dome Gorges) all showed evaporation signatures, whereas those collected from the Khan River did not. From these results we concluded that there is no evidence that significant amounts (> 10 %) of stable isotope enriched water from the mining operations have contributed to the ground water in the Khan River (Talma & Meyer, 1997, **Appendix 3**).

Uranium concentrations

Ten water samples, collected in March 1997 from boreholes in the Khan River and lateral gorges, as well as samples from tailings seepage were analyzed for uranium concentrations and isotope ratios. The objective was two-fold. Firstly, to determine the uranium concentrations in ground water around the mine, and secondly, to establish whether or not contamination from uranium has occurred in the past.

The Central Namib Area is known to have high levels of uranium in the surface layers of the peneplain, most probably derived from the weathering of uranium bearing rocks in the area. High levels of dissolved uranium in the ground water and in the river beds thus do not necessarily indicate uranium pollution caused by modern mining activities. Uranium derived from freshly ground rock can, however, be distinguished from uranium dissolved during natural weathering of surface rocks by means of the activity ratio of the uranium isotope ^{238}U and its daughter isotope ^{234}U. Under natural conditions dissolved uranium has an activity ratio, $^{234}U/^{234}U > 1$, while uranium dissolved from freshly broken rock shows a ratio equal to 1 (Kronveld & Vogel, 1991). Determination of this activity ratio in the water samples around the mine should thus show the extent of any uranium pollution from the mining activity (Oschadleus & Vogel, 1997). The complete report by Oschadleus and Vogel is appended to this report (**Appendix 4**).

Oschadleus and Vogel (1997) concluded that insignificant amounts of uranium polluted water have reached the sampling points in Panner, Pinnacle or Dome Gorges as well as the Khan River along the mine frontage. The measures installed to prevent polluted water from the tailings dam reaching the Khan River have so far been successful. There is no evidence that Rössing's mining activities are adding uranium pollution to the water environment of the Khan River, although the background uranium concentrations in the area are higher than normal due to geological reasons.

Modelling calculations of throughflow in the Khan River and inflow from the gorges showed that the dominant factor causing water quality changes in the Khan River was lateral inflow (Kehrberg, 1996a). Modelled abstraction of ground water from the Khan River showed little influence on uranium concentrations.

4.4 General ecological characteristics

The ecological characteristics and any unique features of the habitats or organisms of the region around the Rössing Mine were largely unknown before mining operations started. Approximately eight years after the start of mining operations at Rössing, the State Museum of Namibia carried out detailed ecological surveys of the region around the mine. This was followed in 1990-91 by the compilation of an internal detailed Environmental Impact Statement (EIS) for the Rössing Mine (Ashton *et al.*, 1991). This EIS used appropriate portions of earlier published information, supplemented with studies made by the State Museum staff and personal observations to compile a description of the environmental conditions that prevail around the Rössing Mine. The descriptions of the biotic environment listed in this Report are based on this earlier work by Ashton *et al.* (1991).

4.4.1 Vegetation

The Rössing Mine is located towards the eastern edge of the Central Namib vegetation zone. This Central Namib zone extends southwards to the Kuiseb River, where the so-called "sand sea" of the Southern Namib Desert begins, and to the east which is demarcated by Semi-desert and Savanna Transition vegetation referred to as the Escarpment Zone. The extent and diversity of vegetation is largely determined by altitude and the regional rainfall patterns (Geiss, 1971; Brown *et al.*, 1985; Huntley, 1985). Within the Central Namib zone the vegetation has a marked east-west distribution pattern which is closely related to the inland distribution of coastal fogs (Louw & Seely, 1982; Huntley, 1985).

Episodic rivers drain the interior plateau and flow towards the coast, eroding deep channels into the surrounding countryside. Their alluvium-filled beds provide the major sources of water for perennial vegetation and function as linear oases. Species that are more characteristic of the Escarpment Zone colonize these drainage lines and extend their range into the Central Namib Desert. Several tree species flourish along these river beds, their distribution often extending for several tens of kilometres beyond the foot of the Escarpment and almost reaching the coast (Huntley, 1985). The most common tree species found along these river beds are: *Acacia erioloba, Faidherbia albida, Tamarix usneoides, Euclea pseudebenus, Ziziphus mucronata, Salvadora persica* and *Prosopis glandulosa* (Huntley, 1985; Craven, 1986).

The woody plant communities along the rivers are of great importance to the survival of animals, providing shelter and food to plains game during critical periods (Huntley, 1985). The size of individual trees and the numbers of trees per unit area is influenced by their position relative to flood pathways and silt deposits. Variations in the frequency, intensity and duration of floods cause constant fluctuations in the structure and vitality of these plant communities (Ward & Breen, 1983; Theron *et al.*, 1985). In addition, over-exploitation of groundwater from these alluvial river beds can have dramatic effects on the riparian trees. This was demonstrated clearly in the large-scale die-off of *Faidherbia albida* trees along the lower Kuiseb River following excessive water abstractions near Walvis Bay.

The aquatic sedges and reeds, *Cyperus marginatus, Phragmites australis* and *Typha capensis* are dependent on natural surface waters and wetlands. These species occur on patches of wet soil or small areas of open water in the beds of the Khan and Swakop Rivers.

The woody vegetation of the lower Swakop River has been extensively modified by livestock ranching up to 1977 when most of the small-holders were bought out and their land incorporated into the Namib-Naukluft Park (Vinjevold *et al.*, 1985). The reduced frequency of floods in the Swakop River has promoted the growth of large areas of *Tamarisk* trees in the river bed. Numerous *Prosopis* trees occur on the small-holdings along the Swakop River.

4.4.2 Fauna

Twenty nine species of large mammal have been listed from the Namib Desert Park (Stuart, 1975). Many of these species are nomadic, moving widely throughout the area, only entering an area when food is more plentiful after rains, and may not form a part of the area's permanent populations. Many of the species found in the Namib Desert area are sparsely distributed and vulnerable to disturbance or habitat loss.

Klipspringers are frequently seen around the Khan River gorges and are thought to be the only antelope species that is resident in the area around the Rössing Mine and the KARS Dam site. Gemsbok, Springbok and Hartmann's mountain zebra are occasionally seen at wetland areas along the Khan River, while Rock dassies, Black-backed jackal and troops of Chacma baboon have been seen occasionally in Panner and Pinnacle Gorges (James, 1985; Ashton *et al.*, 1991).

Four species of shrew, eight species of bat, two species of hare and 16 species of indigenous rodent have been recorded from the Namib Desert Park and may also occur in the vicinity of the Rössing Mine (Withers, 1979). Many rodent species found in the Namib Desert Park occupy rocky habitats or wooded areas. Similar habitats occur along the Khan River and several of these species should occur there. Two species of introduced rodent have been recorded in the mine area (James, 1985).