Ephemeral River Basins

Sharing temporary waters in southern Africa

A hydrogeological review of the Orange-Fish River Basin, Namibia

Frank Bockmühl

January 2009

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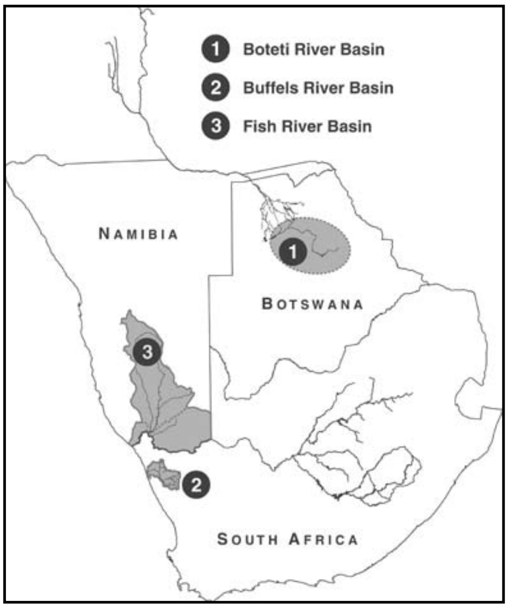
Ephemeral River Basins in Southern Africa Project

Ephemeral River Basins (ERB) in Southern Africa is a project that promotes the sustainable, equitable and improved utilisation of water and other natural resources in ephemeral river basins in southern Africa through the process of integrated resource management (IWRM). Although IWRM is accepted – internationally and regionally – as the approach promoting sustainable management of water resources and the river basin is considered the ideal unit over which to apply it, the basin management approach has not been widely tested and implemented in ephemeral river basins in southern Africa.

The ERB in Southern Africa Project, however, explores the potential and options for basin management in three ephemeral river basins in southern Africa – the Boteti, an outflow of the Okavango Delta, in Botswana, the Buffels, a westward-flowing ephemeral river in the Northern Cape, in South Africa and the Fish River Basin, a tributary of the Orange River, in Namibia.

Despite being ephemeral, all three river basins are essential water resources in their areas. The three basins have different biophysical and socio-economic characteristics and are managed under different legislative, policy and institutional arrangements. Together, they thus provide good examples to explore the potential and options for basin management in ephemeral rivers and on which to base a comparative analysis for wider application.



The purpose of the project is met by five main activities:

- Sensitising managers and users of natural resources to the concepts of IWRM and basin management
- Assessing the potential for the application of integrated basin management
- Establishing appropriate forums for promoting IWRM in the three basins
- Documenting the biophysical and socio-economic status of the three basins
- Documenting best practices, lessons learnt and case studies as a comparative analysis for wider application.

This is one of many reports emanating from the ERB in Southern Africa Project. For more information on the project, visit our website at http://www.drfn.org.na/erb/index.html

The project is funded by the Norwegian Ministry of Foreign Affairs and co-ordinated by the Desert Research Foundation of Namibia (DRFN). Work in the Boteti River Basin is being led by the Harry Oppenheimer Okavango Research Centre (HOORC), in the Buffels by the Surplus People Project (SPP) and in the Fish by the DRFN.

Abbreviations and acronyms

%	per cent
Ca	calcium
$CaCO_3$	calcium carbonate (indicates 'hardness' of water)
Cl	chloride
dm^3	cubic decimetre(s); 1 dm^3 = 1 ℓ
F	fluoride
Fe	iron
K	potassium
km	kilometre(s)
ℓ	litre(s); 1 ℓ = 1 dm^3
m	metre(s)
m^3	cubic metre(s)
m^3/h	cubic metre(s) per hour
m^3/m	cubic metre(s) per month
Ma	million years ago
mbgl	metre(s) below ground level
mg	milligram(s)
mg/ℓ	milligram(s) per litre
mm	millimetre(s)
N	nitrogen
NamWater	Namibia Water Corporation
OFRB	Orange-Fish River Basin
pH	measure of acidity or alkalinity of a solution
RWL	rest water level
$S0_4$	sulphate
TDS	total dissolved solids

Contents

Orange-Fish River Basin, Namibia

1 Introduction

The Orange-Fish River Basin (OFRB) covers an extensive part of southern Namibia, draining an area of nearly 120,000 km^2 (Figure 1).

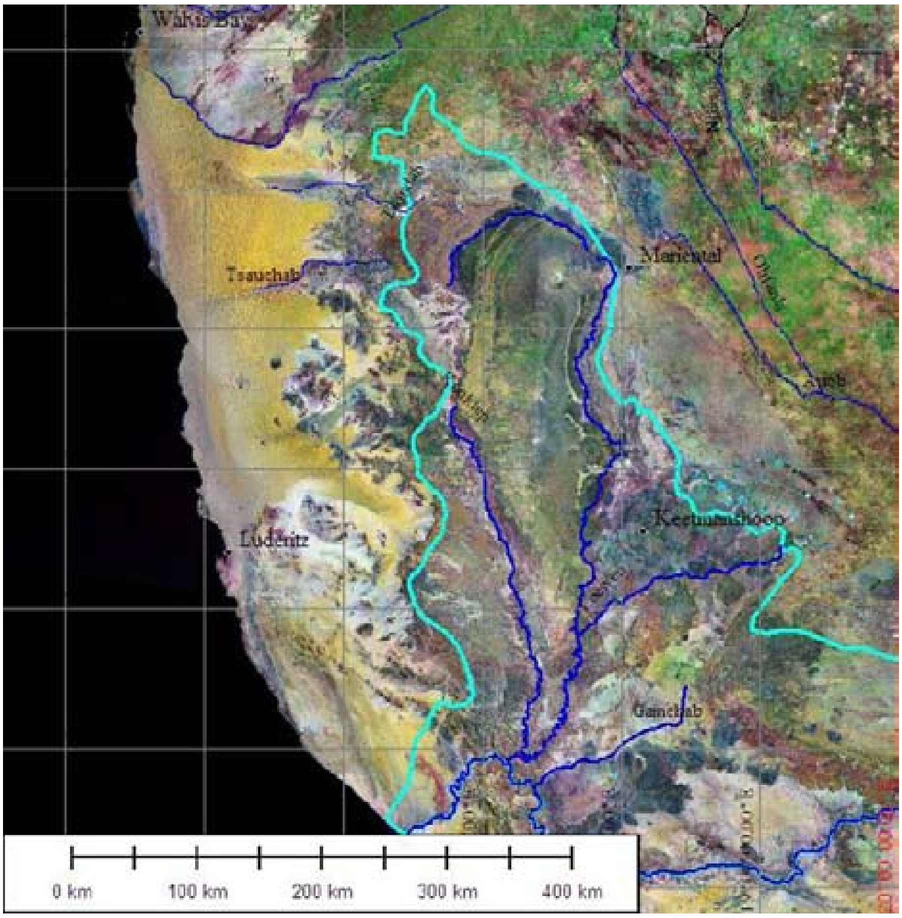


Figure 1: Satellite image of the OFRB, showing major rivers and towns
Adapted from: Swart (2008)

The basin includes examples of all major rock formations that occur in Namibia. The landforms of the basin reflect a wide variety of lithologies (rock types) as well as the long geomorphological history of the area. Geology has influenced the location, quantity and quality of groundwater resources in the basin.

Towns and rural communities depend mainly on groundwater for domestic use, watering stock and to a lesser degree for industrial use. In a region with low and erratic rainfall, recharge of the aquifers is similarly low and erratic. With predominantly shallow groundwater tables in the basin and very limited overburden, recharge of groundwater happens very fast after rainfall events. As a result, pollutants can also easily be transported into the aquifer system and therefore special precautions are always necessary to prevent this.

Most of the groundwater resources in the OFRB are of good quality, suitable for both domestic and livestock use. The water quality is generally also suitable for irrigation purposes. However, some water quality problems exist in certain geological environments, especially the Dwyka tillite and shale areas with associated dolerite intrusives, and in the basement around Warmbad.

Sulphate, fluoride, high sodium and high chloride concentrations are some of the more important ions in the groundwater that determine whether it is suitable for domestic use. Fluoride in high concentrations can lead to severe dental and skeletal problems, while sodium concentrations can affect people with heart conditions. High nitrate values make the water unsuitable for babies under the age of one. **Increased nitrate concentrations are almost always a result of contamination due to human and livestock activities close to the boreholes**. This type of pollution cannot be reversed, but new abstraction points can be protected by siting habitation, sewerage systems and livestock pens appropriately.

In general, boreholes have a low yield, and care should always be taken when high and constant abstraction is planned. Scientific data regarding the character and behaviour of the groundwater in the area are very limited. Understanding the hydrogeology of the basin is important for its management, which also includes protection of the vulnerable resource. A greater distribution of water level gauging wells and a better chemical water quality monitoring system should be established in the OFRB.

In order to understand the geohydrology of the area, a short general introduction to the hydrologic cycle will be necessary. The different aquifers are discussed in this report in geo-chronological sequence. Geological descriptions have been adapted from *The Fish River Basin: An earth science review for the Ephemeral River Basins Project* (Swart 2008).

2 Explaining processes and terms

2.1 The hydrologic cycle

The hydrologic cycle consists of a few basic phenomena observed all over the world and which come together to drive most lifecycles.

Evaporation of water from the oceans, lakes, streams and vegetation, especially the rain forests, results in major amounts of moisture being transported to zones where *condensation* results in the formation of clouds. These release the transported moisture to reach the ground surface through the process of *precipitation*.

Rainwater (precipitated water) can either:

- *evaporate* from the surface very shortly after precipitation,
- form *surface runoff*, which will
- *infiltrate* to the *groundwater* at localities where precipitation did not occur, or
- collect in some surface lakes or artificial impoundments (dams) to again *evaporate*, or
- ultimately reach the oceans to be available for evaporation again.

A percentage of rainwater immediately starts to reach subsurface levels. The process of *infiltration* of water into the shallow layers provides water to the root-systems of plants. *Uptake* of this shallow soil water transports nutrients to the growth points of the plants. Water is lost to the atmosphere through the plants' leaves by *transpiration* (or *evapo-transpiration*). Infiltrated water which is not taken up by plants is available to reach the *groundwater* by the process of *percolation*.

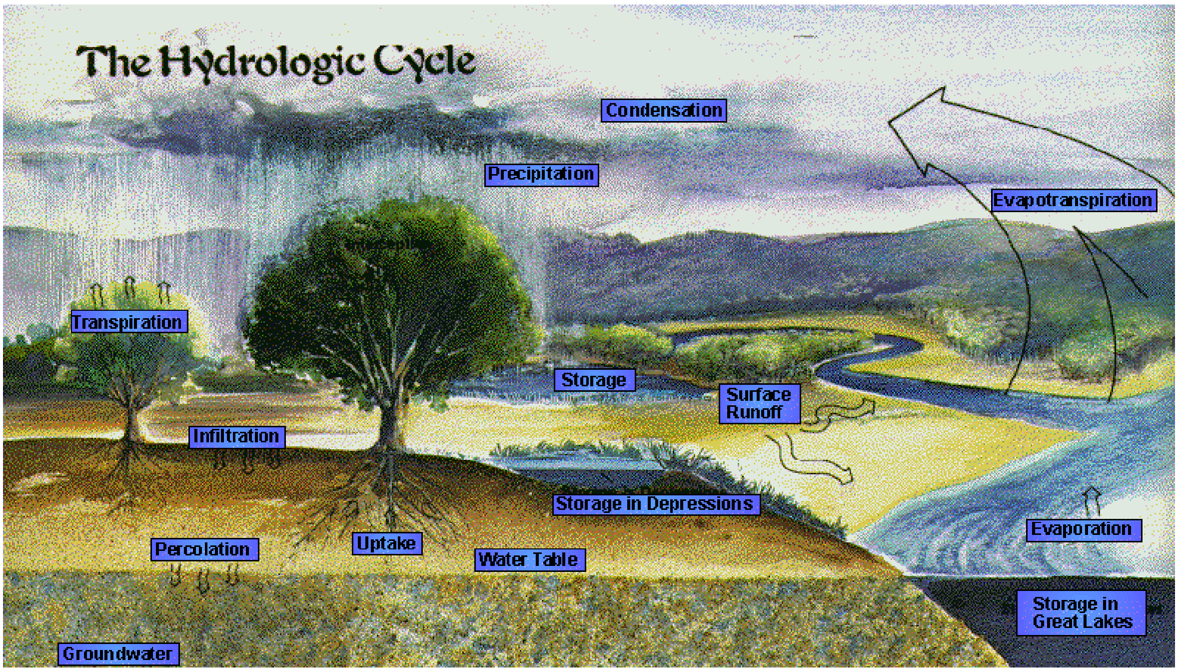


Figure 2: A generalised schematic presentation of the hydrologic cycle

Most of the world's water finally returns to the oceans by surface run-off. This process is continuous, with no additional water normally entering the cycle.

Hot and dry conditions in the OFRB drive vectors such as evapo-transpiration and evaporation significantly and a large percentage of water stored in open impoundments is lost through evaporation. Average annual evaporation rates for much of the basin are greater than 2,200 mm/annum. The average annual rainfall in the basin varies from less than 50 mm/annum in the south-west to around 250 mm north of Mariental. The average water deficit is more than 2,100 mm/annum, with an extreme of more than 2,500 mm/annum around Keetmanshoop. A significant portion of all rainwater is also lost as it leaves the area in major drainages such as the Fish River and its tributaries during intensive runoff events. Water stored underground in aquifer systems is not exposed to this high evaporation rate and should thus only be abstracted from the ground when necessary.

2.2 Groundwater

Fresh potable groundwater only constitutes some 1% of all the water distributed on earth. In general terms, *groundwater* is subsurface water that fills open spaces. The geological formation that stores and provides this groundwater is called an *aquifer*. An aquifer can be hosted in any homogenous geological unit, which has the same properties at all locations, or in a heterogenous geological unit, which has different properties in the same unit and at different locations. The latter is generally the case in the OFRB.

Aquifers can be hosted between *confining* layers, which are geological units with little or no intrinsic permeability, and can be subdivided into aquifuges, aquicludes and aquitards. These aquifers can have different characteristics based on the kinds of open spaces in which they are situated. In the OFRB, aquifers with pores are mostly *primary* aquifers and occur predominantly in sandstone horizons and in shallow alluvial basins, whereas aquifers with joints represent the majority of *secondary* aquifers. Karst aquifers are very limited in the OFRB, and are restricted to minor carbonate geological units mainly along contacts with limestone and dolomitic limestone in the Kuibis Subgroup of the Nama Group.

2.3 Water quality guidelines

Chemical water quality guidelines have been developed in Namibia as follows:

Table 1: Water quality guidelines

Parameter	Unit	Group A	Group B	Group C	Livestock-watering
pH		6-9	5.5-9.5	4.0-11.0	4.0-11.0
conductivity	mS/m	150	300	400	
TDS (determined)	mg/ℓ				6000
sulphate as SO_4	mg/ℓ	200	600	1200	1500
chloride as Cl	mg/ℓ	250	600	1200	3000
fluoride as F	mg/ℓ	1.5	2.0	3.0	6.0
nitrate as N	mg/ℓ	10	20	40	100
nitrite as N	mg/ℓ				10
$CaCO_3$	mg/ℓ	300	650	1300	
calcium as Ca	mg/ℓ	150	200	400	1000
magnesium as Mg	mg/ℓ	70	100	200	500
sodium as Na	mg/ℓ	100	400	800	2000
potassium as K	mg/ℓ	200	400	800	
iron as Fe	mg/ℓ	0.1	1	2	10
manganese as Mn	mg/ℓ	0.05	1	2	10

Group A and Group B water is suitable for human consumption, whereas Group C water should preferably only be used for watering livestock.

2.4 Borehole yields

Borehole yields are expressed in m^3/h, and normally indicate the rate at which water can be abstracted from the borehole. This has to be determined by controlled pumping tests through careful measurment of water levels and pumping rates. However, this is often not carried out, as the costs involved are generally considered unwarranted. Yields recorded in this report therefore need to be interpreted with care, as they are largely derived from short-term pumping by drillers, without the necessary measurements recorded, and are generally optimistic and not sustainable over a long period.

As a guideline, a 1 m^3/h borehole (sustainable yield; or 1000 ℓ/h) over an eight-hour period would supply sufficient water for 160 head of large stock, or up to 1,600 small stock. For rural settlements, the *minimum* water requirement for human consumption is about 25 ℓ/person/per day: these 8,000 ℓ daily would thus serve about 300 people/day.

2.5 Other terms explained

Within the context of this report, *salinity* of groundwater always refers to the total amounts of salts dissolved in the water. This includes nitrates, nitrites, fluorides, sulphates, as well as dissolved sodium chloride and carbonates, and any other possible salts that might occur in groundwater. Salinity of borehole water is expressed in mg/l and generally referred to as *total dissolved solids* (TDS) and is a determining factor in the electrical conductivity of the water (refer to Table 1 above).

When referring to the *strike* of a fault, formation or structure, the lateral bearing on the surface of this feature is described. The strike of any linear feature will be referred to in geographic terms such as north, south, east or west, or in degrees and is generally determined with a compass.

The *dip* of a fault or formation refers to the incline from the horizontal of this feature. In selecting suitable drillings sites along a fault or fracture zone, the target should be intersected well below the water table and for this to be successful, the dip should be determined as accurately as possible. With simple trigonometric calculations it is then possible to determine the distance from an outcrop where a possible drill site should be selected.

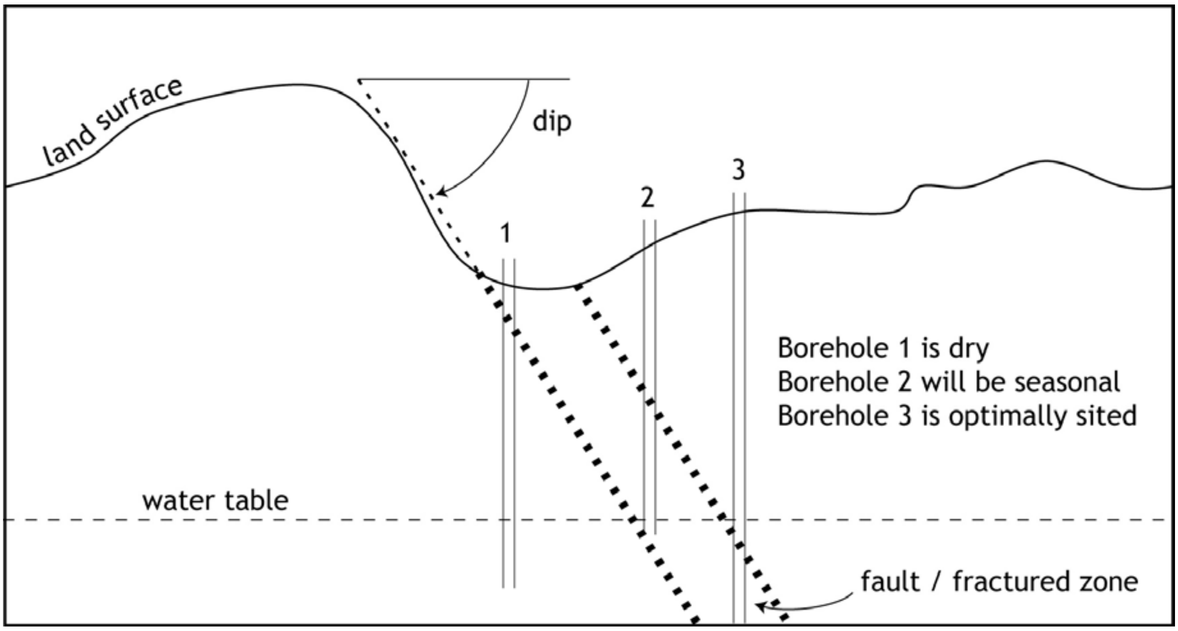


Figure 3: General terms explained

3 General geology, geohydrology

3.1 Orange River Group

Highly deformed and metamorphosed amphibolites, metasediments and associated intrusive rocks make up the oldest rocks in southern Namibia (between 2,000 to 1,700 million years old (Ma)). Known as the Orange River Group, this group of lithologies are geohydrologically insignificant due to the small extent of outcrop. Geohydrological properties however are similar to those described under the Namaqua Metamorphic Complex (see Section 3.3).

3.2 Elim Formation and Rehoboth Sequence

Isolated outcrops of sedimentary and volcanic rocks belonging to the Elim Formation and Rehoboth Sequence (1,670-1,420 Ma) occur on the margins of the basin and in adjacent areas. These rocks are, like the Orange River Group, geohydrologically insignificant due to the limited extent of outcrop.

3.3 Namaqua Metamorphic Complex

The highly deformed Namaqua Metamorphic Complex, which covers an extensive part of southern Namibia, and the volcano-sedimentary Sinclair Sequence of central Namibia (see below) were formed between 1,800 Ma and 1,000 Ma. Major shear zones, or large fault zones, such as the Tantalite Valley shear may be over 500 km long and were the loci for the emplacement of mafic intrusions and pegmatites.

In the south-eastern Karas Region, to the south of the town of Karasburg and extending to the Orange River, expansive outcrops of Mokolian basement rocks occur. The town of Warmbad is centrally situated in this area. Along the course of the Orange River, basement is exposed from 20° E, westwards to an area south of Rosh Pinah.

An area stretching generally north-east from the Orange River boundary of the /Ai-/Ais Park past the Grünau–Holoogberg area to farm Naauwpoort 304 is also predominantly underlain by basement.

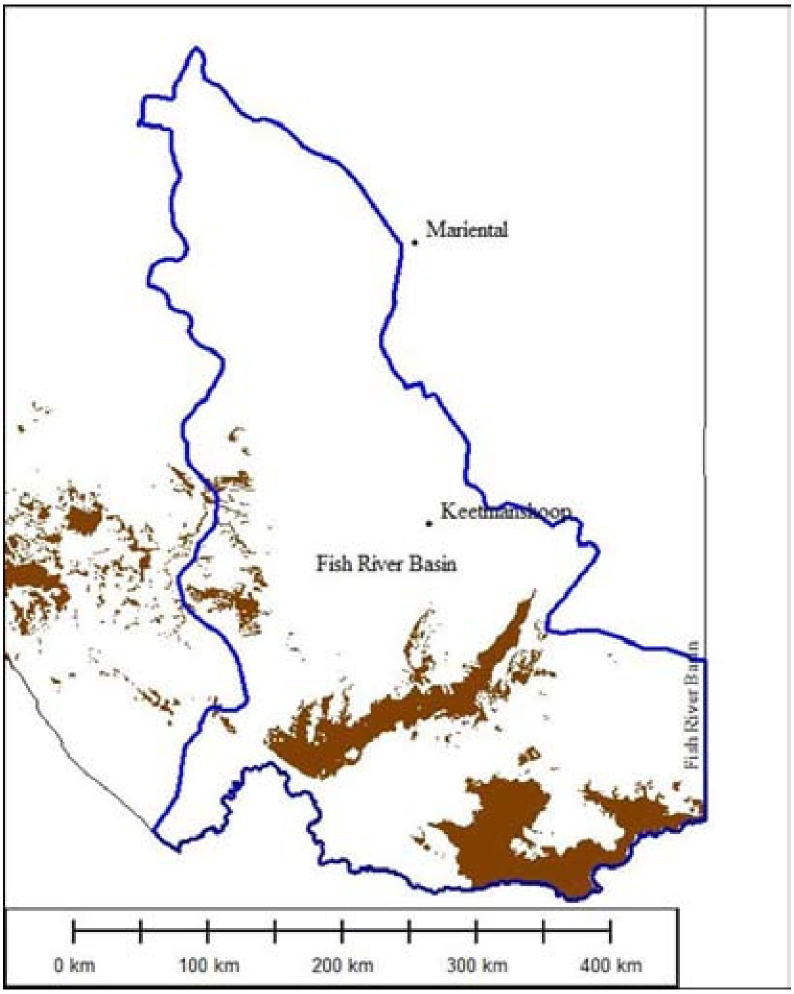


Figure 4: Extent of outcrop areas of the Namaqua Metamorphic Complex
Source: Swart (2008)

3.3.1 Geomorphology

The greater portion of the area is a plain of erosion sloping south towards the Orange River. In the east, and to a lesser degree in the north, an escarpment formed by overlying Nama sedimentary rocks defines the borders of the area. The western and south-western areas are mountainous, while along the Orange River the plain is highly dissected.

Drainage is normally dendritic from the north towards the Orange River. Dominant (seasonal) rivers are the Kainab, Ham and Udabis rivers in the east and the Velloor and Hom rivers in the central portion. The Haib, Aniegamoep and Gamkab rivers expose the basement more towards the west. The Fish River drains the area through the /Ai-/Ais Park.

Basement outcrops in this area are of Mokolian age (1,200 to 2,000 Ma) and are divided into the Haib Group and Vioolsdrif Granite Suite Complex in the west and south-west, and the Namaqua Metamorphic Complex in the eastern and north-eastern areas. Intrusive rocks such as granites, augengneisses, gabbros, norites and pegmatites are generally younger than the metasedimentary and metavolcanic rocks such as (meta-) gneisses and older metamorphosed lavas. In an area to the south-east of Warmbad, unconsolidated quaternary sediments are overlying the rocks of the Namaqua Metamorphic Complex.

The basement rocks have been exposed to erosion and weathering for up to 600 Ma, during which a palaeo-landscape was formed. During the late Namibian (± 650 Ma) to Cambrian Period (± 500 Ma), the basement rocks were partially covered by sedimentary rocks of the Nama Group, which in turn were also partially covered by Karoo-age sediments (Carboniferous to Permian 345 to 230 Ma). The latter were intruded by post-Karoo dolerites of Jurassic age.

The younger horizons have subsequently been removed by erosion, re-exposing the basement. Erosion started in the south and has presently reached the area to the south of Karasburg, where deeply incised rivers, such as the Hom, open windows of basement (see Section 3.3.3 Dreihuk Dam: Water supply potential to Karasburg).

Major, regional, north-west striking faults have displaced the Haib Group and Vioolsdrif Granite Suite Complex with rocks belonging to the Namaqua Metamorphic Complex. A second regional fault-line strikes north-east from the farm Hakiesdoorn 187 to Norechab Farm 129. Abundant smaller faults have been mapped, indicating no preferential direction of strike. In low-lying areas, these faults represent prime targets for groundwater exploration.

3.3.2 Hydrogeology

Available potable water in the southern Karas Region underlain by basement rocks is very limited. Poor water quality further aggravates the situation.

Rainfall in the area is low: a 67-year mean for Karasburg was calculated at 123 mm (1990).

As the abundance of old hand-dug wells indicates, the area has a long history of habitation. Wells have primarily been dug along river courses in shallow alluvium and deeply weathered channels and basins. Wells around Warmbad were mostly dug before 1930 (Tredoux 1970). The few boreholes drilled before 1920 were generally sited along or close to river courses.

Natural fountains also occur predominantly along riverbeds. At Warmbad, a thermal spring is fault-controlled (± 34° C), and at Tzamab-Gruendorn 57, some 3 km north of the Hamab Station, another warm spring is associated with an inlier of gneiss (Haughton and Frommurze 1936). Artesian boreholes have been located on the farm Nieuwefontein Ost (Tredoux 1970).

The only detailed survey of boreholes and wells in the area to the south of Karasburg, underlain by rocks belonging to the Namaqualand Metamorphic Complex, was conducted by the CSIR during 1969. More than 783 boreholes and wells were located.

During this survey water samples were collected from 338 boreholes, wells and artesian boreholes.

- 445 dry boreholes were recorded, presumably only a part of those in existence. As dry boreholes are not of any use to people, details are not normally recorded and are thus lost over the years. Dry boreholes are significantly found on, or close to, the watershed between the Hom and Ham rivers.
- Depths of boreholes generally did not exceed 130 m, with the majority being shallower than 50 m.
- Water levels during the CSIR survey were generally shallower than 30 m.
- Yields below 2.3 m^3/h were recorded for 63% of the yielding boreholes, while only 16% yielded more than 5.4 m^3/h.
- Nearly 80% of all the water in the sources surveyed proved not to be suitable for human consumption. High concentrations of fluoride, high nitrates, and to a lower degree sulphates, affected the water quality.
- Only 20% of all the water sources analysed proved not to be suitable for livestock watering purposes. (High concentrations of sulphates cause water to taste bitter, preventing the animals from drinking.)

The high incidence of poor quality water in the area seems to be geologically controlled. It is known that high concentrations of fluorides are often associated with granitic terrain. Sulphates are often associated with gypsum deposits.

Water for both domestic and livestock use can always be treated in specially designed chemical treatment plants. As significant costs are involved, such plants can probably only be warranted for larger communities. Village-scale desalination plants are available on the market and, for remote areas, plants that are operated on solar power could also be an option. With adequate maintenance by sufficiently trained people, these water treatment plants can be a viable alternative to the present practice of trucking in drinking water.

Exploration for groundwater should be concentrated along faults and, where feasible, as close as possible to riverbeds in order to facilitate and enhance recharge. North of Warmbad, a typical fault has been used for drilling a borehole (Figure 5). Weathered and decomposed zones within the granitic terrain and also in areas close to riverbeds might be promising targets.

Geological investigations and geophysical methods to determine drilling sites are essential for maximising success rates. Electromagnetic surveys as well as electrical resistivity sounding- and profiling-arrays have been successfully employed previously.

Figure 5: Drill site WW33768 selected geologically to intersect a partly silicified, faulted contact (ridge in background) forming an east-southeast trending feature. (Borehole drilled to 100 m depth, water strike at 61 m; blow test yield, 2.89 m3/h; RWL, 53.38 mbgl; water quality, Class B).

Figure 6: Fault-controlled drainage channel north of Warmbad enhancing recharge in decomposed granites

3.3.3 Dreihuk Dam: Supply potential to Karasburg

During 1977 a dam wall was constructed across the deeply incised valley of the Hom River at Dreihuk, 16 km south-west of Karasburg. The planning and construction of this dam is a glaring example of how geological (and hydrological) evidence was ignored by policy makers, with obvious results. For the first 20 years after completion, the dam did not fulfil its objective of stabilising water supply to Karasburg. Even at the present high water levels, leakage substantially contributes to the fast decline of the volumes stored in the dam. However, recharge to the underlying aquifer has been considerably enhanced by this leakage and the water supply to Karasburg has been improved, as will be seen later in this section.

The site was geologically evaluated and found unsuitable for the following reasons:

- Prior to the sedimentation of the Karoo shale, the palaeo-surface was exposed to weathering. This weathered surface was not removed by erosion and still underlies the remaining sheet of Karoo rocks.
- The Hom River is deeply incised, totally cutting through the Karoo sediments, and again exposing the old underlying basement.
- Along the course of the Hom River, this weathered zone is normally half a metre thick, but within the riverbed itself several deeply weathered channels have been geophysically indicated.
- Along the course of the riverbed, both upstream and downstream of the dam site, several fountains discharge water into the river from the weathered contact-zone between the baked and thus brittle shales, and the underlying basement.
- The weathered zone will act as a transmission zone if the water-level within the dam basin rises above it, with water from the dam basin seeping into it, percolating down-gradient and resulting in increased discharge of fountains further downstream.

An attempt at grouting the weathered zone to prevent leakage within the area of the dam wall proved to be unsuccessful. As a result of the upstream fountains, a permanent pool of water collects in the dam basin. A drainage pipe in the eastern side of the dam wall, draining seepage water from within the dam wall and its foundations, had a measured outflow of 7.5 m^3/h (August 1985). This outflow, however, increased to in excess of 40 m^3/h after the dam received its first inflow in December 1985. This leakage had been predicted by investigating geologists before the construction of the wall was started.

On the western side of the riverbed below the spillway of the dam, water seeped through the weathered zone (which was grouted to seal off this seepage!). The amount lost with no water in the dam was negligible. After the 1988 inflow, about 12 m^3/h were measured, decreasing to about 3 m^3/h at the end of October 1988 as the water level within the dam basin declined.

Groundwater quality in the Dreihuk Dam area in general is poor when there is no inflow into the dam. High concentrations of sulphate, chloride and sodium result in Class D water. After inflow into the dam, the water quality of the drainage pipe, boreholes and the pit temporarily deteriorates due to a flushing effect. Some time after inflow into the dam, the water quality from all sources improves.

Depending on the water level in the dam basin, supply of groundwater to Karasburg from the Dreihuk Dam is estimated to be between 190,000 m^3/a and 60,000 m^3/a. The Namibia Water Corporation (NamWater), in 2000, supplied a total of 223,320 m^3 to the Municipality of Karasburg. This means that groundwater from the Dreihuk Dam area could supply up to 80% of Karasburg's water demand in times of crisis (refer also to Section 3.6.1).

3.4 Sinclair Group

The slightly younger Sinclair Group (1,400-1,200 Ma) was formed during rifting of the early craton and is geohydrologically insignificant.

3.5 Nama Basin

The Nama Basin developed as a broad, gentle foreland basin in response to the orogenies that were developing to the north and west. The Nama Group has been sub-divided into three formations – a basal Kuibis Subgroup, middle Schwarzrand Subgroup and an upper Fish River Subgroup. In Figure 8, these are indicated as yellow (Kuibis), green (Schwarzrand) and orange (Fish River Subgroup). Two sub-basins are also recognised, the northern Zaris Basin separated from the southern Witputs Basin by the Osis Ridge. In the deepest parts of the sub-basins, the depths of sediments are around 2-3 km thinning to less than 1 km towards the Osis Ridge (Grotzinger 2000).

Towns such as Aroab, Maltahöhe, Kalkrand (via a pipeline), Gibeon (partly only), Berseba and Bethanien are all supplied with groundwater pumped from rocks of the Nama Group.

The deeply dissected margins and canyon lands within the Nama Group allow detailed mapping of ancient sedimentary environments and the relationships between them. The Nama Group consists generally of carbonate shelf sediments interbedded with shallow marine siliciclastic sediments (Kuibis and Schwarzrand subgroups), overlain by largely fluvial red sandstones and shales with minor shallow marine units (Fish River Subgroup).

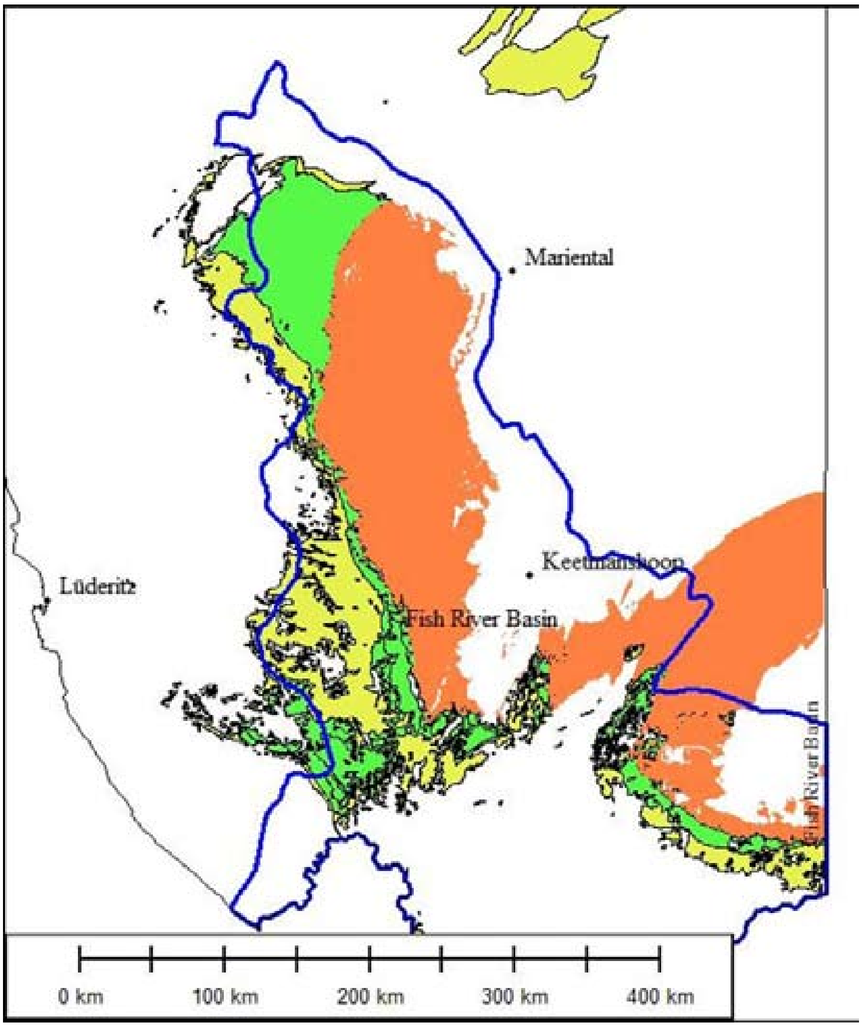


Figure 7: Distribution and type areas of the Nama Group in Namibia;
Fish River Subgroup = orange, Schwarzrand Subgroup = green, Kuibis Subgroup = yellow
Adapted from: Swart (2008)

3.5.1 Geomorphology

Due to the nature of its predominantly horizontal bedding rocks, the Nama Group tends to weather and erode in layers, resulting in flat plains, with major drainages resulting in canyons and canyon-like incisions.

Rivers in these areas also tend to accumulate limited thicknesses of alluvium, which can also be ascribed to the fact that erosion takes place in layers. The western boundary of the Nama Group is clearly defined as the major escarpment adjacent to the Schwarzrand.

3.5.2 Geology

The Nama Group is sub-divided as shown below. The geohydrology of the various formations and subgroups differs, as described in Section 3.5.3.

The lower part of the Nama Group was deposited in a shallow to moderately deep sea, divided into two embayments by the easterly trending Osis Ridge, resulting in a facies differentiation between north and south in the Kuibis Subgroup. With increased thickness of sedimentation, the upper part of the Schwarzrand Subgroup and the overlying Fish River Subgroup were not much affected by facies changes.

Table 2: Subdivisions of the Nama Group

Group	Subgroup	Formation	Lithology
Nama	Fish River	Gross Aub	Red shale and red sandstone, locally greenish
		Nababis	Red shale and red to purple sandstone, locally greenish
		Breckhorn	Red to purple quartzitic sandstone and some subordinate red shale
		Stockdale	Basal red to purple coarse-grained quartzitic sandstone with thin conglomerate layer; red, friable sandstone, shale
	Schwarzrand	Vergesig	Green shale with green and red sandstone
		Nomtsas	Reddish shale and reddish sandstone, becoming green south of Maltahöhe, with basal coarse conglomerate in many places; limestone towards the south-west
		Urusis	Greenish shale and greenish sandstone (in the north), with dark blue limestone and black limestone inter-layered and intercalated (in the south)
		Nudaus	Green shale and greenish sandstone, grey to greenish quartzite
	Kuibis	Zaris	Bluish-green shale, sandstone, pink and grey to black limestone
		Dabis	Grey to white quartzite, some grey dolomitic limestone, grey to greenish quartzite

It is assumed that the sedimentation of the Kuibis Subgroup took place in the late Cambrian Era, and that all the rocks of the Nama are older than 450 Ma.

All the units of the lower part of the Nama Group become thinner eastwards, and many thin out completely. The Kuibis Subgroup, to the east of the Karas Mountains is reduced to only the Kanies Quartzite Member.

Important tectonic movements (uplift) affecting the Nama exposures took place towards the end of the Schwarzrand deposition. Dips, in general, are very shallow to the east, except where folding has taken place and where doming, e.g. the Ubiams-Vleiveld area, has resulted in local shallow dips radiating away from the dome.

Across most of the outcrop area, the Nama Group is not folded. It rests unconformably on basement and other older rocks, although between Gobabis and the Sossusvlei area the Nama Group is quite intensely folded.

Faults generally, but not always, strike in a northerly direction and have been mapped at frequent intervals across the entire outcrop area. Extensive swarms of joints appear throughout the Fish River Subgroup.

3.5.3 Hydrogeology

Inherently, rocks belonging to the Nama Group are impermeable, i.e. with little or no primary porosity and very low permeability. Groundwater is contained in faults and joints (in sedimentary rocks of clastic origin, such as quartzitic sandstone, quartzite and shale) and in secondary solution features in limestones and dolomites. Faults occur in the western parts of the OFRB and slope from north-to-south to north-west-to-south-east and are generally normal faults, although some strike slip movement has been observed. Some of these faults have remained active and may reflect the edge of a new proto-continent. These faults are prime targets for groundwater exploration, however they represent difficult drilling targets especially in the quartzitic lithologies, as severe collapse can occur during drilling. Collapse at several depths will require that boreholes are drilled at varying diameters, in order to be able to install successive lengths of casing (a process known as 'telescoping').

The Karas Mountains to the north-west of Karasburg are also fault-controlled. Apparently, these faults have been intruded by hydrothermal quartz, sealing off potential aquifer structures, and do not represent viable exploration targets for groundwater.

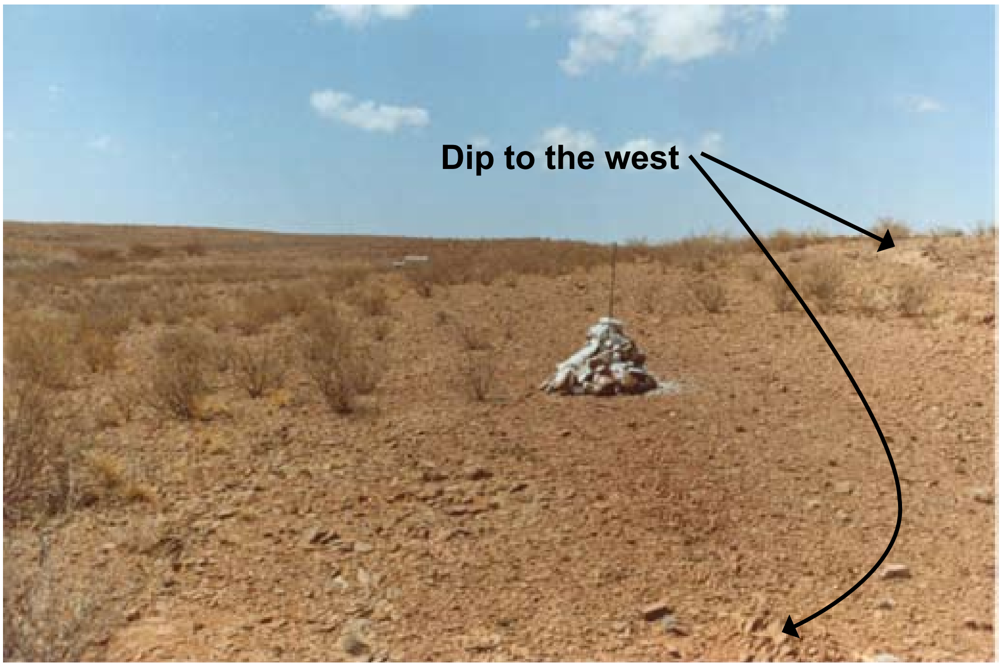


Figure 8: Drill site selected on a north-striking, westerly dipping fault; sandstone of Nababis Formation, Farm Cunab

In the Hardap and Karas regions, water levels are generally shallow in the east, close to the course of the Fish River, but become progressively deeper towards the escarpment in the west, where water levels deeper than 200 m are recorded. Drilling targets are mostly fractured rock as expected in faults and joints.

These targets can be located by geological surveys, especially with the help of aerial photography. Detailed fieldwork is essential for locating and identifying the dip of faults and to determine an optimal site for drilling appropriately. (In Figure 9 the dip of the fault can be clearly recognised from up-turned fractured sandstone, see arrows.) Figure 10 also clearly indicates a dipping fault in quartzites.

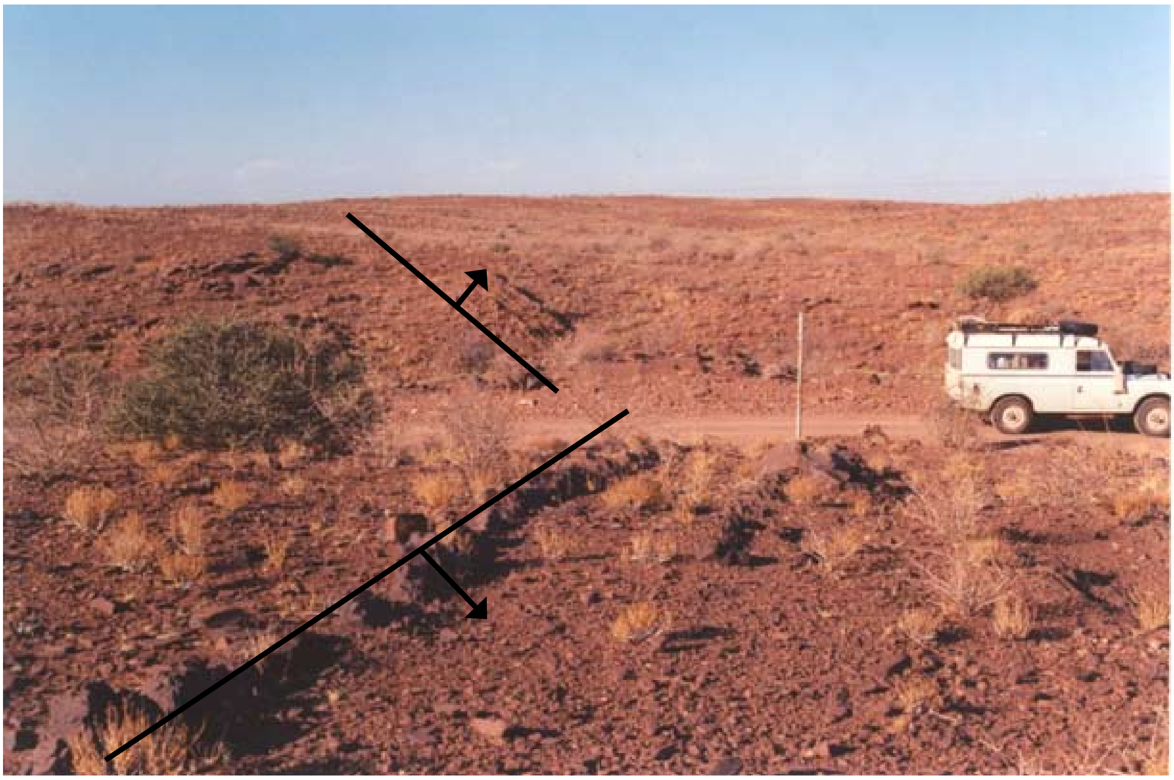


Figure 9: Looking north at a north-striking fault, dipping eastwards; sandstone, Nababis Formation, Farm Aneis, along District Road 1075

Jointing in the Fish River Subgroup can quite often only be recognised during a field survey. These structures are mostly vertical to sub-vertical, and once identified, drilling sites can be placed quite accurately.

Figure 10: Drill site WW34684, placed on joint in sandstone-shale intercalated Stockdale Formation; RWL expected at >70 mbgl); note up-turned sandstone fragments in foreground, creating an impression of an anticlinal structure.

The drill site illustrated above delivered a constant yield of 1.5 m^3/h of potable water. Water was intersected at 86.8 m and at 93 m. The rest water level was recorded at 74.6 m. Due to a nitrate concentration of 37.5 mg/l this water was classed as C quality, low risk water.

Figure 11: WW34684, drilling in progress

Joints in the Fish River Subgroup often are recognisable by a linear *anticlinal* feature (see Figure 10). A narrow band of up-turned shale and/or sandstone within otherwise horizontally bedded layers is probably a result of swelling of the more argillaceous horizons due to percolation of groundwater and the infiltration of rainwater along the strike of the joint.

Boreholes in the Fish River Subgroup can be sub-divided according to the different formations:

- In the low-lying Gross Aub Formation, with the associated shallow water table, drilling targets are selected geologically. A high success-rate can be maintained.
- A high success-rate can also be maintained in the Nababis Formation. Selection of drilling sites, however, should be made carefully. Water levels in general are deeper than in the lower lying Gross Aub Formation.
- In both the Breckhorn and the Stockdale Formations, up to 30% dry boreholes have been recorded. This is probably due to the deeper water table and the resultant difficulty in accurately determining a drilling site. With more precise fieldwork, the probability of intersecting groundwater on suitable structures should be increased.
- In the Schwarzrand and the Kuibis Formations, drilling sites should also be selected along structures such as faults. Contacts between limestone and rocks of clastic origin are viable targets.

Water quality in the Fish River Group, in general, is acceptable. High nitrate values however, can make the water unsuitable for babies under the age of one. **Increased nitrate concentrations are almost always a result of contamination due to human and livestock activities close to the boreholes.** This type of pollution cannot be reversed, but new abstraction points can be protected by appropriately siting habitation, sewerage systems and livestock pens.

3.5.4 Amas V46

A prominent fault in quartzitic sandstone of the Kuibis Subgroup along the Amas River gives rise to a strong permanent fountain on Farm Amas V 00046 north-east of Karasburg. In late 1985, five boreholes were selected to determine whether this fault had the potential to abstract enough water to supply Karasburg. In September 1991, a sixth borehole was drilled to a depth of 80 m.

A long-term pumping test was conducted (start of test 07/08/93) the results of which indicated the production potential of an estimated maximum annual supply of 100,000 m^3 water. This yield did not warrant the construction of a pipeline at that time because of the site's distance from Karasburg. Currently, these boreholes are not utilised.

3.6 Karoo Sequence

Sedimentary and volcanic rocks of the Carboniferous to Jurassic Karoo Sequence occur in the Aranos Basin on the north-eastern edge of the OFRB as well as the Gamkab Basin in the far south (Figure 12). The basal unit of the Karoo succession comprises the Dwyka glaciation, a major trans-continental unit the equivalent of which is found on all five Gondwana Continents (Africa, India and Arabia, Australia, South America, Antarctica). Recent dating of ash beds found at Ganigobis give an age of 300-302 Ma for the sequence (Bangert et al., 2000).

In the OFRB, the Karoo Sequence is largely represented by the final phase of Karoo crustal evolution. The eruption of 360 m of basaltic lavas made up the Kalkrand Formation in the Late Triassic-Early Jurassic around 178 Ma (Marsh et al. 1997). This is part of the more extensive volcanism that makes up the Drakensberg Mountains and is also found in north-eastern Namibia near Grootfontein and the Batoka Gorge on the Zambezi. Extensive dolerite sills and dyke swarms (Figure 13) of this age intrude the Karoo Group rocks. The Giants Playground area near Keetmanshoop is all dolerite sills, a rock type which seems to be preferred by *Aloe dichotoma*, although not exclusively so.

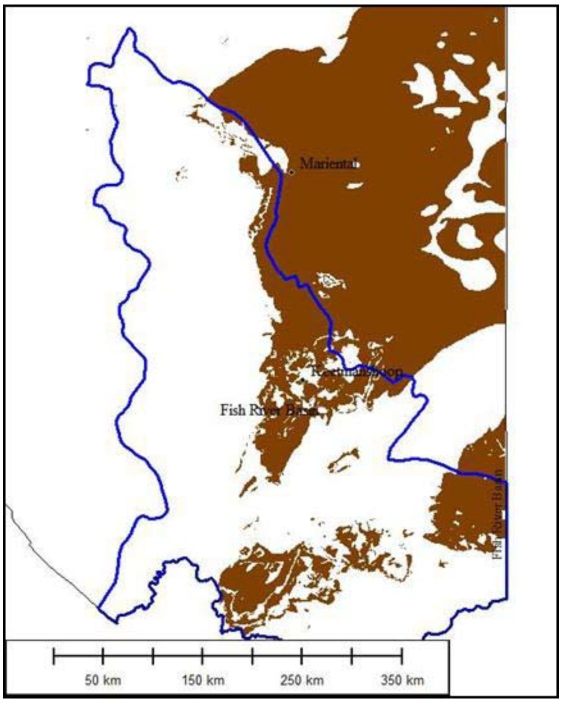


Figure 12: Distribution of Karoo Group sedimentary rocks in southern Namibia
Source: Swart (2008)

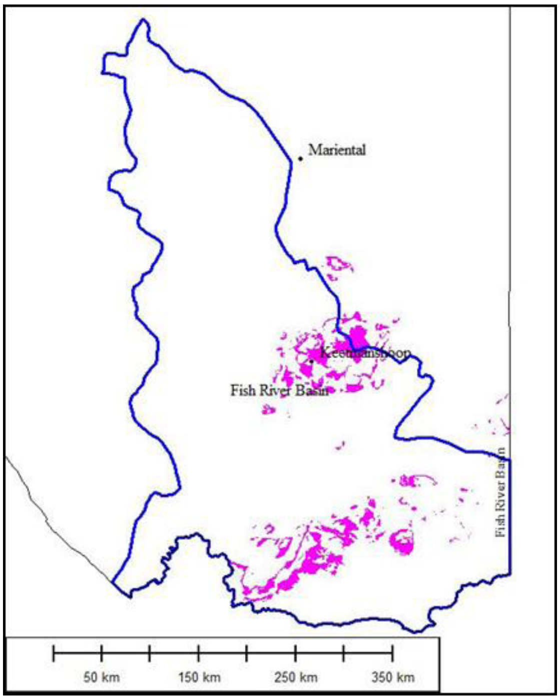


Figure 13: Distribution of Karoo dolerites in southern Namibia
Source: Swart (2008)

3.6.1 The Karasburg Bondelsdam Aquifer

The Bondelsdam Aquifer at Karasburg is unique in Namibia. The intrusion of a significant dolerite dyke into Dwyka shale resulted in the formation of a relatively high-yielding aquifer hosted in shale. The molten lava created a zone of baked, fragile shale on both sides of the dyke. Shrinkage occurred when the dyke cooled down; this zone of baked shale on the northern contact of the dyke further developed into a locally high-potential aquifer. It has been utilised for several years to provide the town of Karasburg with fresh groundwater. Boreholes WW5419, WW5420, WW5457, WW8624 and WW8652 have provided a total of 2.87 million m^3 since 1986. On average, this represents 130,600 m^3 annually. In 2000, the Namibia Water Corporation (NamWater), supplied a total of 223,320 m^3 to the Municipality of Karasburg. This is a combined figure and includes water supplied from the aquifer fed by the Dreihuk Dam. It is clear that on average the relatively small aquifer at Bondelsdam could supply in the order of 60% of the water demand of a town the size of Karasburg. In this case, direct recharge from water accumulated in the dam significantly supports the potential of this scheme.

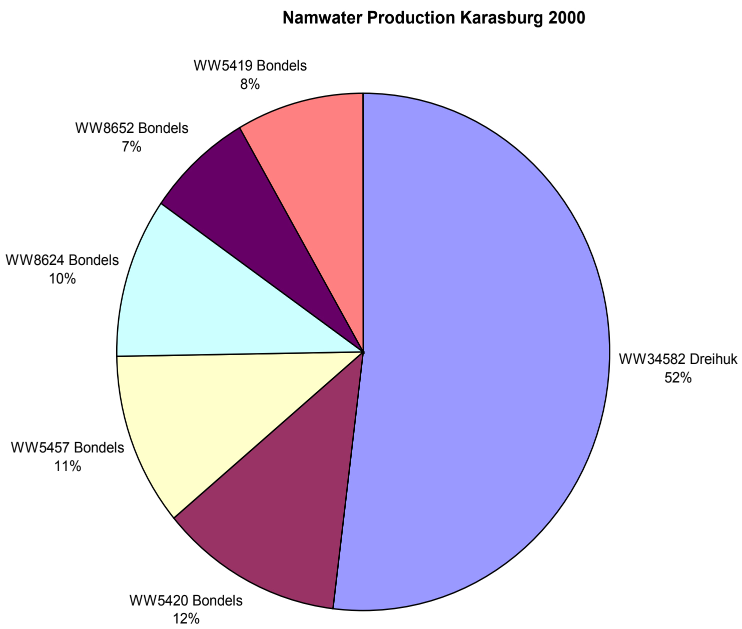


Figure 14: Relative production of borehole water from aquifers recharged by the Bondels and Dreihuk dams

Borehole WW5420 is one of the original boreholes within this aquifer. Depending on the state of recharge of the aquifer, this borehole has been used to provide up to 8,200 m³ per month, representing 293 m³ per day at a pumping rate of 27 m³/h (NamWater production data, February 1987). The rest water level in the borehole is at around 13 m.

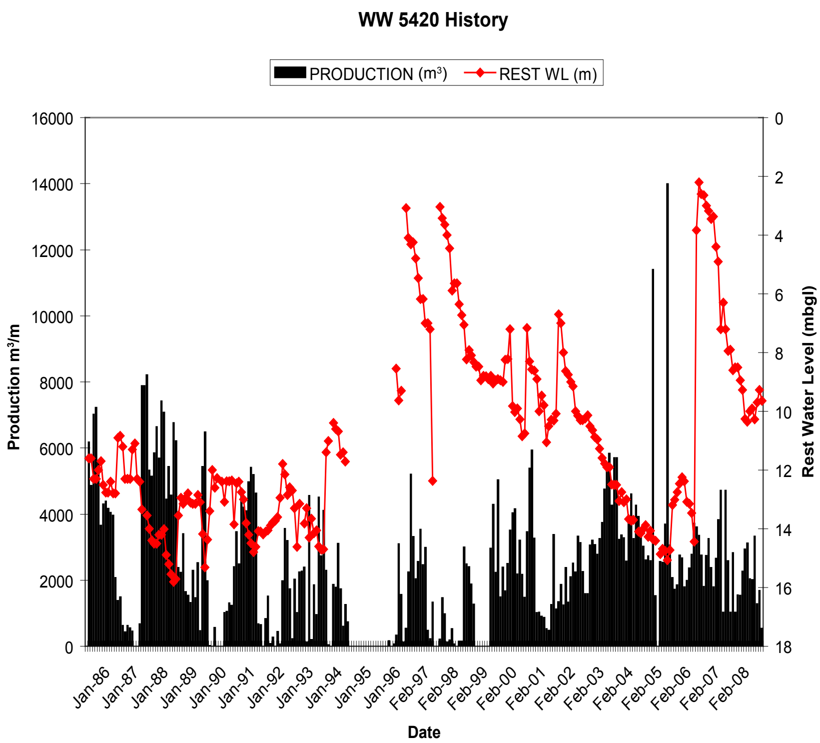


Figure 15: Production and water level history of WW5420, Bondelsdam Aquifer

Major recharge events occurred during December-January 1995/1996, and again between March and April 2006.

It is clear from this graph that water levels react quite fast to any major recharge event. Recharge events always occur when surface water accumulates in the Bondels Dam basin.

- This indicates that the aquifer is of limited extent and is therefore prone to overexploitation in times of drought.
- It also indicates the severe danger that can be caused by pollutants transported in surface water to the dam area that infiltrate and percolate down to the aquifer.

3.6.2 Tses

The village of Tses is dependent on groundwater. The Namibia Water Corporation operates a small borehole scheme consisting of seven boreholes spread out along the Tses River.

Figure 16: View of Tses from the south-west, with railway line in foreground with borehole on the bank of the Tses River; the escarpment in the background indicates calcrete covered Prince Albert Formation.

Borehole yields vary between about 2 m^3/h to 8 m^3/h. Boreholes in this environment typically reflect annual recharge events. Borehole WW24550 has been operative since February 1987.

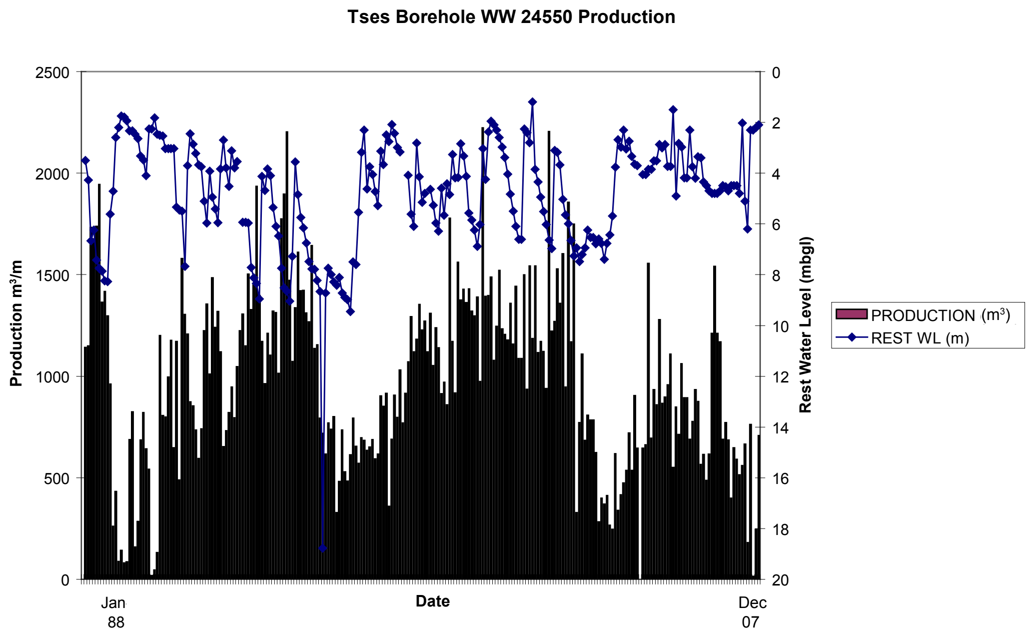


Figure 17: Production history WW24550, Tses

The Tses River has a significant influence on the recharge of these boreholes. A seasonal fluctuation is clearly recognisable. During the period 1999 to 2004 abstraction could be maintained at a relatively high rate, but this decreased drastically during 2004, probably as a result of high abstraction from other boreholes.

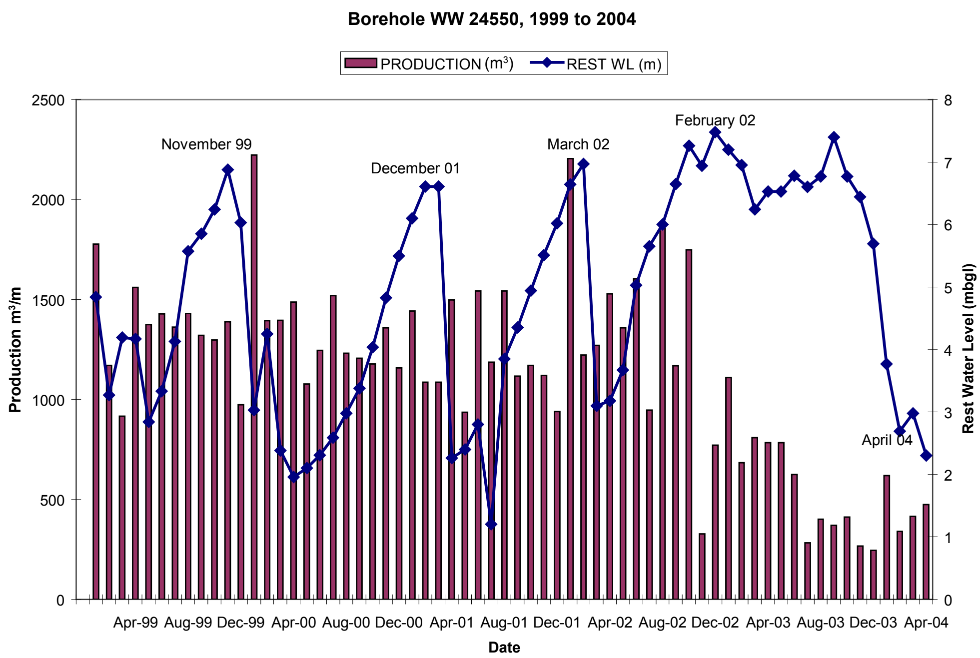


Figure 18: Chart indicating influence of flood events on groundwater recharge, Tses.

3.6.3 Water quality in the Dwyka Group

Poor water quality in the OFRB is evidently restricted to outcrop areas of the Dwyka Group and associated dolerite intrusions. Figure 19 shows regional zones of saline water, while Figures 12 and 13 (Section 3.6) show the extent of both the Dwyka Group and the dolerite intrusions.

Figure 19: Areas of poor water quality (high salinity) in the OFRB

3.7 Kalahari Group

The Kalahari Group, which covers large portions of the rest of Namibia, does not occur extensively in the OFRB. These cover deposits only occur as isolated patches, mainly as fluvial terraces of the Orange River. Geohydrologically, the Kalahari Group is insignificant in the OFRB.

4 Monitoring

The Ministry of Agriculture Water and Forestry, as the custodian for groundwater resources, is responsible for the management of these resources. Management can only be effective once sufficient knowledge of this resource can be evaluated. For this purpose, a monitoring network has been established throughout Namibia. Water levels are recorded on a continuous basis in order to be able eventually, to predict the behaviour of the resource in times of need.

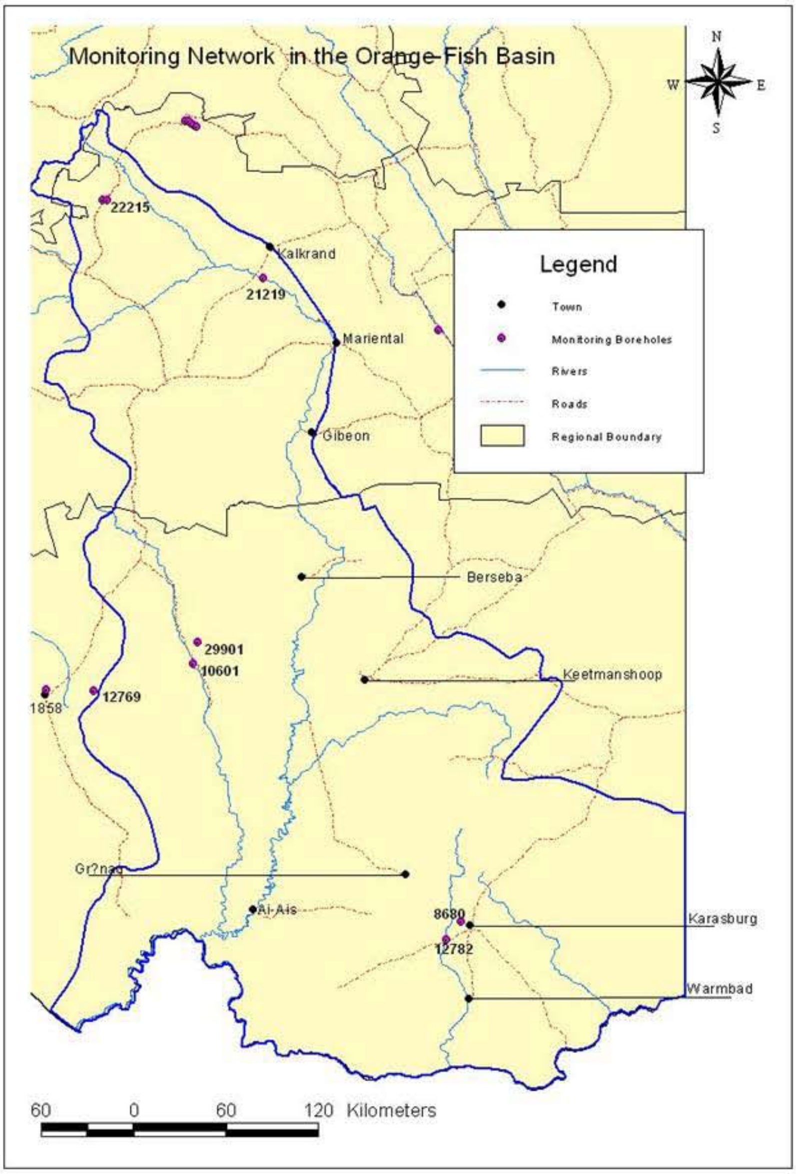


Figure 20: Monitoring network

4.1 Water levels

Within the OFRB, only seven monitoring boreholes have been equipped with water level recorders. Data obtained can contribute towards the better understanding of aquifers. Seasonal fluctuations as observed at Bethanien are normal tendencies.

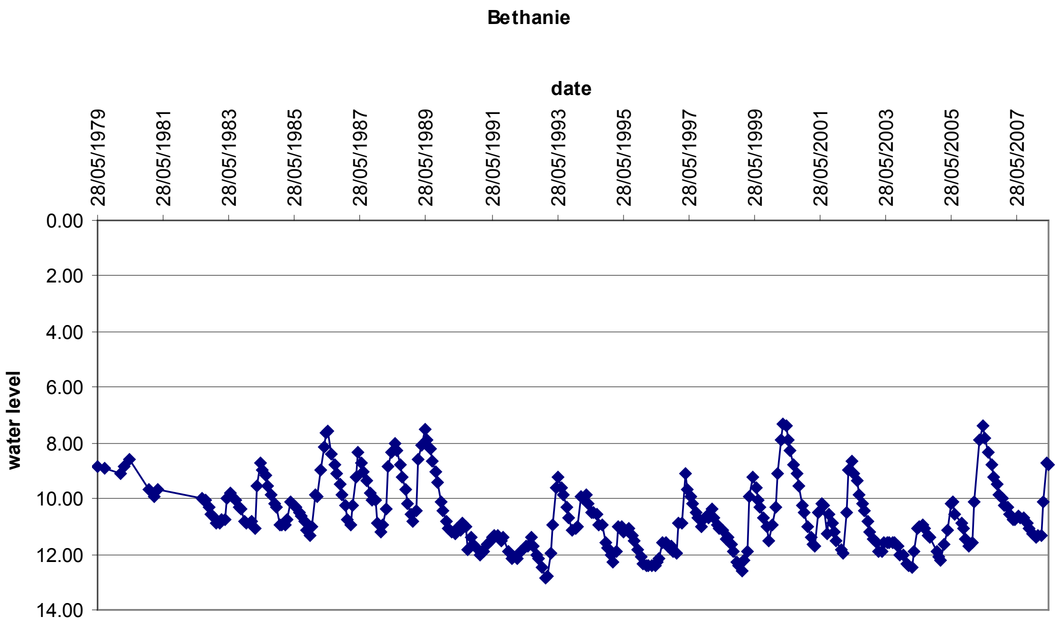


Figure 21: Monitoring data at Bethanien

Taking into consideration the area which is covered by this network, there are too few monitoring points. At present an effective knowledge of the groundwater resources in the OFRB cannot be maintained and additional, well-situated gauging stations need to be established.

4.2 Water quality

The chemical, physical and biological quality of groundwater is of pertinent importance. Water quality of aquifers changes over time and it should be part of any monitoring programme to include the collection and analysis of water samples on a regular basis. Unfortunately only very old data could be found.

4.3 Groundwater vulnerability and protection

Being below the surface, groundwater resources are naturally protected to a certain extent. Nonetheless, they are vulnerable and can be destroyed by certain hazards. These include over abstraction and the infiltration of pollutants. Quantitative protection can be planned when sufficient water-level data is available.

The quality of any aquifer might be endangered or even destroyed if there is insufficient protection. Numerous examples worldwide show groundwater resources that have been damaged or destroyed by pollution resulting from inappropriate agricultural or industrial land-use activities, both above-stream and up-gradient of these groundwater systems. In Namibia, and in the OFRB, such potential hazard from private, municipal and industrial activities, particularly the discharge of wastewater effluents (e.g. sewage), the siting of landfills or refuse dumps, the use of artificial fertiliser and the large-scale use of herbicides and pesticides need to be assessed before these activities/developments take place.

- Small settlements and farms often discharge sewage into pit latrines in close proximity to their boreholes. This can cause severe nitrate (and nitrite) poisoning of the groundwater, which will develop some time after the construction of the toilets. Small-scale farmers should always try to construct kraals for livestock several hundred metres away from boreholes.
- Unused boreholes and wells should never be used as refuse tips. Their surface openings should be sealed when not in use.
- Larger settlements quite often do not have any properly planned sewage treatment plants, nor do they have any well-planned and maintained refuse dumps.
- Large-scale agriculture and intensive farming practices always have an impact on the groundwater resources:
    - Large-scale irrigation agriculture is practised downstream of the Hardap Dam, as well as at Naute. In both cases very shallow groundwater tables are prone to be recharged with percolating water which has an increased concentration of salts and chemicals used during fertilisation and insect and weed control.
    - Intensive farming practices, including the concentration of large numbers of cattle in feedlots, are a cause of major concern. Huge quantities of dung and urine are potent pollutants that need to be controlled. Regular use of insecticides on cattle in these conditions, and most importantly, use of antibiotics, compound the potentially detrimental effect on groundwater resources of such farming operations.
- Combating reed growth with herbicides as a flood control measure also potentially contributes to pollution of aquifers.
    - The history of the use of herbicides and arboricides as experienced in Vietnam, is a case in point. The notorious *Agent Orange*, which was used to defoliate Vietnamese rainforests, contained significant concentrations of dioxin. Vietnamese people who were exposed to the chemicals still suffer from birth defects and increased levels of cancer today. Until recently (the early 1980s) these chemicals were still manufactured using dioxins, resulting in traces of the chemical being present in the finished product.
    - Nowadays, a stringent regulatory framework prevents any arboricides that contain dioxins, or contain any component which is manufactured in any process using dioxins, from being used in countries such as the USA and Europe.
    - In Namibia, with our underdeveloped regulatory framework, which does not entail the testing of health impacts of such chemicals, we should be extremely careful of importing cheap herbicides and arboricides from countries where no documented control is evident. Are these products safe? Do they make use of outdated chemical processes that make use of dioxins in the synthesis of these cheaper products?

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