Water supply of the Etosha National Park

The Etosha National Park, Namibia's best known tourist attraction, is one of the largest nature reserves in Africa, comprising an area of 22 270 km^2. The unique hydrogeological setting with 50 to 60 permanent springs, mostly contact springs situated along the southern rim of the Etosha Pan, has attracted man and wildlife throughout history.

Today, boreholes tapping groundwater from various aquifers supply most of the waterholes frequented by game, as well as the tourist camps. Many contact springs have dried up because the water table was lowered by pumping. Most of the waterholes are supplied by groundwater from the calcretes of the Unconfined Kalahari Aquifer (UKA_{EL}). The calcretes cover the entire area south and west of the Etosha Pan. The calcrete groundwater quality is of Group A and B, i.e. suitable for drinking, only in the western and southern park area, declining to Group D, suitable only for wildlife and road construction, towards the southern rim of the Etosha Pan. Alternative groundwater resources had to be developed at greater depths for the three rest camps.

At Okaukuejo, groundwater of Group B quality from a quartzitic horizon of the Mulden Group (MGA) is tapped to supply drinking water, while the Group C water of the calcretes is used for landscape gardening, the waterhole and the swimming pool.

At Halali, poor quality groundwater from the calcretes is pumped from the Klein Halali wellfield to the reservoir, where it is mixed with fresh groundwater of the Otavi Dolomite Aquifer (ODA) from the Renosterkom wellfield. This scheme is situated on a dolomite outcrop about 6 km south of Halali.

Drinking water for Namutoni is supplied by a wellfield at the Lindeque Gate 14 km east of Namutoni and taps groundwater from the Oshivelo Artesian Aquifer (OAA_{AN}). The well at Namutoni on the same aquifer is slightly brackish and can only be used to fill the artificial game-viewing waterhole and for the camp gardens. The combined water consumption of the 3 tourist rest camps was 0.5 Mm^3/a in 1994 and is met by the aquifers, but water conservation is necessary to cope with the growing demand in the future. A total of 41 000 day visitors and 193 000 overnight guests were recorded in 1998, giving a relatively high average water demand of 210 L/d per tourist.

A few waterholes for game watering in the west near Otjovasandu and south of the park at Ombika/Anderson Gate tap fresh groundwater (Group A) from calcretes, dolomites and quartzites. In contrast, the majority of the waterholes located in the central and eastern parts of the park provide brackish groundwater of Group C-D quality. Most of these do not meet the guideline values for human consumption and in cases exceed even those for livestock watering. The problematic parameters are TDS, sodium, chloride and sulphate. Poor quality water may also adversely affect wildlife.

K DIERKES

Wilhelm Struckmeier

Karstified dolomites close to the artificial water hole at Halali

Wynand du Plessis

The Etosha National Park – unique hydrogeological setting with 50 to 60 permanent springs

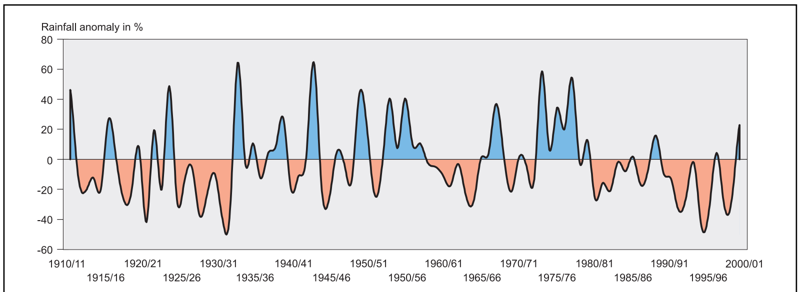
Otavi Mountain Land

The hydrogeological region of the Otavi Mountain Land comprises the northern Otjozondjupa, the southern Oshikoto and the south-eastern Kunene regions. It stretches from the Otavi, Grootfontein, Tsumeb triangle in the east along the southern rim of the Etosha basin and westwards to 70 km beyond Outjo.

The Otavi Mountain Land is a dolomitic massif rising up to 2 090 m asl, some 500 m above the surrounding plains as shown in this photograph west of Hoba. In the south there is a gentle slope towards Goblenz (1 250 m asl) and northwards to Oshivelo and Etosha Pan (1 080 m asl). The Otavi Mountain Land represents a watershed draining westwards into the Ugab River catchment, northwards into the Etosha Pan, south and eastwards into the Omatako Omuramba, a tributary of the Okavango River.

The area receives a mean annual rainfall of 540 mm, decreasing to 450 mm towards Outjo. The graph shows the deviation of annual rainfall sums, based on the average from 50 stations, from the long-term annual mean (1926 - 1992) from 1911 to 1999. The large variation in rainfall with time is evident and amounts to 50 - 60 % of the mean. It is clear that the Otavi Mountain Land mainly received below mean annual rainfall over the past two decades. The mean annual potential evaporation is between 2 800 and 3 000 mm. Due to a mean annual rainfall double that of the country as a whole (540 mm/a vs 270 mm/a) and good quality soils, this commercial farming area is important for cattle and maize production. Most of the region has been declared a “Groundwater Control Area”, underlining the national importance of its groundwater potential.

The area is also known for its high base metal potential, mainly copper, lead, zinc, silver and vanadium. The mines at Tsumeb, Khusib Springs and Kombat are operational, whilst those at Berg Aukas, Abenab and Abenab West have closed. The opposite table shows the characteristics of these mines and their potential to contribute to water supply. The ore bodies at depths of up to 1 800 m bgl are found along hydraulically favourable structures such as paleokarst cavities and fault conduits, and the mine water drainage rates can reach up to 12 Mm³/a. Some of this is purified and used for domestic water supply.



Deviation of the annual rainfall sums (average of 50 stations) from the long-term annual mean (1926-1992) for the time period from 1911 to 1999.

Dieter Plöthner

View, looking west, from Hoba over the dolomitic massif of the Otavi Mountain Land (Brandwag) rising above the surrounding plain where maize is grown

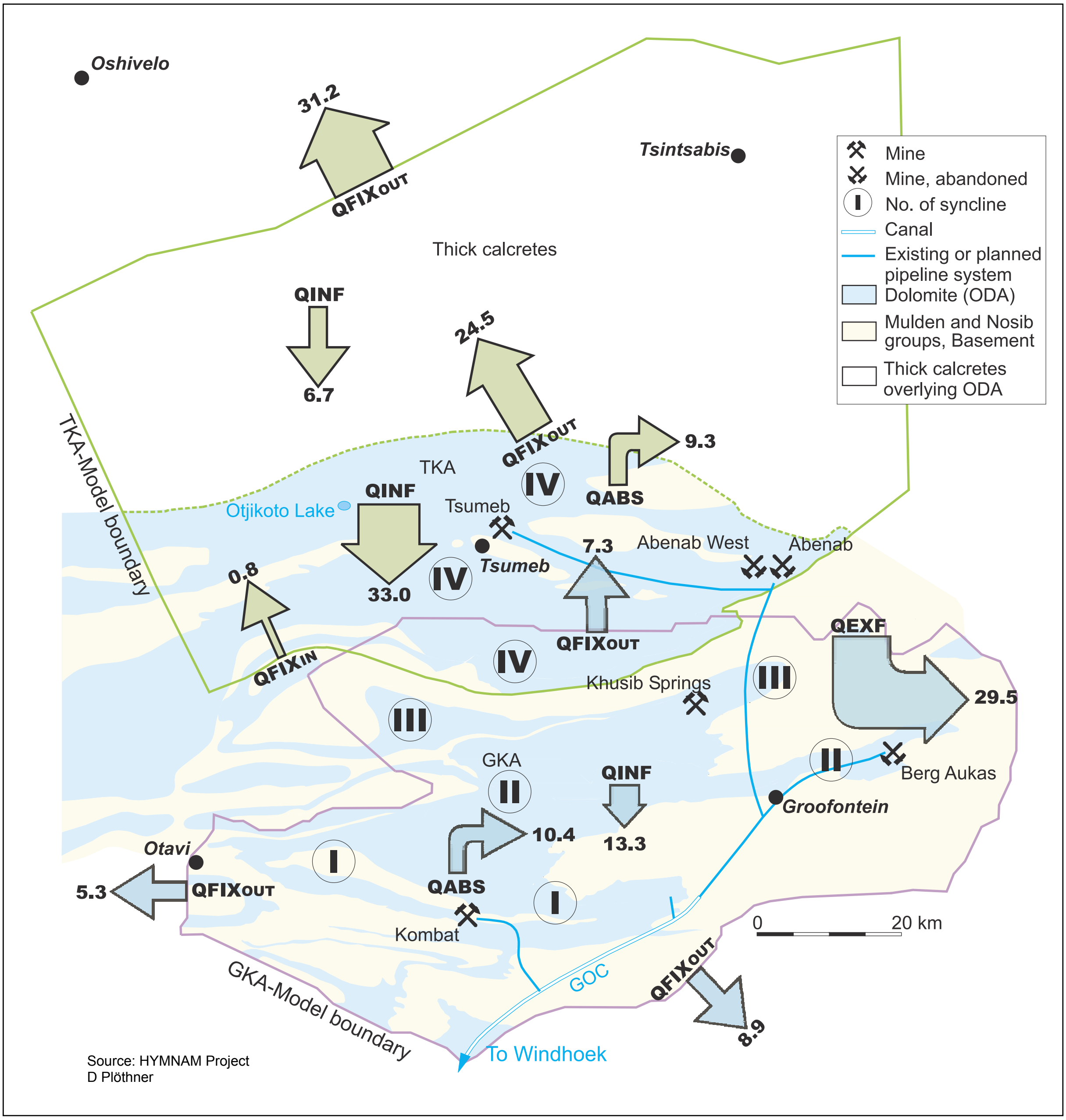
Geology

The Otavi Mountain Land lies on the northern shelf platform of the Otjiwarongo branch of the Damara Orogen. Approximately 6 000 m of sediments of the northern facies of the Damara Sequence have been accumulated on the granites and gneisses of the Grootfontein Basement Complex. The Proterozoic Damara Sequence consists of a basal arenaceous unit (Nosib Group, up to 1 500 m), a middle carbonate unit (Otavi Group, up to 3 000 m) and an upper clastic unit (Mulden Group, up to 1 700 m). The rocks of the Otavi Group have been stratigraphically subdivided into the Abenab and the Tsumeb subgroups and a number of Formations as shown in the table on stratigraphic succession. The dolomitic rocks contain interbedded layers of limestone, marl and shale. The strata were moderately folded during the Pan-African Orogeny (680 - 450 Ma) into several synclines and anticlines generally trending east-west evident in this map. From south to north, the three dolomite synclines are the Otavi Valley-Uitkomst (I), Grootfontein-Berg Aukas (II), Harasib-Olifantsfontein (III), and Tsumeb-Abenab (IV) synclinorium further north. The core of the synclines is filled with the low permeable rocks of the Mulden Group, whereas the anticlines reveal low permeable rocks of the Nosib Group and Basement.

The Kalahari Sequence is represented locally by a thin aeolian sand blanket and by calcretes which contain substantial amounts of silt and clayey material. The calcretes, in general, cover the low-lying groundwater discharge areas. They can be up to 20 m thick around Tsumeb, across the Nosib Anticline and the Basement high near Grootfontein, and up to 50 m thick near Brandwag/Uitkomst on the eastern tip of the Otavi Valley-Uitkomst Syncline (I). They widely cover the foreland where the thickness increases to 70 m towards the south and even 150 m towards the north.

Stratigraphic succession of the Otavi Mountain Land and its hydrogeological significance

System	Sequence	Group	Subgroup	Formation	Lithology	Average thickness [m]	Hydrogeological significance	
Quaternary, Tertiary	Kalahari (< 65 Ma)			**Karst Phase IV (34 000 to 14 000 a BP)**				
				Recent, Andoni	Aeolian sand, calcrete	20	Not considered	
				Disconformity (130-65 Ma), Karst Phase III				
Cretaceous, Jurassic, Triassic,	Karoo (300-130 Ma)			Rundu (Kalkrand)	Dolerite dykes in TKA	n/a	**Vertical Conduit**	
				Etjo	Aeolian sandstone	not pres.	n/a	
Permian, Carboniferous, Devonian, Silurian, Ordovician, Cambrian				Omingonde	Conglomerate, grit, mudstone	not present	n/a	
	Disconformity (550-300 Ma), Karst Phase II							
Namibian	Damara	Mulden (570-550 Ma)		Owambo	Marl, sandst., siltst., shale, limest., dolomite	not present	**Aquitard MGA**	
				Kombat	Phylitte, dolomite, conglomerate, shale	> 500		
				Tschudi	Arkose, grit, conglomerate, argillite	> 700		
		Disconformity (760-570 Ma), Karstic Phase I						
		Otavi (830-760 Ma)	Tsumeb	Hüttenberg	Dolomite, shale, chert	840	**Aquifer**	**O D A**
				Elandshoek	Dolomite	> 1200		
				Maieberg	Dolomite	180		
					Limestone, shale beds	700	**Aquitard**	
				Chuos	Quartzite, tillite, shale	200		
			Disconformity					
			Abenab	Auros	Dolomite, limestone	200	**Aquifer**	**O D A**
					Marl, shale	50	**Aquitard**	
				Gauss	Dolomite	750	**Aquifer**	
				Berg Aukas	Dolomite, limestone, shale	550		
		Disconformity (840-830 Ma)						
		Nosib (950-840 Ma)		Varianto (Ghaub)	Mixtite, quartzite	1200	**Aquitard**	
				Askevold	Phyllite, agglomerate			
				Nabis	Quartzite, arkose, conglom., schist, phyllite			
Mokolian		**Disconformity (1500-950 Ma)**						
		Grootfontein Basement Complex (Metamorphic Complex) (1580 Ma)			Granite, gneiss, shist, meta-gabbro (Grootfontein, Berg Aukas)	n/a	**Aquiclude / Aquitard at shallow depth**	



Generalised geological map of the Otavi Mountain Land and the boundaries of the GKA and TKA numerical models

Doleritic dykes and dyke swarms with a length of several kilometres are present in the Tsumeb-Abenab Synclinorium (IV). These intrusive bodies of Karoo age intruded open axial tension structures and follow a roughly north north-west to north north-east direction. Water strikes are mainly related to these directions.

Four karstification periods of the dolomitic rocks of the Otavi Group have been found. The first and oldest period of karstification is presumed to have lasted from 750 Ma to 650 Ma in a period of uplift and erosion. A second karstification period interrupted by glaciation and sedimentation lasted from 450 Ma to 280 Ma. The third karstification period occurred in early Tertiary (65 Ma). The last major phase of karst processes developed during the Pleistocene approximately 34 000 to 14 000 years ago. These are shown in the table on stratigraphic succession. The fractured dolomites are karstified near the surface over a wide area and locally covered by soil. Deep karstification (e.g. Dragon's Breath Cave, Harasib Cave, Otjikoto and Guinas lakes) and paleo-karst (Tsumeb, Berg Aukas) only occur locally. The Hüttenberg Formation is the most highly karstified dolomite unit in the Tsumeb area, especially where it is covered by rocks of low permeability of the Tschudi Formation. Experience from Tsumeb Mine provides evidence of widely varying transmissivity values that range from 10 to 6 000 m^2/d.

Dieter Plöthner

Olifantsfontein Spring with discharge gauge

Hydrogeology

The high groundwater potential of the Otavi Mountain Land (dark green colour on the Map) is evident in the high inflow of groundwater into the abandoned Berg Aukas, Abenab and Abenab West mines and the operating Kombat, Tsumeb and Khusib Springs mines, the large perennial springs such as Otavifontein (1 Mm^3/a), Olifantsfontein (0.3 Mm^3/a) and Strydfontein (0.1 Mm^3/a), and former flows from the now dry springs at Grootfontein and Rietfontein.

The major springs (depicted on the Map) are contact springs bound to the contact dolomite/bedrock (Nosib or Basement) and have a fairly constant discharge, which according to isotope data originate from recharge at higher altitudes.

The depth to groundwater is relatively shallow (20 m bgl) south of Guinas Lake, whereas it may be more than 100 m deep below the higher altitude recharge areas north of Kombat Mine and south of Tsumeb as indicated by the contours on the Map.

In the Tsumeb area, Karoo dyke systems are considered as vertical conduits ($T = 1\,200$ m^2/d) intersecting the entire multi-aquifer/aquitard system. The Tsumeb water supply wells are drilled into these structures.

The Kalahari calcretes do not form a major aquifer in the centre of the Otavi Mountain Land. Yields of 1 and 5 m^3/h have been reported for the area of the Nosib Anticline, however, with increasing distance from the dolomite outcrops it may become an important aquifer, especially northwards, where the calcretes of the Etosha Limestone Member are up to 150m thick south of Oshivelo. In the south, for example on the Farm Schwarzfelde, the calcretes have abundant ponors (karst holes) into which runoff, after heavy downpours, can percolate rapidly with little lost to evaporation. This type of indirect groundwater recharge is significant for the low-lying parts of the southern foreland.

The low permeable phyllites and quartzites of the Kombat Formation (Otavi Valley) and the Tschudi Formation (Tsumeb area) constitute the fractured Mulden Group Aquitard (MGA) with transmissivity values of 3 m^2/d.

From the top down, the Otavi Dolomite Aquifer (ODA) is composed of the fractured to karstified dolomite aquifer of Hüttenberg, Elandshoek and the upper part of the Maieberg Formations (Tsumeb Subgroup), while the thin-bedded limestone and shale of the lower Maieberg Formations act as an aquitard. For instance, north of Kombat Mine and in the Abenab area it separates the two abandoned mines hydraulically. The dolomites of the Elandshoek and Hüttenberg Formations have the highest average transmissivity values of 300 and 1 700 m^2/d respectively, and are therefore, the most important aquifers in the Tsumeb area, especially the Hüttenberg Formation.

The Chuos Formation ($T < 1$ m^2/d) crops out only in the south-west, where the weathered tillite and shale act as an aquitard separating the dolomite aquifer of the underlying Abenab Subgroup from the dolomite aquifer of the overlying Tsumeb Subgroup. The fractured dolomites of the Auros, Gauss and Berg Aukas Formations represent the

The numerical groundwater models of the Grootfontein Karst Aquifer (GKA) and Tsumeb Karst Aquifer (TKA)

Two three-dimensional numerical groundwater flow models have been established for the GKA and TKA, in which the GKA model includes the southernmost part of the TKA. The model areas and the calculation results are shown in the figure "Generalised map of the Otavi Mountain Land". The opposite sketch outlines the flow system of the GKA. The calculated water balance figures are summarised in the table below. The GKA model simulation is for the period between 1979 and 1997 and is based on an initial calculated groundwater table distribution, which represents the hydraulic situation at the end of 1978, characterised by good replenishment during 3-4 years of above mean rainfall i.e. the system was relatively full. Within the TKA modelling, transient long-term calibration was executed for the period 1968-1998.

The values of horizontal hydraulic conductivities KH and storage coefficients S, assigned to the hydrogeological units, are shown in the table and in the schematic profile of the TDK.

	GKA model		TKA model (top layer 0-150 m)	
	KH [m/d]	S [-]	KH [m/d]	S [-]
Aquiclude	$3.5 \cdot 10^{-3}$	$4 \cdot 10^{-3}$	–	–
Aquitard	$3.5 \cdot 10^{-2}$	$4 \cdot 10^{-3}$	$1 \cdot 10^{-2}$ - $7 \cdot 10^{-2}$	$1 \cdot 10^{-4}$ - $3 \cdot 10^{-4}$
Aquifer	$3.5 \cdot 10^{-1}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-0}$ - $7 \cdot 10^{-0}$	$1 \cdot 10^{-3}$ - $1.5 \cdot 10^{-3}$
Aquifer (Grootfontein area)	$3.5 \cdot 10^{0}$	$2 \cdot 10^{-2}$	–	–

Small S values ranging from $1 \cdot 10^{-4}$ to $1.5 \cdot 10^{-3}$ indicate that confined groundwater conditions prevail in the TKA area.

The groundwater models have assigned potential recharge factors, e.g. in the TKA area 4 % (or 21 mm) for dolomite outcrops, 1.5 % (8 mm) for transition zone covered by less than 20 m thick calcretes, and 0.25 % (1 mm) for Mulden Group. Groundwater recharge rates based on results of an isotope study range from 0 to 9 mm (0-1.7 % of the mean annual rainfall). The calculated recharge factors for the GKA area vary between 1.3 % (7 mm) and 5 % (28 mm) of the mean annual rainfall. As an average over 19 years, the mean recharge factor for the dolomite outcrops of the GKA area is 1.7 % (9 mm), corresponding to a mean recharge rate of about 18 Mm^3/a.

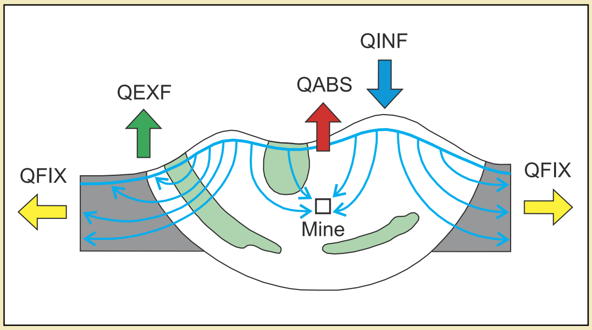
The discharge areas of the GKA model are springs or seeps where more vegetation occurs than in the surrounding area, e.g. at Khusib, Olifantsfontein, Mariabronn and at Brandwag. Due to the drought, the groundwater discharge of the springs and seepage (QEXF) dropped from 72.3 Mm^3/a in 1979 to 29.5 Mm^3/a in 1997.

The groundwater outflow across the system boundaries decreases with the decreasing hydraulic gradient. When the system was almost completely replenished in 1978, the total groundwater outflow ($QFIX_{OUT}$) from the modelled area amounted to 31.9 Mm^3/a (1978) decreasing to 21.5 Mm^3/a in 1997. The largest reduction occurred at the northern boundary with a decrease from 16.2 Mm^3/a in 1978 to 7.3 Mm^3/a in 1997, while in the south it decreased from 11.2 to 8.9 Mm^3/a and in the west from 6.8 to 5.3 Mm^3/a. Outflow to the east and west towards the Platveld Kalahari Basin is negligible.

Water balance of the groundwater models of the Grootfontein Karst Aquifer (GKA) and Tsumeb Karst Aquifer (TKA)

	GKA model			TKA model
Component of water balance	1979 [Mm^3]	1996/1997 [Mm^3]	1979 to 1997 Total amount [Mm^3]	2000 [Mm^3]
Groundwater reserves end-1978			+3400	
QINF	+12.8	+13.3	+370	+33.0
$QFIX_{IN}$	0.0	0.0	0	+0.8
$QFIX_{OUT}$	-31.9	-21.5	-450	-24.5
QEXF	-72.3	-29.5	-740	0.0
QABS	-5.7	-10.4	-170	-9.3
STOR	*-97.1*	*-48.1*	*-990*	*0*
Groundwater reserves end-1997			+2410	

The 19-year (1979 to 1997) change in groundwater storage (STOR) totalled some 990 Mm^3 in addition to the cumulated recharge (QINF) of 370 Mm^3. Most (87 % or some 1190 Mm^3) were natural groundwater discharge



Fluxes of the GKA model

($QEXF + QFIX_{OUT}$) and only about 13 % or some 170 Mm^3 (QABS) was abstracted, e.g. for Kombat Mine water drainage and domestic water supply to Grootfontein and Otavi. The potential groundwater reserves of some 3 400 Mm^3 stored in the upper 150 m of the saturated dolomites in 1979, were reduced by 29 % by the end of 1997 to 2 410 Mm^3. This resulted in a 10-30 m decline of the groundwater table in the highest central parts of the Otavi Mountain Land, representing the major recharge area of the system.

The GKA modelling results indicate that the determination of a sustainable yield and conventional development of the GKA dolomite aquifer system using relatively shallow wells may not be appropriate. However, the cavities formed underground represent easily accessible groundwater, which could in the short term be abstracted during prolonged periods of droughts at rates exceeding the sustainable yield. This can be conveyed via the Eastern National Water Carrier (ENWC) to the central areas of the country (Windhoek, Okahandja, Karibib, Otjihase and Navachab mines) to overcome temporary, emergency water shortages there.

As a result of the TKA model, the long-term sustainable groundwater abstraction rate has been assessed at about 4 Mm^3/a in addition to the present groundwater abstraction. Tsumeb and Abenab West mines are recommended abstraction points.

Applying an abstraction rate of 2 Mm^3/a at both mines and an annual increase of the current abstraction by 0.75 %, water levels at Abenab West Mine will decline by more than 100 m for average rainfall conditions from 2001 to 2016, and only by 10 to 20 m in the vicinity of the Tsumeb Mine. Further away, the water table will drop by 2 to 7 m and 25 to 40 m in the Tsumeb and Abenab areas, respectively. A net balance close to zero and no further significant decline in groundwater levels were predicted after a period of 60 years, indicating that steady state conditions will be reached after 2061.

For short-term (3 year) emergency bulk water abstraction, up to 10 Mm^3/a of groundwater could be abstracted from Tsumeb (7 Mm^3/a) and Abenab West (3 Mm^3/a) mines and exported to the central areas of Namibia, providing that the remaining water allocation does not exceed 5.5 Mm^3/a.

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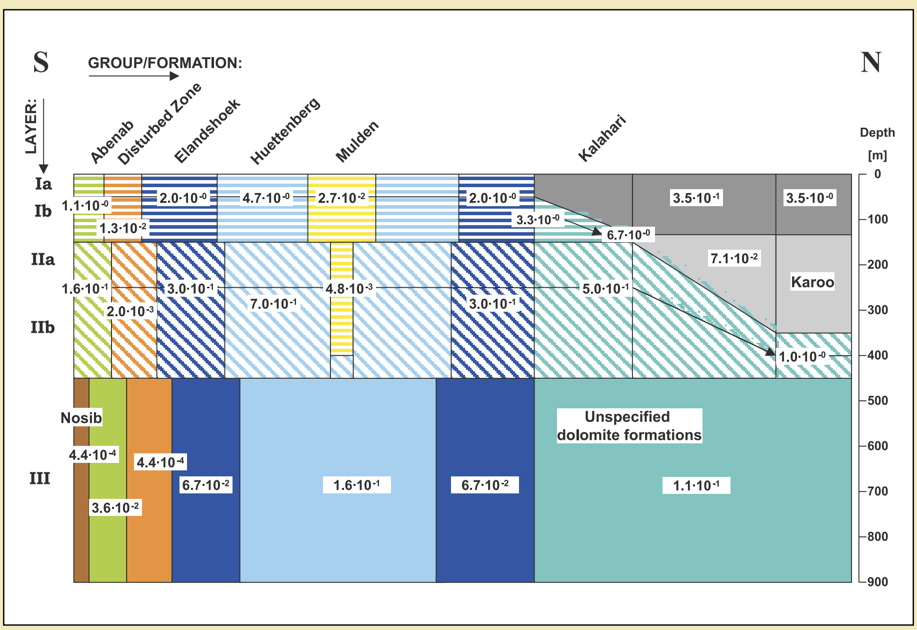

Schematic north-south profile of the TKA. The data labels contain the depth related hydraulic conductivities [m/d] of the rock formations according to the 3-D model calibration.

major lower aquifer with transmissivities values ranging from 10 to 500 m^2/d. The 50 m thick shale of the lower Auros Formation acts as an aquitard, for instance, in the Abenab area.

The meta-sediments of the Nosib Group are considered a fractured aquitard (T< 1 to 3 m^2/d). The rocks with low permeability of the Nosib Group outcrop within the Nosib Anticline which separates the Grootfontein Karst Aquifer system (GKA) from the Tsumeb Karst Aquifer system (TKA). This results in relatively low groundwater flow from the south towards the north and is indicated by a very steep gradient of groundwater contours.

Mineralogical and hydrogeological characteristics of operating and abandoned Cu-Pb-Zn-Ag-V ore mines in the Otavi Mountain Land and their mine water quality, mine water drainage rates, and sustainable yields for water supply (ENWC)

	Khusib Springs Mine	Kombat Mine	Tsumeb Mine	Berg Aukas Mine	Abenab Mine (AM) / Abenab West Mine (AWM)
Type of deposit	Cu-Pb-Zn-Ag	Cu-Pb-Ag	Pb-Cu-Zn-Ag	Zn-Pb-V	Pb-Zn-(V) deposit
Status	operating since 1995, closed from 1997 to 2000, re-opened in April 2000	operating since 1962, closed from Nov. 1988 to Sept. 1990 due to flooding, closed from 1997 to 2000, re-opened in April 2000	operating since 1907, closed in August 1996 and flooded, re-opened in April 2000, since then operating up to 8th level; No.1 shaft, De Wet Shaft	operated from 1958 to 1978, No. 2 Shaft: sunk in 1968, gear head removed in 1996, four 360 m^3/h-pumps installed and linked with ENWC in 1997	AM operated from 1921 to 1947 AWM operated from 1947 to Jan. 1958
Syncline	Harasib - Olifantsfontein (III)	Otavi Valley - Uitkomst (I)	Tsumeb Synclinorium (IV)	Grootfontein - Berg Aukas (II)	Tsumeb Synclinorium (IV)
Concentration of ore metals (production or ore reserves)	6.5 % Cu, 1.2 % Pb, 1.4 % Zn, 350 g/t Ag	3.1 % Cu, 1.1 % Pb, 26 g/t Ag	5.8 % Cu, 3.5 % Pb, 1.2 % Zn, 0.04 % Cd, 179 g/t Ag	4.0 % Pb, 16.8 % Zn, 0.5 % V	AWM: 16 % Pb, 37 % Zn, (V)
Ore minerals	tennantite, chalcocite, galena, minor sphalerite	bornite, chalcopyrite, galena, chalcocite	galena, tennantite, sphalerite, chalcocite, bornite, enargite	descloizite, sphalerite, chalcocite	descloizite, galena, cerrusite, willemite, limonite
Host lithology	T2/T3 Maieberg Fm., limestone/dolomite contact; ore located in platy limestones of the T2	T8 Hüttenberg Fm. dolomite overlain by phyllites of Kombat Fm., paleo-karst structures; Kombat West Fault acts as a major groundwater conduit	Upper Elandshoek and Hüttenberg Fm., steep complex pipe-like paleokarst structure, filled with feldspathic sandstone, Mississippi Valley Type	Gauss and Berg Aukas Fm. dolomite with abundant karst cavities	AM: Maieberg Fm. dolomite, pipe-like ore body, AWM: Auros Fm. dolomite, limestone
Depth of mining	> 120 m	> 800 m	1800 m	750 m (No 2 Shaft)	AWM: 380 m AM: 215 m
Type of ore	sulphidic	sulphidic/oxidised (> 60 m)	oxidised/sulphidic ore (0-1500 m), sulphidic (> 1500 m)	sulphidic/oxidised (0-800 m)	oxidised/sulphidic (AW), mainly oxidised (Abenab)
Mine water quality (1997) with parameters exceeding Max. Admissible Concentration (MAC) [*TH: Total Hardness]	Group B: TH* (sampled in Jan. 2001)	Group D: Al, Pb	No. 1 Shaft: Group D: TH*, Ca, SO_4, Cd, Mn De Wet Shaft: Group B: TH*, Fe, Pb, Mn; (purified for domestic water supply until 1996)	Group B: TH*	AWM: Group B: TH*, Mg AM: Group D: Fe
Transmissivity	n/n	n/a	n/a	100 to 200 m^2/d	210 to 220 m^2/d
Storage coefficient	n/a	n/a	n/a	0.005 to 0.01	0.011 to 0.012
Sustainable yield	not yet established	not yet established	2.0 Mm^3/a	2.0 Mm^3/a	AWM: 2 Mm^3/a
Three year emergency yield	not yet established	not yet established	7.0 Mm^3/a	4.5 Mm^3/a 6.5 Mm^3/a, if water-tight doors will be opened	AWM: 3 Mm^3/a water-tight are presumed to be installed at all levels
Recent or former drainage rate (abstraction rate)	1995: 0.3 Mm^3/a 2001: 0.9 Mm^3/a 80 % of mine water drainage is being artificially recharged into the aquifer	1970: 2.0 Mm^3/a 1988: 6.0 Mm^3/a 11/1988 - 09/1990: Flooded 1992: 4.7 Mm^3/a 1998: 8.8 Mm^3/a 2001: 12.3 Mm^3/a	1907: 0.7 Mm^3/a 6.0 to 9.5 Mm^3/a 1993: 5.9 Mm^3/a June 1996: drainage ceased July 2000: drainage re-started 2001: 3.1 Mm^3/a	AWM: up to 4.5 Mm^3/a	AWM: up to 5 Mm^3/a


Dieter Plöthner

View over the head of No. 2 shaft of the abandoned Berg Aukas Mine: Four strong submersible pumps of which each has a capacity of 360 m^3/h were installed in the shaft in 1997 to lift groundwater from the open underground mine workings and the dolomitic host rock. The four pumps can be run simultaneously, but presently the set-up is two production pumps and one stand-by pump.

The granites and gneisses of the Basement are an aquiclude at great depth, however, at shallow depth, as in the Grootfontein area and in the Nosib Anticline, they act as a fractured aquitard ($T < 0.005\ m^2/d$).

Groundwater quality

The groundwater in the Nosib Anticline is predominantly characterised by the $Mg/Ca\text{-}HCO_3$ water type, the Total Dissolved Solids (TDS) range from 150 to 1200 mg/L. Locally, elevated sodium, chloride and nitrate concentrations occur in the vicinity of boreholes used for livestock watering.

The dolomite groundwater may be characterised as a low mineralised (TDS ~500 mg/L, from 150 to 1300 mg/L), very hard, near-neutral $Ca/Mg\text{-}HCO_3$ water. Within the irrigated areas of the Tsumeb Karst Aquifer, elevated sodium, chloride, sulphate and nitrate concentrations indicate contamination by irrigation return flows. Groundwater beneath irrigated land is subject to salinisation due to evaporation and the dissolution of fertilizer components. In this partly karstic terrain, the high vulnerability of groundwater to agricultural pollutants is of concern.

Some of the groundwater abstracted from the mines at Kombat is purified for drinking water purposes (until August 1996 this was also true for water from the Tsumeb mines). The water, regularly tested by NamWater, is suitable for drinking. The groundwater is sufficiently buffered to prevent heavy metals from the mines dissolving to any harmful extent despite the relatively high proportion of oxidised ore.

The table on the mineralogical and hydrogeological characteristics of the mines in the area show that according to tests in 1997, the water from Kombat, Tsumeb (No. 1 Shaft) and Abenab mines is of Group D quality and that of Tsumeb (De Wet Shaft) and Abenab West mines of Group B quality, as a result of the total hardness and unacceptable concentrations of aluminium, lead, calcium, cadmium, manganese, iron and magnesium. As experience from Tsumeb Municipality has shown, once treated, the mine water can be used for domestic supply as these metals are relatively easily removed by precipitation, and hardness is not a health concern. Because the groundwater in the mines is under pressure and supersaturated with calcite and dolomite, these and some of the heavy metals precipitate out at ground level and thus the water quality in the canal at the Okakarara off-take improves to Group A or B.

Utilisation of groundwater

This hydrogeological region hosts eight major water supply schemes of which Outjo (107), Kombat, Grootfontein (105) and Tsumeb (108) are independent waterworks, while the Otavi (79), Brandwag (16), Karstland (45) and Berg Aukas/Otjituuo (12) schemes and the stand-by abstraction scheme from Berg Aukas Mine are managed by NamWater. In 1999, these schemes abstracted over 7 Mm^3/a of groundwater.

Outjo waterworks produces 0.8 Mm^3/a of drinking water. Domestic water supply to the mine town at Kombat is 0.15 Mm^3/a and is abstracted through wells that belong to Ongopolo Mining and Processing Ltd., OMPL. The 20 wells at Grootfontein comprise four clusters of wells. In 1978, abstraction was 1.7 Mm^3/a, and this almost doubled to 3.2 Mm^3/a by 1997.

Until the early 1990s, the domestic water supply to Tsumeb Municipality was entirely dependent on the 2.5 Mm^3/a of groundwater supplied, and purified, from the mine. With time, as the ore body dwindled, the municipality drilled more than 15 production wells and until the Tsumeb Mine closed in June 1996, groundwater from the mine was purified and mixed with groundwater from the wells. Since then, groundwater abstraction by wells increased to a high of 3.1 Mm^3/a in 1997, but by 1999 had been reduced to 1.7 Mm^3/a. OMPL supplies an additional 1 Mm^3/a to the Tsumeb Municipality from 3 wells, northeast of the smelter.

Otavi is dependent on five wells and the inflow of an eighth of the total spring discharge of Otavifontein. The total production of local waterworks amounts to 0.5 Mm^3/a.

The Brandwag wells form the first phase of the Karstland scheme. These relatively shallow wells are sited along the south-eastern tip of the Otavi Valley-Uitkomst Syncline (I) next to the Nosib bedrock contact. Due to the prolonged dry period and low recharge, the scheme is currently dry. The Karstland scheme comprises some stand-by wells east of Kombat Mine and one well gallery of 20 stand-by wells tapping the dolomite aquifer of the Harasib-Olifantsfontein Syncline (III). These are shown on the Map. Tests done in 1996 estimated a total yield of 3 Mm^3/a for this scheme, yet it has never been fully implemented nor linked to the Eastern National Water Carrier, ENWC.

Groundwater abstraction at the Berg Aukas-Otjituuo scheme started in 1986. Some 0.7 Mm^3/a from two strong wells is piped to Otjituuo to augment the local water supply . Until it closed in 1978, Berg Aukas Mine drained more than 4 Mm^3 of groundwater annually. In 1996, the gear head of No.2 shaft was removed and 4 strong pumps each with a capacity of 360 m^3/h were installed in the shaft shown in the photograph. In 1999, an 80-day test run at discharges varying from 5 to 8.5 Mm^3/a transferred 2 Mm^3 of groundwater from the mine into the ENWC. Results showed that the long-term sustainable yield is assessed to be 2 Mm^3/a at an expected drawdown of up to 150 m bgl, and that should it be necessary to cope with a 3-year water emergency in the central region, the yield could be increased up to 6.5 Mm^3/a with an expected drawdown of up to 400 m bgl.

Water abstraction from the Khusib Springs and Kombat mines continued between 1996 and 2000, and after the take-over of the mines by Ongopolo from Tsumeb Corporation Limited, TCL, ore production recommenced in April 2000. From 1995, when mining operations at Khusib Springs Mine commenced, water drainage increased from 0.3 Mm^3/a to 0.9 Mm^3/a in 2001. About 80 % of the drained mine water is being artificially recharged into the dolomite, while 20 % is used for ore dressing and to keep dust down. Kombat Mine increased the mine water drainage rate from some 2 Mm^3/a in 1970 to more than 6 Mm^3/a in November 1988, when the mine was accidentally flooded. Since October 1990, when mining operations resumed, mine water drainage increased from 5.5 Mm^3/a to 12.3 Mm^3/a (1 400 m^3/h on an average) in 2001. Nearly half, 5.7 Mm^3/a, of the mine water drained is exported via the ENWC, a quarter, 3.1 Mm^3/a, is used for ore dressing, processing and dust depression, 22 % or 2.6 Mm^3/a for irrigation of the golf course and public gardens in Kombat, and the remaining 0.9 Mm^3/a is supplied to two commercial farmers to grow maize. As there is 250 ha of irrigable land in the vicinity of Kombat Mine, up to 4 Mm^3/a of the mine water could be used for irrigation. Between 1998 and 2001 an average of 2.3 Mm^3/a of Kombat Mine water supplied the Okakarara treatment plant from where it can be piped further to Otjituuo, as depicted on the Map. In October 2001, OMPL and NamWater negotiated an assured supply of 4.4 Mm^3/a from the mine for export to the ENWC at a price of 0.35 N$/$m^3$.


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Otjikoto Lake, one of the Karst sinkholes in Namibia

From 1921 to 1947, when still operational, Abenab Mine drained 3 to 4 Mm^3/a, this increased to 4.4 Mm^3/a in the last four years of operation (1955 - 1958) from Abenab West Mine. Groundwater is still abstracted for irrigation purposes at a rate of 0.2 Mm^3/a.

Annual drainage from the Tsumeb Mine was between 6 and 9.5 Mm^3. In 1993, 5.9 Mm^3/a of groundwater was abstracted from the De Wet Shaft, of which 2.9 Mm^3/a was used by TCL for the ore washing plant and smelter and about 2.5 Mm^3/a supplied to Tsumeb Municipality. In the early 1990s, the oval-shaped cone of depression of the mine extended some 9 km east-west and about 8 km north-south.

When mining and hence drainage ceased in June 1996, Tsumeb Mine got flooded, and due to the complicated karst hydrology of the mine workings, the water table rose slowly up to 60 m bgl. By the end of July 2000, after the take-over of the mine by OMPL, drainage recommenced. The water table dropped to 240 m bgl, where it is currently maintained. Groundwater was initially drained off at 5.3 Mm^3/a but decreased to 3.1 Mm^3/a in 2001. About 20 % of the mine drainage water is used on public gardens by the Municipality of Tsumeb and the rest for ore dressing and processing, the smelter, and keeping down dust at the mine.

In summary, Kombat and Berg Aukas mines can supply from 6.4 Mm^3/a to 16.5 Mm^3/a to the ENWC, the latter only in emergencies. As soon as Tsumeb and Abenab West mines are linked to the ENWC, the water supplied by mines could be increased by 4 to 10 Mm^3/a, totalling 10.4 to 26.5 Mm^3/a.

Some 90 irrigation farms rely on groundwater within the Otavi Mountain Land and its foreland, especially in the northern Tsumeb area where 83 farms abstract groundwater to grow vegetables, maize, wheat, lucerne, cotton, and citrus. Although only 1100 ha or 0.1 % of the Tsumeb Karst Aquifer area is under irrigation, 5.7 Mm^3/a or 55 % of the total groundwater is abstracted from the TKA for irrigation.

As shown in the water balance of the Grootfontein Karst Aquifer, more than 0.3 Mm^3/a is pumped from Otjikoto and Guinas lakes for irrigation. The two lakes are collapsed sinkholes (dolina) in the dolomites of the Maieberg Formation and are the only permanent lakes in Namibia. The lakes have a diameter of 100 and 140 m and a depth of more than 75 and 150 m, respectively, and provide "windows" to the groundwater. They are also home to one of Namibia's rare, endemic fish species, the Otjikoto tilapia. Isotope data suggest that recharge to the two lakes is from altitudes from 1600 to 1900 m asl, somewhere south of Tsumeb or north of Kombat. The travel time of the groundwater from the southern recharge areas to the lakes is estimated to be only 30 - 40 m/a. West of Guinas Lake there are two other collapsed sinkholes on the farms Hoasis and Obab. Even though these are dry, boreholes sunk into the filling of the sinkholes abstract groundwater for small-scale irrigation, livestock watering and domestic water supply.

In the GKA area, there are only 7 irrigation farms and some 255 ha of land under irrigation, of which 185 ha is irrigated by Kombat Mine groundwater, 20 ha by spring water from Otavifontein and the remaining 50 ha by groundwater abstracted via boreholes. Rietfontein Farm, one of the few dairies in the country, stopped irrigation when Rietfontein spring dried up in 1989. In 2001, this large farm used 0.25 Mm^3/a of groundwater abstracted by boreholes.

Groundwater use for livestock farming is the same in the Tsumeb Karst Aquifer area and Grootfontein Karst Aquifer area, each use approximately 1 Mm^3/a.

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FURTHER READING

- Bäumle R, T Himmelsbach and R Bufler. 2001. Conceptual hydrogeological models to assess the groundwater resources of the heterogeneous fractured aquifers at Tsumeb (Northern Namibia). In: Seiler & Wohnlich (Eds): New Approaches Characterising Groundwater Flow. Proceedings International IAH Congress, Munich.
- Hedberg RM. 1979. Stratigraphy of the Ovamboland Basin, South West Africa. Bull. Precambrian Research Unit. University of Cape Town.
- Schmidt G and D Plöthner. 2000. Hydrogeological Investigations in the Otavi Mountain Land. In: Silio, O. et al. (Eds). Groundwater: Past Achievements and Future Challenges. Proceedings International IAH Congress, Cape Town.
- Schwartz MO and D Plöthner. 1999. Removal of heavy metals from mine water by carbonate precipitation in the Grootfontein-Omatako Canal, Namibia. Environmental Geology, 39. Tucson.
- Vogel JC and H van Urk. 1975. Isotopic composition of groundwater in semi-arid regions of southern Africa. Journal of Hydrology, 25.