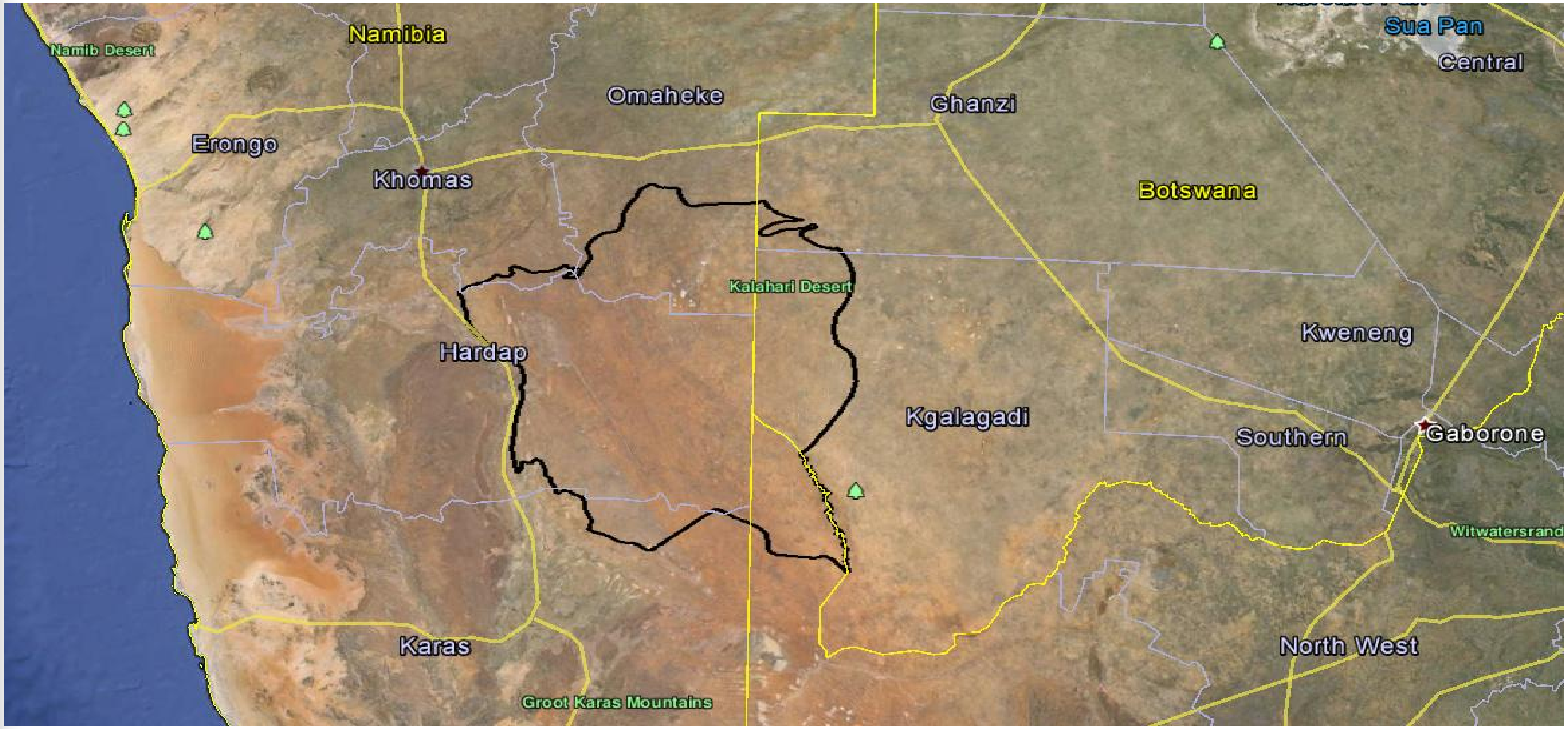
The Stampriet Transboundary Aquifer System in Southern Africa

Chapter 2: Hydrogeology (Draft)



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That is probably why Namibia’s DWA and UNESCO asked me to act as the Project Coordinator

GGRETA Data capture post-mortem

The project is about the advantages expected from common management of transboundary aquifers. Data and information collection has been completed and a final report is underway. It may be too early for a post mortem but it appears appropriate to consider what the challenges were and what final result can justifiable be expected.

We will have to look at

- The specialist teams; and their experience and finally
- The quality and sufficiency of the available data and information of a rather complex aquifer structure; consider
- The project surrounding.

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As Groundwater is the basis of the whole project the following observations deal mainly but not exclusively with the hydrogeological aspects of it.

What do we know about the Groundwater there?

In Namibia the Stampriet Artesian Basin has been investigated for more than 100 years. Botswana's interest started in the 1970s and so far the artesian sandstones have not yet been explored in South Africa. Obviously most data and information stems from Namibia and the least from South Africa.

However it is not the quantity but rather the quality of the available information that counts.

The SPECIALISTS

For this desk study UNESCO had contracted one half-time working hydrogeological; socio-economic and environmental; as well as legal specialists for each of the three countries. The experience of these specialists ranged from zero to about ten years. The specialists had not previously worked in the SAB.

For persons without local experience it is difficult to find information in a surrounding where the institutional memory has largely been lost. This was partly compensated through the world wide web and the experience of the Regional Coordinator.

However, when dealing with other persons' findings one always has to ask oneself the question: "Is that true - can that be?"

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DATA and INFORMATION

There are correct data; wrong data; and no data. Wrong data are either artefacts; typing mistakes; wrongly allocated; or "computer errors". No data include not captured; lost; withheld oer not found data. Similarly we can discern between correct and wrong information. Information stems from person's work in the SAB; or from persons who did a desk study. Both may have come to correct or wrong conclusions.

A complicating factor was the fact that the available socio-economic data were based on constituency or district boundaries rather than an the hydrogeological (Ecca) boundary of the investigation area.

Three Examples

If one finds that the catchment boundary in an area with pans but no surface drainage is such that the surface rises by about 100 m for a distance of more than 100 km from the catchment boundary towards the discharge area then the boundary must obviously be wrong (e.g. Hydrology's Nossob catchment in the Aminuis area in Namibia.)

If a calculated evapotranspiration figure is only half of the measured evaporation than that must likewise be a mistake.

If a model is presented about the economic value of water and that model claims that under Namibian circumstances (with a prime rate of about 10%) the value of water is always negative meaning that the more water one wastes the higher the profit than there is obviously also something wrong.

The PROJECT ENVIRONMENT

1. Funding is a limiting factor
2. (Over?)ambitious donor expectations may complicate matters
3. Lacking support of Governments makes progress more difficult
4. Data collection problems
   a) Specialists only collecting metadata
   b) Hydrogeologists to collect and evaluate economic and Economists to deal with some hydrogeological data.
   c) Lack of GIS support

IN SUMMARY

1. Due to lack of data the eastern and southern project boundary is somewhat vague.
2. The occurrence and recharge in the Auob catchment can be sufficiently well described.
3. In the Nossob catchment there is no recent recharge.
4. Groundwater quality aspects have so far not been dealt with convincingly.
5. Apart from the difficulty to relate socio-economic constituency and district data with the SAB boundary more detail about the economic potential is desirable.
6. Hydrogeological manpower deficiencies in the DWA’s need attention.
7. Drilling and abstraction control is necessary.

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This said some details:

Hydrogeology

Like Mining Geology and Petroleum Geology Hydrogeology investigates the **Origin**; **Development**; **Occurrence** and **Location** of the Earth's underground resources.

Groundwater is **renewable**, moves and changes its properties at a much faster rate than Gas, Oil or Ores. This requires an additional time dimension of investigations.

Long term **Monitoring** time-series **Water level**; **Abstraction**; and **Water quality** data are the basic requirements for managing the resource. **Management** includes the maintenance of the recharge areas; loss control (leaking boreholes and wastage); protection from pollution; and over-use.

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The STAS Project is a Desk Study

All work had therefore to rely on the findings and evaluations of previous investigators. The table below shows the number of reports, data bases and maps on which this study is based.

	Botswana	Namibia	South Africa
Reports	50	89	42
Data bases	Not disclosed	3	1
Hydrogeological Maps	2	6	5

The data bases of the Botswana DGS and DWA were unfortunately not made available.

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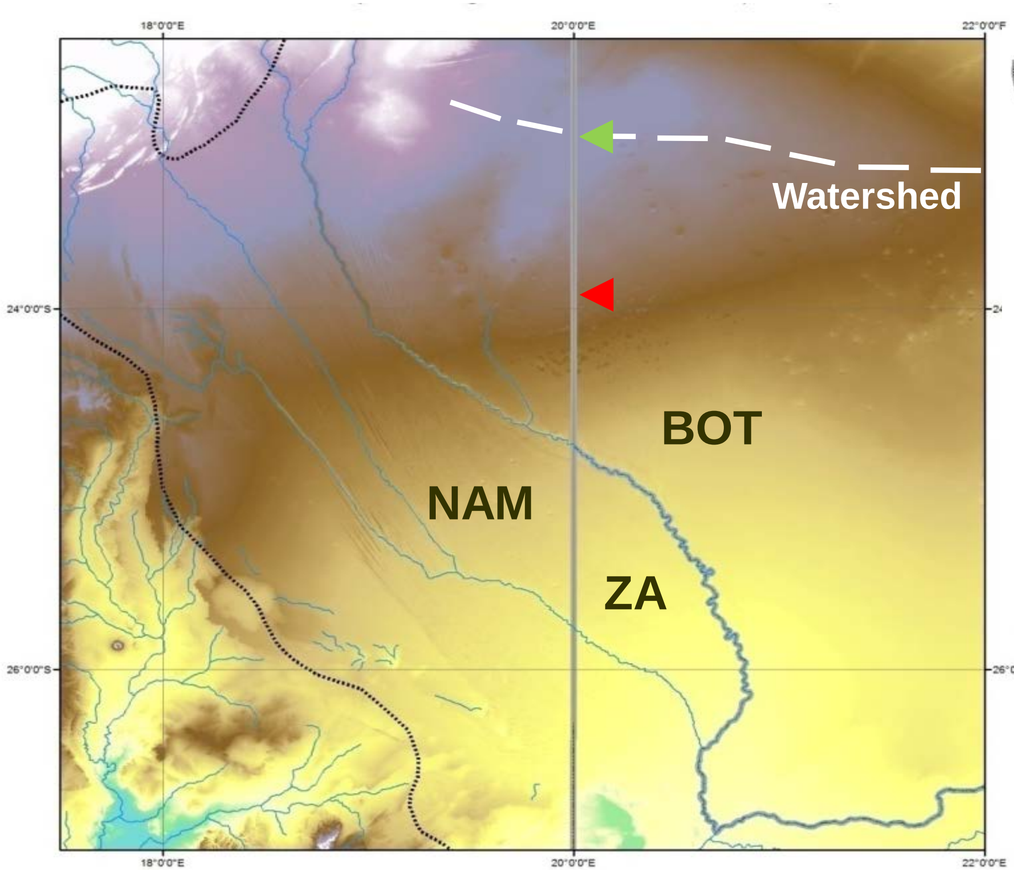
Definition

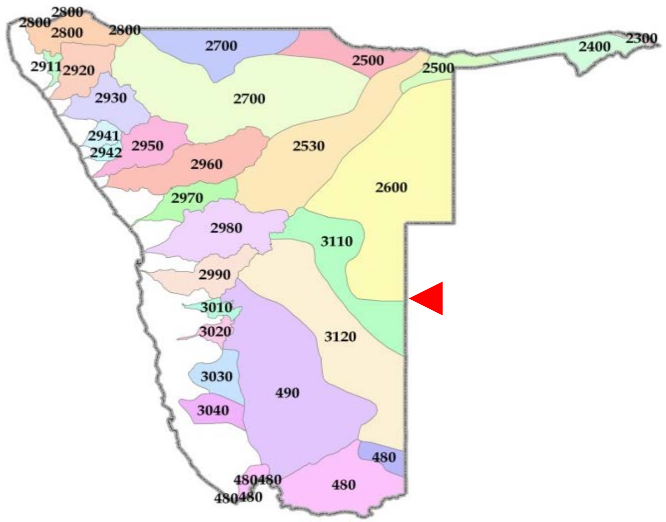
The Stampriet Artesian Transboundary Aquifer System (STAS) was defined as that area within the Auob and Nossob River catchments where **Ecca** Formations occur. It is 86643 km^2 in size. With over 70000 km^2 Namibia occupies the largest part of the basin. In Namibia and South Africa the confined Ecca aquifers have been named **Auob** and **Nossob** after the rivers along which boreholes tap free-flowing artesian aquifers. In Botswana these aquifers are named **Otshe** and **Lower Kobe** or Ncojane sandstone respectively. This chapter deals with the hydrogeology of the Ecca transboundary aquifers.

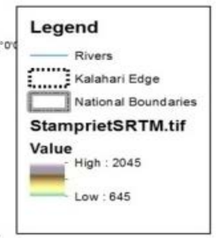
The whole area is overlain by **Kalahari** aquifers. In addition there are a some aquifers of lesser importance.

Topography and Elevation

The SRTM model shows elevations between ~ 1350m in the north and northwest falling to about 900 m in the SE.

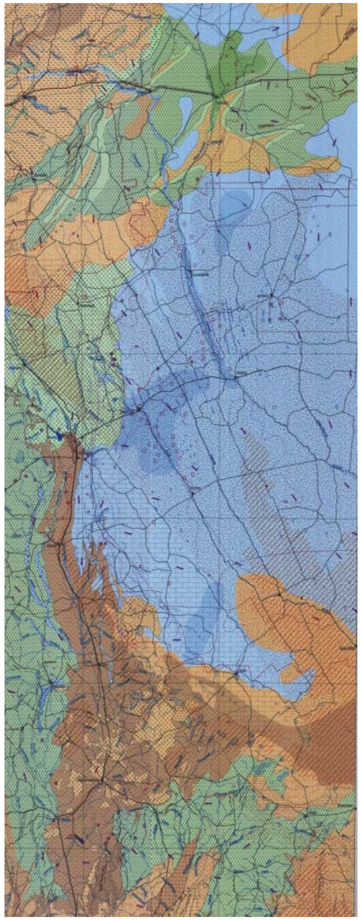


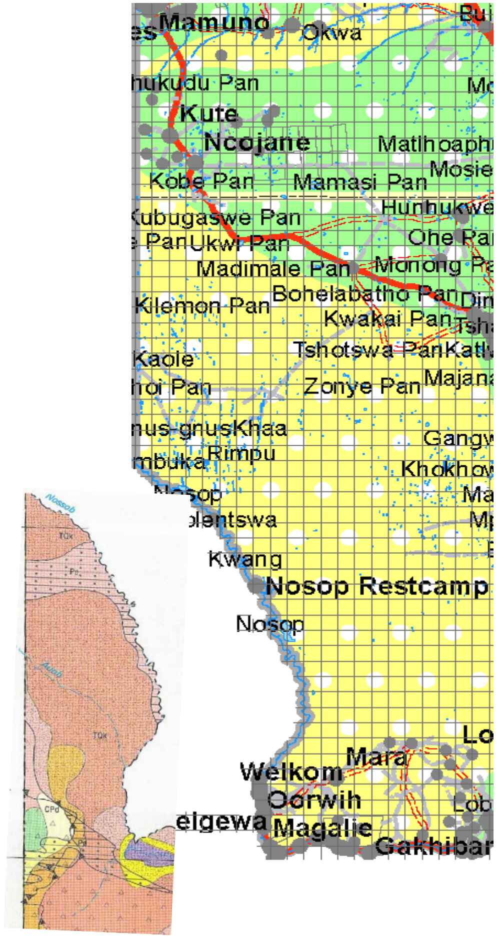




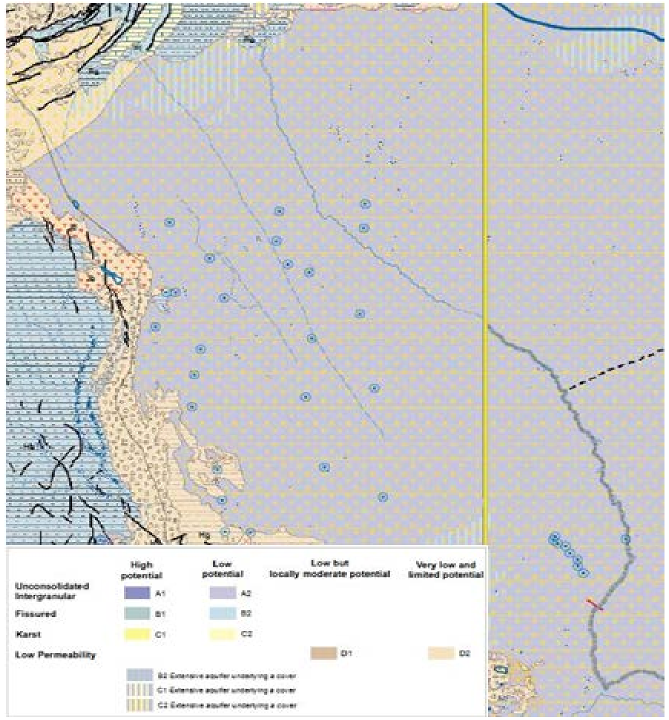
NB: Hydrology's Nossob catchment boundary is more than 100 km out.

Hydrogeological maps

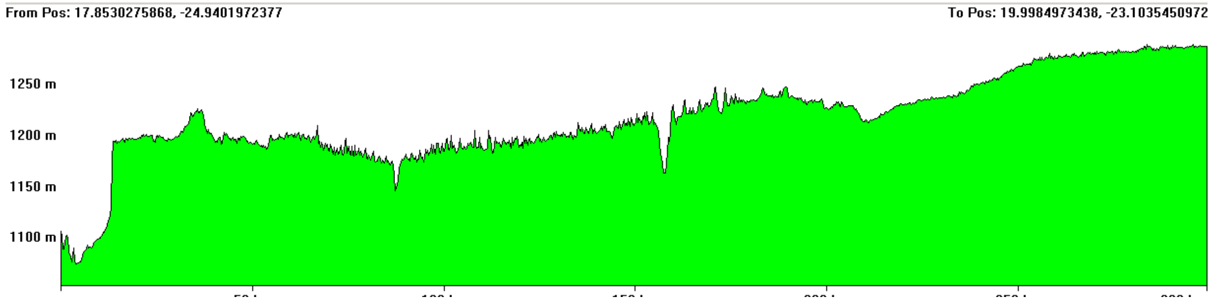




Hydrogeological maps exist for all three countries as well as a SADC map at scales between 1:500 000 and 1:2 500 000.



Stratigraphy



KALAHARI (Tertiary to Quaternary)		Sand, gravel, calcrete Calcrete-cemented conglomerate W (= water strikes)
KAROO	KALKRAND	Basalt W
KAROO	(Jurassic to Triassic)	Dolerite (W at U & L contacts)
KAROO	RIETMOND (Permian)	Varicoloured sandstone, shale, yellow shale, coal, black shale W Yellow shale Grey shale W Whitehill; black shale, black limestone Grey shale
KAROO	AUOB (Permian)	U Ss; coarse grained; medium to fine grained (A5) W U coal, black shale M Ss; medium to fine grained (A3) W L coal, black shale L Ss; coarse grained; med. to fine grained (A1) W
KAROO	MUKOROB (Permian)	U Muk. sandstone; medium to fine grained W? U Muk. sandstone-siltstone-shale, bioturbated Mukorob shale, grey to black
KAROO	NOSSOB (Permian)	U Nossob sandstone; medium to coarse W U Nossob sandstone; fine grained U Nossob siltstone-shale L Nossob sandstone; medium to coarse W L Nossob sandstone; fine grained L Nossob siltstone-shale
KAROO	DWYKA (Carboniferous)	Mudstone, grey, with dropstones Tillite
PRE-KAROO (Cambrian)		U Nama - Red sandstone, shale L Nama – grey shales, sandstones Kamtsas – pink arkoses

A WSW-ENE elevation profile from Mariental to the Botswana border near Aminuis shows the steep Weissrand; the incised Auob and Nossob Rivers and the dune area in the middle of the basin.

The Stampriet aquifer system consist of up to eleven individual aquifers, twelve if one includes the river alluvial aquifers.

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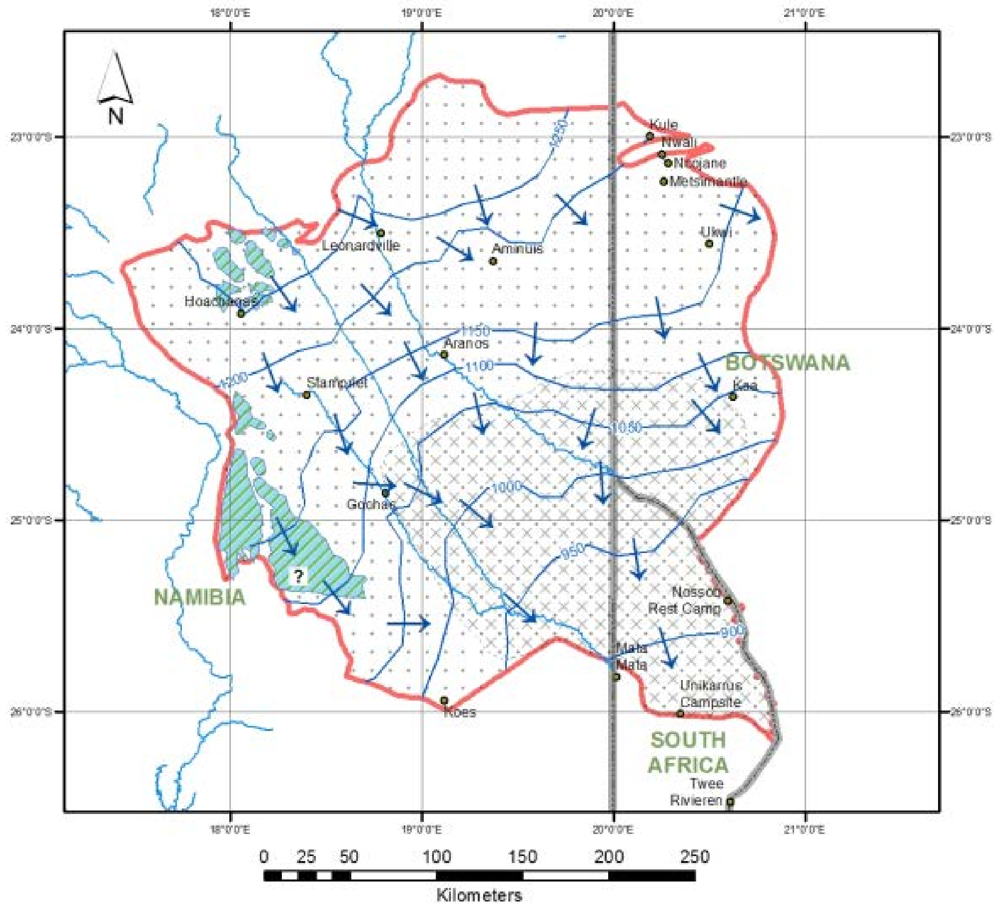
Geo-referenced Boundary

The Stampriet TBA Basin was delineated based on the occurrence of <u>coherent Ecca</u> strata <u>within the Auob and Nossob catchments</u>.



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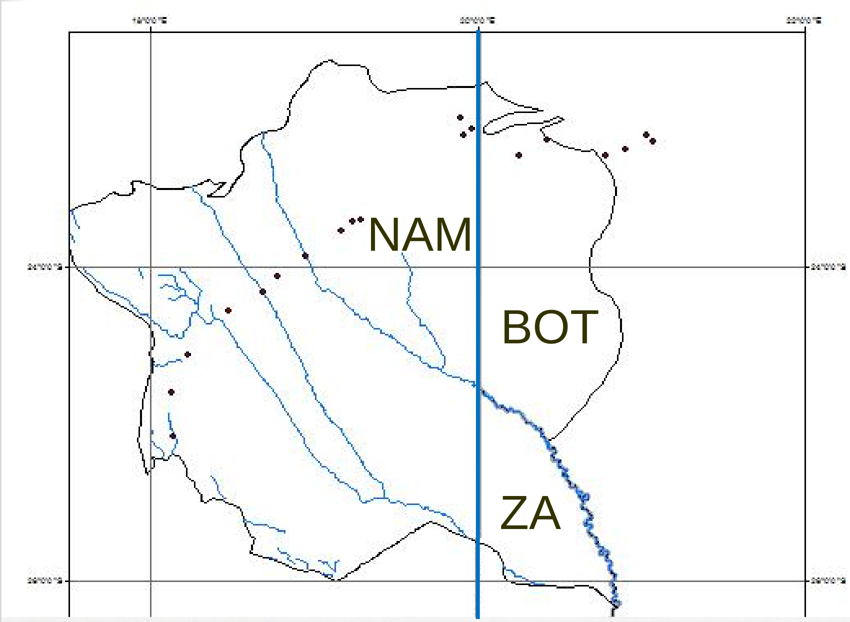
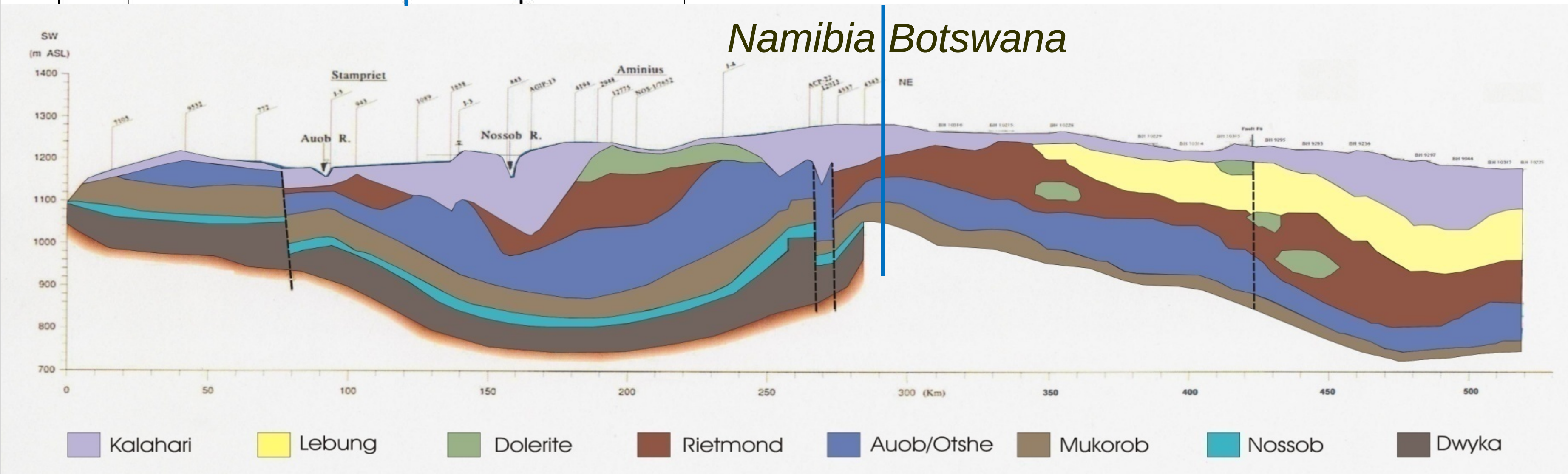
WSW-ENE cross-section

Stampriet-Ncojane





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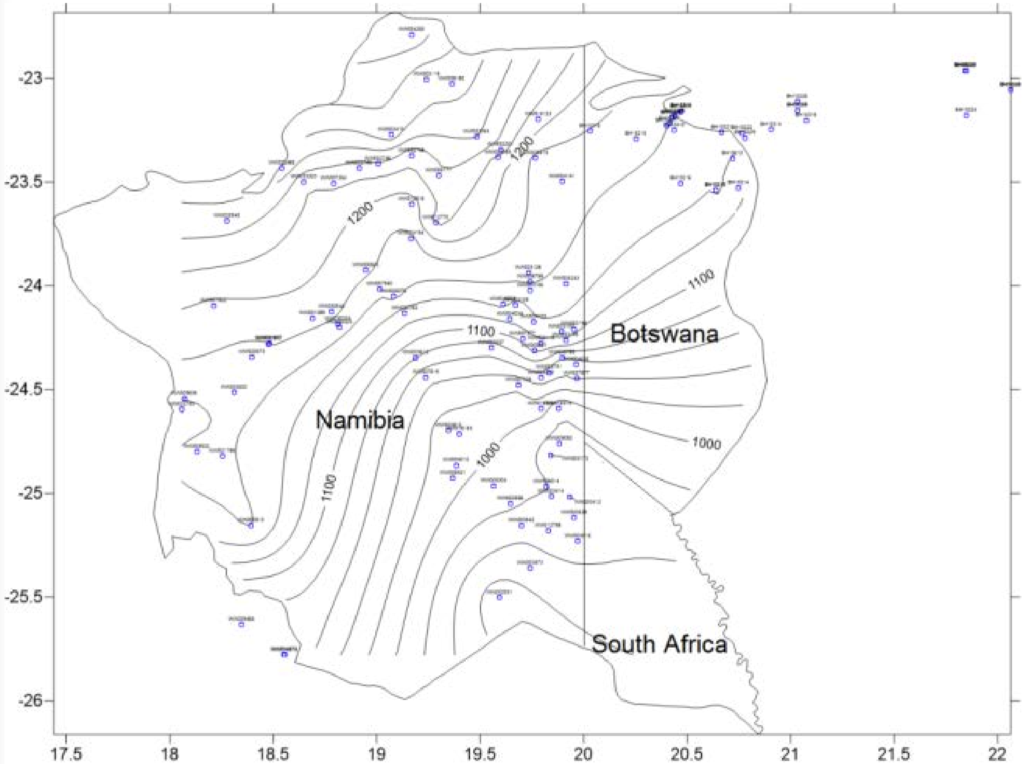
The Auob/Otshe Water table



The Auob piezometric water table shows that the groundwater is flowing from northwest to southeast with a branch in the north that flows eastwards into Botswana than gradually turning through southeast, and south to southwest towards the lower Nossob River.

The Auob/Otshe: Depth to top

There are **outcrops** of the Auob formation on the Weissrand. In pre-Kalahari erosion channels it is buried under **up to 250 m** of overburden. In Botswana the Otshe has been struck at depths of up to **360 m**.
In South Africa Ecca was struck at depth between 223 and 243 m – a value of 336m is under suspicion.

The Auob/Otshe: Aquifer thickness

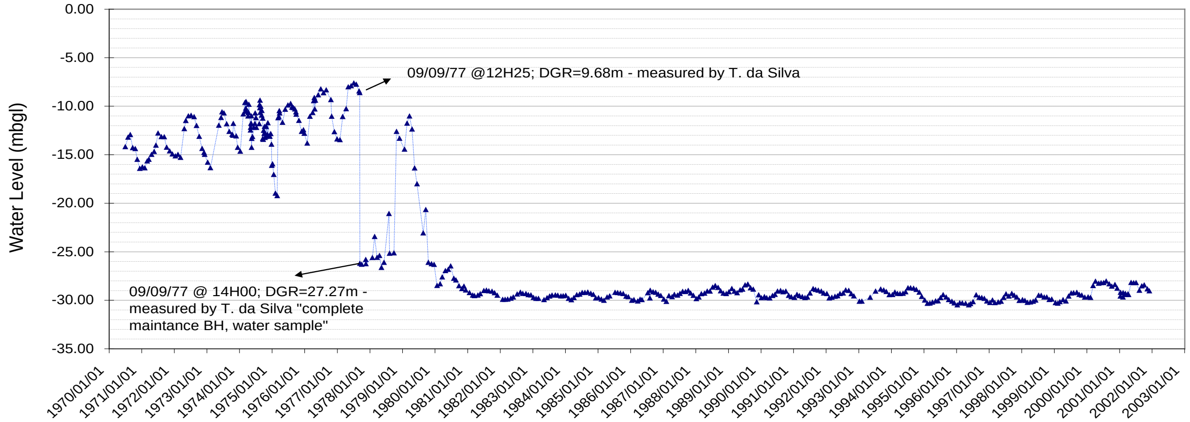
In some places the Auob Formation has not been deposited in some others it has been remove by pre-Kalahari erosion. Following Miller (2008, vol. 3, Fig. 16.51) over large areas the Auob has not been penetrated. There its assumed **thickness** varies between **50 to 150 m.** Maximum thicknesses of **up to 185 m** have bee recorded.

Confinement

Between the recharge and the discharge areas the Auob and Nossob aquifers are **confined**. Locally there may be a connection with the over- or underlying aquifers

- along fault planes;
- along dolerite contacts; and
- where artesian or subartesian boreholes have not been properly sealed; casing is corroded; or seals became leaking.

The latter appears to be a major threat to the TAB. The figure below shows that corroded casing caused a drop in the water level of more than 20 m. Considering the quantity abstracted from a borehole lowering the water level by 20 m when pumping 24h/d seven days a week the water losses must be substantial. All (sub)artesian boreholes older than say 30 years are probably leaking.



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Depth to top, Thickness, Confinement

	Nossob	Auob	Ntane	Kalahari
Depth to top	0-284-400	0-98-178	40-100->150	0
Thickness	6-20	0->150	0-55-115	0-279
No. of aquifers	1-2 (3)	1-3	1	
Confinement	confined	confined	unconfined-semiconfined	unconfined

Where 3 values are given the middle one is the mean of values found

Data for the four aquifers were extracted mainly from:
Miller, 2008: Geology of Namibia (based on JICA, 2002) and
Masie et al., 2008: Matsheng Groundwater Development Project

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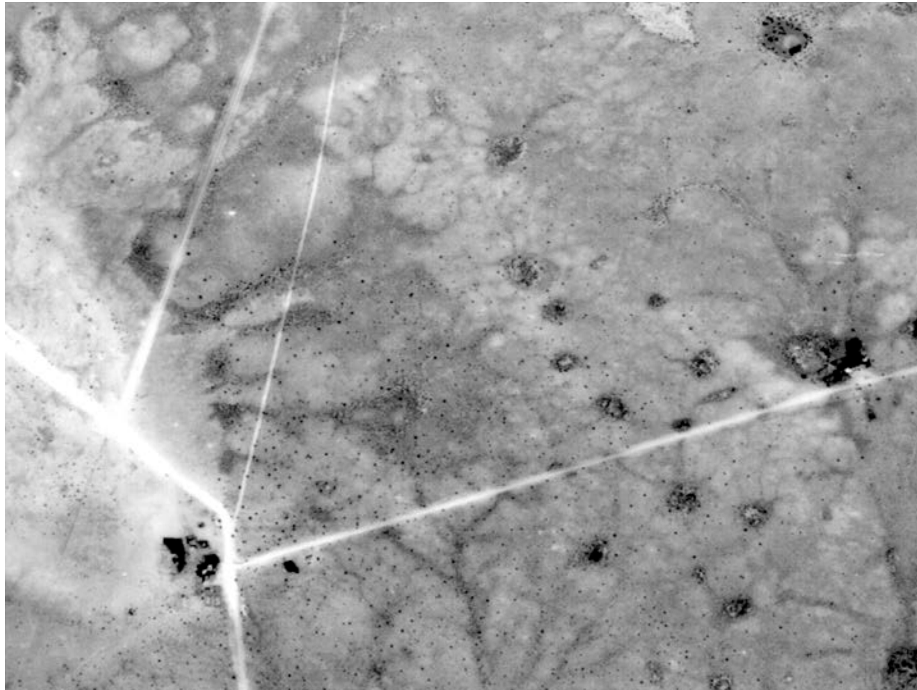
TBA Recharge occurs through SINKHOLES in calcrete



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Hydrogeological Characteristics

Aquifer Recharge

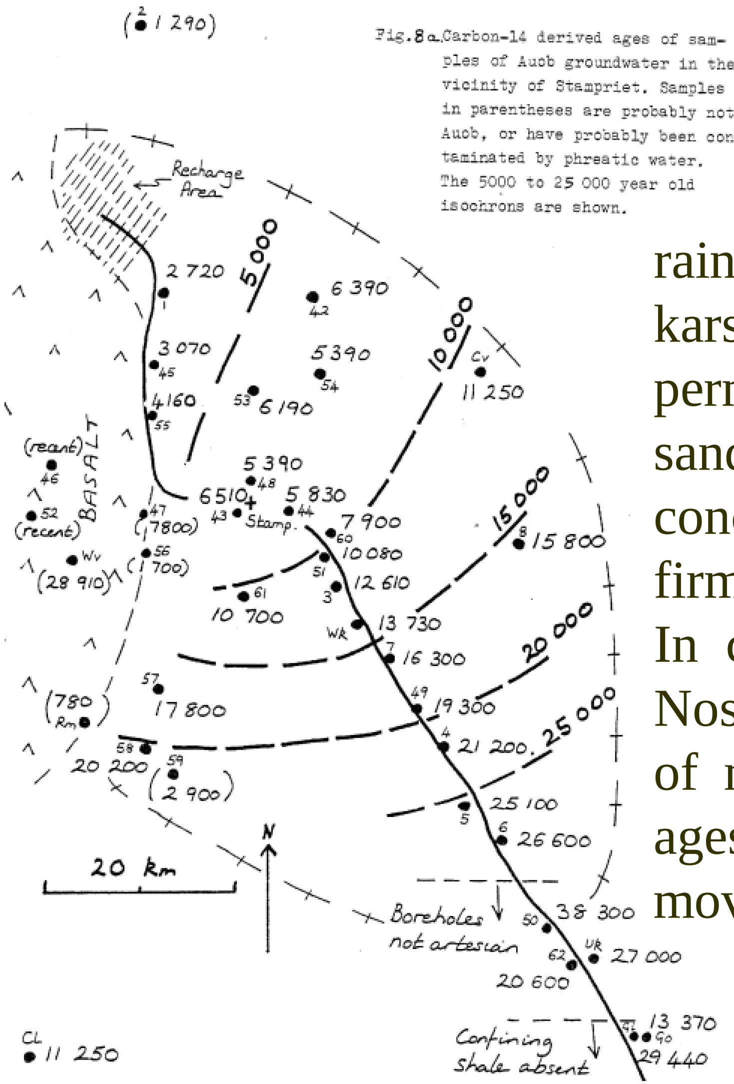


Fig. 8a. Carbon-14 derived ages of samples of Auob groundwater in the vicinity of Stampriet. Samples in parentheses are probably not Auob, or have probably been contaminated by phreatic water. The 5000 to 25 000 year old isochrons are shown.

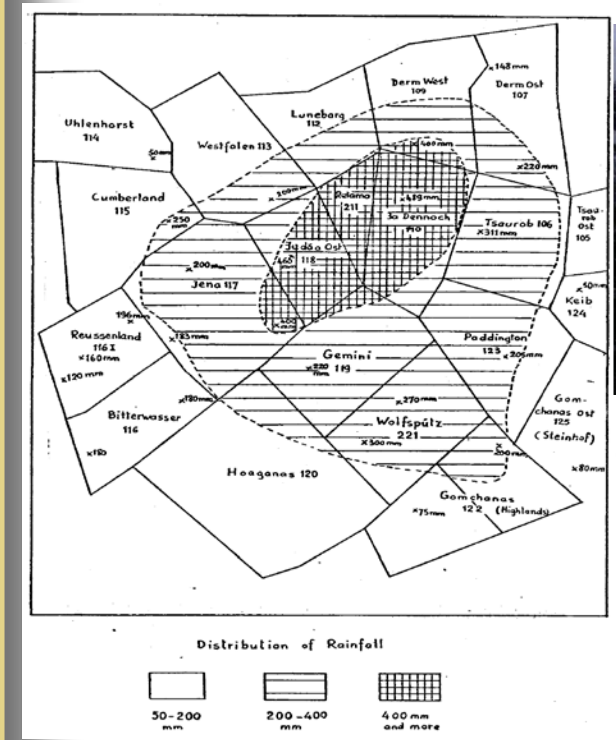
In the CisNossob - west of the Nossob River - the Auob aquifer is recharged from rainfall in areas near the basin boundary where karstified calcrete is overlying - or through permeable faults in contact with - the Auob sandstone. These areas are indicated on the conceptual model. ^{14}C age determinations confirm this and also indicate the flow velocity.

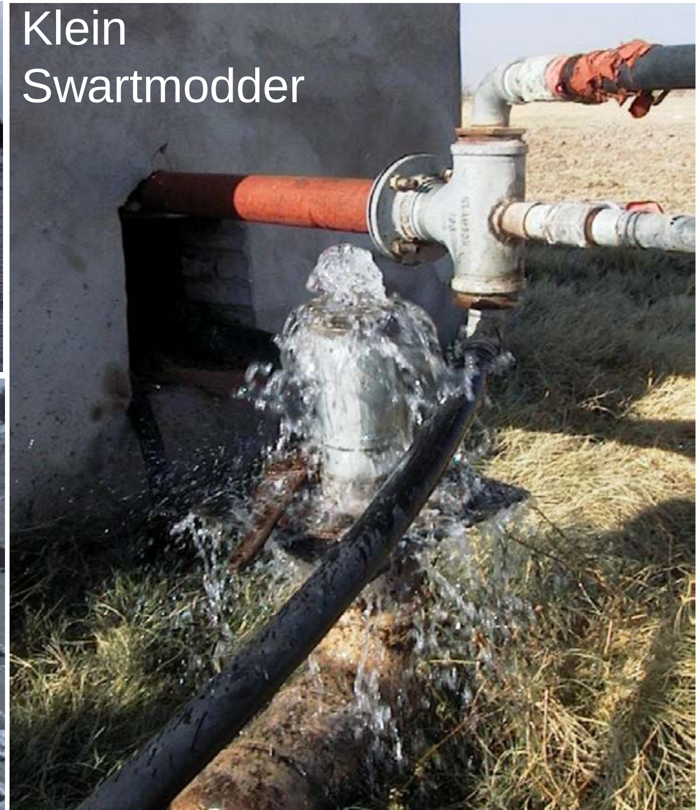
In contrast in the TransNossob - east of the Nossob River - TBA waters start with ^{14}C ages of more that 20 000 years reaching apparent ages of up to 40000 years as the groundwater moves east and southwards.

TBA water in the TransNossob was last recharged during the last Pluvial 20000 YBP.

Recharge occurs during high rainfall events such as the

UHLENHORST CLOUD BREAK





- Schalk investigated the extraordinary rainfall event in the night of 24 February 1960 when it rained up to 489 mm within 12 hours. A borehole on Klein Swartmodder 50 km away started flowing three weeks later with a head of 1.3 m

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Recharge calculations

Schalk calculated the amount of rainwater that infiltrated after the Uhlenhorst cloudburst as approximately: **$Q=100*10^6$ m^3.** He did not estimate the amount that could have reached the TBAs. Vogel et al. applied Darcy's Law Q = kD*b*i [m^3/d], using an average gradient i=1/1000, average transmissivity Kd=11.3 m^2/d with an aquifer width b=55 km above Stampriet. This resulted in an average annual recharge rate for this area only of: **$Q=0.68*10^6$ m^3/a**.

JICA calculated the combined recharge for all three aquifers using three approaches :

Modelling = **$6.1*10^6$ m^3/a**

Cl Mass balance = **$34*10^6 m^3$/a**

Water balance = **$134*10^6$ m^3/a**

Auob Aquifer Lithology

a Namibian example

Member	Formation		Lithology
Auob Member	Upper Sandstone	(A5)	White, massive sandstone weathering light yellow. Coarse-grained to locally gritty; high porosity and permeability; accessory biotite; cross beds and clay pellets up to 13 mm. . Common brownish black, calcareous concretions up to 3.6 m. , in places coalescing to form a continuous layer;
	Upper Auob Bituminous Shale and Coal	(A4)	
	Middle Sandstone	(A3)	Light grey to light brown, well bedded, fine to medium-grained sandstone; sand grains well rounded and well sorted; accessory biotite; isolated clay pellets. Petrified wood, often inside elongate, calcareous concretions in a layer of red, Fe-rich or yellowish white clayey sandstone; logs up to 50 cm. , 23 m long. Wood – *Dadoxylon porosum* and *Phyllocladopitys capensis* mainly, also *Abietopitys perforata*, *Dadoxylon rangei*, *Medullopitys sclerotica*; leaf impressions – *Glossopteris*, *Cordaites hislopi*.
	Lower Bituminous Shale and Coal	(A2)	
	Lower Sandstone	(A1)	Medium-to coarse-grained, white to cream-coloured, thick bedded, faintly cross bedded channel sandstones. Mainly multistory channel sands up to 30 m thick. Thickness 5 to 30 m.

Porosity

Kalahari	Tu 1	22	22
	Tu 2	18	26
	OL 2	22	36
	average	21	28
Auob	Tu 0	23	23
	OW 1	26	26
	OW 2	3	21
	average		23
Nossob	Tu 3	20	24
	OL 3	23	27
	OL 4	26	28
	Ga 1	2	19
	Ga 2	29	29
	Ga 3	28	30
	average		**26%**

The table shows the porosity [%] calculated by Vogel et al. 1982 for different sandstones. The values were calculated for the Calcium cemented samples and for the pure sandstone after the removal of the carbonate. For Botswana a porosity of **20%** is assumed based on data from neutron porosity logging data (Masie, Masedi et al. 2008).

Transmissivity

Highly variable transmissivities were obtained from pumping tests that were done on the JICA boreholes. Tests carried out by Kirchner at Olifantswater W, Tugela and Galton in the late 1970s yielded values between 10 and 14m^2/d (Vogel, Talma et al. 1982).

Parameter	No. of samples	Maximum	Minimum	Median	Average
Transmissivity (m^2/d)	7	1240	0.006	25.2	222.7
Permeability (m/day)	7	6.6E-3	2.3E-9	3.9E-6	9.73E-4

In Botswana a transmissivity value of 137 m^2/d was determined for the Otshe and 52 m^2/d for the Ntane aquifer.

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Total groundwater volume

Values for the transboundary aquifers can only be approximated as the aquifer volumes can only be guessed and the distribution of the porosity is also not known. In addition any value calculated is **hypothetic** because of insufficient cementing **aquifers will collapse** around any borehole once dewatered.

Aquifer	Surface Area [m²]	Aquifer Thickness (m)	Saturated Matrix Volume [m³]	Average S	Water Reserves [m³]	Exploitable Reserves [m³]
Ecca Aquifer (Otshe), Ncojane Block	4 391 115 829	81	307 378 108 012	4.43E-04	157566409	**31513282**

For Namibia the same arguments are valid. There are not sufficient data to describe this parameter for any of the 11 aquifers. It is not known if the formations do exist in certain areas or not.

Aquifer	Thickness (m)	Area (m²)	Volume (m³)	Porosity (%)	Storage (m³)
Kalahari (Saturated)	0-250	$52.6E^{9}$	$2.36E^{12}$	5	$120E^{+9}$
Auob Aquifer	0-150	50.7^{E9}	$3.60E^{12}$	5	$180E^{+9}$
Nossob Aquifer	0-60	$9.93E^{9}$	$1.24E^{12}$	5	$57E^{+9}$

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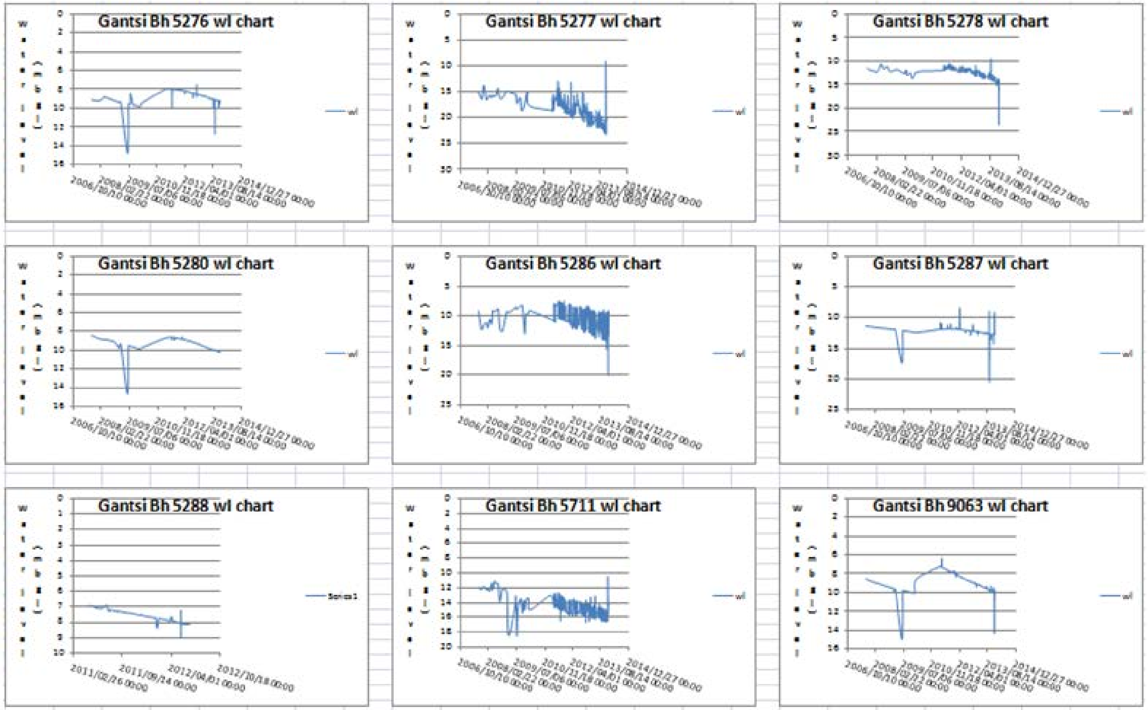
Groundwater depletion I



For Recharge and Depletion assessment long term water-level records are needed. For Botswana only short-term raw data have been made available to the specialist. From the limited data it will appear that there is a downward trend. This confirms the recharge observations for the “TransNossob”.

Groundwater in the TransNossob is mined.

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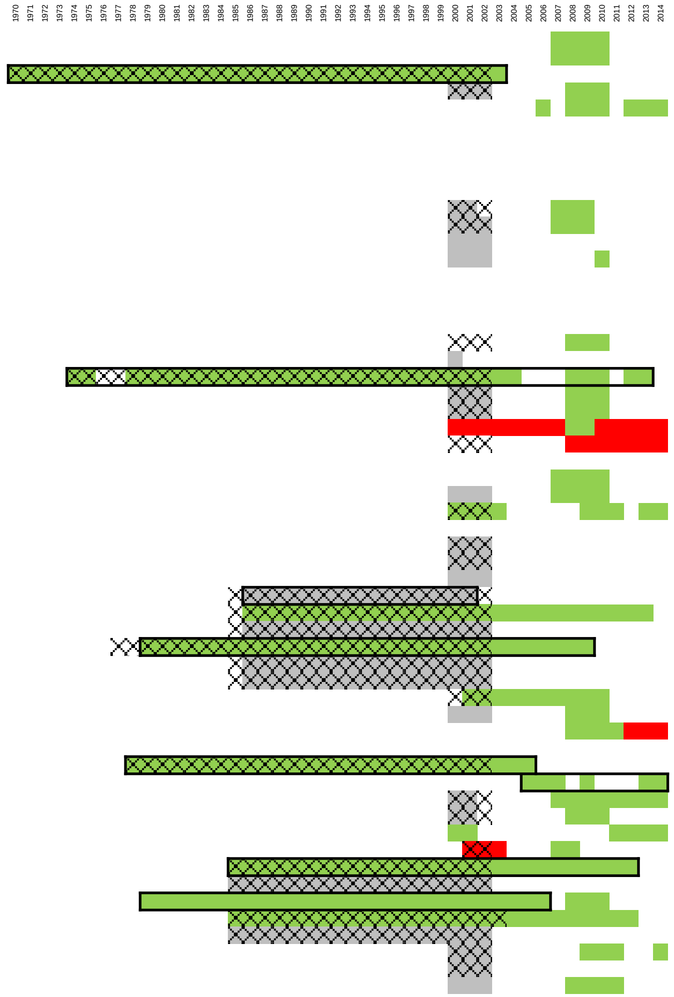
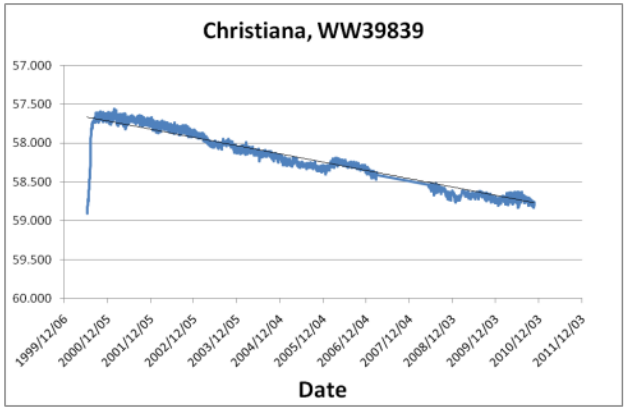
Groundwater depletion II

Borehole_no	Locality	Latitude	Longitude	Aquifer
WW 40960	Boomplaas	24.54990	18.56330	
WW 40961	Boomplaas	24.54980	18.56330	
WW10120	Boomplaas			
WW 39839	Christiana	23.25400	18.98720	Auob
WW 40963	Christiana	24.09060	18.50330	
WW 9854	Gobabis Power Station	22.44610	18.97070	
WW 25877	Gobabis Town	22.50450	18.97940	
WW 29334	Groot Aub	23.07140	17.18420	
WW 16919	Grünental 151	22.40760	18.38060	
WW 11592	Nauaspoort	23.07140	17.19980	
WW39849	Cobra	24.79990	19.33590	Kalahari
WW 39850	Cobra	24.80040	19.33630	Auob
WW 39851	Cobra			Nossob
WW 37194	Dagbreek	25.44560	18.26430	Nossob
WW 24604	Galton 25	23.28300	18.73390	
WW 24604	Galton 25	23.28300	18.73390	
WW 24605	Galton 25	23.28370	18.73430	
WW 24605	Galton 25	23.28370	18.73430	
WW 37225	Glencoe	25.07250	18.10950	
	Gochas			Nossob
WW 8399	Gomchanas M122			Auob
WW 39873	Gumuchab	23.52860	18.29340	Auob
WW 39852	Jackalsdraai	25.29130	18.41780	Kalahari
WW 39853	Jackalsdraai	25.29110	18.41760	Nossob
WW 39857	Klein Swartmodder	24.00130	18.21640	Auob
WW 39848	Maritzville			Nossob
WW 40962	Müritz	24.09070	18.50340	
WW 39872	Neu Simmern	23.56010	18.31740	Nossob
WW 39874	Neumark	23.60273	18.34315	Auob
WW 39874	Neumark	23.59860	18.34670	Kalahari
WW 39845	Okonyama	23.40010	19.62600	Kalahari
WW 39846	Okonyama	23.40049	19.62580	Auob
WW 39847	Okonyama	23.40080	19.62730	Nossob
WW 21784	Olifantswater West	23.68440	18.39460	Auob
WW 21814	Olifantswater West	23.68440	18.39460	
WW 21815	Olifantswater West	23.68440	18.39460	
WW 22544	Olifantswater West	23.68470	18.39460	Auob
WW 22545	Olifantswater West	23.68260	18.39400	
WW 22546	Olifantswater West	23.68520	18.39240	
WW 39840	Olifantswater West	23.64720	18.38970	Auob
WW 39841	Olifantswater West	23.64780	18.38960	Nossob
WW 40964	Sandverhaar	23.77160	19.22800	
WW 40965	Sandverhaar	23.77160	19.22810	
WW 32457	Spes Bona			Auob
WW 40959	Spes Bona	24.32930	18.39970	Auob
WW 39842	Steynsrus	24.04580	18.79450	Kalahari
WW 39843	Steynsrus	24.04760	18.79420	Auob
WW 39844	Steynsrus	24.04667	18.79410	Nossob
WW 40007	Tsaurob	23.74540	18.20700	
WW 22556	Tugela	24.81940	18.25400	Auob
WW 22581	Tugela	24.81940	18.25400	Kalahari
WW 22837	Tugela	24.82050	18.25390	Nossob
WW 22838	Tugela	24.82050	18.25380	Nossob
WW 22839	Tugela	24.81950	18.25280	
WW 39854	Tweerivier	25.46110	19.43380	Kalahari
WW 39855	Tweerivier			Auob
WW 39856	Tweerivier			Nossob



For Namibia the situation doesn't look much better. The greyed data have been lost and the more recent data are not edited.



In the TransNossob declining water levels are observed.

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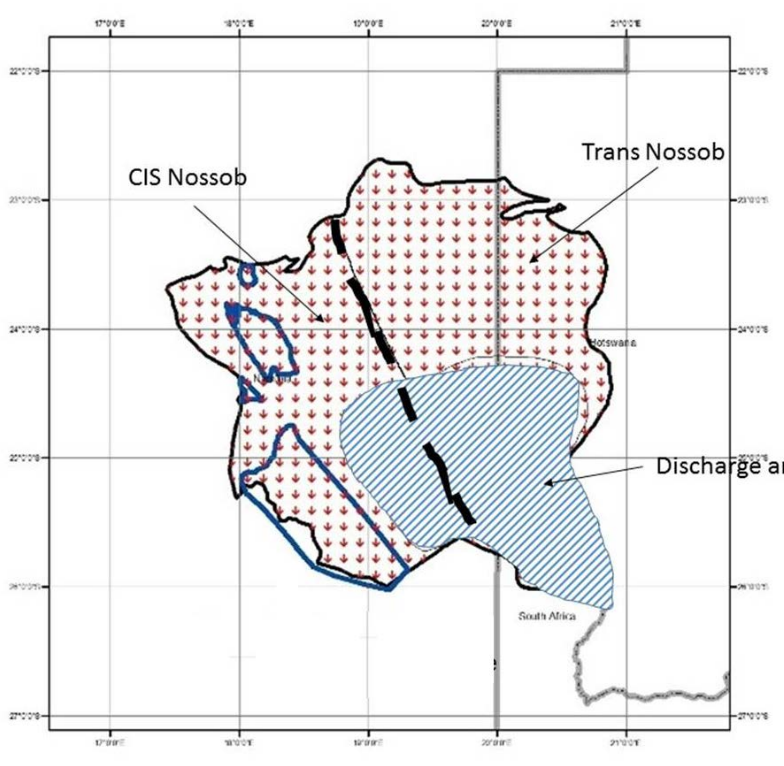
Groundwater depletion III

In the CisNossob the situation is different: It appears that after an initial drop of the water table a new equilibrium has developed. After extraordinary rainfall



events/years (e.g. 1934; 1974 and 1976; 2000; 2001; 2012 the water levels seem to recover to the previous levels.

However, the recent observation that the spring at Hoachanas fell dry gives rise to concern.

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Natural discharge mechanism

BOTSWANA: As in Namibia and South Africa it must be assumed that evapotranspiration at the lower end of the aquifer is the prevailing discharge mechanism.

NAMIBIA: At the lower end of the basin - in the Saltblock area - groundwater flows out of the TBAs into the Kalahari. **Evapotranspiration** is then the discharge mechanism of the Kalahari aquifer. Discharge by springs is minimal.

SOUTH AFRICA: In line with the depth to the water table, there are no visible groundwater discharges. The absence of springs, etc. coupled with the limited recent recharge leave evaporation and evapotranspiration losses from the top of the saturated formations as the driving natural discharge mechanism.

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Conclusions I

- Irrigation is the main (TBA) water user, followed by stock watering and human use, both from Kalahari and TBAs.
- The Ecca transboundary aquifers are only recharged in the CisNossob part (W of the Nossob River). In the TransNossob the aquifers were last recharged some 20 000 years ago.
- It appears that after an initial water-level decline a new equilibrium has been reached in the CisNossob indicating that over longer periods there is possibly no TBA depletion.
- Water quality decreases from drinking water quality in the north and west to unsuitable in the southeast. In the few TBA boreholes that have been analysed more than once the water quality is decreasing with time indicated by rising EC.
- Data capture in Namibia and possibly in Botswana is wanting.

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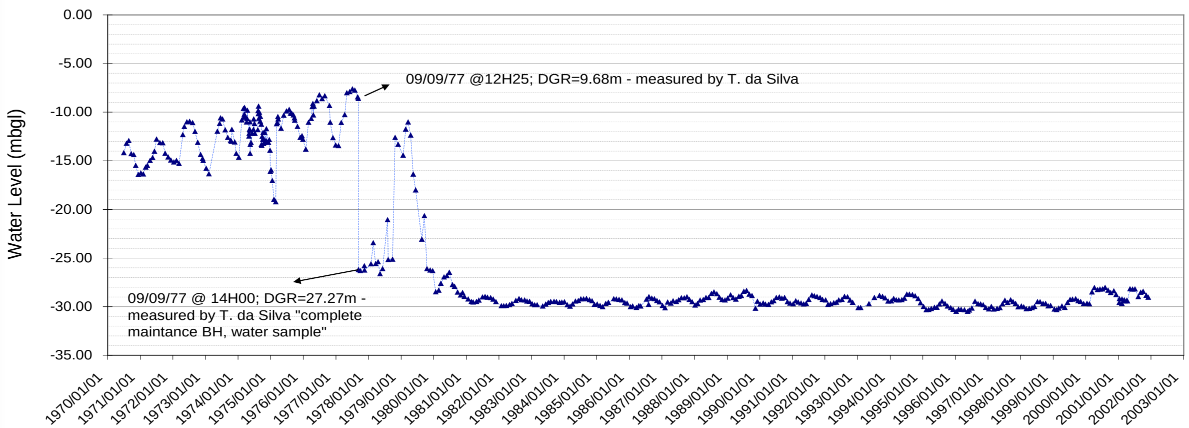
Conclusions II

- Water is wasted



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Recommendations

- **Monitoring water level; quality; and abstraction data** are the A and Ω of any groundwater resources management. These data must be **reliably captured; edited; stored and processed**.
- A **common TBA data base** should be created and TBA **management procedures** be negotiated and implemented.
- **Drilling and construction requirements** and permitting of TBA boreholes should be harmonised between the three countries. This includes **obligations to measure and submit** abstraction and water level data by permit holders.
- Policing is necessary to ensure **legal requirements are adhered to** and illegal drilling is stopped.
- **The law must be enforced.**
- Attention must be given to the problem of **TBA boreholes with leaking seals**.

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