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TECHNICAL COOPERATION

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DATA BASE FOR FURTHER DECISIONS REGARDING THE NECESSITY AND FEASIBILITY OF FUTURE GEOPHYSICAL AND HYDROGEOLOGICAL INVESTIGATIONS IN THE STUDY AREAS OSHIVELO, EASTERN CAPRIVI AND EASTERN TSUMKWE-OTJINENE (NORTH-EASTERN NAMIBIA)

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GEOnumerix®

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4. EASTERN PART OF THE OTJINENE AND TSUMKWE DISTRICTS

4.1. Background and Previous Work

The Otjinene and Tsumkwe districts are situated in northeastern Namibia, bordering to Botswana. The original Project Area, as proposed in Fig. 1.1, comprises mainly the Gam and lower Eiseb catchments in the south and the Tsumkwe area in the north, covering an area of about 20,000 km^2. On request by the DWA the area was extended to the west and south and includes now also the upper Eiseb catchment, the Epukiro catchment and the water divide between Tsumkwe and the Omuramba Omatako in the northwest (Fig. 4.1), covering an area of approximately 40,000 km^2. The enclosed database includes borehole information from the whole area between the 19°00' and the 22°00' Latitude and the 19°00' to the 21°00' Longitude. As in the other Project Areas the outside data was used for better interpolation results.

The success rate of boreholes drilled in the Otjinene District is less than 10 % and a lot of money is wasted every year for the drilling of dry boreholes in areas known for the low groundwater potential. Areas with better groundwater potential should be outlined and further investigated by means of sophisticated remote sensing and geophysical surveying techniques.

The main objective of this study is to summarise previous work done in the Project Area and to provide the basic hydrogeological information for the drafting of project proposals as part of the technical co-operation between the DWA and the BGR.

In the early 1970s an isotope study was carried out in the catchment areas of the omiramba Eiseb, Otjinoko, Rooiboklaagte and Epukiro by the CSIR (Vogel, 1974). Main aim was to investigate the recharge pattern in the Omaheke Region where a thick layer of Kalahari sediments covers rocks of the Damara Sequence, which crop out at the margin of the basin. It was assumed that the sand cover prevented recharge to the deeper Kalahari aquifers and that the groundwater derives only laterally from areas where the underlying hard rock is exposed. If this was the case the groundwater age should gradually increase with distance from the margin of the basin in an easterly direction. 39 samples were analysed for radiocarbon and it was concluded that:

- Most of the groundwater sampled is of relatively recent age.
- No large-scale age pattern is discernible indicating that the water is not all derived from the basin margin. Despite this, the water in the northeast tends to be older than in the southwest.
- Local recharge definitely takes place in some parts of the omuramba valleys. The variability in age indicates local recharge outside the drainage channel as well.

- Infiltration of partially evaporated water from standing pools is not common.
- The sampled wells contain water derived from local precipitation, irrespective of age.
- Most of the sampled wells contain bicarbonate water of good quality.

Between 1973 and 1982 some 1,000 Schlumberger soundings were carried out by the CSIR in the Okakarara and Otjinene Districts to investigate the geological and hydrogeological inventory of the region. Main aim was to provide basic information for future groundwater exploration projects. The results were presented in a number of reports including geophysical and hydrogeological maps and cross-sections. The results are discussed in more detail in the BGR review of the geophysical work done in the Project Area (Fielitz, in prep.). The most interesting result with reference to the Project Area is the identification of a deep Kalahari/Karoo trough along the veterinary fence near 20°E, 21°S. This geophysical feature could be related to the Eiseb Graben Aquifer (EGA), which is located about 50 km to the northeast, at the Botswana border.

In 1983 a total of 76 Schlumberger electrical soundings were carried out by the CSIR around and to the west of Gam. The authors concluded that the groundwater potential of the Gam area is very low and that the aquifers in the area cannot serve as a major source of groundwater (De Beer et al., 1984). The potential of the Kalahari trough located in the immediate south of Gam was also considered to be low due to the fact that the trough contains large volumes of low permeability Lower Kalahari strata.

In 1981, the CSIR presented a report on a hydrochemical investigation implemented in the former Bushmanland. A total of 46 boreholes and wells were sampled and analysed for standard constituents and the results were presented in form of figures, tables and thematic maps (Huyser, 1981). It was concluded that the water quality in the former Bushmanland (now the Tsumkwe District of the Otjozondjupa Region) is of generally good quality. Only locally, in the vicinity of pans, e.g. at Dobe Pan, north of Tsumkwe, brackish water was encountered. Elevated nitrate concentrations were observed in the Daneib catchment area.

Between 1990 and 1993 a groundwater study was carried out by consultants for the DWA in the Kavango and Bushmanland areas. The 2-phased study included a desk study, field reconnaissance, remote sensing, geophysical survey and the drilling and test pumping of nine boreholes. A final report including geological cross-sections, hydrogeological maps and recommendations regarding further work was presented by the consultants (NGDC, 1991).

It was concluded that the primary Kalahari Group sediments constitute the most important aquifers in the region. Secondary aquifers are important where the Kalahari cover is thin or absent, like in the area northeast of Tsumkwe, where quartzite of the Nosib Group and Post-Karoo basalt are exposed. The latter underlies large areas of the Tsumkwe District.

It was found that the available groundwater resources in the Tsumkwe District are generally sufficient to sustainably supply the required amount of potable water to the local population. Due to the limited number of people and livestock in the Tsumkwe District (ca. 4,000 people and only about 1,000 head of cattle and goats) no major future supply problems were anticipated.

Between 1990 and 1993 Leo Hatz and HHO Consultants conducted an investigation to determine the extent of groundwater resources in East Hereroland. The study was implemented in three phases and included a desk study, hydrocensus, geophysical investigation, drilling and test pumping (App. 3.1). The results were presented in a number of reports including thematic maps of the geological, geophysical and hydrogeological inventory. The main objective of the study was to analyse the existing groundwater regime in the region and to make recommendations as to future potential sustainable resources (HHO, 1993).

As a result of the investigation a conceptual model of the hydrogeological regime was developed and it was concluded that the Kalahari Sequence aquifers have been dewatered due to reduced recharge from low permeable bedrock formations around the basin margin and higher outflow rates into Botswana. The unweathered fractured bedrock more than 100 m below the Kalahari Sequence-bedrock interface was identified to be the main aquifer, while the middle Kalahari was interpreted to be a confining layer. Groundwater resource calculations indicated that present abstraction is 50 – 75 % higher than sustainable resources and that it is inconceivable that groundwater resources can support further growth and development in the region.

In 1993 the Ministry of Lands Resettlement and Rehabilitation planned to develop 862,000 ha of grazing land in the so-called Gam Block in the central part of the Project Area (App. 3.2). The purpose was to resettle about 4,000 Hereros and Mbanderus that were to be repatriated from Botswana, with an estimated 50,000 cattle. It was estimated that the water supply requirement would be about 2,500 m^3/day (0.9 x 10^6 m^3/annum). The MLRR employed Interconsult Namibia to implement the groundwater investigation.

A major borehole siting survey was carried out in the area around and west of Gam. Exploration targets, selected from air photographs or from the airborne magnetic survey interpretation, were followed up in the field by ground geophysical surveys, which included the use of magnetometer, resistivity and horizontal loop electromagnetic methods. Subsequently, 83 boreholes were drilled of which 19 were considered successful and recommended for installation at specific pumping rates (App. 3.1). Successful boreholes were mainly drilled on or close to the Gam lineament and north of Gam, where bedrock of the Damara sequence crops out on surface. In the other areas, where thick unsaturated Kalahari deposits overlie the bedrock, the success rate was very poor.

A consultant was appointed by the DWA to review the project in 1995 (Lloyd, 1995). It was found that the Gam block cannot sustain the required water supply of 2,500 m^3/day, and that alternative settlement areas should be investigated.

The project area was then shifted from the Gam block towards the Eiseb area where an extensive primary aquifer was assumed in earlier studies. The evaluation of drilling reports and geoelectrical soundings and profiles carried out at the Eiseb lineament indicated a graben structure in this area (CSIR, 1982). The depth of the Kalahari trough is still unclear although geoelectrical soundings done by Interconsult indicated depths > 750 m. This conclusion is, however doubted because it attributes the low resistivity at depth only to Kalahari sediments and excludes the possibility that they might also be interpreted as Karoo (Fielitz, in prep.). Ten exploration boreholes were drilled to depths between 160 and 200 m of which nine yielded more than 1 m^3/h. Nine boreholes were subsequently recommended for installation with a combined yield of 222 m^3/day. Another 90 boreholes with similar yields would have to be drilled into the graben system to supply the required 2,500 m^3/day.

It was concluded that a primary aquifer, of unknown extent and hosted by Kalahari Sequence sediments underlies the Eiseb Block area. Abstraction rates of 12 – 36 m^3/day were expected from new boreholes drilled in the Eiseb Graben Aquifer (EGA). The limited life expectancy of the aquifer potential was, however, emphasised and the long-term sustainable supply from this aquifer was doubted (Lloyd, 1995).

As part of the establishment of a wildlife conservancy in the Tsumkwe District, a groundwater investigation was launched by the World Wildlife Fund (WWF) and the Nyae Nyae Farms Cooperative and implemented by a groundwater consultant. Five new boreholes were drilled of which three were recommended for installation to supply water to the wild animals in the area (App. 3.1).

In the first phase of the investigation the general hydrogeology of the area was described and the results presented in form of small scale maps (Interconsult, 1998).

Since 1993 the post graduate college of the University of Würzburg has been busy studying the groundwater recharge mechanism under semi-arid condition in Namibia. Up to now, three PhD theses have been completed covering areas in the western part of the Otjozondjupa Region. A recent thesis, initiated by Prof. P. Udluft in 1998, and carried out by Ms H. Klock, deals with groundwater recharge mechanism of the Kalahari basin in northeastern Namibia, which includes the BGR Project Area. Main aim of the thesis is the quantification of recharge reaching the basin from the margins and the development of a conceptual and numeric model of the groundwater flow pattern. First results are awaited not before the year 2000.

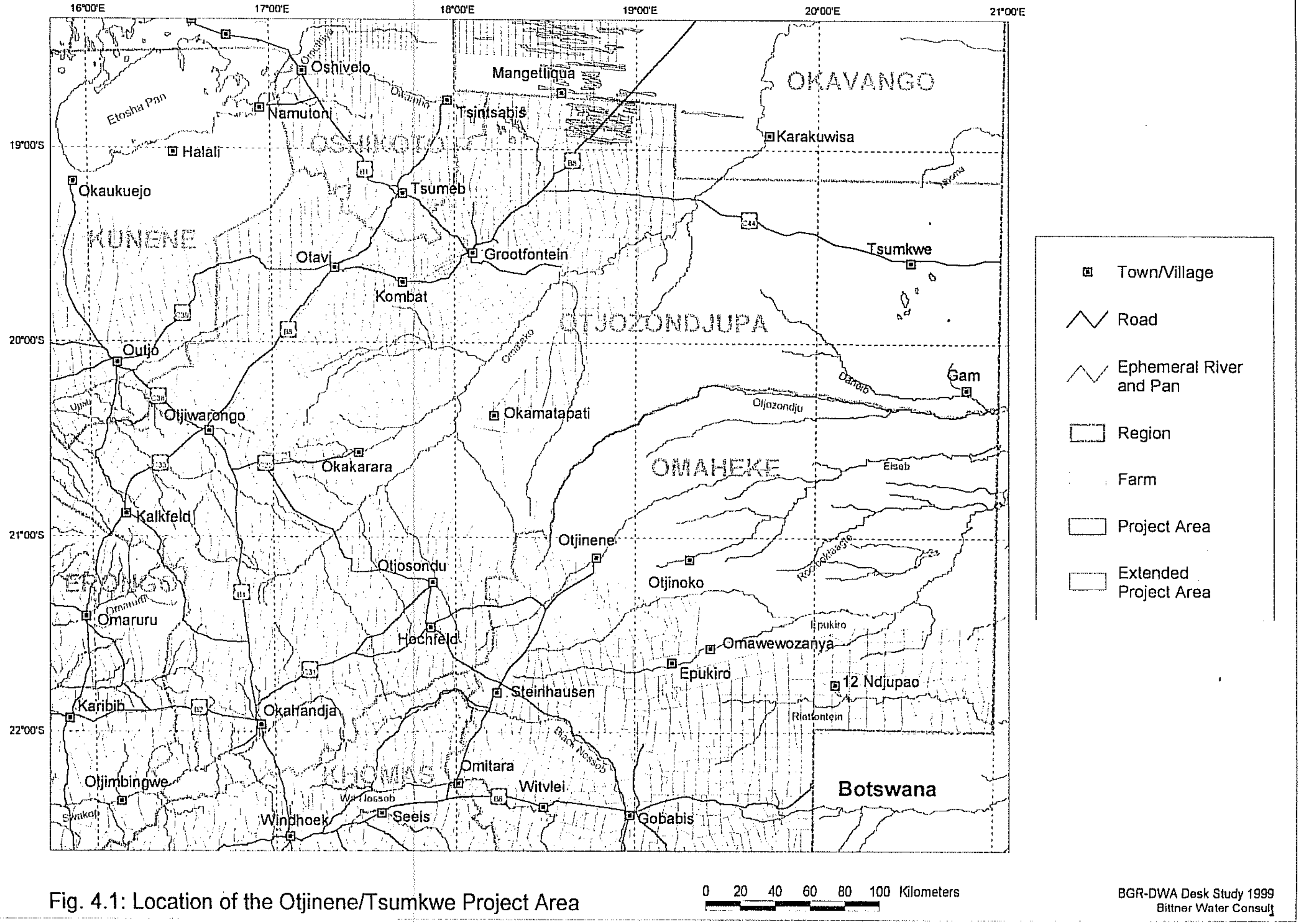

Fig. 4.1: Location of the Otjinene/Tsumkwe Project Area

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4.2. Physiography

The climatic and the geological settings are comprehensively described by Leo Hatz (1991 and 1993), and Interconsult (1995) and summarised by (Lloyd 1995). Most of the comments on the physiography and geological setting in this report are derived from these earlier studies, in particular from the Lloyd report.

4.2.1. Climate

The climate of the project area is semi-arid and the climatic region is defined as Hot Steppe, according to the Koeppen system. A rainfall station exists at Epukiro Post 10, a NamWater supply scheme just outside the southwestern border of the Project Area (Fig. 4.1).

The hottest period of the year is from December to January when average daily maximum temperatures reach 35° C, on average the maximum daily temperature exceeds 30° C for some 150 days per year. In July, which is the coldest month, temperatures can drop to 0° C or just below. The average daily minimum temperature during July is 4-5° C.

Humidity is low, with an annual average relative humidity of 40 % and a diurnal range of 25 %.

Potential annual average evaporation is calculated as being between 2,750 and 3,000 mm, keeping with the high temperatures. Regional maps of monthly potential evaporation are available.

Rainfall increases generally in a northeast direction. However, due to the unfavourable morphological conditions, i.e. the flat terrain and the relatively low elevation, the average annual rainfall in the Project Area is generally only between 300 mm and 400 mm, and is therefore less than the average annual rainfall at Epukiro Post 10 (400 mm), which is situated southwest of the Project Area but at higher elevation. Only in the Tsumkwe District the average annual rainfall increases to values between 400 mm and 500 mm.

The main precipitation period is November to April. Drought frequency analyses (Leo Hatz, 1993) indicate that there is a 42 % chance that rainfall will be less than 80 % of the mean, while there is a 25 % chance that 60 % or less of the mean annual precipitation will occur in any year. There is a 10 % chance that these expectancy figures can occur over three consecutive years.

4.2.2. Topography

The Project Area can be subdivided into three sub-basins, the Eiseb Basin south of Gam, the Kavango Basin northeast of Tsumkwe and the Omatako Basin in the northwest.

In the south, the surface elevation drops with a gradient of 0.01 between Ovinjuru (~1,550 m a.m.s.l.) in the southwestern corner of the Project Area and the origin of the Omuramba

Rooiboklaagte (~1,250 m a.m.s.l.). From there to the so-called Eiseb Graben near the Botswana border (~1,050 m a.m.s.l.) the gradient is more flat, in particular in the central part of the Project Area, where the gradient is approximately 0.0015.

In the north the surface drops gently from the water shed area between Tsumkwe and the Omuramba Omatako (~1,220 m a.m.s.l.) towards the Omuramba Omatako in the north and the Botswana border in the east (~1,100 m a.m.s.l.).

4.2.3. Drainage

There are no perennial rivers in the area and the only known spring is at Gam. No flow gauging stations exist.

Ephemeral rivers, so-called omiramba drain towards the basin centres in an easterly direction. The omiramba Otjozondu, Eiseb, Alexeck and Epukiro originate in the higher elevated areas of the Damara Orogeny, in the Steinhausen-Hochfeld-Summerdown triangle, approximately 300 km southwest of Gam (Fig. 4.1). In the upper catchment areas the omiramba are deeply incised into the bedrock and the well-defined channels often expose outcrops of the Damara basement. Towards the basin centre the omuramba channels are less prominent due to the lower gradient and consist of a series of depressions. East of the Botswana border the river courses become less defined and often end in a series of pans. It is believed that during climatically different Tertiary times the omiramba drained in form of perennial rivers into the endoreic Okavango Delta basin.

The omiramba Daneib and Nhoma originate in the watershed area between the Omuramba Omatako and the Omuramba Eiseb and drain towards Gam and the Okavango River respectively.

Runoff occurs frequently in the upper catchment areas of the omiramba but the floods usually do not reach the lower omuramba drainage, where local runoff after rainfall events results in the development of ponds and water filled pans from which most of the water is evaporated.

4.3. Water Demand

In 1990, the total population of the Tsumkwe District was estimated to be approximately 4,000 people. At a growth rate of 2.3 % about 4,900 people would populate the Tsumkwe District in 1999 and the projected population would be approximately 7,100 in the year 2015. A field survey carried out in 1990 as part of a groundwater investigation in the former Bushmanland showed that there are only 865 cattle (LSU) and 420 goats (SSU) in the area (NGDC, 1992). No recent figures are available but it is not assumed that the number of livestock has drastically increased.

More recent data is available from the Gam and Eiseb blocks in the Omaheke Region (App. 3.2). A population breakdown for the respective areas in the year 1997 is presented in the 1997/98 annual report of the MLRR. A total number of 2,387 and 593 people were counted in the Gam and Eiseb blocks respectively. A number of 762 people were counted at Gam Centre alone.

Table 4.1: Estimated present water demand in the Tsumkwe District

Consumer	No	Unit Cons.	Demand 1999			
		l/day	[m³/hour]	[m³/day]	[m³/month]	[m³/annum]
Population	4,900	25	5.1	123	3,675	44,100
LSU	1,000	45	1.9	45	1,350	16,200
SSU	500	8	0.2	4	120	1,440
TOTAL			**7.2**	**162**	**5,145**	**61,740**

Table 4.2: Predicted future water demand in the Tsumkwe District

Consumer	No	Unit Cons.	Demand 2015			
		[l/day]	[m³/hour]	[m³/day]	[m³/month]	[m³/annum]
Population	7,100	25	7.4	178	5,325	63,900
LSU	2,000	45	3.8	90	2,700	32,400
SSU	1,000	8	0.4	8	240	2,880
TOTAL			**11.6**	**276**	**8,265**	**99,180**

After the conclusion of the repatriation programme of Herero speaking people from Botswana a total of 2,986 people were registered as new Namibian citizens and distributed in the Gam and Eiseb block areas (MLRR, 1998). An estimated 7,000 head of LSU and more than 5,000 head of SSU accompanied the repatriated farmers. Originally it was planned to repatriate more than 4,000 people and 50,000 head of livestock (DWA, 1994). The project was stopped because of the insufficient water resources in the area.

An independent evaluation, carried out by a Consultant of the DWA, recommended the stop of the repatriation project in the area because, according to him, the available groundwater resources in the Gam and Eiseb block areas are not sufficient to provide the additional 2,500 m³/day, required for the repatriation project (Lloyd, 1995).

Table 4.3: Estimated present water demand in the Gam and Eiseb Blocks

Consumer	No	Unit Cons.	Demand 1999			
		[l/day]	[m³/hour]	[m³/day]	[m³/month]	[m³/annum]
Population	2,980	25	3.1	75	2,235	26,820
LSU	15,000	45	28.1	675	20,250	243,000
SSU	10,000	8	3.3	80	2,400	28,800
TOTAL			**34.5**	**830**	**24,885**	**298,620**

The total number of livestock in the Gam and Eiseb Block areas is not known. A total of 200,000 LSU and 110,000 SSU were counted in the Otjinene and Okakarara Districts at the time of the inventory in 1990 (LHC, 1993). areas. Most stock was found to be heavily concentrated around available water points in the southwestern and southern areas, outside the Project Area and it is estimated that not more than 15,000 LSU and 10,000 SSU are present in the Gam and Eiseb blocks.

A total of 830 m^3/day is required to supply in the present demand of the population and the livestock in the Gam and Eiseb Block areas. For comparison, the combined sustainable yield of all equipped boreholes drilled during the 1994 – 1995 drilling programme for the MLRR in the Gam Block and the Eiseb Graben area is 490 m^3/day.

The future demand cannot easily be estimated and depends on the possible migration of people and livestock. The carrying capacity of the vegetation suite is with 8-10 ha/LSU or 10 LSU/km^2 similar to that in the Oshikoto Region (Leo Hatz, 1993). The Gam and Eiseb Block areas could therefore sustain about 130,000 LSU, which alone have a water demand of 5,850 m^3/day (2.1 Mm^3/annum). This amount of water is not available from local groundwater resources (par. 4.4.4) and the only alternative would be the import of freshwater from the Karst Area or the Okavango River via a pipeline network. The pressure from population in the overgrazed upper catchment areas where most of the livestock is concentrated to move into the undeveloped grazing areas in the east is high, and the DWA is forced to annually drill expensive and mostly unsuccessful boreholes in the remote grazing areas.

4.4. Hydrogeology

4.4.1. Geology

The Geology in the Project Area comprises Precambrian to Recent age rock types. The geological succession is summarised in Table 12 and the surface geology within the Project Area is presented in Fig. 4.2.

Table 4.4: Geological succession in the Project Area

Age	Sequence	Lithology
Recent		Sandy soil, sand, silt and clay
Cretaceous to Quaternary	Kalahari	Aeolian sand, sandstone, calcrete, silcrete and interbedded clay
Carboniferous to Jurassic	Karoo	Basic intrusives and basalt
Namibia	Damara	Phyllite, schist, carbonate, quartzite and granite
Mokolian	Grootfontein Metamorphic Complex	Porphyritic granite, metabasite dykes, metagabbro, schist, quartzite, calc-silicate rock, hornblende gneiss, amphibolite

The Grootfontein Metamorphic Complex, which is exposed locally in the vicinity of Tsumkwe, comprises following rock types: Coarse-grained, porphyritic, gneissose hornblende-biotite granite and diorite; aplite and metabasite dykes; metagabbro; schist, quartzite, calc-silicate rock, hornblende gneiss and amphibolite.

The Damara Sequence underlies most of the Project Area. Dominant rock types are phyllite, schist, marble and quartzite. Damara marble is exposed in the Ahaberge area some 60 km north of Gam and locally at Gam. Isolated outcrops of marbles occur in the Otjozondu, Eiseb and Rooiboklaagte catchments. Phyllite crops out in the small area around Nama Pan. Quartzite of the Nosib Group is exposed in the area between Tsumkwe and Sikereti. Precambrian granite is locally exposed southeast of Tsumkwe and in the Rooiboklaagte catchment.

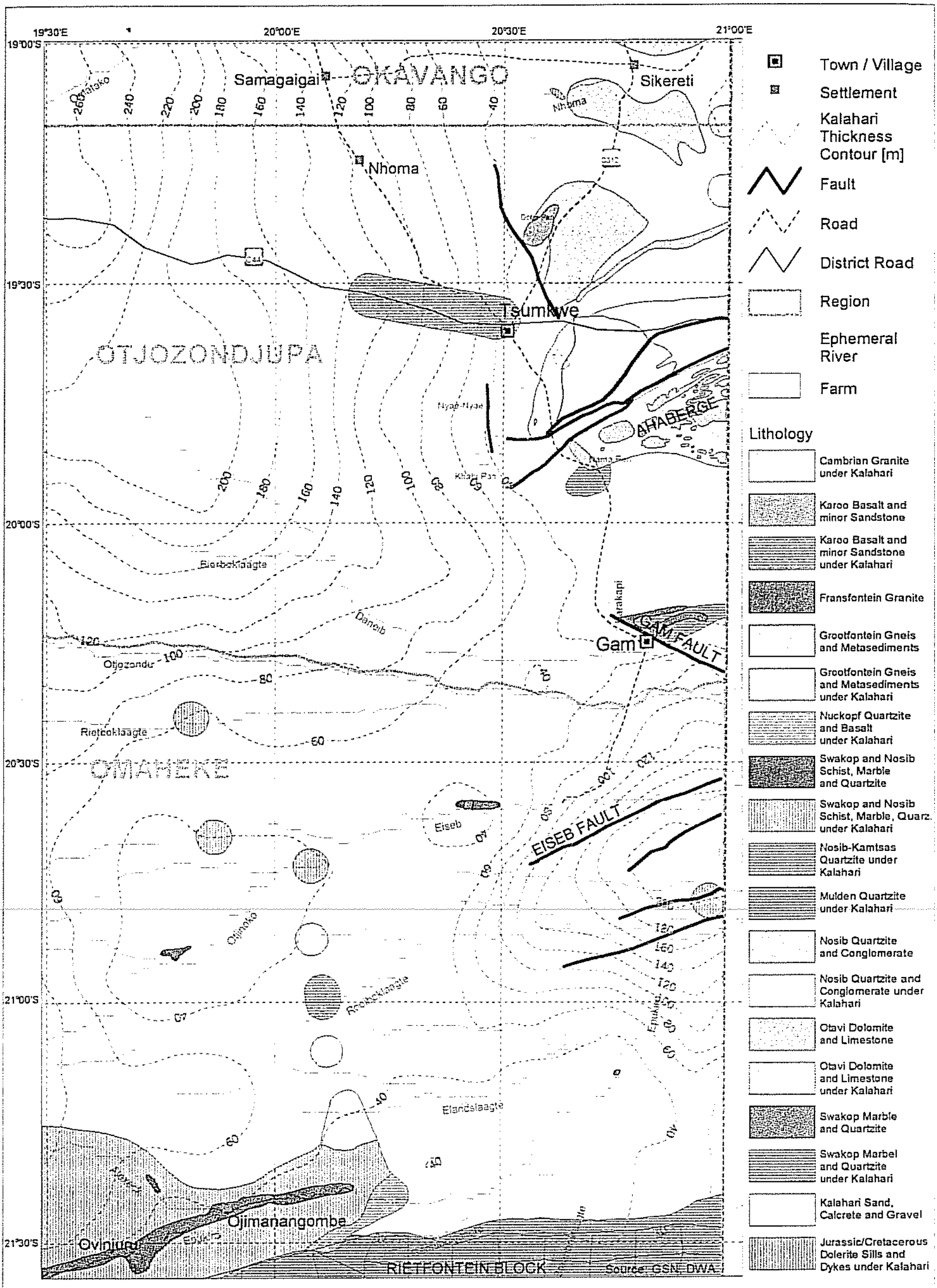
The only known outcrop of Karoo age basalt is at Dobe Pan, north of Tsumkwe. Sub-outcrops, encountered during drilling are reported from the area around Tsumkwe and from the immediate north and south of Gam. No sedimentary units of Karoo age have been identified in the area, although red clay encountered at the Precambrian interface may be of Karoo age (Leo Hatz, 1993 and Interconsult, 1999). A similar situation exists in the Rundu area, in the Kavango Region, where red clay overlies Karoo age basalt. At Rundu, the red clay is interpreted as weathering product of the basalt.

The Kalahari Sequence extensively overlies the older rocks and may exceed a thickness of 250 m in the Eiseb Graben. Geophysical investigations carried out for borehole siting in the Eiseb Graben indicated a much greater Kalahari thickness of up to 750 m (Interconsult, 1995), but none of the subsequently drilled boreholes was drilled to depths > 250 m, and these depths are therefore not confirmed. The Kalahari Sequence is regionally divided into lower, middle and upper units with the following general lithologies:

Upper Kalahari	⇒	aeolian sand
Middle Kalahari	⇒	sand, sandstone, silcrete and calcrete
Lower Kalahari	⇒	mudstone, siltstone, sandstone and consolidated gravel

The middle and upper units are variably exposed throughout the area. The lower unit has been encountered in boreholes in the immediate vicinity of Gam and may be present in down faulted blocks in the lower Eiseb catchment and in the Kalahari trough northwest of Tsumkwe.

Recent deposits in form of a thin but extensive veneer of soil and hill wash material occur throughout the area. Sand dominates in topographically higher areas (dunes) with silty clay in depressions (interdunes).



0 10 20 30 40 50

Kilometers

Fig. 4.2: Geological Map of the Otjinene/Tsumkwe Project Area

The Precambrian sequences were deposited in a geosynclinal environment and subsequently, heavily deformed and metamorphosed with a resultant northeast-southwest fabric. The fabric represents the major Precambrian fold and thrust trend of the Damara Orogeny. The Damara basement rocks were subjected to uplift and erosion prior to the Carboniferous when deposition of the Karoo sediments occurred regionally. During the Jurassic, Karoo basic intrusion occurred along northwest trending discontinuities and the Karoo basalt was extruded.

In the Cretaceous a major intra-continental basin developed extending form Zaire to the northwestern Cape Province in South Africa and the deposition of the dominantly fluvial Kalahari Sequence occurred.

During the lower to middle period of the Kalahari deposition the northwest trending fracture zones were reactivated and faulting created a major down-faulted block of Kalahari sediments to the immediate south of Gam. Similarly, reactivation of southwest trending faults created depositional troughs in the Eiseb catchment close to the Botswana border (Fig. 4.2).

A major land surface developed during the late Tertiary to early Quaternary, sloping gently eastwards in Omaheke with northeasterly to easterly drainage, a topographic pattern that is still maintained. A period of extensive silcrete and calcrete development of the middle Kalahari sandstone unit occurred under progressive aridity with easterly trending longitudinal dune development in the upper Kalahari period. Calcrete was also developed over basement rock exposures at this time.

The dunes have become stable and have controlled the surface drainage pattern. In the shallow valley sides the silcrete-calcrete land surface has been slightly incised and incipient karstification of the calcrete has occurred. In the Damara outcrop areas some dissolution of the calcretised bedrock has occurred to produce small depressions and pans.

The dunes have been structurally displaced in the Eiseb catchment close to the Botswana border by Recent movements related to tectonic adjustment along the dominant southwesterly faults. The shallow valleys have become partially filled by hill wash and aeolian sand with the consequence that distinct watercourses are absent in the lower catchment area.

4.4.2. Aquifer Distribution

The main identified aquifer in the Project Area is the Tsumkwe Aquifer. The aquifer is bound by bedrock outcrop along the Botswana border in the east, by the Gam Fault and the Ahaberge outcrop in the south and the Omuramba Omatako in the west (App. 3.3). The aquifer extends far into the Kavango Region, where the Kalahari Aquifer increases in thickness towards the Omuramba Omatako (NGDC, 1991).

The other identified primary aquifer within the Project Area is located between the Omuramba Eiseb in the north and the Omuramba Rooiboklaagte in the south, adjacent to the Botswana border. The western border of the aquifer is not properly defined due to a lack of borehole information in this area (App.3.3). Four sub-parallel regional faults originating in the area of the Okavango Swamps in Botswana and trending southwest across the Namibian border through the Project Area control the geometry of the Eiseb Graben (Fig. 4.2). The lateral extent of the Eiseb Graben Aquifer (EGA) is yet unknown but exceeds 1,200 km^2 (Interconsult, 1996).

The geophysical investigation along the 20° E longitude between the Eiseb and Rooiboklaagte omiramba, carried out by the CSIR in 1981, revealed a low resistivity layer at depths deeper than 200 m and was interpreted it as being part of the Karoo Sequence. The low resistivity layer could, however, as well represent clay rich layers of the Lower Kalahari Aquifer, which could be related to the Eiseb Graben (Fielitz, in prep.). There is, however, no evidence from drilling that the EGA extents further west than to the 20°30' E longitude.

The EGA was identified by earlier drilling but was more systematically investigated as part of the Herero Repatriation Project of the MLRR. Ten boreholes were drilled to depths between 160 m and 200 m. The lithology was described as fine grained sand, sandstone, clayey silt, calcrete, minor silcrete and minor gravel, which could be related to the Middle and Lower Kalahari groups (par. 4.4.1). None of the boreholes reached bedrock. The aquifer is unconfined with a water table at depths between 120 and 150 m b.g.l. (App. 3.10).

The by far largest amount of groundwater of the Omuramba Eiseb catchment is contained in bedrock structures. Secondary bedrock aquifers supply about 95 % of the boreholes drilled in the former East Hereroland (LHC, 1993). The aquifers are associated with tectonic structures, syn and post tectonic intrusions and karstic limestone or dolomite units within the Damara Sequence. The detection of the secondary water bearing structures beneath thick layers of unsaturated Kalahari sediments showed to be extremely difficult resulting in a very low success rate. Only areas with a thin Kalahari cover (< 40 m) and a relatively shallow depth to the water table within the bedrock (< 40 m) can be considered as aquifers with development potential, because standard geophysical and hydrogeological borehole siting methods can be applied with a degree of confidence in the results.

In Appendix 3.8 an attempt is made to identify areas of groundwater potential by showing the position of the piezometric level relative to the bedrock topography in conjunction with the thickness of the Kalahari cover. Yellow to blue coloured areas indicate that the piezometric level is within the Kalahari. If the aquifer is unconfined the colours represent the thickness of the saturated Kalahari. The brown colours represent areas where the piezometric level is within the bedrock. Good groundwater potential can be expected in areas with saturated Kalahari (Tsumkwe Aquifer and

Eiseb Graben Aquifer) and in areas where the piezometric level is within the bedrock (< 40 m), but where at the same time the Kalahari thickness is less than 40 m.

The lower Omuramba Epukiro catchment, located at the southern margin of the Eiseb Block, was identified during earlier studies (Leo Hatz, 1993) as such a possible aquifer, which could be worthwhile to be investigated. In this desk study the aquifer is defined as Lower Epukiro Aquifer (App. 3.3). Other areas of local groundwater development potential are the marble and granite sub-outcrops between Gam and Tsumkwe and the quartzite outcrops northeast of Tsumkwe (Fig. 4.2). Unfavourable are areas with the piezometric level deep in bedrock (dark brown) and additionally a thick Kalahari cover (> 40 m).

4.4.3. Water Quality

Groundwater quality in the Project Area is generally suitable for domestic consumption, with the majority of samples classified as A- and B-Class according to the DWA classification system for drinking water standards in Namibia.

Vogel, 1974, carried out isotopic dating studies on water from 39 boreholes distributed throughout the Otjinene District. In his findings he concluded that there is no clear pattern in the groundwater ages and hydrochemistry in the area. Evolutionary hydrochemical trends do occur from the basin margins toward the central trough but there are many inconsistencies.

Isolated and without clear pattern some elevated values for salinity are reported (App. 3.4). In the Tsumkwe area the higher salinity is confined to the vicinity of pans, e.g. the Dobe Pan, some 25 km northeast of Tsumkwe.

High sulphate concentrations, C-Class and D-Class, are found in boreholes drilled near the upper and middle catchments of the omiramba (App. 3.5). High sulphate is an indication for stagnant groundwater conditions. It is therefore assumed that runoff water in the ephemeral rivers does not contribute significantly to the recharge of the Kalahari and bedrock aquifers. A similar hydro-chemical situation is known from Epukiro Post 3, the NamWater scheme just outside the south-western corner of the Project Area. High sulphate water (C-Class and D-Class) is confined to the boreholes drilled into the Omuramba Epukiro channel, while boreholes drilled into Kalahari cov-ered bedrock only a few hundred metres away from the omuramba is of excellent quality (Bittner, 1993).

The findings of the sampling and analysing of 46 boreholes in the Tsumkwe District, the former Bushmanland, revealed that most of the groundwater there is of excellent or good quality (Huyser, 1981). Boreholes drilled in the vicinity of major pans showed locally higher salinity and sulphate values, e.g. at Dobe Pan, northeast of Tsumkwe.

Except from an anomaly in the upper catchment area of the Omuramba Daneib, which could be related to local natural enrichment within the Kalahari sediments, nitrate is generally A-Class (App. 3.6). The rest water level in the upper Daneib catchment is deep and antropogenic pollution is not considered to be the reason for the anomaly, which was already recognised in earlier studies (Huyser, 1981).

Some boreholes in the vicinity of Tsumkwe and further towards northwest show C-Class fluoride concentrations (App. 3.7). The reason for this isolated fluoride anomaly is unknown but could be related to the Karoo basalt, which underlies the Kalahari sediments at depth (Fig. 4.2).

4.4.4. Recharge and Groundwater Flow

The likelihood of active groundwater recharge by rainfall in the Kalahari is widely debated. The most common result of the various investigations is that infiltration, both from direct precipitation and runoff ponding, is taken up by evapotranspiration and the recharge into and through the Kalahari Group is minimal (Lloyd, 1995). It is widely accepted that direct recharge occurs, where bedrock or calcrete surfaces are exposed. In the Project Area this is the case northeast and southeast of Tsumkwe where quartzite, phyllite and marble of the Damara Sequence are exposed. In the basement outcrop areas north of Gam a calcrete surface has developed where recharge is possible along old dissolution features indicated by depressions and pans.

An attempt was made in an earlier study to estimate a hydrological balance for the regional basin. The Gam outcrop in the north, the shallow Rietfontein sub-outcrop in the south and the Omuramba Epukiro were considered to be the main recharge areas. Depending on the transmissivity values applied the total amount of recharge to the Kalahari basin in the Otjinene District was calculated as being between 0.4 Mm^3/annum and 1.2 Mm^3/annum (Leo Hatz, 1993). This figure, however, can only be seen as a first rough estimate and without extensive recharge studies comprising various techniques such as isotope chemistry, soil moisture, hydrometeorology and regular water level monitoring, no tenable recharge data are available (Lloyd, 1995).

The piezometric level above mean sea level generated from collar elevation and static water level data is presented in Appendix 3.9 and Appendix 3.10. The accuracy of the plot is dependent on the estimates of collar elevations from the 1:50,000 topographic maps. In spite of this constraint, the topography of the piezometric surface clearly indicates the main directions of groundwater movement.

The main regional flow characteristic, suggested by the piezometric level map, is the throughflow into the southern sub-basin of the Project Area predominantly along bedrock geological strike from the southwest. The Kalahari is dewatered in the central and southwestern parts of the Project Area (App. 3.8). Throughflow from the Gam area in the north and from the Rietfontein Block in the south across geological strike is considered to be a minor component, reflected by the steeper water table gradient close to the Eiseb Graben. Outflow from the basin occurs through the bedrock trough into the deep Eiseb Graben across the Botswana border. The piezometric level tends to mimic that of the bedrock topography (App. 3.9).

The groundwater head in the Eiseb Graben is with 925 m a.m.s.l. similar to or even below the level of the Okavango Delta, which is considered to be the discharge area during pluvial periods. Due to the depletion of the Kalahari sediments during the ongoing semi-arid conditions within the sub-continent, the groundwater flow system is almost dormant and, near the perennial rivers, reversed. The perennial Okavango River is no longer fed by groundwater as it was the case during pluvial periods, and the flow is directed away from the river into the depleted Kalahari sediments. The flow of the remaining groundwater, recharged through bedrock outcrop along the basin margins, is within fractured bedrock towards deeper parts of the basin, where the groundwater is collected in tectonic graben structures (See also Leo Hatz, 1993).

Potential recharge areas are located in the southwestern border of the study area, in the upper catchment of the Omuramba Epukiro, in the lower catchment area of the Omuramba Epukiro between the Rietfontein Block and the Eiseb Graben and in the unconfined outcrop areas of the Ahaberge between Tsumkwe and Gam. It is assumed that direct recharge into the unconfined middle and upper Kalahari sediments occurs in the Tsumkwe area where depth to the water table is less than 10 m (App. 3.10) and where the average annual rainfall is between 400 and 500 mm.

The flow from this water table "mount" in the Tsumkwe area is in all directions, but the main flow is in a northern and eastern direction towards the Omuramba Omatako and the Kaudom Game Park and from there further towards the Okavango River drainage system. The water divide between the Eiseb and the Omatako catchments follows a northeast trending line between Nhoma and Samagaigai in the northwestern part of the Project Area, while the water divide between the Okavango and Eiseb catchments is directed towards the Botswana border and follows a line between Tsumkwe and Gam (App. 3.9).

The flow to southern directions towards the Omuramba Daneib is characterised by steeper gradients caused by the flow across the geological strike and groundwater barrier effects of the northwesterly trending Gam Fault and northeasterly trending faults north of the Ahaberge (Fig. 4.2). The Gam contact spring is situated on the Gam Fault and is fed by the flow from the recharge area in the north.

4.4.5. Aquifer Potential

The Tsumkwe Aquifer is the aquifer with the highest potential in terms of sustainability, yield and economical utilisation within the Project Area. As a consequence a number of State Water Schemes were established by the DWA along the main road between Grootfontein and Tsumkwe, which were subsequently taken over by NamWater in 1997 as Water Supply Schemes. The water level / production graph of one of the production boreholes of the Tsumkwe Water Supply Scheme is presented as an example for the aquifer behaviour in Fig. 4.3. The rest water level fluctuates between 5 and 8 m b.g.l., and regular recharge occurs, e.g. in the 1993/94 and 1996/97 rainy seasons. The abstraction from the borehole does not significantly effect the water level, thus confirming the potential of the Tsumkwe Aquifer. The shallow pump water level indicates a good borehole efficiency.

Due to the porous nature of the Tsumkwe Aquifer, borehole siting is not a critical factor and successful boreholes depend mainly on drilling depth and a proper borehole design. The yields are sufficient to meet the rather limited actual and future demand of the local population (App. 4.2).

The potential of the EGA is not fully investigated yet. Test pumping of the nine successful boreholes drilled for the MLRR in 1996 indicated sustainable abstraction rates of 12 – 36 m^3/day for each borehole. The water table is very deep, which resulted in pump installation depths between 145 and 185 m. The viability of the exploitation of the resource is therefore questionable.

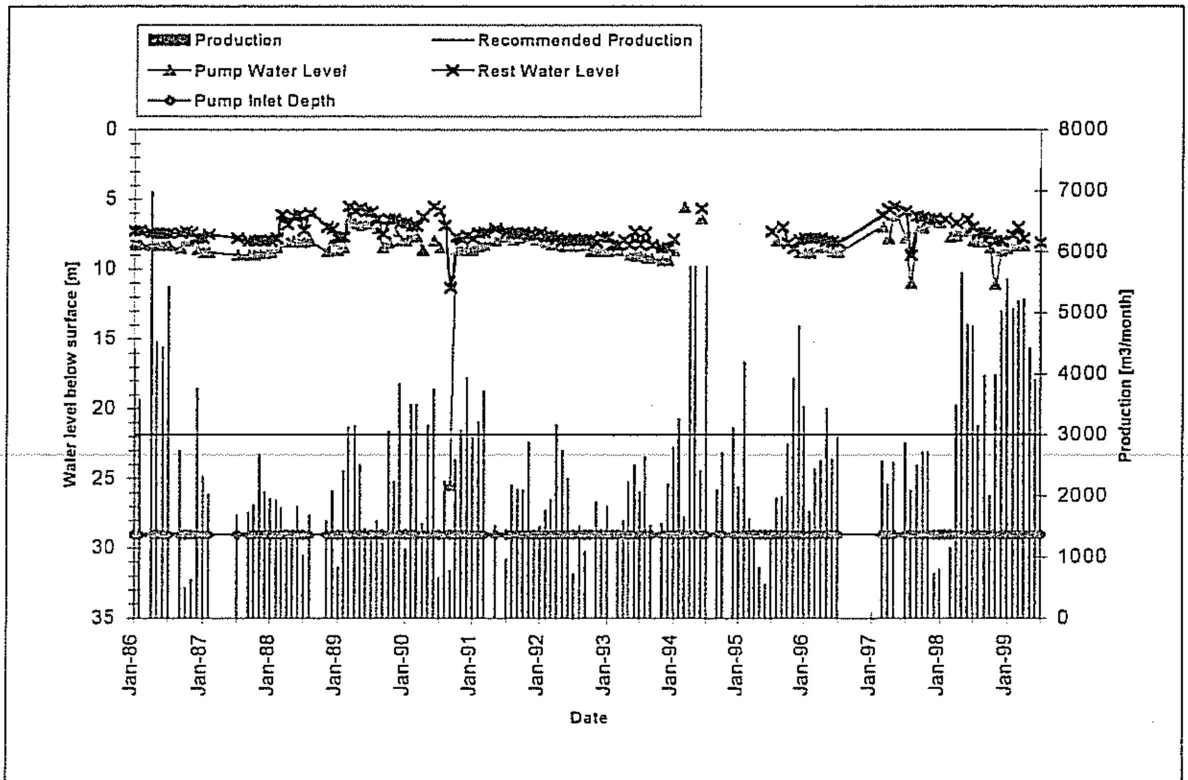


Fig. 4.3: Water level/production graph of NamWater production borehole WW16561 at Tsumkwe

In addition, recharge conditions do not suggest long-term sustainability and it must be concluded that the long-term groundwater resources of the EGA do not appear to be promising. In any case the resource could not be exploited to supply on a regional level but rather for the supply to small stock farming communities.

The potential of the bedrock aquifers is rather low compared to the primary aquifers mainly due to low drilling success rates. More than 35 % of all boreholes drilled in the former Hereroland East are reported to be "dry" (HHO, 1993). A thick cover of unsaturated Kalahari sediments, which often function as confining layers, complicates or prevents the exploration of potential water bearing bedrock structures by applying conventional geophysical techniques.

Out of 83 boreholes drilled in the Gam block for the MLRR in 1995 only 19 were successful and yielded more than 1 m^3/h. The only high yielding borehole was drilled in the Ahaberge, where the bedrock is exposed and the water table is shallow. Other areas with similar conditions and therefore higher potential are the lower Epukiro catchment and the quartzite outcrops northeast of Tsumkwe (App 3.3). The bedrock aquifers are not of regional importance and can only sustainable supply for small local communities.

4.5. Gaps of Knowledge Regarding Groundwater Resources

The groundwater potential of the Gam Block is regarded as generally very low. Even if there are still gaps of knowledge regarding aquifer distribution and recharge pattern, it is suggested to focus future studies on areas where at least some groundwater potential can be expected.

This is mainly the case in areas where the saturated Kalahari is more than 50 m in thickness and where the aquifer parameters are of such quality that substantial amounts of water could be abstracted. In the south of the Project Area this is only the case in the Eiseb Graben (App 3.8).

The thickness and lateral extent of the EGA is yet not fully explored. Deep exploration boreholes are needed to assess the groundwater potential of the deeper Kalahari. The down-faulted basement structure investigated by the CSIR along the 20°30' Longitude may well be an extension of the Eiseb Graben and should be included in future investigations.

The results of a geophysical investigation as proposed in the BGR review on geophysical projects carried out in the area (Fielitz, in prep.) could be utilised for extrapolation into larger areas after correlation with the drilling results. The airborne and ground geophysical data could provide additional information on possible water-bearing linear structures within the underlying bedrock and under certain circumstances also on similar structures within the Kalahari Sequence.

Information on the depth to the non-magnetic bedrock in general is available only in certain areas where boreholes were drilled deep enough to reach bedrock and where reliable records were kept.

Within the Project Area this is the case only in the Gam Block, where most of the boreholes drilled during the MLRR project in 1994 reached bedrock. Airborne geophysical techniques as described in the geophysical BGR report (Fielitz, in prep.) could be applied to map the bedrock topography in more detail than indicated in Appendix 3.9.

Not much is known on the Lower Epukiro Aquifer, adjacent to the Eiseb Graben in the north. A few good yielding boreholes were drilled into granitic and quartzitic bedrock. The rest water level is shallow and it seems as if the relatively thin Kalahari cover is partly saturated. The lower Epukiro catchment is outlined in Appendix 3.3 as a potential aquifer and should be included as a target for future investigations.

There are many unknown factors with regard to the Tsumkwe Aquifer in the northern part of the Project Area, such as aquifer parameter and aquifer thickness. However, the water demand of the local population is relatively low due to the traditional way of living (hunting and gathering, very limited livestock farming) and borehole siting is mostly unproblematic because of the porous nature of the aquifer and the good borehole yields (App. 3.3). There are no major water supply problems foreseeable in this area and additional geophysical and/or hydrogeological work is at this stage not deemed necessary.

4.6. References

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