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HOANIB RIVER CATCHMENT STUDY, NORTHWESTERN NAMIBIA
Water

May 2001

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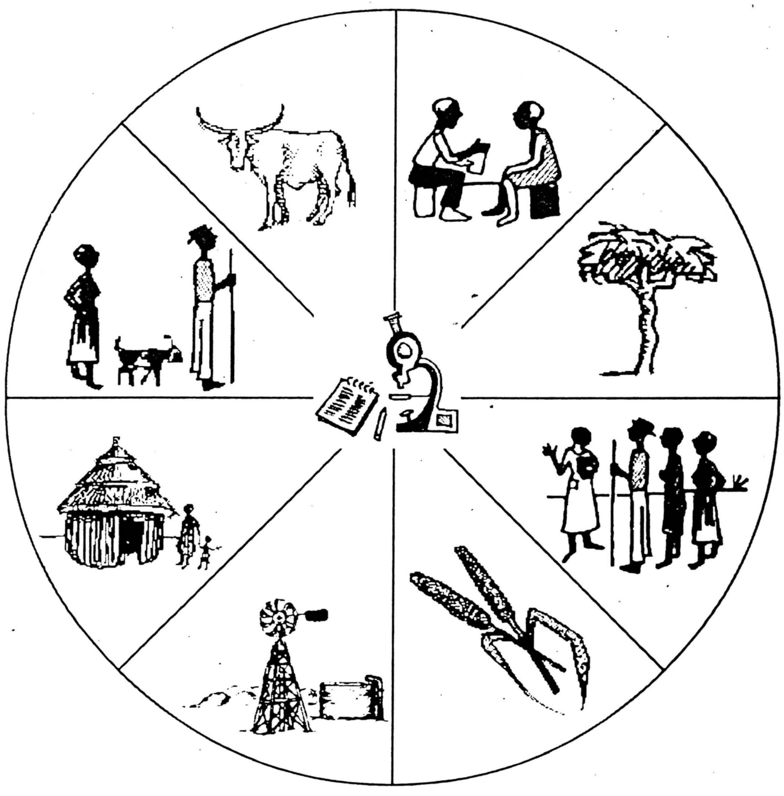

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SECTION I

WATER CHEMISTRY OF SELECTED WETLANDS AND SPRINGS OF THE HOANIB CATCHMENT, NORTHWESTERN NAMIBIA

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GENERAL INTRODUCTION

This paper is a result of the research work carried out during the Hoanib River Catchment Study (HRCS) which began in 1998. The HRCS focused on appropriate basic socio-economic, biophysical and policy research on environmental issues important for sustainable use and development of natural resources in the Hoanib River catchment. The investigation examined present methods of lands and associated living conditions and highlighted potential alternatives to existing demands and expectations. Potential conflicts in the area revolve around the dynamics of different discourses and include: escalating, uncontrolled tourism; increasing aspirations and expectations of local residents often based upon popular misinformation; interactions between and among Non Government Organisations (NGOs), Government Ministries, and local people of different language groups; limited water availability and a relatively fragile environment.

This study has been a collaborative effort between relevant Government Ministries and Departments as well as local NGOs. The communities of the Hoanib River catchment are an integral part of the project, as a collaborative process has been used to identify problems, collect data and disseminate results.

As a result of the HRCS, four occasional papers have been published by the Desert Research Foundation (DRFN). These papers cover the general topics of soil, water, fauna, and vegetation in the Hoanib catchment, and are available for purchase through the DRFN library.

ABSTRACT

The chemical quality of a water source can determine its use by wildlife, domestic stock and people. Ten wetlands and seven springs in the Hoanib River catchment were analysed quarterly over a 2-year period to determine the seasonal and spatial variations in pH, conductivity, dissolved oxygen, turbidity, dissolved solids and temperature.

All of the wetlands were located in the riverbed of the Hoanib River and its tributaries throughout the catchment, while the springs were located away from the river and concentrated around the Sesfontein and Khowarib basin.

With the exception of a saline spring (Auses), one polluted and one saline wetland (Palmfontein-1 and Oasis, respectively), the water quality of the wetlands and springs was of sufficient quality for consumption by wildlife, domestic stock and people.

There appeared to be little seasonal variation in pH, conductivity and total dissolved solids in either the wetlands or springs (with the exception of Auses). However, seasonal variations were observed in dissolved oxygen concentration, turbidity and temperature in wetlands and springs. There appeared to be a relationship between the distance from the coast and pH, conductivity, total dissolved solids and temperature in wetlands. The closer to the coast, the greater the pH, temperature, conductivity and total dissolved solids concentrations became. While dissolved oxygen and turbidity appeared to be unaffected by the distance from the coast. With the exception of Auses, the water quality of the springs did not appear to change with distance from the coast.

KEY RESEARCH QUESTIONS

The key research questions investigated during this study were:

(a) Does the chemical water quality of the springs and wetlands change with distance from the coast?

(b) Is there a seasonal variation in chemical water quality?

(c) Is the water quality of springs and wetlands affected by large-scale water development projects?

BACKGROUND

The pH, conductivity, total dissolved solids, dissolved oxygen, turbidity and temperature of selected springs and wetlands in the Hoanib River catchment were analysed over a two-year period. The chemical properties of the water sources were determined not only for their suitability for use by humans, but also for the livestock and wildlife that are dependent on them. Very little historical data exists for the springs and wetlands of the Hoanib catchment. However, the water chemistry of ephemeral rivers has been reported by Jacobson *et al.* (2000a), Fisher and Minckley (1978); Sharma *et al.*, (1984). In addition, little is known of the spring and wetland flora and fauna (Steffan, 1997)

Conductivity

The conductivity of a solution refers to the ability of that solution to conduct electric current. The unit of measure is termed a millisemens (mS/m or mS^{-1}). Pure water is actually a poor electrical conductor and it is the dissolved chemicals in water that determine how conductive a solution will be. Conductivity is acknowledged as a quick and reliable measure to indicate the general chemical quality of water (Hem, 1982; Auer, 1997). For environmental purposes the conductivity of water is an indicator of:

- total dissolved solids (TDS) (salinity)
- dissolved mineral compounds

- fertiliser concentration
- human and industrial effluent

Water that has a conductivity of less than 150 mS^{-1} is considered to be good quality water and suitable for human consumption (Department of Water Affairs, 1991). However, water that has a conductivity of less than 900 mS^{-1} is considered to be only suitable for consumption by domestic stock (Department of Water Affairs, 1991).

The total dissolved solids (TDS) in water consist of inorganic salts and dissolved materials. In natural waters, salts are chemical compounds comprised of anions (e.g. carbonates, chlorides, sulphates and nitrates) and cations (e.g. potassium (K), magnesium (Mg), calcium (Ca) and sodium (Na)). They are present in balanced proportions at ambient temperature (USEPA, 1987). If there are additional inputs of dissolved solids to the system, the balance is altered and detrimental effects may result.

The source of most salinity in a natural environment is the erosion of geologic formations of marine origin. This is exacerbated in areas similar to north-western Namibia, where evaporation exceeds precipitation, concentrating the salts in water bodies to proportionally higher levels. As water evaporates from standing water bodies, salt concentrations increase. Additionally, precipitation itself contains minute traces of salts and hence evaporation after rain leaves salts in the soil. These salts may then be carried in irrigation waters or in overland flow during the infrequent rains (Perfetti and Terrel, 1989).

High salinity may have several environmental effects. It may interfere with the growth of aquatic vegetation: salt may decrease the osmotic pressure, causing water to flow out of a plant to achieve equilibrium. Under these conditions less water can be absorbed by the plant, causing stunted growth and reduced yields. High salt concentrations may cause leaf tip and marginal leaf burn, bleaching or defoliation (Perfetti and Terrel, 1989). High levels of total dissolved solids may give water an unpleasant taste – not ideal for human consumption. Furthermore, levels greater than 250mg/L of sodium sulphate and magnesium sulphate may have a laxative effect (USEPA, 1987).

pH

The pH of a solution is defined as the negative $\log_{10}$ of the hydrogen iron concentration and is measured on a scale between 0 and 14. The pH of neutral solutions, such as pure water, is equal to 7. Alkaline solutions have a high pH value (8-14) and acidic solutions have a low pH value (1-6).

The pH of water is controlled by the equilibrium achieved by dissolved compounds in the system. In natural water, the pH is primarily a function of the carbonate system, which is composed of carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) (AWWA, 1990). The applicable equilibrium equations and the estimated pH ranges at which each are present are:

$CO_2 + H_2O$ < - - > H_2CO_3 (pH: <6.4)

H_2CO_3 < - - > $(H^+) + HCO_3^-$ (pH: 6.4 – 10.33)

HCO_3^- < - - > $(H^+) + CO_3^{2-}$ (pH: >10.33)

The environmental effects of pH change can be quite severe. A reduction in pH (increased acidity) may allow the release of toxic metals that would otherwise be absorbed into the sediment and essentially removed from the water system. As the hydrogen ion concentration increases, the metal cations experience greater competition from H+ ions for binding sites. Some metal cations will be out-competed and liberated into the overlying water. Once mobilised, these metals are available for uptake by organisms. For many metals, the rate of uptake is directly proportionate to the levels of metal availability in the environment. Thus, a decrease in pH increases metal availability, lending itself to greater metal uptake by organisms. Metal uptake can cause extreme physiological damage to aquatic life (Connell and Miller, 1984).

Acidification of aquatic systems also inhibits microbial activity in the benthos, reducing decomposition and nutrient cycling. This may lead to a reduction of the invertebrates and plankton that are a vital part of the food chain. Eventually, a shift in community structure may occur (Smith, 1990). In addition, some amphibians are sensitive to acidification. Their fertilisation stage is most noticeably affected by acid because the amphibian sperm disintegrates at low pH. This disintegration can occur in some species between a pH of 4.0 and 5.0. The effect on humans is much the same as for aquatic life, with the ingestion of heavy metals posing a substantial health risk.

Dissolved Oxygen

Dissolved oxygen (DO) refers to the volume of oxygen contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen) and with decreasing salinity (fresh water holds more oxygen than salt water). As pressure decreases with altitude, gas solubility also decreases both the partial pressure and the degree of saturation of oxygen will change (Smith, 1980).

Once absorbed, oxygen is either incorporated throughout the water body via internal currents, or is lost from the system. Flowing water is more likely to have a higher dissolved oxygen level than stagnant water because of water movement at the air/water interface. In flowing water, turbulence causes oxygen-rich water at the surface to be continuously replaced by water containing less oxygen, creating a greater potential for exchange of oxygen across the air-water interface. Because stagnant water undergoes less internal mixing, the upper layer of oxygen-rich water remains on the surface, resulting in lower dissolved oxygen levels throughout the water column. Oxygen losses readily occur when water temperature rises, when plants and animals respire and when microbes decompose organic matter.

Microbes play a key role in the loss of oxygen from surface waters. Microbes use oxygen as energy to break down long-chained organic molecules into simpler, more stable end-products, such as carbon dioxide, water, phosphate and nitrate (Dunne and Leopold, 1978). As microbes break down the organic molecules, oxygen is removed from the system and must be replaced by exchange at the air-water interface. Each of these steps results in the consumption of dissolved oxygen. If high levels of organic matter are present in water, microbes may use all available oxygen.

The environmental effects of exposure to low levels of dissolved oxygen may not directly kill an organism but it will increase its susceptibility to other environmental stresses. Exposure to <30% saturation (<2 mg/L oxygen) for one to four days may kill most of the biota in a system. If oxygen-requiring organisms perish, the remaining organisms will only be air breathing insects and anaerobic bacteria (Gower, 1980)

Higher temperatures often exacerbate low dissolved oxygen levels in lakes and reservoirs and encourage the microbial breakdown of organic matter; a process that requires dissolved oxygen. Warm water naturally holds less dissolved oxygen, thus persistent warm conditions may lead to the depletion of dissolved oxygen in a water body (USEPA, 1987).

Turbidity

Turbidity is measured by quantifying the degree to which light travelling through a water column is scattered by the inorganic particles and suspended organic (including algae). The scattering of light increases with a greater suspended load. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU).

Increased turbidity in a water body may lead to changes in the composition of an aquatic community (Wilber, 1983). First, turbidity due to a large volume of suspended sediment will reduce light penetration, thereby suppressing photosynthetic activity of phytoplankton, algae and macrophytes, especially those further from the surface. If turbidity is largely due to the algae, light will not penetrate very far into the water and primary production will be limited to the uppermost layers of water. Cyanobacteria (blue-green algae) are favoured in this situation because they possess flotation mechanisms (Sullivan, 2000). Overall, excess turbidity leads to fewer photosynthetic organisms being available to serve as food sources for many invertebrates. As a result, overall invertebrate numbers may also decline, affecting the overall ecology of the water system.

If turbidity is largely due to organic particles, dissolved oxygen depletion may occur in the water body. The excess nutrients available will encourage microbial breakdown; a process that requires dissolved oxygen. In addition, excess nutrients may result in algal growth. Although photosynthetic by day, algae respire at night depleting the dissolved oxygen in water. This can lead to the death of other respiring organisms.

INTRODUCTION

The Hoanib River Catchment (HRC) is one of twelve major ephemeral river catchments that occupy the semi-arid areas of north-western Namibia. All twelve rivers flow into the Atlantic Ocean or end in the Namib Sand Sea. Many originate in commercial farmlands, flow through communal farming areas and, near their mouths, traverse a protected conservation area. The Hoanib catchment in particular occupies an area of 17 200 km^2, 3% of which lies in private farm lands, 91% in communal farm lands and 6% is in protected Etosha National Park and Skeleton Coast Park (Jacobson *et al.,* 1995).

The Hoanib River constitutes the boundary between the former Damaraland and Kaokoland. Since Namibia's Independence in 1990, these two areas have been incorporated into the Kunene and Erongo Regions (see Figure 1). The catchment area of the Hoanib can be divided into three broad geographic sections. The eastern section (east of the Khowarib Schlucht) is relatively densely vegetated with mopane woodland being dominant. The western section of the Hoanib (from the Khowarib Schlucht to Skeleton Coast Park eastern boundary) is sparsely vegetated. In the extreme western section of the river (from the Park boundary to the coast), virtually no vegetation exists outside of the river course. A broad flood plain (some 70km^2), in front of the moving dunes of the coast, offers substantial grazing for wildlife after flood events during the wet season.

In the catchment area, there are numerous wetlands and springs. The Hoanib River forms a "linear oasis" where the wetlands in the river are the most important biological and socio-economic areas in the catchment. They provide water for domestic stock and wildlife, as well as providing a readily available source of water for communities living in the area. The ubiquitous springs and wetlands of the catchment are increasingly being used as a water source for garden and irrigation projects, and for the expanding tourism industry. This leaves a diminishing number of waterpoints available for the use of wildlife. The biophysical nature of wetlands and other water sources vary over time and are dependent on rainfall, water extraction and human influences. The chemical and physical properties of the water available at water points often determine the use by domestic stock, people or wildlife.

In many places throughout the catchment boreholes have been sunk to supplement the supply of water to human populations and domestic stock. At Erwee in the southern edge of the catchment, a water development project has, over the last 15 years, reduced permanent springs at Palmfontein (approx. 7km northwest from Erwee) to seasonal springs. In 'normal' rainfall years, these springs are now no longer flowing for the driest months of the year, forcing the local inhabitants to dig wells in the riverbeds to obtain water. This has greatly influenced the life-styles of people living down stream of the water extraction points and also the wildlife that once used this area extensively as a dry season watering point (Fuller, 2000).

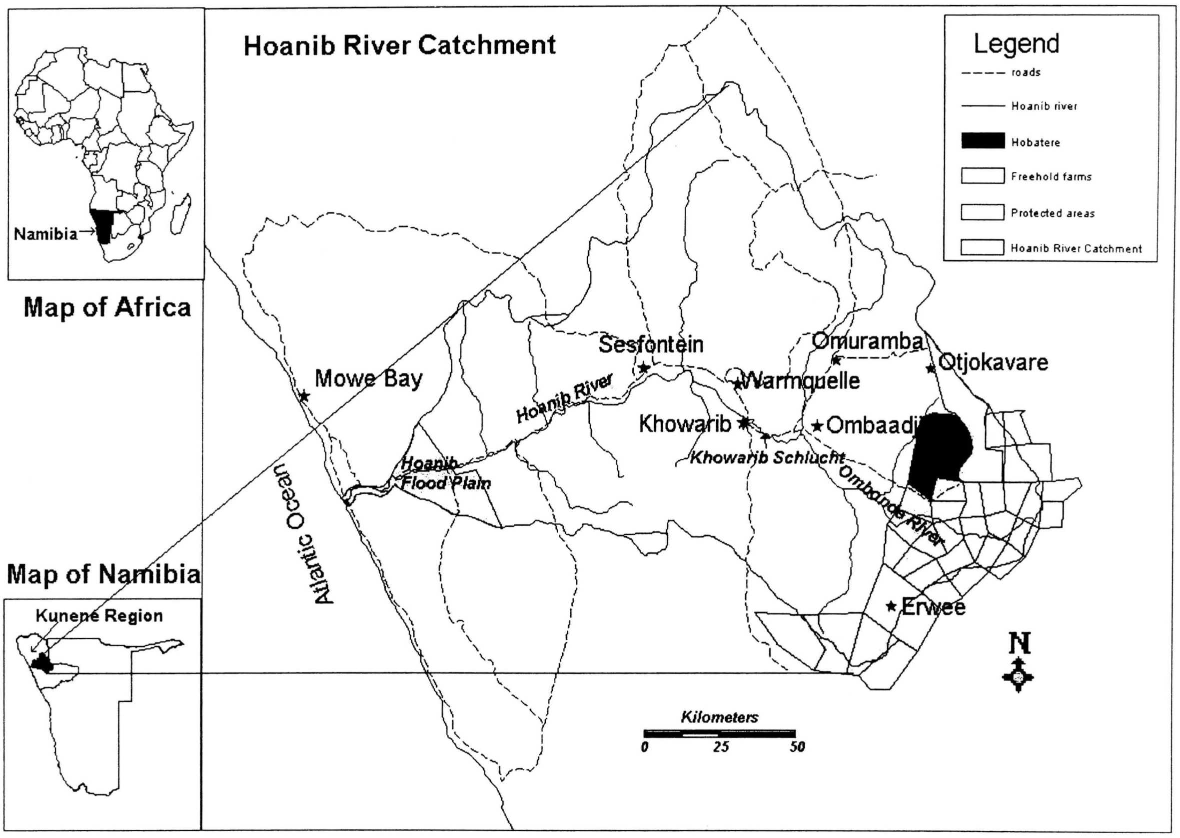


Figure 1: Location of the Hoanib River Catchment

METHODS

WETLANDS AND SPRING STUDIES

Three-monthly surveys of ten wetlands and seven springs tested for water quality that included the following water properties:

(a) pH

(b) conductivity (Cond.) (mS^{-1})

(c) dissolved oxygen (D.O.) (mg/L)

(d) turbidity (turb.) (NTU)

(e) total dissolved solids (TDS) (mg/L)

(f) temperature (^{o}C)

Sampling was undertaken at selected springs and wetlands, which are shown in Table 1 and 2, respectively. They are also shown schematically in Figure 2. For the purposes of this study, a wetland is defined as an upwelling of water in an existing riverbed and a spring is defined as an upwelling of water away from any known riverbeds. The distance of springs from the coast was measured as a straight-line distance using a GIS programme, MAPINFO, while the distance of wetlands was measured along the river and tributary beds, again using MAPINFO.

Table 1: Survey site locations and distance from the coast of selected springs in the Hoanib River catchment

Location	GPS reading		Distance from river mouth[1]
	Latitude (°S)	Longitude (°E)	
Auses	-19.40328	12.89008	16
Sesfontein-3	-19.11885	13.61184	98
Sesfontein-2	-19.11982	13.61187	100
Sesfontein-1	-19.12355	13.61882	100
Anabeb	-19.12870	13.73208	110
Otjontunda	-19.04467	13.74252	115
Ongongo	--19.13207	13.82105	120

[1] Spring distances were measured as a straight-line distance from the coast, using a GIS programme.

Table 2: Survey site locations and distance from the coast of selected wetlands in the Hoanib River catchment

Location	GPS reading		Distance from river mouth[1]
	Latitude (°S)	Longitude (°E)	
Oasis	-19.44624	12.82406	10
Dubis-3	-19.22356	13.41056	72
Dubis-2	-19.21134	13.44742	77
Dubis-1	-19.21620	13.45397	79
Khowarib –3	-19.27200	13.90230	138
Khowarib-2	-19.29960	13.92502	141
Khowarib-1	-19.30638	13.94905	144
Palmfontein-3	-19.65238	14.22279	208
Palmfontein-2	-19.65547	14.22954	210
Palmfontein-1	-19.65467	14.25043	213

[1] Wetland distances were measured along the riverbed, from the mouth (at the coast), to the upper tributaries, using a GIS programme

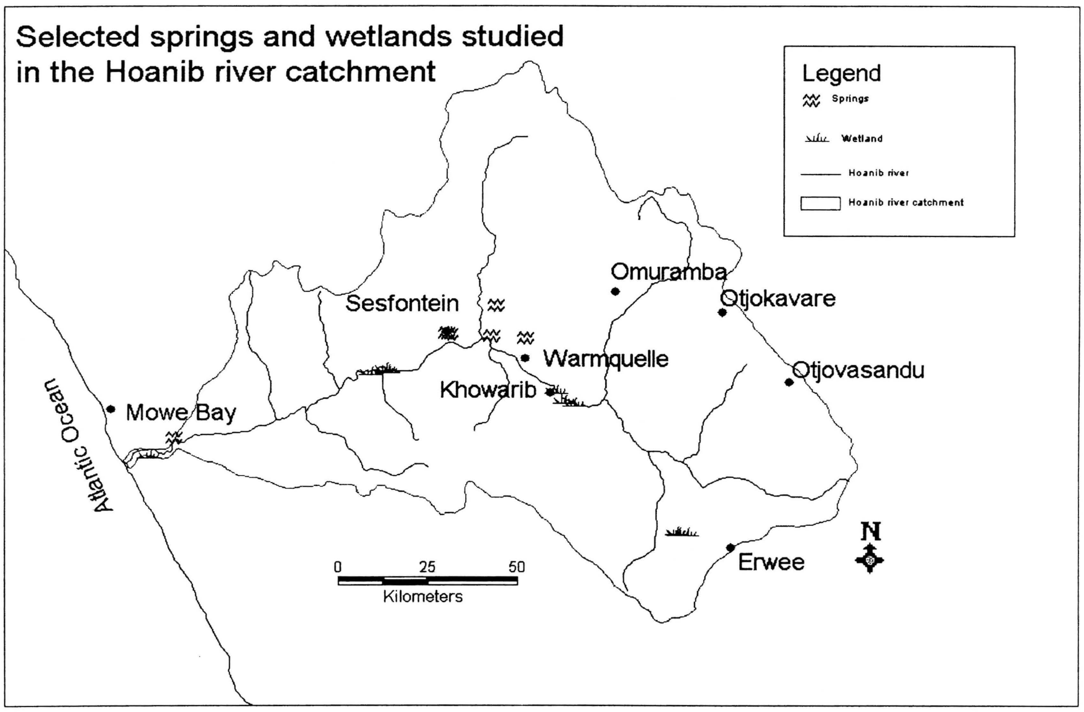


Figure 2: Locations of selected springs and wetlands in the Hoanib River catchment

Photographs were taken of each spring and wetland site, as it is believed that they are the best way to monitor seasonal and long-term changes in water sources (K. Roberts, pers.com., 1998). Spring and wetland characteristics and chemistry were recorded on data sheets (see Appendix A) and stored on a database.

FIELD SAMPLING METHODS

The field testing units were chosen so that all samples could be taken 'in situ', so there would be no need for additional chemical analysis in a laboratory.

- All pH measurements during this project were taken on a Mettler pH meter (model MP 120FK).
- All conductivity and total dissolved solid measurements were taken on a Mettler conductivity meter (model MC 126-2M).
- All dissolved oxygen measurements during this project were taken on a Mettler dissolved O_2 meter (model MO 128-2M).
- All NTU measurements were taken using a Hach 2100P Portable Turbidity meter.

The data sets obtained for both wetlands and springs are by no means complete as floods and mechanical failure of some of the testing units, hindered data collection.

RESULTS

WATER CHEMISTRY

The mean values and standard deviation of chemical properties from the selected wetlands and springs studied in the Hoanib River catchment are shown in Tables 3 and 4.

Table 3: Mean values and standard deviation (in brackets) of chemical properties from selected wetlands in the Hoanib River catchment

Location	Distance from coast	PH	D.O.	Cond.	T.D.S.	Turb.	Temp.
	(km)		(mg/L)	(mS^{-1})	(mg/L)	(NTU)	(°C)
Oasis	10	8.09 (± 0.10)	82.0 (± 4.80)	837 (± 84)	4060 (± 400)	2.24 (± 0.3)	27.4 (± 0.1)
Dubis-3	72	8.79 (± 0.10)	84.0 (± 4.76)	5.33 (± 1.36)	1040 (± 140)	6.16 (± 2.56)	29.3 (± 0.99)
Dubis-2	77	8.68 (± 0.28)	85.5 (± 20.01)	2.30 (± 0.23)	1700 (± 170)	1.50 (± 0.97)	29.6 (± 0.78)
Dubis-1	79	8.62 (± 0.11)	113.8 (± 41.6)	2.87 (± 0.48)	1230 (± 120)	9.70(± 7.16)	29.8 (± 2.32)
Khowarib–3	138	8.00 (± 0.18)	80.5 (± 28.0)	1.35 (± 0.14)	670 (± 60)	15.4 (± 20.4)	29.6 (± 2.62)
Khowarib-2	141	8.33 (± 0.13)	63.2 (± 0.99)	1.21 (± 0.22)	600 (± 113)	6.80 (± 5.37)	20.8 (± 3.61)
Khowarib-1	144	8.28 (± 0.33)	79.4 (± 14.57)	1.18 (± 0.24)	595 (± 120)	3.80 (± 1.27)	18.0 (± 0.01)
Palmfontein-3	208	8.02 (± 0.16)	32.5 (± 24.3)	1.18 (± 0.28)	603 (± 157)	3.60 (± 2.61)	21.0 (± 7.79)
Palmfontein-2	210	8.05 (± 0.18)	69.9 (± 80.7)	1.25 (± 0.18)	621 (± 83.4)	9.80 (± 13.70)	20.4 (± 11.10)
Palmfontein-1	213	7.68 (± 0.81)	8.5 (± 12.02)	1923 (± 956)	949 (± 481)	447 (± 507)	21.8 (± 10.53)

Table 4: Mean values and standard deviation (in brackets) of chemical properties from selected springs in the Hoanib River catchment

Location	Distance from coast	PH	D.O.	Cond.	T.D.S.	Turb.	Temp.
	(km)		(mg/L)	(mS^{-1})	(mg/L)	(NTU)	(°C)
Auses	16	7.17 (± 1.58)	66.0 (± 51.0)	7186 (± 7462)	2183 (± 822)	13.2 (± 19.63)	29.3 (± 0.17)
Sesfontein-3	98	7.23 (± 0.29)	31.0 (± 25.2)	0.92 (± 0.12)	467 (± 71.0)	2.78 (± 0.84)	25.0 (± 3.74)
Sesfontein-2	100	7.08 (± 0.11)	22.0 (± 7.11)	0.82 (± 0.04)	410 (± 17.32)	0.93 (± 0.17)	29.3 (± 2.20)
Sesfontein-1	100	7.13 (± 0.17)	45.0 (± 14.06)	0.82 (± 0.05)	486 (± 117)	1.01 (± 0.35)	28.1 (± 3.38)
Anabeb	110	7.46 (± 0.13)	112.1 (± 82.4)	1.07 (± 0.07)	515 (± 7.07)	1.52 (± 0.48)	29.1 (± 3.77)
Otjontunda	115	7.86 (± 0.16)	115.7 (± 2.93)	1.01 (± 0.22)	440 (± 6.00)	2.05 (± 0.66)	27.9 (± 3.72)
Ongongo	120	7.61 (± 0.29)	41.8 (± 21.0)	0.81 (± 0.06)	407 (± 23.1)	1.27 (± 0.53)	25.9 (± 4.76)

The data indicated the following trends:

pH

The pH for wetlands is substantially higher than that observed for springs. The wetlands also appeared not to have any correlation between the distance from the coast and a decreased pH ($r^2 = 0.307$, $P < 0.005$). In comparison, there appeared to be a strong correlation between the distance from the coast and an increase in the pH of the springs ($r^2 = 0.770$, $P < 0.005$).

Dissolved Oxygen (D.O.)

The dissolved oxygen readings appeared not to differ significantly from wetlands to springs nor to be dependent on whether the water source was saline or fresh. There appeared to be no correlation between distance from the coast and increasing or decreasing dissolved oxygen concentrations ($r^2 = 0.195$, $P < 0.005$ for wetlands and $r^2 = 0.272$, $P < 0.005$ for springs). The amount of biological productivity and dissolved oxygen level was generally linked to the time of day that the sampling was undertaken. The low dissolved oxygen level observed at Palmfontein 1 was linked to a high chemical oxygen demand caused by organic decomposition. Palmfontein 1 had a high population of cattle associated with it and often a strong urine smell was associated with the wetland.

Conductivity (Cond.)

In general, the conductivity of the wetlands and springs decreased the greater the distance away from the coast. This meant that the wetlands and springs closest to the coast also contained the higher concentration of dissolved salts and organic compounds, though there appeared to be no correlation between distance from the coast and conductivity concentrations ($r^2 = 0.371$, $P < 0.005$ for wetlands and $r^2 = 0.051$, $P < 0.005$ for springs). The only exception to this appeared to be Palmfontein-1, where conductivity was again high. This was probably due to the large numbers of domestic stock using the wetland.

Total dissolved solids (T.D.S.)

The T.D.S. of a solution is closely linked to the conductivity, where high T.D.S. concentrations are generally related to high conductivity levels (see Table 3). As with conductivity, the greater the distance away from the coast, the lower the T.D.S. concentration was found to be. There appears to be a strong correlation between distance and T.D.S. concentration for wetlands ($r^2 = 0.842$, $P < 0.005$). However, this correlation does not appear to exist for springs ($r^2 = 0.085$, $P < 0.005$).

Turbidity (Turb.)

In most cases, the turbidity of the water sources measured was low. During floods, turbidity increased dramatically in the rivers and wetlands, but as soon as the flood abated, the turbidity of the water in the wetland declined. Palmfontein 1 again appeared to be the exception and had readings far greater than any other wetland. The springs located away from the river had low year-round turbidity readings, with only a small increase in turbidity observed at Auses. With the exception of the sample sites already mentioned there appeared to be no correlation between distance and NTU values ($r^2 = 0.018$, $P < 0.005$ for wetlands and $r^2 = 0.007$, $P < 0.005$ for springs).

Temperature (Temp.)

The average temperature of the wetlands appeared to decrease the further the distance from the coast, although only a weak correlation between distance and temperature was observed ($r^2 = 0.479$, $P < 0.005$). However, there appeared to be no correlation between the temperature of the springs and distance from the coast ($r^2 = 0.008$, $P < 0.005$). In addition, there appeared to be very little variation between the temperatures of the springs, while the wetlands temperature varied markedly.

PREVIOUS STUDIES

Table 5 compares data obtained in a previous study by Steffan (1997) to data obtained during this study.

Table 5: Conductivity, pH and temperature for Ongongo and Sesfontein.

Chemical property	Ongongo		Sesfontein	
	Steffan (1997)	This study	Steffan (1997)	This study
Conductivity (mS^{-1})	0.512-0.518	0.818	1.269	0.92
pH	7.5-7.7	7.61	8.3-8.5	8.3-8.5
Temperature (°C)	27-29.1	25.9	25.5-31.0	25.0-29.3

There appeared to be very little difference in the results reported by Steffan (1997) and those obtained during this study.

SEASONAL VARIATION IN WATER CHEMISTRY

While the data sets presented in the following section are by no means complete, an indication of the seasonal changes in the water chemistry of selected springs and wetlands of the Hoanib River catchment can be inferred.

pH

The seasonal change of pH in selected wetlands and springs in the Hoanib River catchment is presented in Figures 3 and 4 respectively.

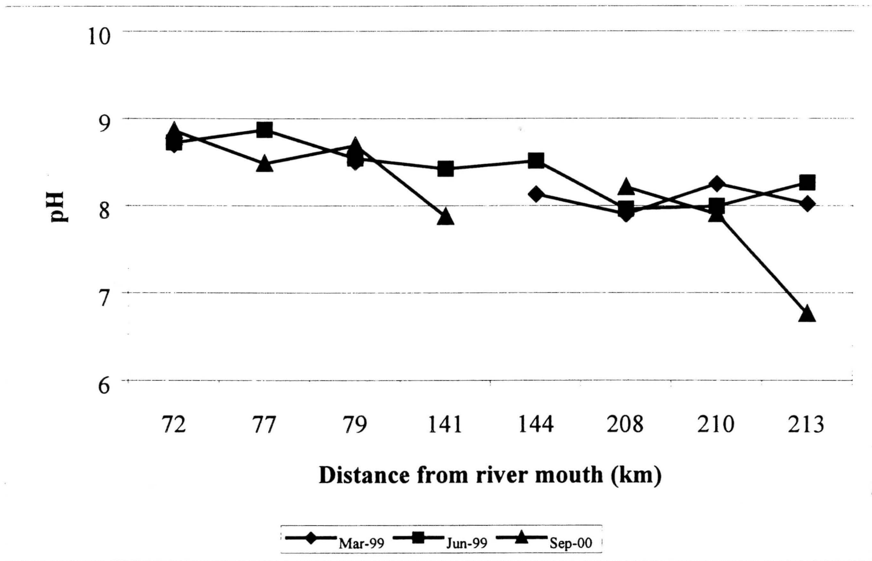


Figure 3: Seasonal changes in pH at selected wetlands in the Hoanib River catchment

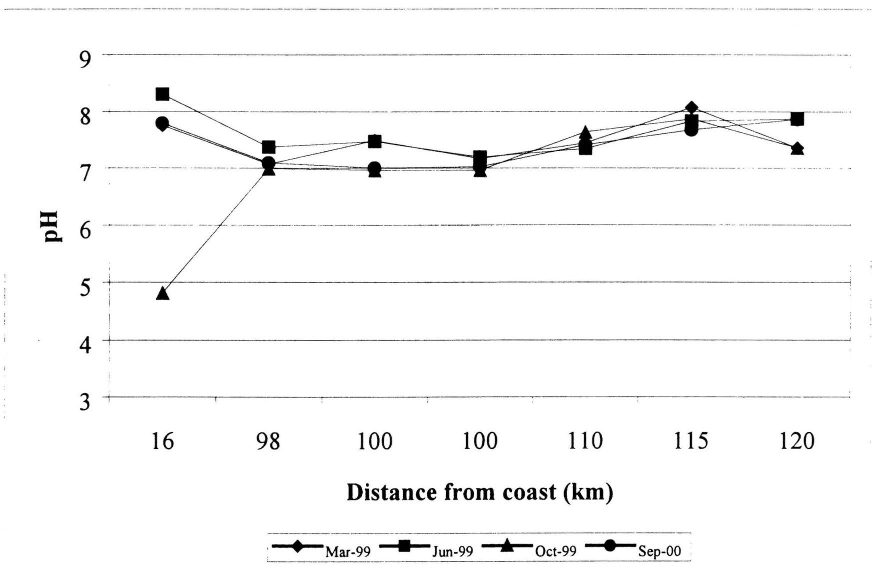


Figure 4: Seasonal changes in pH at selected springs in the Hoanib River catchment

During all three surveys undertaken, the pH of wetlands appeared to decline in accordance with the distance from the coast. There appeared to be little seasonal variation in the pH readings at any one site. However, the pH of the wetlands was consistently higher – i.e. more alkaline - than the pH of the springs. In comparison, the springs appeared to be the opposite of the wetlands with a larger variation in pH readings at the coast (Auses) than away from the coast. With the exception of Auses, there also appeared to be very little difference between the pH of the springs measured.

Dissolved oxygen (D.O.)

The seasonal change in dissolved oxygen concentrations in selected wetlands and springs in the Hoanib River catchment is presented in Figures 5 and 6 respectively.

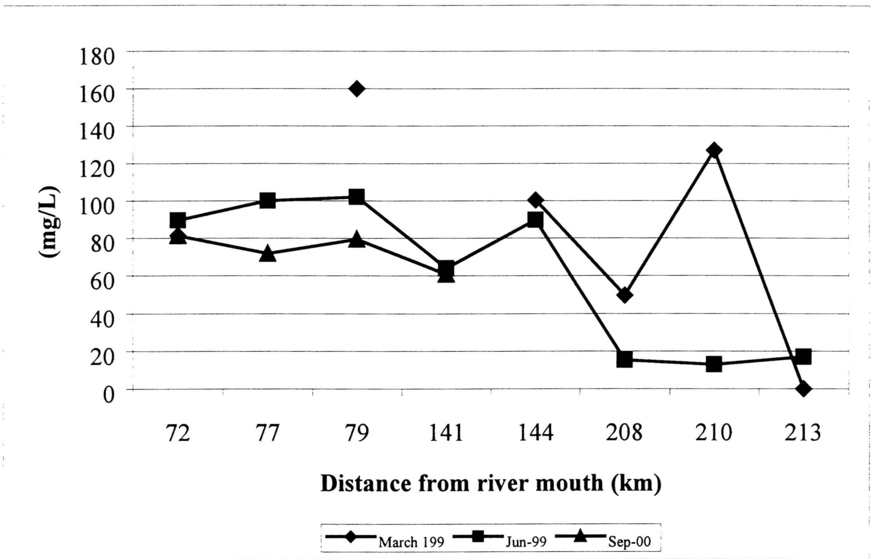


Figure 5: Seasonal changes in dissolved oxygen (mg/L) concentrations at selected wetlands in the Hoanib River catchment

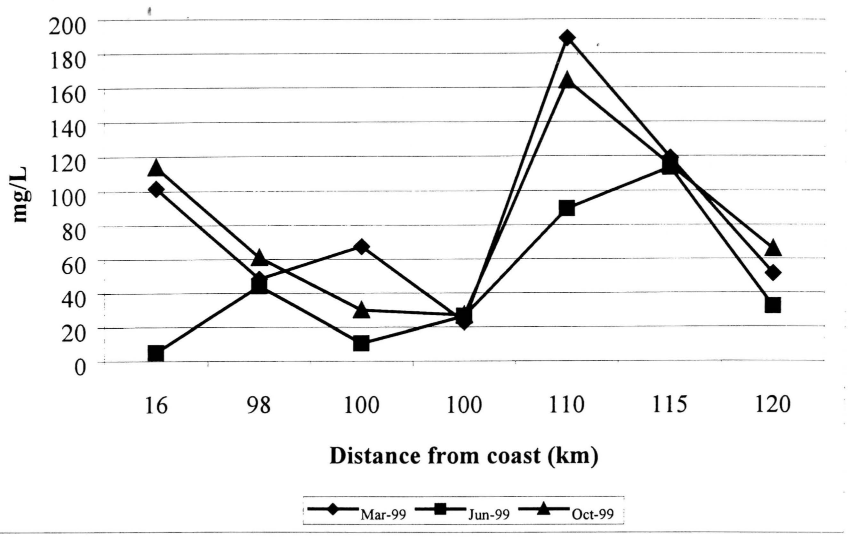
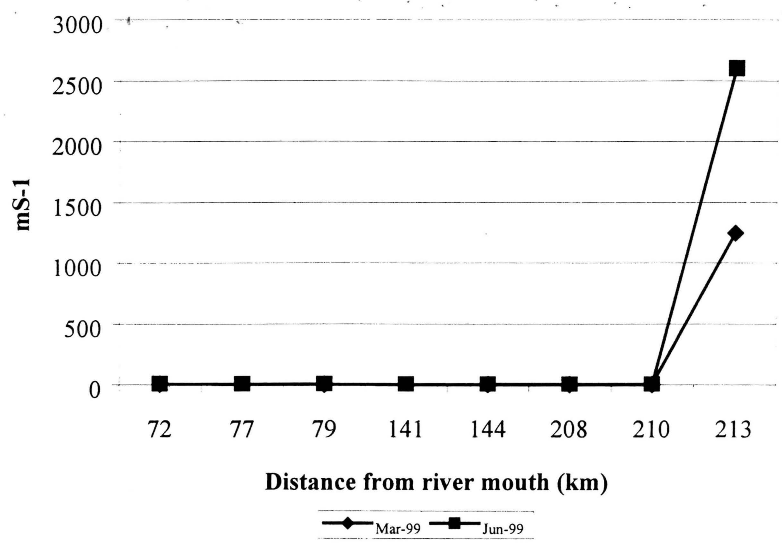


Figure 6: Seasonal changes in dissolved oxygen (mg/L) concentrations at selected springs in the Hoanib River catchment

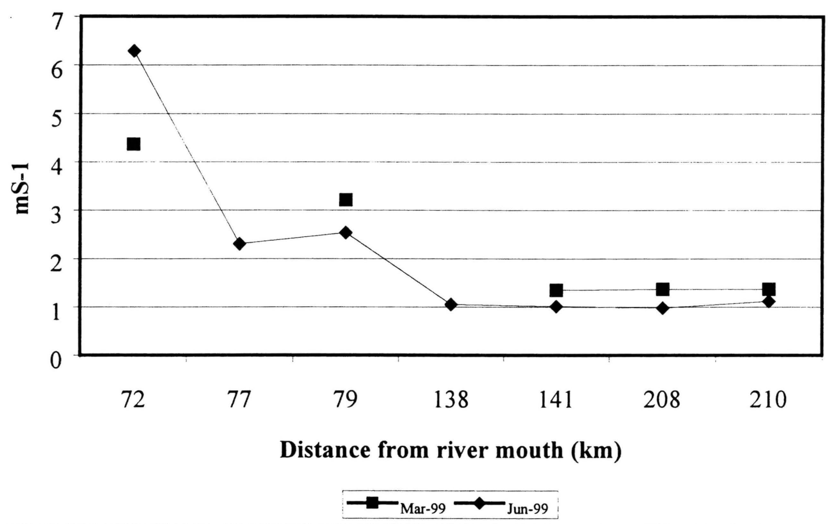
As has already been noted, the dissolved oxygen concentration in most springs and wetlands was dependent on the time of day that the readings were taken. With the exception of Palmfontien-1, all wetlands were biologically productive with high dissolved oxygen concentrations. In general, the springs' level of biological productivity equalled that of wetlands, but this appeared to be dependent on the number of domestic stock and wildlife using the springs. For example, the two springs where large numbers of domestic stock and wildlife drank (Anabeb and Otjontunda) were found to have higher concentrations than the Ongongo springs where few animals drank. The dissolved oxygen concentrations also appeared to be linked to temperature, with higher dissolved oxygen concentrations observed during the warmer months (March and September) of the year.

Conductivity (Cond.)

The seasonal change in conductivity levels of selected wetlands in the Hoanib River catchment is presented in Figures 7a and 7b. The difference between the two is the removal of the Palmfontein 1 data set. Data from selected springs is presented in Figures 8a and 8b. Similarly, the only difference between the two is the removal of the Auses data set.



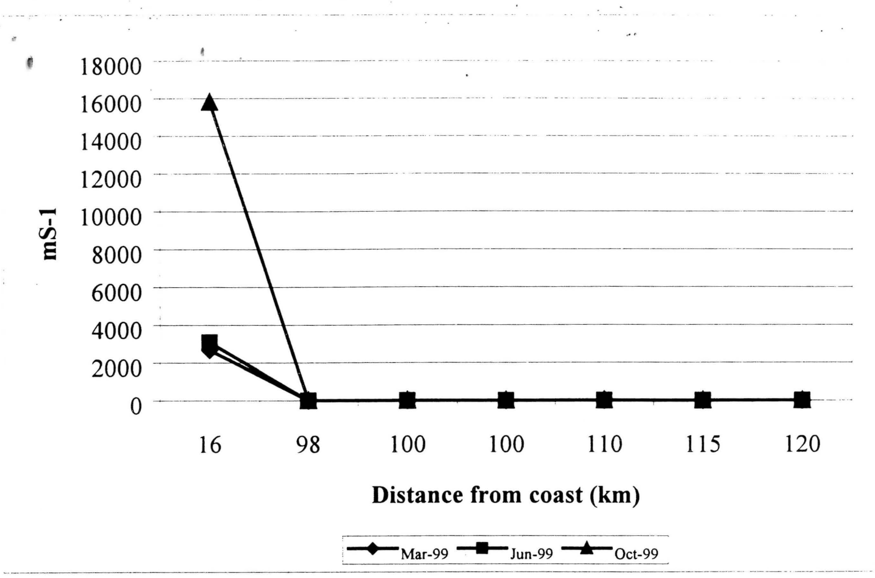
7a



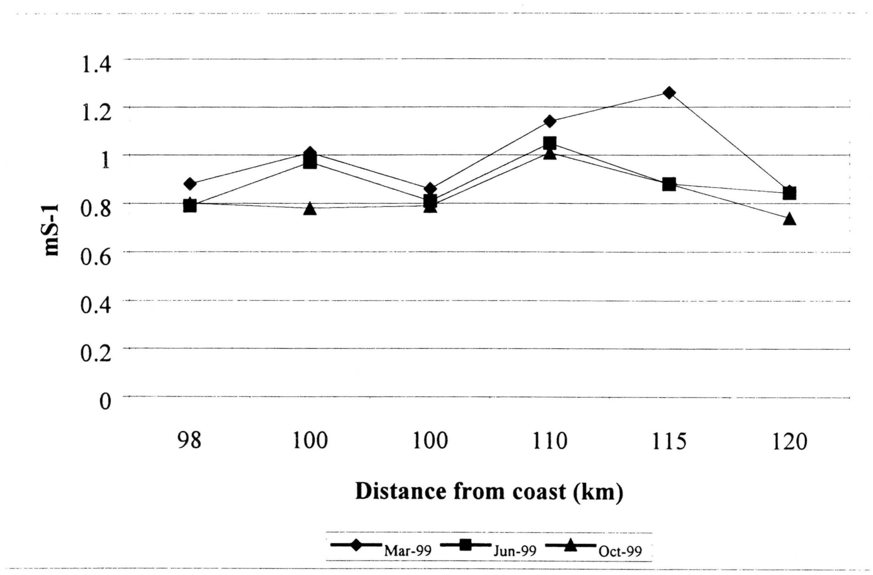
7b

Figure 7a and 7b: Seasonal changes in conductivity (mS^{-1}) at selected wetlands in the Hoanib River catchment

(Note: 7b is the same as 7a with the removal of the Palmfontein-1 data set)



8a



8b

Figure 8a and 8b: Seasonal changes in conductivity (mS^{1}.) at selected springs in the Hoanib River catchment
(Note: 8b is the same as 8a with the removal of the Auses data set)

There appeared to be a decreasing trend in conductivity away from the coast for both springs and wetlands. If the Palmfontein-1 wetland is ignored, it can be seen that conductivity decreases as distance from the coast increases. There also appeared to be some seasonal differences in conductivity that are associated with flood events. If the coastal saline spring (Auses) data is ignored, then there appeared to be very little difference in conductivity of the other springs with little seasonal variation. There appeared to be a substantial seasonal variation in conductivity readings of both Auses (spring) and Palmfontein 1 (wetland).

Total dissolved solids (T.D.S.)

The seasonal change in T.D.S. of selected wetlands in the Hoanib River catchment is presented in Figure 9, and data from selected springs is presented in Figures 10a and 10b. The only difference between the two is the removal of the Auses data set.

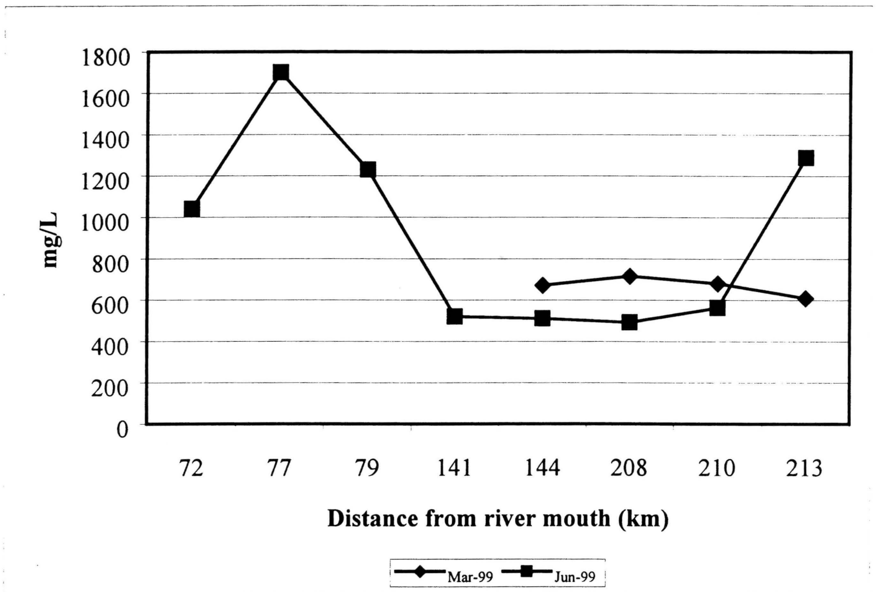
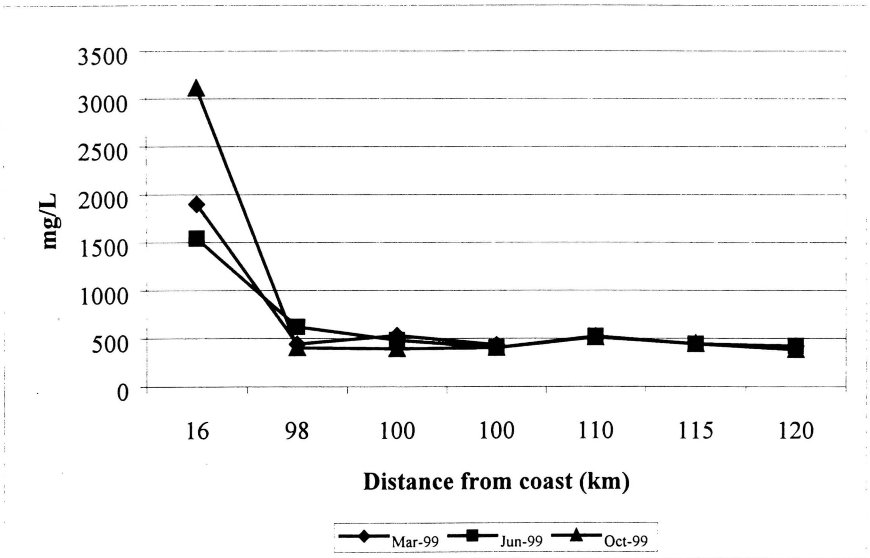
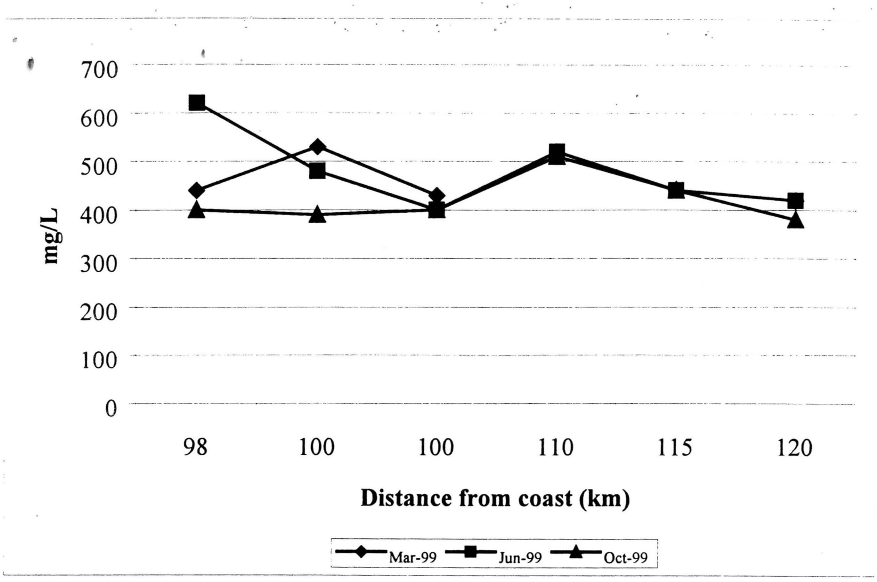


Figure 9: Seasonal changes in total dissolved solids (mg/L) at selected wetlands in the Hoanib River catchment



10a



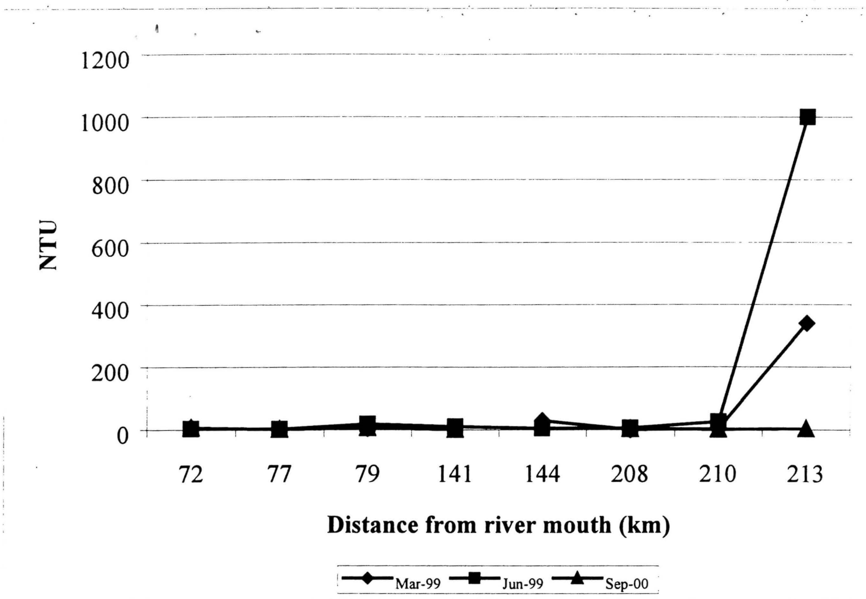
10b

Figure 10a and 10b: Seasonal changes in total dissolved solids (mg/L) at selected springs in the Hoanib River catchment
(Note: 10b is the same as 10a with the removal of the Auses data set)

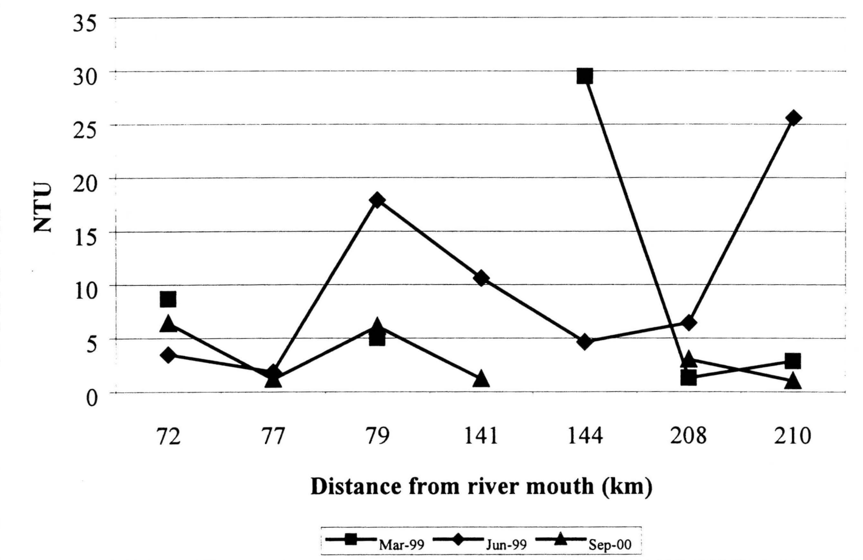
The total dissolved solids data mirror the conductivity results in that higher concentrations of total dissolved solids are found nearer the coast and decrease as distance from the coast increases. With the exception of Auses, there appeared to be little seasonal variation in the total dissolved solid concentration in springs. Whereas wetlands appeared to have some degree of seasonal variation (especially at Palmfontein-1), but limited data made it difficult to quantify this.

Turbidity (Turb.)

The seasonal change in turbidity of selected wetlands in the Hoanib River catchment is presented in Figures 11a and 11b. The difference between these two is the removal of the Palmfontein 1 data set; the data from selected springs is presented in Figure 12.



11a



11b

Figure 11a and 11b: Seasonal changes in turbidity (NTU) at selected wetlands in the Hoanib River catchment

(Note: 11b is the same as 11a with the removal of the Palmfontein-1 data set)

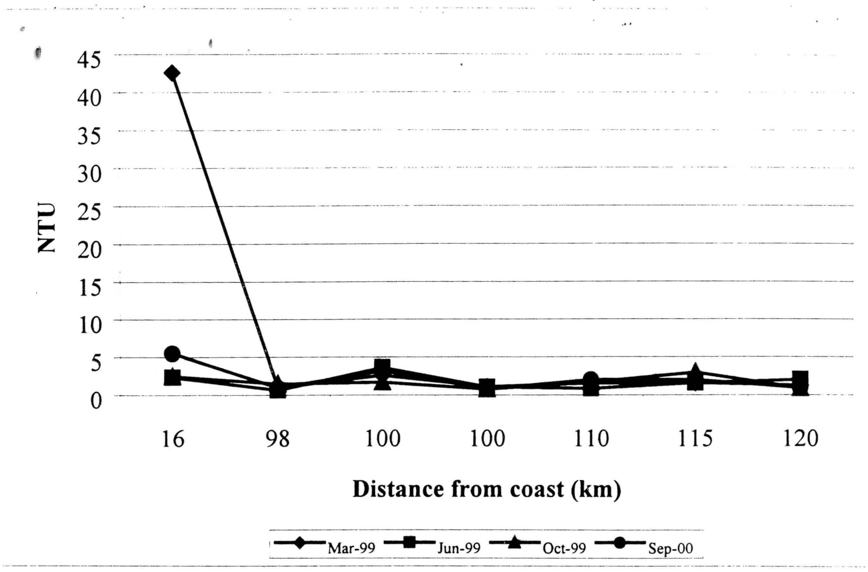


Figure 12: Seasonal changes in turbidity (NTU) at selected springs in the Hoanib River catchment

In the wetlands, the turbidity of the water appeared to be seasonally related and in most areas low. Palmfontein 1 was the obvious exception, as disturbance from domestic stock appeared to have affected the turbidity of the water. Other areas were more affected by seasonal floods and biological productivity than by disturbance by domestic stock or wildlife.

Temperature

The seasonal change in temperature of selected wetlands in the Hoanib River catchment is presented in Figure 13, and the data from selected springs is presented in Figure 14.

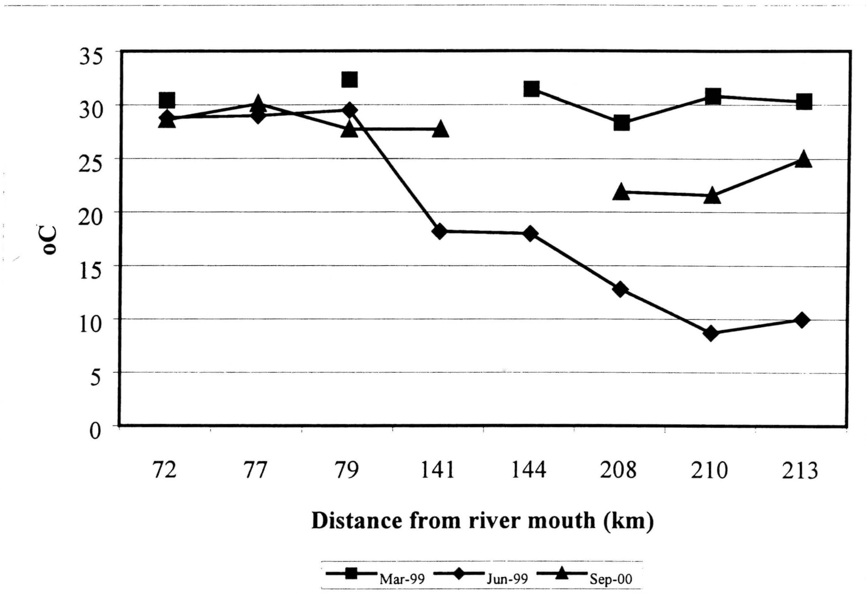


Figure 13: Seasonal changes in temperature (°C) at selected wetlands in the Hoanib River catchment

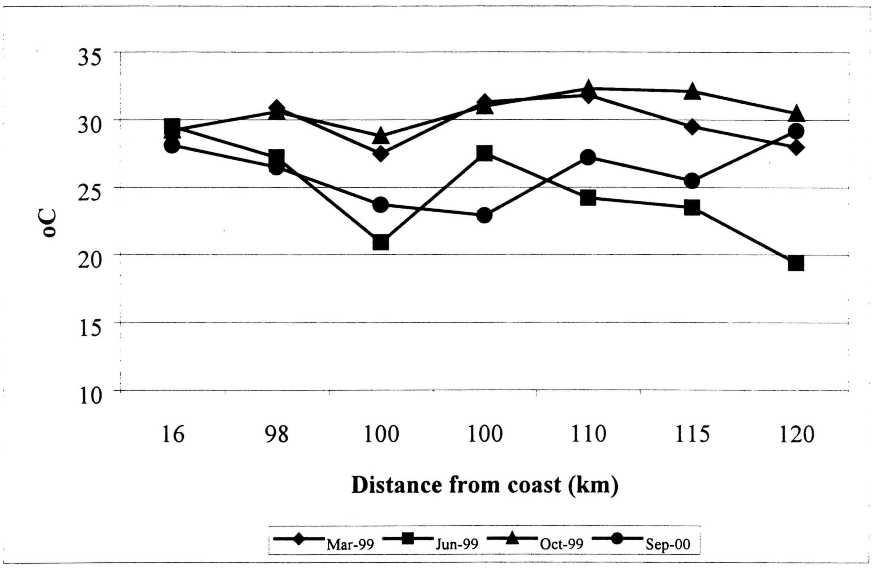


Figure 14: Seasonal changes in temperature (°C) at selected springs in the Hoanib River catchment

The temperature of the wetlands appeared to vary more substantially than the temperature of the springs. In addition, it appeared that the greater the distance from the coast, the higher the seasonal temperature variation for both springs and wetlands.

DISCUSSION

With a few notable exceptions, the springs and wetlands in the catchment area had a conductivity of less than 900 mS^{-1}, making them suitable for consumption by domestic stock and wildlife (Auer, 1997). In addition, the majority of the springs and wetlands in the catchment were also suitable for human consumption having a conductivity of less than 150 mS^{-1}.

The following discussion deals with the observed chemical differences between water sources and the possible reasons for these differences.

SPRINGS

The Auses spring appeared to have a completely different chemistry compared to the other springs studied. At the time of the study, Auses was a large spring with a substantial pool of water, approximately 100m long and 50m and up to 1.5m deep. Auses was a saline spring and obviously fed from a completely different water body than any of the other springs studied. The spring appeared to have significant seasonal changes in pH, conductivity and total dissolved solids. The change in water chemistry could be due to one of two factors:

(a) the influx of 'new water' into the water body;

(b) the 'turnover' of bottom water to the surface due to temperature inversion within the water column.

Both processes would provide nutrient rich water to the surface layers and promote biological activity in the surface water (higher dissolved oxygen levels). High conductivity and total dissolved solid concentrations as well as an unusually low pH reading are indicators for a major change in the nature of the water body. Additional studies would be needed to confirm these results.

Wildlife, particularly gemsbok and springbok, have been observed to drink the saline water at Auses. As the nearest fresh water was 30 km away to the north-east, this may have been from necessity. According to Auer (1997) wildlife - and in particular gemsbok - would avoid water of this salinity. In addition, several filmmakers have observed elephants using Auses as a bathing place but it is unlikely that they would drink the water.

All other springs studied had similar chemical properties with little seasonal variation. There appeared to be little difference between them, with slight variations in dissolved oxygen and conductivity readings. Slight elevations in conductivity, total dissolved solids and turbidity were observed in those springs from which domestic stock and wildlife routinely drank (Anabeb and Otjontunda). However, springs that were used exclusively for human consumption (Sesfontein 1, 2, 3 and Ongongo) had relatively lower readings. The disturbance caused to the bottom sediments by domestic stock and wildlife wading into the water to drink has probably contributed to the higher chemical properties of the water. The addition of faecal material from the wildlife and domestic stock has also probably added to the increased chemical properties of the water.

WETLANDS

The wetlands appeared to have both spatial and seasonal changes in chemistry. The closer the wetlands (Oasis, Dubis 1, 2 and 3) were to the coast, the greater conductivity and total dissolved solid concentrations were found to be. The western catchment area receives very little rain (0-50mm annually) (Leggett *et al.,* 2001), therefore the water reaching the western section of the catchment originates in the eastern catchment usually in the form of flood events. These flood events carry with them soil and its associated nutrients and salts, as well as organic and inorganic debris (including, grass, wood and small rocks). According to Jacobson *et al.* (1995), discharge in ephemeral rivers tends to decrease downstream due to the combined effects of evaporation and infiltration. The deep sands and gravel beds associated with the Hoanib River channel fill with water as the flood passes, decreasing the volume of flow. Infiltration into the riverbeds is thought to be the main factor in decreasing discharge volume while evaporation concentrates the organic and inorganic salts in the remaining water. Salinity around the wetlands is further exacerbated by the high rate of evaporation of the water in the western areas, leaving behind the natural salts on the soil surface frequently resulting in highly saline soils (Graf, 1988; Jacobson *et al.,* 2000b).

The seasonal fluctuations in conductivity and total dissolved solids are due to annual flooding that removes the surface salts and recharges the water body feeding the wetlands.

All other wetlands (with the exception of Palmfontein 1) had neutral pH's, low conductivity and total dissolved solid concentrations with low turbidities. The seasonal chemistry of wetlands was significantly influenced by the influx of floodwaters that greatly increase turbidity levels, changed river courses and removed water flora and fauna affecting dissolved oxygen concentrations.

As the distance from the coast increased, there was a general decrease in the temperature of the water in the wetlands. The reason for this is unknown. The greatest variation in the temperature of the wetlands water was observed at Palmfontein 1, 2 and 3, and the smallest variation occurring at Oasis.

Palmfontein 1 was a relic wetland. In previous years it had a strong spring associated with it and rarely ran dry (D. Gilchrist, pers.com., 1998). However, in recent times, the spring was dry for several months of the year and the farmers needed to dig in the riverbed to obtain water for domestic stock and people during these dry months. The decrease in water volume of the spring is a result of the extraction of water for the community of Erwee, 7 km away. Two boreholes fitted with electric pumps provide approximately 200 000 L a month to a population of approximately 500 people from the same water source as the wetlands (Fuller, 2000). This has resulted in a decreased volume of water in the wetlands. While Palmfontein 2 and 3 also ran dry for several months of the year, no water holes were dug in these areas, as they did not have the same numbers of people and domestic stock associated with them.

The water chemistry of the Palmfontein 1 wetland appeared to be influenced by the human and domestic stock pressure. The dissolved oxygen, conductivity, total dissolved solids, turbidity and pH appeared to be directly related to the number of domestic stock using the wetland. The water chemistry is seasonally dependent on the annual flood events and all chemical properties studied changed dramatically with the influx of the annual floods.

CONCLUSION

In the Hoanib River catchment, there is very little horticulture, no industrial development and few human development growth points. Therefore it is safe to assume that the vast majority of the water chemistry associated with the Hoanib River water sources is due to 'natural' processes. Some of the springs and wetlands in the catchment are under pressure from humans to provide for an increasing population and, thus, higher water demand. However, the water quality of most of the selected springs and wetlands measured in the Hoanib River catchment appeared to be of excellent quality for both human, domestic stock and wildlife consumption. There is a danger that a situation such as that existing at Palmfontein-1 will spread to other areas in the catchment as water demand increases.

To ensure that the impact of people on the water sources is kept to a minimum there should be:

- an appropriate and systematic approach to the positioning of additional water developments;
- monitoring and evaluation of any effect of the development on springs and wetlands; and
- environmental impact assessment on any water development projects (including tourism developments and town planning).

REFERENCES

American Water Works Association (AWWA) (1990) *Water Quality and Treatment: A Handbook of Public Water Supplies*. 4th Edition, McGraw-Hill, NY.

Auer, C. (1997) *Water availability and chemical water quality as important factors for sustainable wildlife management in the Etosha National Park and for domestic stock in farming areas of Namibia*. Research Discussion Paper, No. 26, Directorate of Environmental Affairs, Ministry of Environment and Tourism, Namibia.

Auer, C. (1998) *Water availability and chemical water quality as important factors for sustainable wildlife management in Etosha National Park and for domestic stock in farming areas of Namibia*. Unpublished manuscript.

Connell, D.W. and Miller, G.J. (1984) *Chemistry and Ecotoxicology of Pollution*. John Wiley and Sons, NY.

Department of Water Affairs (1991) *Guidelines for the evaluation of drinking water for human consumption with reference to the chemical, physical and bacteriological quality*. Department of Water Affairs, Namibia.

Dunne, T. and Leopold, L.B. (1978) *Water in Environmental Planning*. W.H. Freeman and Company, NY.

Fisher, S.G. and Minckley W.L. (1978) "Chemical characteristics of a desert stream in flash flood". *Journal of Arid Environments*, **9**: 105-118.

Fuller, B. (2000) *Divided by history, united by water: Impacts of water development in the upper Hoanib catchment*. Unpublished manuscript. Windhoek, Namibia.

Gower, A.M. (1980) *Water Quality in Catchment Ecosystems*. John Wiley and Sons, NY.

Graf, W.I. (1988) *Fluvial processes in dry lands*. Springer-Verlag, Berlin.

Hem, J.D. (1982) "Conductance: a collective measure of dissolved ions". In: Minear R. A. and L.H. Keith (eds). *Water Analysis, Vol. I: Inorganic Species, Part 1*: 137-161.

Jacobson, P.J., Jacobson, K.M. and Seely, M.K. (1995) *Ephemeral Rivers and their catchments: Sustaining people and development in western Namibia.* Desert Research Foundation of Namibia, Windhoek, Namibia.

Jacobson, P.J., Jacobson, K.M., Angermeier P.L. and Cherry, D.D. (2000a) "Variation in material transport and water chemistry along a large ephemeral river in the Namib Desert". *Freshwater Biology,* **44:** 481-491.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L. and Cherry, D.S. (2000b) "Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert". *Journal of Arid Environments*, **45:** 21-34.

Leggett, K.E.A., Fennessy, J. and Schneider, S. (2001) "Rainfall, water sources and water use" in *Hoanib River Catchment Study, Northwestern Namibia: Water*. DRFN Occasional Paper No. 15. Windhoek, Namibia.

Perfetti, P.B. and Terrel, C.R. (1989) *Water Quality Indicators Guide: Surface Waters*. USDA Misc. Publ., SCS-TP-161, US Government Print Office, Washington, DC.

Sharma, K.D., Choudhari, J.S. and Vangani, N.S. (1984) Sediment transport characteristics of the desert streams in India. *Journal of Hydrology*, **67:** 261-272.

Smith, R.L. (1980) *Ecology and Field Biology.* 3rd Edition, Harper Collins Publishers, NY.

Steffan, A.W. (1997) "Physiographische und biozönotische Bewertung permanenter Quellgewässer im südwestlichen Afrika (Namibia: Damaraland und Kaokoveld)". *Namibia Scientific Society*, Windhoek, **45**: 13-44.

Sullivan, D.J. (2000) *Nutrients and suspended solids in surface waters of the upper Illinois River Basin in Illinois, Indiana and Wisconsin, 1978-97.* US Department of the interior, US Geological Survey, Denver, CO.

US Environmental Protection Agency (USEPA) (1987) *Quality Criteria for Water*. EPA Publication 440/5-86-001, US Gov. Print Office, Washington, DC.

Wilber, C.G. (1983) *Turbidity in the Aquatic Environment: An environmental Factor in Fresh and Ocean Waters.* Charles C. Thomas Publishers, Springfield, IL.

APPENDIX A

(Spring and wetland data forms)

SECTION I

SPRING and POOL DATA SHEET

			Office use	
GPS of spring	S	E	**Spring No**	
¼ DEGREE GRID			**Record No**	
NAME of spring/pool			**Visited**	
REGION			**Samples**	
DIRECTIONS				

Date		Photo available	Yes/No		Attached	
NAME OF SAMPLER			Tel:			

Wetland map

SPRING IN	
Rocky riverbed	
Sandy riverbed	
Pan edge	
Rock outcrop	
Calcreate bed	

Spring has		**Number**	**Length (m)**
Seeps			
Spring-fed pool			
Other Pools			
Streams			

POOLS WITH NO OBVIOUS WATER FLOW	
Floodplain pool	
Oshana	
Ephemeral River pool	
Rock basin	
Depression	
Other Rain pool	
Dam	

Closest permanent water	**km**	**unknown**

Habitat	**Area**	**unit**	**Max depth (cm)**
Water surface			
Reed beds			
Total wetland			

Salinity estimate (out of 3, 1=fresh)	Fresh	Brac k	Salt

Degree of occurrence	**0**	+	+++
Algae mats			
Reed beds			
Submerged aquatic plants			
Floating aquatic plants			
Other aquatic plants			
Sedges			
Grasses			
Bushes			
Trees			
Fishes			
Tadpoles			
Invertebrates			
Reptiles			
Wetland birds			
Sign of large wild mammals			
Sign of small wild mammals			
Sign of Livestock			
Water extraction			
Habitation			

Please note any identified species on reverse side

HUMAN USE	None		occasional		Family		Village		Town	
THREATS	Livestock		Tourism		Extraction		Pollution		Development	
Other threats										
State of wetland.	Good		Fair		Marginal		Degraded		Destroyed	

Biological samples taken	None			Sample code no.

Optional taxa records and numbers. Every bit of information helps

Aquatic Plants					
Associated plants					
Fishes					
Mammals					
Birds					
Invertebrates					

SECTION II

RAINFALL, WATER SOURCES AND WATER USE IN THE HOANIB RIVER CATCHMENT, NORTHWESTERN NAMIBIA

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ABSTRACT

The spatial and seasonal distribution of rainfall in an arid environment such as the Hoanib River catchment influences the seasonal distribution and relative abundance of wildlife, domestic stock and can influence human activities.

Historical rainfall events and general trends of rainfall over the last 50 years are analysed for the Hoanib River catchment area. The rainfall of the 1999 and 2000 wet seasons is analysed in greater depth and comparisons are drawn between rainfall and flood events in the Hoanib River (past the Sesfontein weir). The 1999 wet season appeared to be an 'average rainfall year' across the catchment, while the 2000 wet season was an above 'average rainfall year'.

The distribution and abundance of seasonal and permanent springs, wetlands and boreholes were also investigated. There appears to be few areas in the catchment that do not have seasonal or permanent water sources in close proximity to humans and domestic stock.

The average water consumption in six focus communities was investigated and it was observed that communities where water was available from taps in and around houses used approximately 60L of water per person per day. This was observed to be four times greater than communities where water was fetched by hand from a single water source: consumption per person per day under these conditions was estimated to be approximately 15L. Calculations were made to estimate the consumption of water by humans and domestic stock in each of the focus communities. In most areas, domestic stock water consumption far outweighed consumption by humans.

KEY RESEARCH QUESTIONS

Water is the single most limiting resource in an arid area and the focus of this research was to examine the seasonal and spatial abundance of water and its effect on the environment. Linked to this is the consumption of water by humans and domestic stock in the catchment area. The key research questions for this study were:

(a) What are the historical rainfall patterns in and around the Hoanib River catchment?

(b) Is there a correlation between rainfall and flood events in the Hoanib River?

(c) What is the distribution of springs and boreholes in the catchment area?

(d) Does water consumption vary in each of the six focus communities within the Hoanib River catchment?

(e) Is the variation in consumption related to the relative availability of water?

(f) How much water does domestic stock consume in each of the focus areas?

BACKGROUND

GENERAL BACKGROUND

Rainfall

The structure and function of an arid/semi-arid ecosystem is strongly influenced by the nature of the precipitation it receives (Standford, 1983; Ellis and Swift, 1988; Behnke, 1993; Behnke *et al.,* 1993; Dean *et al.*, 1995; Sullivan, 1996; Sullivan, 1999). Independently, it can provide sufficient information to assess rainfall of an area. However, an understanding of precipitation's importance for plant communities, sediment movements, and human and animal movements is not possible without knowledge of the seasonal distribution of precipitation.

Namibia's rainfall pattern has been well studied. According to Tyson (1986) most of the rain that falls on Namibia originates over the Indian Ocean. By the time the moisture-bearing clouds reach western Namibia, they have passed over all of southern Africa and their moisture content has declined dramatically. This decline becomes even more pronounced when warm moist air from the east meets the prevailing on-shore cool, dry air near the coast. The result is an inversion of temperature, with cool air near the ground and warm air above, and therefore less air turbulence. This situation contributes to very low rainfall near the coast and higher rainfall inland and hence a steep rainfall gradient across the catchment.

Rainfall reaching the ground permeates the soil, filling air spaces between the soil particles with water. As rainwater moves downward to fill spaces below the soil surface, rainfall continues to accumulate on the earth's surface. If the rainfall is gradual and the infiltration rate is faster than the accumulation rate at the surface, then most of the water permeates the surface soil (Jacobson *et al.*, 1995). However, the summer rains in western Namibia usually come in the form of thunderstorms and violent rain where the infiltration rate into the soil is slower than the accumulation rate on the surface. Excess water accumulates in depressions and forms pools. If enough rain falls, excess water will start to move under the influence of gravity and flow downhill. Flowing water, moving rapidly downhill gains enough momentum to move and carry with it objects in its path for example, soil and its associated nutrients and salts, organic and inorganic debris (including, grass, wood and small rocks) (Jacobson *et al.*, 1995; Jacobson *et al.*, 1999; Jacobson *et al.*, 2000).

The rate at which runoff forms and flows is dependent on the rainfall intensity, infiltration rates and slope of the surface on which the rain falls. For example, rainfall that falls on rocky or hilly terrain will have a much greater runoff than on flat, sandy, soil plains. Runoff forms small streams that move along streambeds or channels under the influence of gravity and merge on less steeply sloping ground to form larger streams also moving through recognised channels. Larger streams have a greater momentum than smaller ones and therefore can carry more debris. Large streams tend to merge on less sloping ground to form rivers that flow in one channel toward the ocean (Jacobson *et al.*, 1995). The area of land drained by streams that eventually end in one river is called a catchment. Catchments are usually discrete units that are geographically and geologically defined.

Flood events

The Hoanib River is an ephemeral river and relies upon seasonal rainfall to flow. The exceptions to this are the small spring-fed streams that form year round flows in the river (e.g.

Khowarib Spring), however, these springs are not sufficient to make the Hoanib River perennial. These small surface streams are caused by bedrock interrupting the underground movement of water, forcing it to the surface. Floods in ephemeral rivers occur when heavy seasonal rainfall provides sufficient water for the normally dry river channel to fill and flow. A 'flood event' continues until the flow of water in the river channel finally ceases. The rate at which water is transported in a river channel is called the river's discharge (Jacobson *et al.*, 1995).

Unlike most perennial streams where discharge generally increases downstream as more flow joins the main runoff, ephemeral rivers' discharge tends to decrease downstream due to the combined effects of evaporation and infiltration (Graf, 1988). The deep sand and gravel beds associated with ephemeral river channels fill with water as the flood passes, decreasing the volume of flow. Infiltration into the streambeds is thought to be the main factor in decreasing discharge volume and preventing many floods from reaching the river's end.

Discharge is highly variable and can be described in terms of the flood event. A 'flash flood' is defined as a single peak flood that increases from zero to peak discharge in several minutes. These floods tend to be associated with large thunderstorms and relatively small catchment sizes with large volumes of water being deposited rapidly. 'Single peak floods' last longer than flash floods; from several days to several weeks, depending on the rainfall pattern over the catchment. The flood results from broad precipitation covering thousands of square kilometres. Single peak floods have an initial high peak discharge that subsides to a lower level of flow before stopping completely. 'Multiple peak floods' result from consecutive rainfalls over many days or in different parts of the catchment. These floods are characterised by steady flow interspersed with peaks from different rain events in the catchment (Jacobson *et al.*, 1995).

The ecology of the floods has been well reported by Jacobson *et al.* (1995), Jacobson *et al.* (1999), and Jacobson *et al.* (2000). The flood events move large amounts of sediment, organic material, nutrients and seeds toward the lower end of the rivers. The fine organic material is deposited on the banks and in the floodplain, increasing the fertility of the soil. The floods are also beneficial to the riparian forests by depositing large logs at the base of the trees creating small blockages and causing more debris to collect there. When the floods recede, the deposited sediments serve as germination areas for seeds and the establishment of new vegetation. The debris piles form ideal habitats for small mammals, reptiles and many invertebrates. In addition, the debris pile can change the flow pattern of the river causing the deposition of sediments in bars on their downstream sides, providing vegetation germination areas and disrupting the main river flow (Jacobson *et al.*, 1995).

'Normal' rainfall and drought

Average annual rainfall for an environment represents the amount of rainfall that can be expected in a 'normal' year, with anything deviating from this average referred to as an 'abnormal' condition. However, rainfall averages are often skewed or distorted by years that have had excessive rainfalls recorded. Minimal period data sets or data sets which are not continuous can also distort results, adding to the real significance of what mean rainfall truly does represent.

On the other hand, in arid areas median annual rainfall can provide a somewhat better idea of what amount of rainfall can be expected 'normally' (Jacobson *et al.,* 1995). Representing the median value between the wettest and driest years, this analysis requires a greater number and continuity of data sets for accuracy. Usually the median is a little lower than the average since it is not skewed by the effects of abnormally high falls.

Drought is defined as a period of two years or more with rainfall lower than the long-term mean (Jacobson *et al.*, 1995; Warren and Khogali, 1992). Drought or periods of aridity are the normal occurrence in arid and semi-arid areas.

Springs and wetlands

Springs are common and occur throughout the Hoanib River catchment area. Within riverbeds, small streams and springs are fed by subsurface river flow. However, in most areas of the catchment, springs are usually associated with groundwater emergence related to the surrounding geological features. Discharge from springs may vary from year to year in response to rainfall fluctuations. The response of the springs to changing rainfall is often difficult to predict, as there can be a delay of months or years until the 'fresh water influx' becomes available at a spring. In many areas of the Hoanib River catchment, springs are only active for a few months a year as they dry up as the water table drops. In many cases, this is a natural occurrence associated with periods of lower rainfall (e.g. Otokotoua Spring) and these springs tend to recover quickly after periods of higher rainfall. In other cases (e.g. Palmfontein), the disappearance or periodic drying up of the springs has been associated with ground water extraction from boreholes to supply nearby villages or towns. There are other examples where springs have been excavated and enlarged, resulting in damage from which they may never recover.

Water management and boreholes

A recent initiative of the Directorate of Rural Water Supply has been the establishment of Water Point Associations (WPA) to manage rural water supplies. The community is responsible for developing a management plan based on the local needs for water. The ideas generated from community meetings are written into the WPA constitution and an application for the registration of the WPA is then submitted to the Directorate of Rural Water Supply via the local Extension Officer. The application includes a list of WPA members, Water Point Committee (WPC) members, a copy of the WPA constitution and management plan and a description of the area over which the WPA will manage. After registration, the WPA is a legally constituted body with certain rights and duties enabling it to take responsibility for the effective management of the water points (Ward and Forbes-Irving, 1999).

Boreholes have been drilled in the Hoanib River catchment for many years. Many of the boreholes on the freehold farms in the eastern Hoanib catchment were drilled soon after the establishment of the farms in the late 1940's and early 1950's. Since then, boreholes have been regularly added across the catchment by government, private individuals and communities.

Water Use

According to the Ministry of Agriculture, Water and Rural Development (MAWRD) (1997), the human consumption of water in rural areas is low compared to urban dwellers. A study in the "4-O" region showed the mean daily consumption of water per capita, to be 13.024L. The MAWRD (1997) study indicated that the mean daily consumption of water per capita in the Sesfontein area was assumed to be 20L per person per day. Hoanib River catchment community researchers in each of the six focus communities collected average daily human and domestic stock water consumption data.

According to Forbes-Irving (1996), the average daily consumption of water by cattle was thought to be approximately 45L, goats and sheep approximately 12L, horses and donkeys approximately 20L. The MAWRD (1997) based their calculations on a water consumption of 50L per head of cattle, 10L per head for goats and sheep, 20L per head for donkeys and horses. Generally domestic stock drink daily, however, in hot weather if water is available they may drink twice a day. Although this is dependent on the distance that animals need to cover to find grazing, if grazing is scarce and stock are moving over large distance they may drink only daily (Auer, 1997). Wildlife is more mobile than domestic stock and rarely uses the same water sources as people and domestic stock.

Drinking frequency and amount of water consumed by most wildlife species is far less than for domestic stock. According to Auer (1997), springbok (*Antidorcas marsupialis*) drink every fourth or fifth day and have a daily water turnover of approximately 5L. Gemsbok (*Oryx gazella*) and giraffe (*Giraffa camelopardalis*) have approximately the same water turnover as springbok (Estes, 1991), while plains Zebra (*Equus burchelli*) need to drink two out of three days and have approximately double the water turnover rate of springbok, gemsbok and giraffe. Unfortunately, no data is available for Hartmann's mountain zebra (*Equus zebra hartmannae*), but for the purposes of this study it is assumed that the water turnover in Hartmann's mountain zebra is the same as plains zebra. Most of the moisture requirements of springbok, gemsbok and giraffe are obtained from the vegetation they consume, with a daily water turnover of less than 10L of water per animal per day. This water turnover is thought to be about a third of that of domestic stock with a similar body mass (Auer, 1997).

Elephant (*Loxondonta africana*) are the most water dependent species in the catchment area, requiring approximately 160L of good quality water daily (Sikes, 1971). In addition, elephants are more likely to use water sources frequented by people and domestic stock. However, as there are relatively few elephants in the catchment, they can be generally excluded from the overall water consumption calculations (MAWRD, 1997).

INTRODUCTION

The Hoanib River catchment is one of twelve major ephemeral catchments that occupy the semi-arid areas of northwestern Namibia. All twelve rivers flow into the Atlantic Ocean or end in the Namib Sand Sea. Many originate in commercial farmlands, flow through communal farming areas and, near their mouths, traverse a protected conservation area. The Hoanib catchment occupies an area of 17 200 km^2, 3% of which lies in private farm lands, 91% in communal farm lands and 6% is protected in Etosha National Park and Skeleton Coast Park.

The Hoanib River constitutes the boundary between the former Damaraland and Kaokoland. Since Namibia's independence in 1990, these two areas have been incorporated into the Kunene and Erongo Regions (see Figure 1). The catchment area of the Hoanib can be divided into three broad geographic sections. The eastern section (east of the Khowarib Schlucht) is relatively densely vegetated with mopane woodland being dominant. The western section of the Hoanib (from the Khowarib Schlucht to Skeleton Coast Park eastern boundary) is sparsely vegetated. In the extreme western section of the river (from the Park boundary to the coast) virtually no vegetation exists outside the river course. A broad floodplain (some 70km^2) in front of the moving dunes of the coast offers substantial grazing for wildlife after flood events during the wet season.

The rainfall in the Hoanib River catchment varies from a mean of 13.2mm at the coast, to a mean of 325mm in the eastern section of the catchment (Jacobson *et al.,* 1995). This rainfall has a high degree of variability, up to 50% annually in the east and 90% in the west. Mean potential evaporation from open water surfaces in the Hoanib is around 3 000mm a year, i.e. about ten times greater than mean annual rainfall in the headwaters and more than one hundred times greater in the arid west. Thus rainwater is lost from the ecosystem and water is generally not available on the surface for most of the year. Where surface water is available at springs and wetlands, the high rate of evaporation frequently results in highly saline soils, because as moisture evaporates it leaves natural salts on the soil surface (Jacobson *et al.*, 1995).

The Hoanib River forms a 'linear oasis' where the wetlands in the river provide the most important biological and socio-economic areas in the catchment. They provide surface water for domestic stock and wildlife, as well as readily available water for communities living in the area. The water is increasingly used in garden and irrigation projects, as well as for the expanding tourism industry. The biophysical nature of the wetlands and other water sources varies over time and is dependent on seasonal rainfall and water extraction.

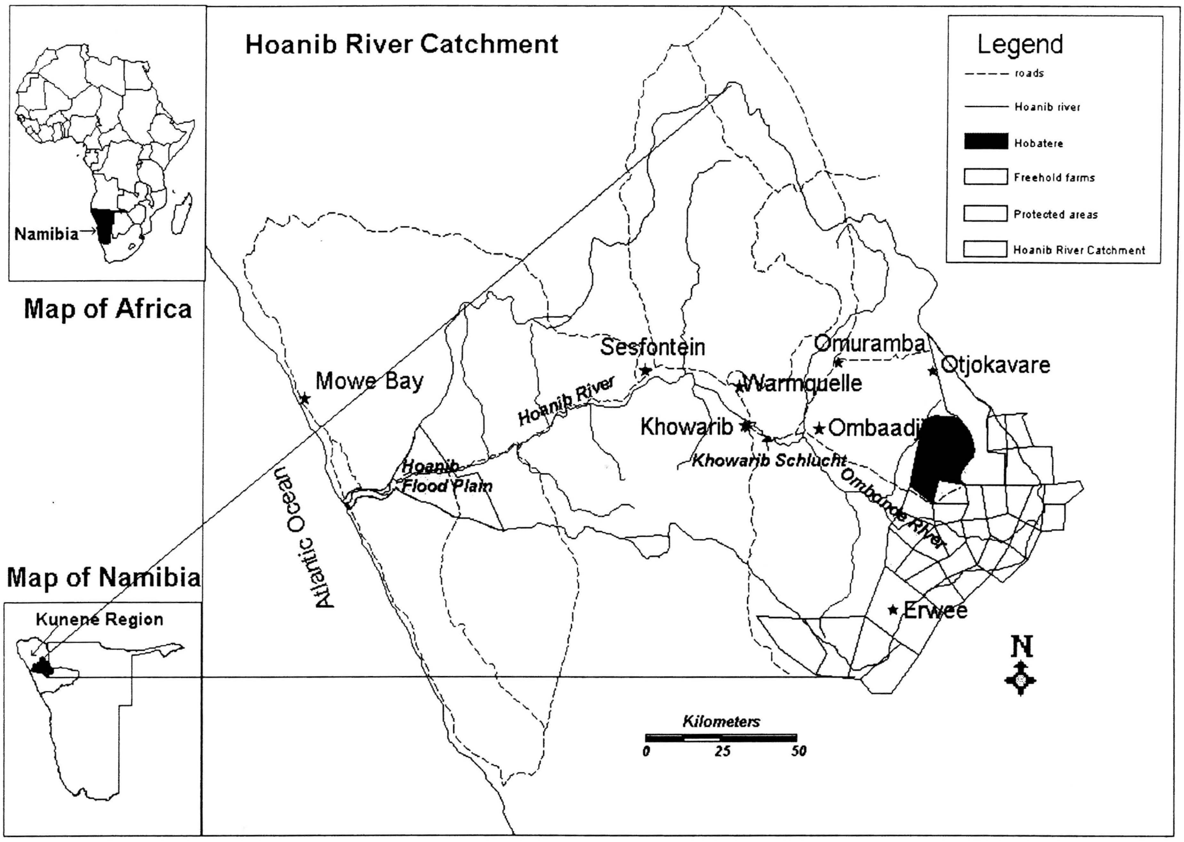

Figure 1: Location of the Hoanib River Catchment

METHODS

HISTORICAL RAINFALL DATA

Historical data sets were collected from various sources including the Bureau of Meteorology Services, police stations, farmers, Ministry of Environment and Tourism offices and individuals living in the Kunene Region, including Steve Braine (Hobatere Game Park), Japie Berger (Oase Garni, Kamanjab) and Dennis Liebenberg (Etendeka Mountain Camp).

1998-2000 CATCHMENT RAINFALL DATA

Six community researchers were each provided with a rainfall gauge (obtained from the Department of Water Affairs, Windhoek) for the specific purpose of obtaining seasonal rainfall data for areas within the Hoanib River catchment.

The HRCS research team provided each community researcher with basic training and understanding of why the collection of rainfall data was important and how it related to the study. The rain gauges were fixed by way of a nail to a wall or preferably a pole (at shoulder height) at a designated site at each house or homestead. After some trial and error in villages where high winds were prevalent, the gauges were soundly secured to prevent any unnecessary loss of moisture.

Once the rainy season started, the rain gauges were checked daily. The gauges had graduated millimetre markings and every morning after rain, the researchers would record the corresponding amount of water they contained. The gauges were then emptied and reinstalled.

FLOOD EVENTS

Historical flood event data was obtained from the Department of Water Affairs, Windhoek. Flood events observed during the 1998/99 and 1999/2000 seasons were recorded at Khowarib, near the Community Rest Camp (GPS -19.27200°S, 13.90230°E). The number and duration of all flood events was noted.

SPRINGS AND WETLANDS DATA

At a series of meetings, communities living in the Hoanib River catchment identified springs and wetlands. The sites were then GPS located by the community and staff researchers. The data presented in the results section is a compilation of data collected by the HRCS researchers, community researchers, Save the Rhino Trust (SRT), Integrated Rural Development and Nature Conservation (IRDNC), conservancy game guards and Ministry of Agriculture, Water and Rural Development (MAWRD) 1997 report.

BOREHOLE DATA

Boreholes were identified in the same manner as springs and wetlands, with additional data obtained from the Department of Water Affairs in Windhoek.

WATER USE

Historical water use and consumption data was obtained from MAWRD (1997) report on the Sesfontein area. Additional data for the catchment area was obtained by the Community researchers employed by the HRCS. Water use data was collected in each of the six focus communities; Sesfontein, Warmquelle, Khowarib, Omuramba, Otjokovare and Erwee.

The HRCS staff researchers provided the community researchers with basic training in how to obtain the data and were then monitored during the collection of the data. In each focus village detailed questionnaires and measurements of water use were made. Each community researcher questioned a minimum of 20 households in each village and water consumption calculations were based on the average volume used by the respondents.

Water consumption data for domestic stock was measured by selecting an animal of average size and allowing it to drink from a measured container. The amount of water consumed by the animal was then recorded, this exercise was repeated for three animals and the average consumption of each animal was recorded. The results obtained from each of the focus communities were then combined and the average figure was then used for all water consumption calculations.

RESULTS

HISTORICAL RAINFALL

Historical rainfall data and annual deviation of rainfall from the long-term mean for Möwe Bay, Sesfontein, Otjovasandu and Kamanjab are shown in Figures 2a and 2b, 3a and 3b, 4a and 4b and 5a and 5b, respectively.

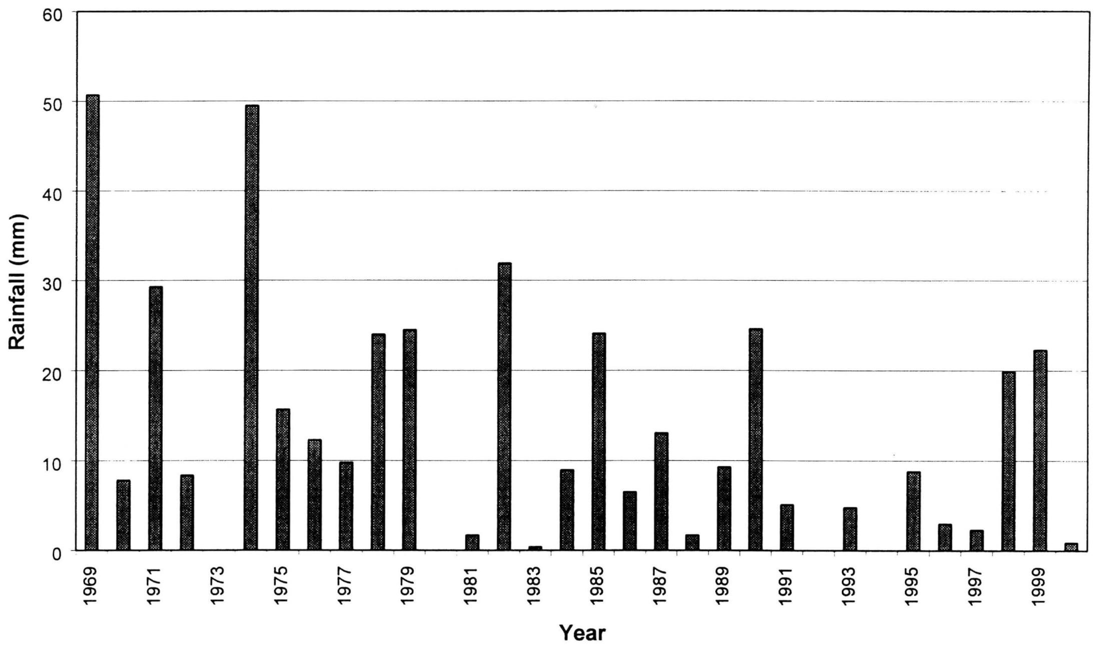

Figure 2a: Historical rainfall data from Möwe Bay

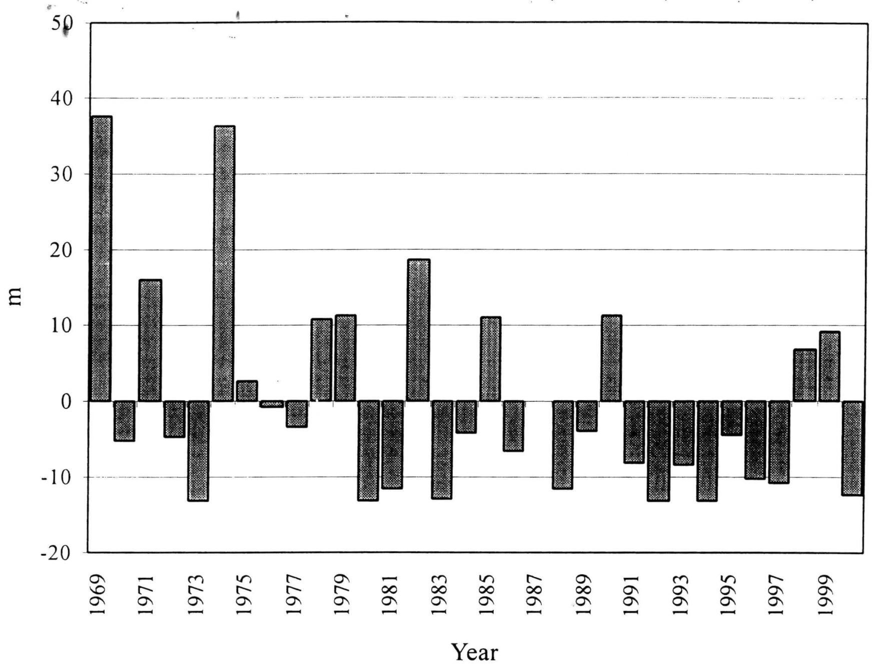

Figure 2b: Annual deviation from the mean rainfall at Möwe Bay

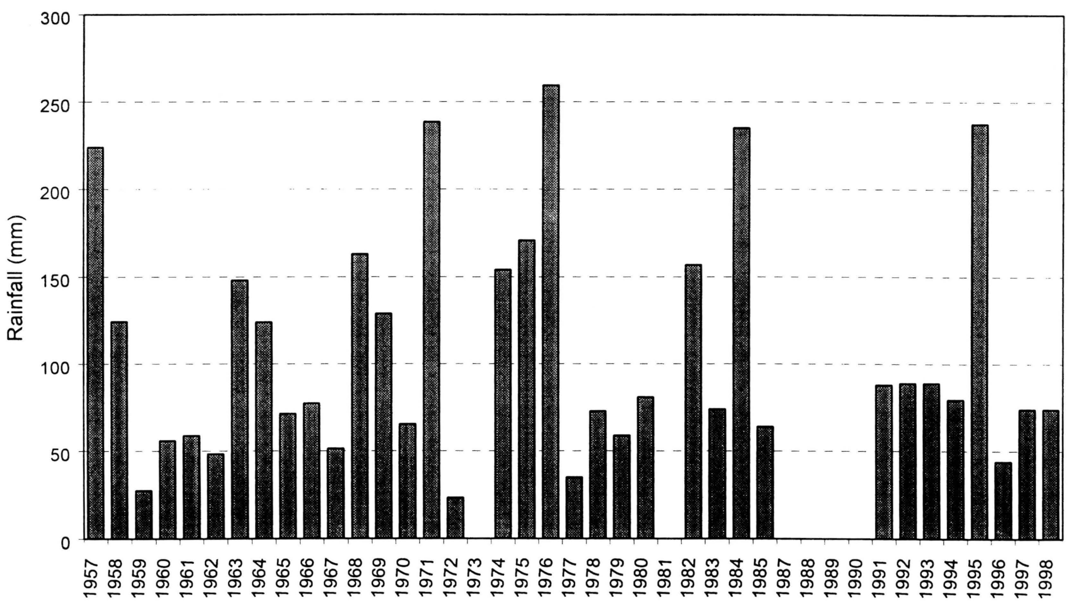

Figure 3a: Historical rainfall data from Sesfontein

(Note: no rainfall data was available for 1973, 1987, 1988, 1989 and 1990)

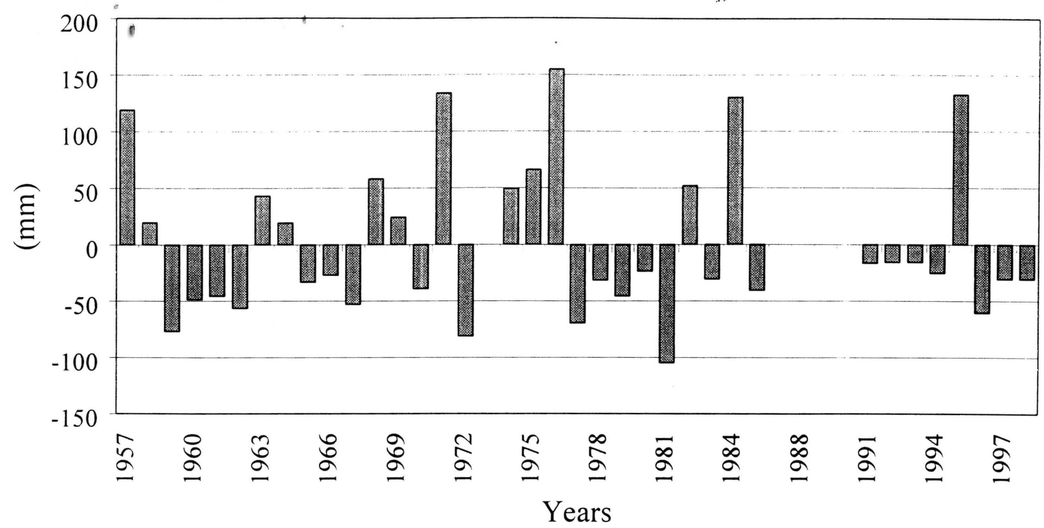

Figure 3b: Annual deviation from the mean rainfall at Sesfontein

(Note: no rainfall data was available for 1973, 1987, 1988, 1989 and 1990)

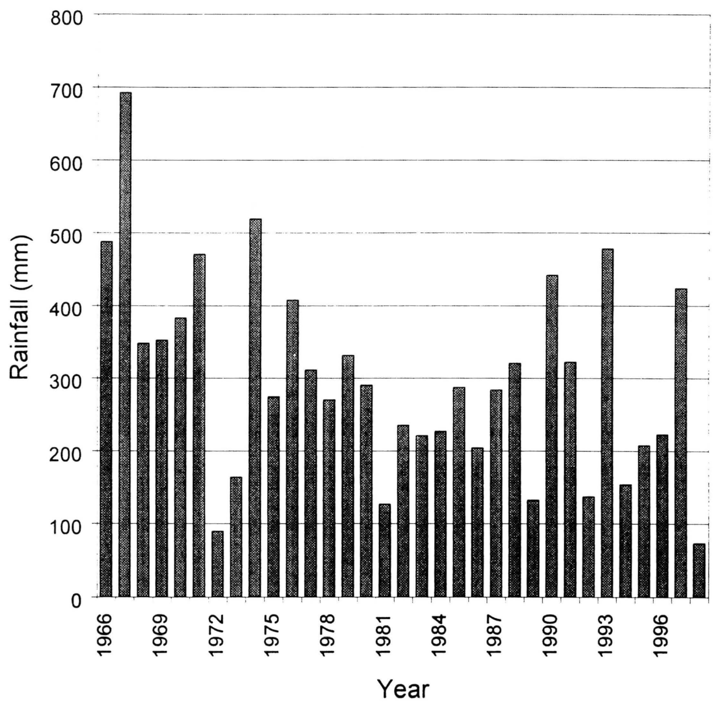

Figure 4a: Historical rainfall data from Otjovasandu

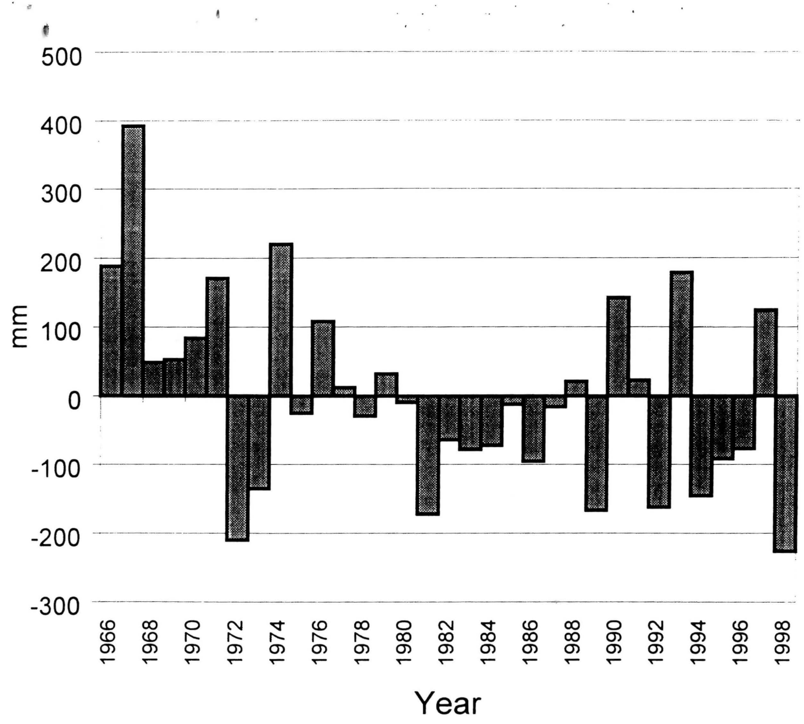

Figure 4b: Annual deviation from the mean rainfall at Otjovasandu

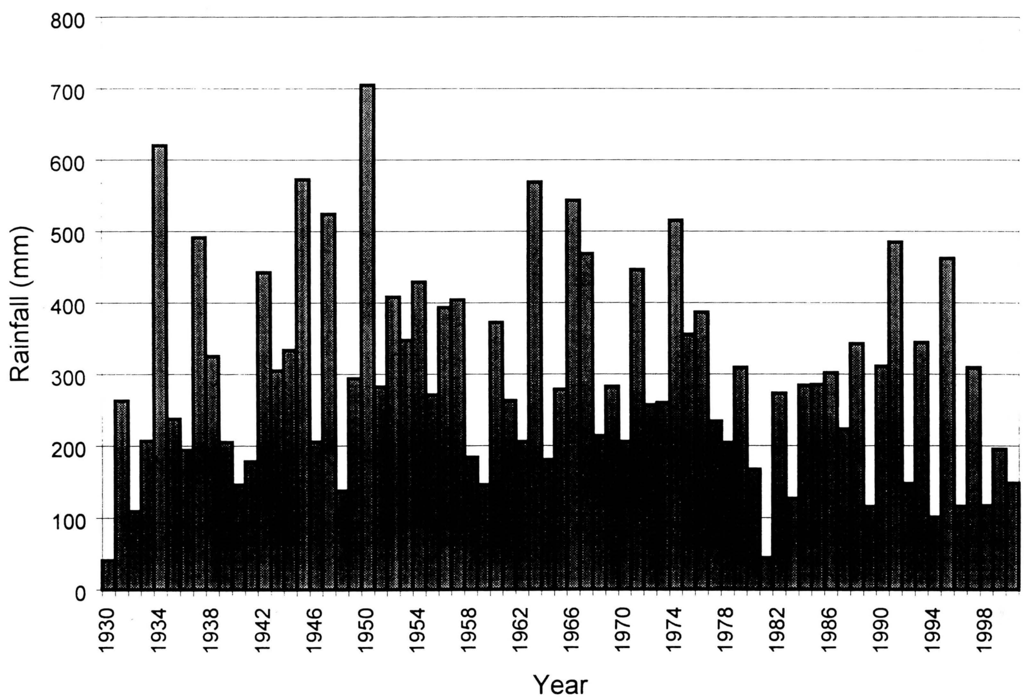

Figure 5a: Historical rainfall data from Kamanjab

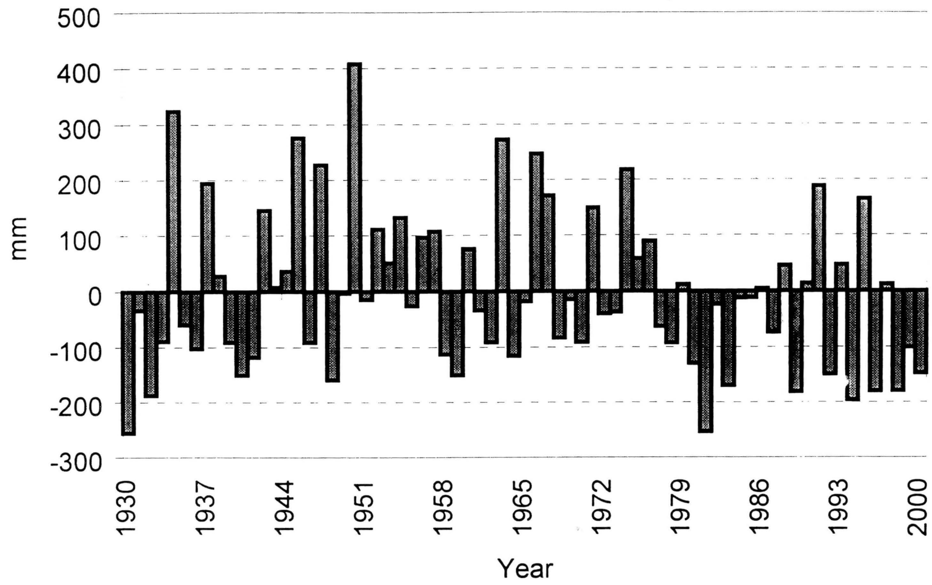

Figure 5b: Annual deviation from the mean rainfall at Kamanjab

The long-term rainfall data indicates that there has been a general trend towards less rainfall in the Kunene Region (including the Hoanib catchment) over the last 20 years. The eastern section (higher rainfall area) appears to be more affected than the western section (lower rainfall area).

The difference between the mean and median values of rainfall for Möwe Bay, Sesfontein, Otjovasandu and Kamanjab are presented in Table 1.

Table 1: Comparison between mean and median values of rainfall

Location	Mean rainfall value (mm)	Standard deviation	Median rainfall value (mm)	Coefficient of variation (%)
Möwe Bay[1]	13.45	13.63	8.4	101.3
Sesfontein	107.9	68.12	79.5	63.1
Otjovasandu	299.8	139.29	287.4	46.5
Kamanjab[1]	305	143	297	46.8
Opuwo[1]	289.1	145.8	289.4	50.4

[1] Located just outside the Hoanib Catchment

When median and mean values are compared, it can be seen that in the eastern section of the catchment, where rainfall is highest and less variable, the mean and median values are similar, while the coefficient of variation is approximately 50%. However, as the rainfall gets closer to the coast, the mean and median values differ substantially and the coefficient of variation increases to be greater than 100%.

DROUGHT EVENTS

If the rainfall records of Kamanjab (see Figure 5a) and Sesfontein (see Figure 3a) are examined, it can be seen that there have been 32 (58%) and 22 (63%) years, respectively, during which rainfall has been below average, while only 23 (42%) and 13 (27%) years when rainfall has been above average. In the case of Sesfontein, many of the below average years were consecutive, with drought years being declared six years out of 10.

1998-2000 CATCHMENT RAINFALL DATA

The 1998-2000 rainfall data collected by the HRCS researchers and community researchers are presented in Table 2. This Table also gives the distance from the coast of each of the monitoring sites.

Table 2: 1999-2000 rainfall data from the Hoanib River catchment.

Location	Distance from the coast (km)	Rainfall 1998-1999 (mm)	Rainfall 1999-2000 (mm)	Long-term mean (mm)	Coefficient of variation (%)
Möwe Bay[1]	0	20.9	2.9	13.45	107
Sesfontein	100		106.5	107.9	N/a
Khowarib	120	115.5	310.5	N/a	64.7
Warmquelle	125		232.5	N/a	N/a
Erwee[2]	150	159	N/a	N/a	N/a
Omuramba[2]	155	N/a	N/a	N/a	N/a
Etendeka Mountain Camp[1]	150	92.5	288	N/a	72.7
Hobatere Game Park	180	182.5	432	251.38	57.4

Otjokavare	185	211.0	431.5	N/a	48.5
Otjovasandu	190	N/a	N/a	299.8	N/a
Kamanjab[1]	210	85	345	305	85.5
Opuwo[1]	215	209	559.4	289.14	64.5

[1] - Located outside the Hoanib River Catchment

[2] - Insufficient data collected

N/a – not available

This data shows that rainfall decreases towards the coast and that it varies significantly between seasons. The rainfall for the 1999/2000 season was well above the long-term mean in all areas of the catchment (with the exception of Möwe Bay).

One rainfall incident between 23rd March and 1st April 2000 was analysed in more detail (see Figure 6).

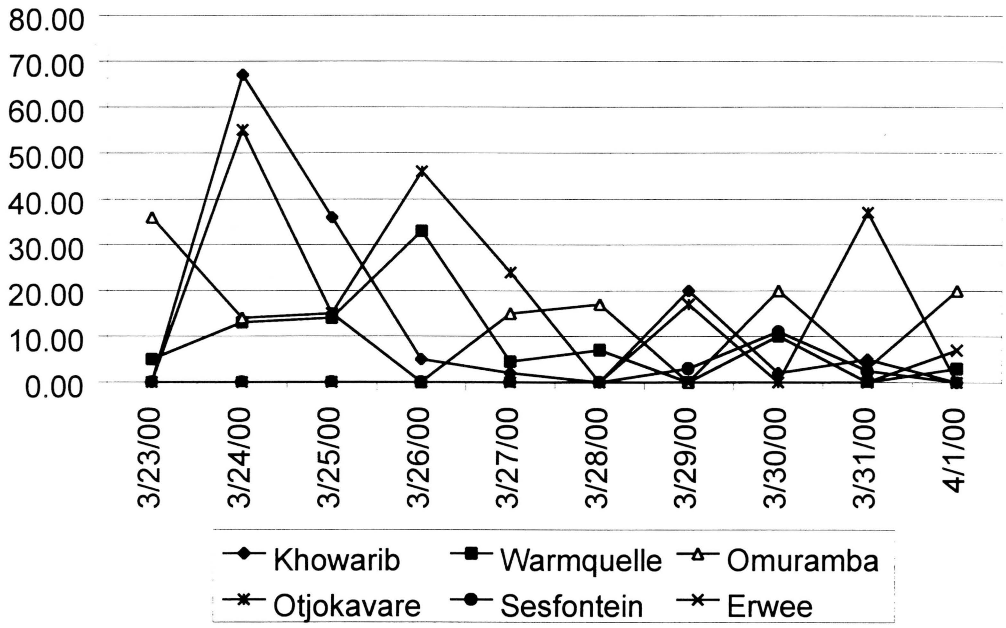

Figure 6: Rainfall across the catchment between 23rd March to 1st April 2000.

With the exception of Erwee, the rest of the areas in the catchment received rainfall during the same days, indicating that the rain was widespread and fell over the entire catchment. Khowarib received some exceptional rainfall, but generally the amount of rainfall decreased from the eastern to western areas of the catchment.

Flood events

Historical flood event data and the variation from the mean flow rate (x 1000m^3) are presented in Figures 7a and 7b.

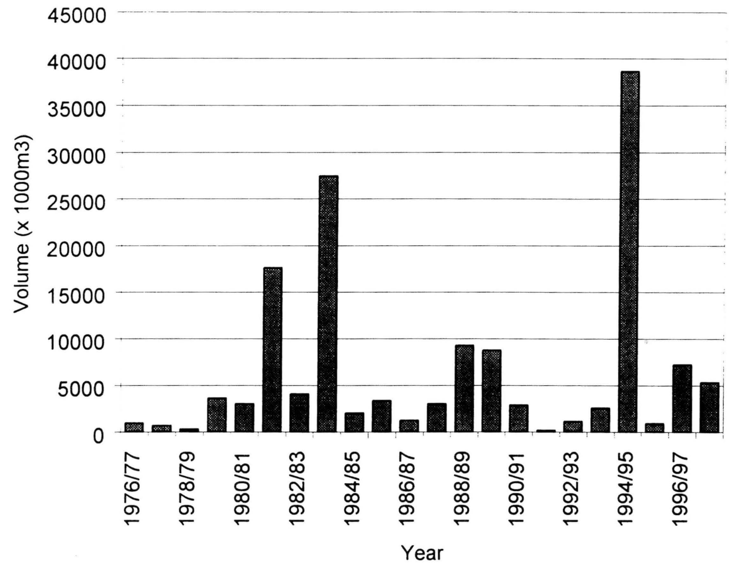

Figure 7a: Historical annual flow rates of the Hoanib River at Sesfontein weir

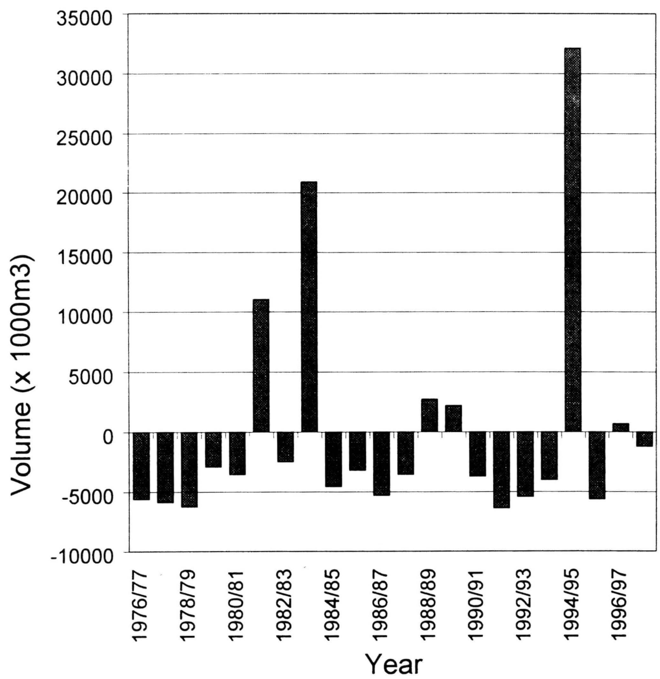

Figure 7b: Variation from mean in annual flow rates of the Hoanib River at Sesfontein weir

The historical number of flood events and corresponding flood periods (in days) measured at the Sesfontein weir is presented in Figure 8.

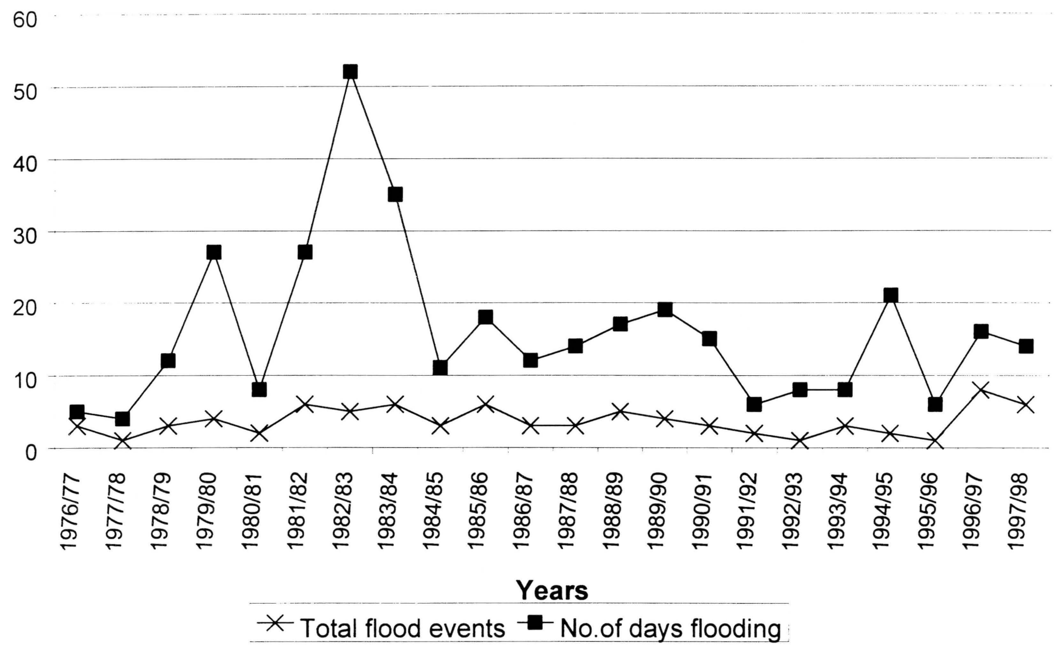

Figure 8: Historical number of flood events and flood periods (in days) at Sesfontein weir

There appears to be no correlation between the number of days of flooding and the number of flood events at the Sesfontein measuring station. For example, there were five flood events in the 1982/83 wet season that resulted in 52 days of flooding in the river. However, in 1993/94 there were again five flood events that resulted in only nine days of flooding.

The date, number of days of the flood events and type of flood event observed at Khowarib during 1998-1999 and 1999-2000 wet seasons are presented in Table 3.

Table 3: Flood events observed in the Hoanib River at Khowarib, 1998-2000.

1998-1999 wet season			**1999-2000 wet season**		
Date	**Duration of flood event (days)**	**Type of flood event**	**Date**	**Duration of flood event (days)**	**Type of flood event**
25/1/99	2	Single peak	17/11/99	2	Single peak
29/1/99	2	Single peak	30/11/99	2	Single peak
13/2/99	2	Single peak	3/12/99	3	Multiple peak
19/2/99	3	Multiple peak	16/12/99	5	Multiple peak
27/2/99	2	Single peak	5/1/00	2	Single peak
9/3/99	4	Multiple peak	22/3/00	12	Multiple peak
16/3/99	2	Single peak	19/4/00	2	Single peak
26/3/99	3	Multiple peak			
31/3/99	4	Multiple peak			

While the number of flood events in 1998-99 was greater than in 1999-2000, there were more days of flood in 1999-2000 (30 as opposed to 24), as a result of multiple peak floods. The total amount of rainfall for the 1998-1999 wet season was less than in the 1999-2000 wet season in all areas of the catchment.

A comparison between the numbers of days of flooding, the volume of rainfall and duration of a flood event is shown in Figure 9. Data are drawn from two sites, one in the eastern catchment at Otjokovare and the other in the western catchment at Khowarib.

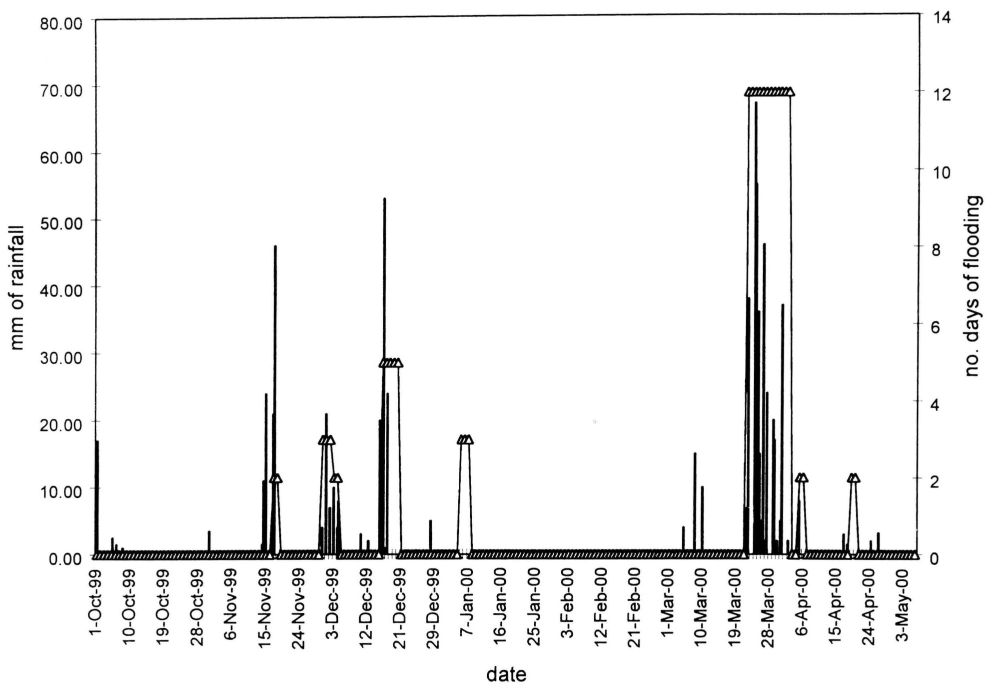

Figure 9: A comparison between rainfall and the duration of the flood event

Figure 9 indicates a direct relationship between the intensity of rainfall and the duration of the flood. The early rains (October and November, 1999) had short duration flood events associated with them, while the later flood events mirrored heavy rainfall events and were of longer duration.

SPRINGS, WETLANDS AND BOREHOLES

The springs and wetlands are numerous and spread throughout the catchment. Some of the springs are saline and some others are thermal, while wetlands are confined to the riverbeds (Jacobson *et al.,* 1995).

The wetlands and springs of the Hoanib River catchment in Figure 10 are shown schematically with a complete list including GPS co-ordinates, in Appendix A.

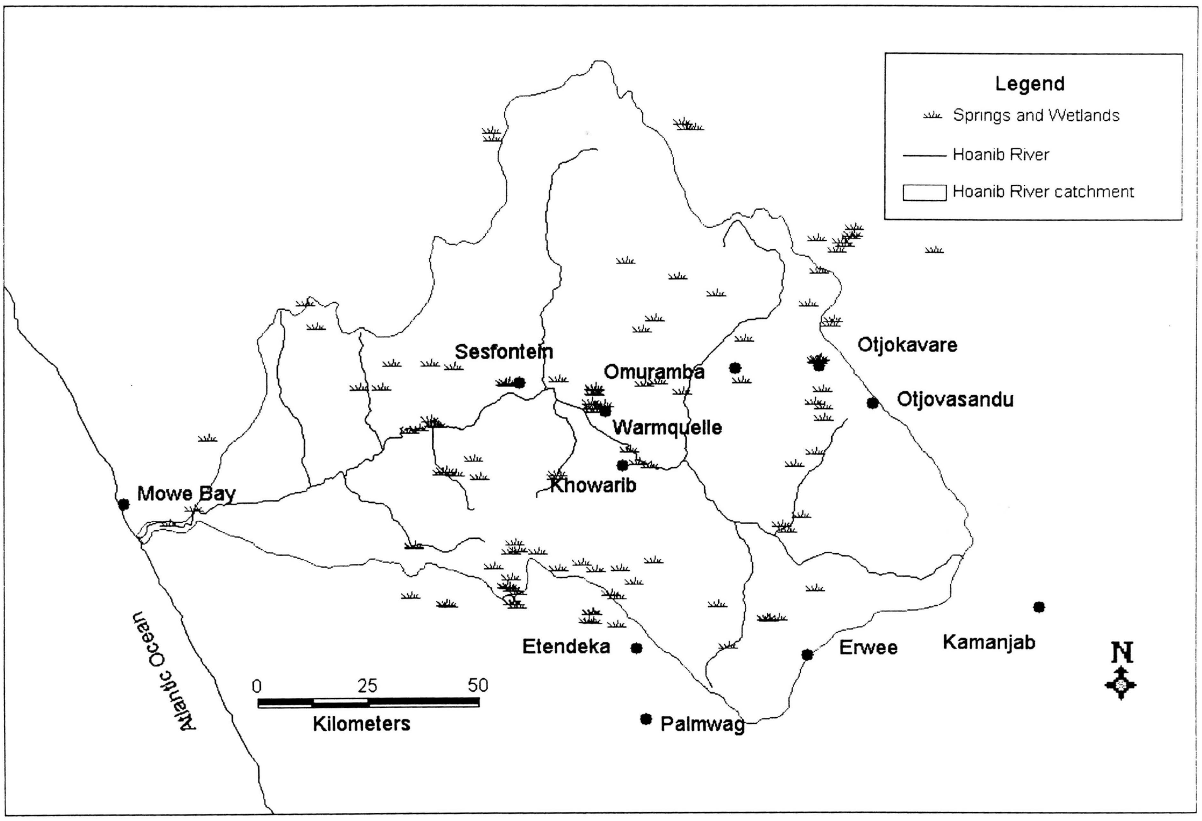

Figure 10: Location of springs and wetlands in the Hoanib River catchment.

The location of the boreholes in the Hoanib River catchment is shown in Figure 11. For the complete list of boreholes with GPS coordinates, see Appendix B.

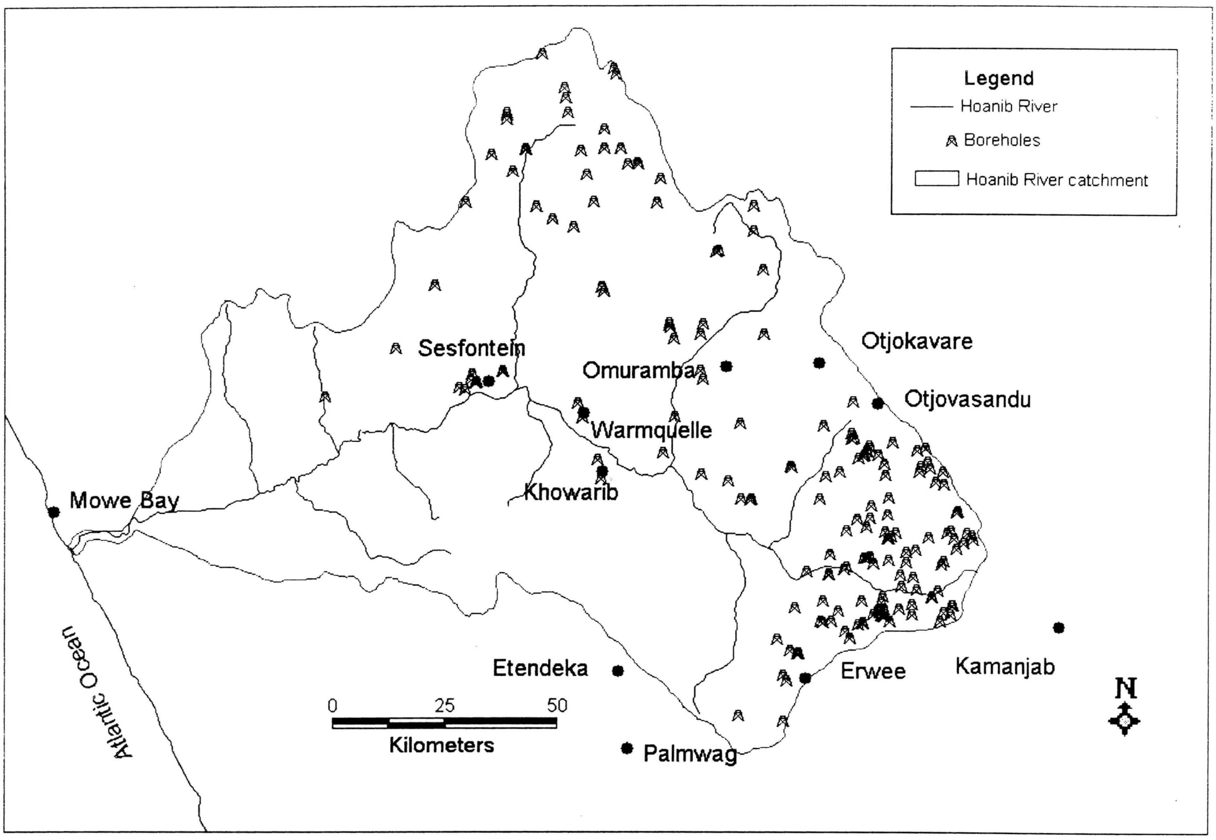

Figure 11: Location of boreholes in the Hoanib River catchment.

As can be seen from Figure 11, the boreholes are concentrated in the eastern Hoanib River catchment on freehold farmland. However, boreholes are also plentiful around the towns, villages and settlements of the western Hoanib River catchment.

WATER USE

The historical water use data for the Sesfontein basin (collected by the MAWRD 1997 study) is presented in Table 4.

Table 4: Water demand in Otjindakui, Sesfontein, Warmquelle and Khowarib in 1997

Village	Persons (20L/day)	Cattle (50L/day)	Goats (10L/day)	Sheep (10L/day)	Horses (20L/day)	Donkeys (20L/day)	Total
Otjindakui							
Number of	180	340	4095	942	0	305	
Demand (m^3/d)	3.6	17.0	40.95	9.42	0	6.10	77.07
Demand (m^3/m)	108	510	1228.5	282.6	0	183	2312.1
Sesfontein							
Number of	617	111	1857	57	7	155	
Demand (m^3/d)	12.34	5.55	18.57	0.57	0.14	3.1	40.27
Demand (m^3/m)	370.2	166.5	557.1	17.1	4.2	93.0	1208.10
Warmquelle							
Number of	601	952	3575	880	10	98	
Demand (m^3/d)	12.02	47.60	35.75	8.8	0.20	1.96	106.33
Demand (m^3/m)	360.6	1428	1072.5	264	6.0	58.8	3189.9
Khowarib							
Number of	348	496	1175	79	14	110	
Demand (m^3/d)	6.96	24.80	11.75	0.79	0.28	2.20	46.78
Demand (m^3/m)	208.8	744	352.5	23.7	8.40	66.0	1403.4

The water use data presented in Table 5 was collected during this study. It represents a combination of data collected by community, socio-economic (Fuller, 2000a and 2000b) and HRCS staff researchers during the study period.

Table 5: Water demand in Sesfontein, Warmquelle, Khowarib, Omuramba, Otjokovare and Erwee between 1998-2000

Village	Persons	Cattle	Goats	Sheep	Horses	Donkeys	Total
Sesfontein							
Litre/capita/day	60	45	12	12	30	30	
Number of	2380[a]	130	1900	60	10	160	
Demand (m^3/d)	142.80	5.85	22.8	0.72	0.30	4.80	177.27
Demand (m^3/m)	4284	175.5	684	21.6	9.0	144	5318.1
Warmquelle							
Litre/capita/day	15	45	12	12	30	30	
Number of	783	1100	3900	390	12	12	
Demand (m^3/d)	11.75	49.50	46.8	4.68	0.36	0.36	113.45
Demand (m^3/m)	352.5	1485	1404	140.4	10.80	10.80	3403.5
Khowarib							
Litre/capita/day	15	45	12	12	30	30	
Number of	236	520	1300	85	17	120	
Demand (m^3/d)	3.54	23.40	15.60	1.02	0.51	3.60	47.67
Demand (m^3/m)	106.2	702	468	30.6	15.3	108	1430.1
Omuramba							
Litre/capita/day	15	45	12	12	30	30	
Number of	360	3500	3085	220	25	120	
Demand (m^3/d)	5.40	157.5	37.02	2.64	0.75	3.6	206.91
Demand (m^3/m)	162	4725	1110.6	79.2	22.5	108	6207.3
Otjokovare							
Litre/capita/day	15	45	12	12	30	30	
Number of	350	2900	3600	450	45	120	
Demand (m^3/d)	5.25	130.5	43.2	5.40	1.35	3.6	189.3
Demand (m^3/m)	157.5	3915	1296	162	40.5	108	5679
Erwee							
Litre/capita/day	60	45	12	12	30	30	
Number of	500	700	3500	100	40	120	
Demand (m^3/d)	30.0	31.5	42.0	1.2	1.2	3.6	109.5
Demand (m^3/m)	900	945	1260	36	36	108	3285

[a] – all persons over 6 years of age

The main observed difference between the data obtained in the 1997 study and this study is the change in the human consumption associated with multiple water points. In villages where water was available to individual households (in the form of standpipes or taps), for example, Sesfontein and Erwee, far more water per head of population was used than in Warmquelle, Khowarib, Omuramba and Otjokavare where only single water points are available. Slight differences in water consumption were also observed for cattle (50L to 45L), goats and sheep (10L to 12L), horses and donkeys (20L to 30L). The water consumption figures were based on actual volumes of water measured by community researchers.

Sesfontein was the only town studied where human consumption was greater than consumption by domestic stock. There also appears to be a substantial difference in the population of Sesfontein at the time of this study and the 1997 study. It appears as though the 1997 did not include school children in the study. Sesfontein school has approximately 1000 enrolled students.

Table 6, presents the approximate water consumption catchment wide of domestic stock, wildlife and people. Number of domestic stock and wildlife number were estimated from aerial and ground by HRCS staff and community researchers, with additional data being supplied by other NGO's (SRT and IRDNC) working in the catchment area. Human population figures were obtained from Jacobson *et al.* (1995). The estimated water consumption of wildlife was based upon the data published by Auer (1997).

Table 6: Estimated water consumption of domestic stock, wildlife and people living in the Hoanib River catchment

	Approximate numbers	**Daily consumption (m^3/d)**	**Monthly consumption (m^3/m)**	**Total (m^3/m)**
People	7900			**7780**
Those with access to one water source (15L /person/day)	3130	187.8	5634	
Those with access to stand pipes (60L/person/day)	4770	71.55	2146	
Domestic stock				**22735**
Cattle (45L/animal/day)	10390	467.55	14026.5	
Goats (12L/animal/day)	18580	222.96	6688.8	
Sheep (12L/animal/day)	2497	29.96	898.8	
Horses (30L/animal/day)	169	5.07	152.1	
Donkeys (30L/animal/day)	1077	32.31	969.3	
Wildlife				**886.5**
Elephants (160L/animal/day)	70	11.20	336	
Springbok (1L/animal/day)	5000	5.00	150	
Gemsbok (1L/animal/day)	1200	1.20	36	
Hartmann's mountain zebra (10L/animal/day)	1200	12.00	360	
Giraffe (1L/animal/day)	150	0.12	4.5	

The calculations in Table 6 show that domestic stock consumed approximately three times more water than people and approximately 25 times more than wildlife in the Hoanib River catchment.

DISCUSSION

RAINFALL DATA

There was a lack of catchment-wide rainfall data both historically and gathered during this project. Traditionally, rainfall data was only gathered at government offices in towns and the data collected depended on the diligence of the local government official. Automatic rainfall stations are present in Kamanjab and Opuwo (both just outside the catchment) with manual recordings still being collected in Möwe Bay (also outside the catchment). An automatic rainfall gauge in Sesfontein has been broken since 1998 and not replaced. During this study, community researchers were given the task of collecting rainfall data. This was carried out with varying degrees of diligence and resulted in patchy catchment-wide data. Rainfall data collected by community researchers in Khowarib, Warmquelle, Otjokavare and Sesfontein were more reliable than the data collected in Erwee and Omuramba.

The rainfall data indicates that there has been an overall decrease in rainfall throughout the catchment over the last 20 years. The decrease in rainfall appears to be more substantial in the eastern section of the catchment, where the deviation from the means was greatest. This area generally receives more rainfall than any other section of the catchment and decreasing rainfall in this area has a greater effect on flood events and spring recharge. In the western section of the catchment, rainfall has only decreased marginally.

In addition, the data showed that there was a general decrease in rainfall from the eastern Hoanib catchment to the western section. This is a general phenomenon associated with the western region of Namibia. However, what is significant is the area of greatest rainfall decline. During the 1999/2000 wet season, the sharpest decline (from 310.5mm to 106.5mm) was observed from Khowarib to Sesfontein, a distance of only 20km in a straight line and 120km and 100km from the coast, respectively. A mountain range separates these two settlements and this probably influences the rainfall pattern. Warmquelle, which is only 5km further west than Khowarib, received significantly less rain than Khowarib. Again, local topographic features are thought to have influenced rainfall distribution.

The rains of the 2000 wet season were significantly higher than the long-term mean in the majority of the catchment, with only those areas closest to the coast (Möwe Bay and Sesfontein) recording average or below average rains. In the eastern catchment the 2000 wet season received the highest falls of rain since the 1977 wet season. The rains of the 1995 wet season were exceptional in the western section of the catchment from Möwe Bay to Sesfontein, but below average rainfalls were reported for the rest of the catchment. The heavy rains of the 2000 wet season occurred over large areas of the eastern catchment and produced flood events that recharged a number of springs, several of which had not flowed for several years. The rains also had a positive effect on the vegetation of the catchment and produced good growths of annual and perennial grasses, forbs, shrubs and trees (Leggett *et al.*, 2001b)

The general rains of the period 23 March – 1 April 2000 showed, that rainfall not only decreased across the catchment (occasional isolated heavy storms aside), but fell at approximately the same time throughout the catchment. The exception to this was Erwee, where a completely different rainfall pattern appeared to be operating. The rainfall pattern around Erwee is probably influenced by local topography, which is mountainous and effectively isolates this area from the rest of the catchment.

FLOOD EVENTS

Historically, flood events in the Hoanib River (measured at Sesfontein weir) have varied significantly in both duration and volume. The results indicated that the majority of flood events were relatively small, with the occasional high volume flow. In fact, 73% of the time the volume of the flood events was below average. The highest annual volume carried in the river was $32x10^6m^3$ of water in 1995 and most of this occurred in one exceptional rainfall month.

There appeared to be no relationship between the total amount of rainfall received in a year, the frequency of flood events and number of days of flooding in the river. Flood events and the number of days of flooding remains linked directly to the intensity and duration of rainfall. It appears that the early rainfall in the catchment does not generally result in flood events. In the 2000 wet season the early rains of the 1 October 1999 (17mm at Otjokavare) and 14 November 1999 (25mm at Otjokovare, 10mm at Khowarib) did not result in a flood event. However, the rains of 17^{th} November (45mm at Otjokovare, 20mm at Khowarib) resulted in a 2-day flood event (at Khowarib). A possible reason for this is that the early rains filled the pore spaces between the soil particles and sediments of the riverbeds, causing the water table to rise. Even substantial early rainfalls (>40mm) appeared not to induce long duration flood events. However, once the first floods have occurred and the water table has risen, any subsequent rainfall may not infiltrate the soil and sediments of the riverbeds to the same extent as the early rains, causing more frequent and longer duration flood events.

Later rains (occurring 30 November to 4 December 1999) produced a seven-day flood even though rainfall at both Otjokovare and Khowarib was not greater than 20mm per day (this does not account for heavy storms elsewhere in the catchment). From the data it also appears that in excess of 20mm of rainfall over a reasonably large section of the eastern catchment was required to induce a flood event. Heavy rainfall events occurring over a large area of the eastern catchment produced flood events of the longest duration.

While the number of individual flood events was lower during the 1999-2000 season than the 1998-1999 season, multiple peak floods were more numerous. This produced more days of flooding during the 1999-2000 season than during the 1998-1999 season. The flood events were of sufficient strength to fill the floodplains and force their way through the dunes near the coast, an event that has not occurred since 1995.

SPRINGS AND WETLANDS

There are several springs and wetlands in the Hoanib River catchment and most of these contain water for at least six months of the year. As with most areas in Namibia, many permanent springs and wetlands are inhabited by people and their domestic stock. This, coupled with the more recent phenomenon of uncontrolled tourism resulting in tourists camping close to springs and wetlands in the western Hoanib River catchment, has restricted the access of wildlife to natural water sources. In many areas, domestic stock and wildlife share springs and wetlands (e.g. Khowarib and Dubis) but it appears that whenever people also share the same water source, wildlife (with the exception of elephants) tend to move away or avoid the water point. The exception to this is the Khowarib wetlands where springbok and ostrich have been observed drinking in close proximity to the human settlement during the hot dry season. Wildlife was not observed drinking at these wetlands during or immediately after the wet season.

BOREHOLES

Most mortalities reported in a drought situation were not from a lack of water as there are sufficient boreholes, springs and wetlands within easy reach of most animals throughout the catchment, but rather as a result of a lack of grazing and browsing. This is true for both wildlife and domestic stock. In the 1981-82 drought, approximately 90% of the domestic stock and 80% of some wildlife species died throughout Damaraland and Kaokoland (Viljoen, 1982).

A common complaint heard from the communities living in the Hoanib River catchment was that there was no water in areas where there was grazing and no grazing where there was water (community meeting minutes are on file). Few of the communities saw the problem as a management issue but saw the solution in drilling new boreholes in areas where grazing was available. However, as sustainable rangeland management is implemented in communal areas of the Hoanib River catchment, there will be difficult decisions to make on sharing resources by the communities.

Traditionally, it was the responsibility of Department of Water Affairs (DWA) to provide water to rural communities, however, many communities have expressed concern that the DWA has not met their needs. A recent development in government policy has been that communities will need to take responsibility (though the Water Point Committees) for their own water supplies. This will mean that the communities will have to pay for the maintenance and upkeep of the boreholes and pumps. This has led to a situation where boreholes have been drilled by private individuals or by communities without consultation with the DWA and therefore resulting in the unregulated use of water.

One such case occurred in June 1998, when the Omuramba community attempted to drill for water at Ouguthia (GPS -19.62237°S, 14.10852°E) next to a seasonal pan in the southern end of the Serengeti plains. This area has no permanent springs or boreholes and consequently there is a lack of domestic stock but abundant grazing and in turn wildlife. A borehole was sunk to a depth of 75m but the subsequent water yield was insufficient and the borehole was abandoned. The good rainfalls during the 1999-2000 wet season have reduced the immediate need for a new borehole in this area, but at the onset of the next arid cycle, the pressure will return.

WATER USE

According to the MAWRD (1997) report, the current supply of water from springs and boreholes in the Sesfontein area is sufficient to meet the current needs. However, as very little is known about the recharge rates of most of the springs and boreholes in the area, concern was expressed in this study for the future supply needs of Sesfontein. The presence of schools, police stations and clinics in an area puts an added burden on the water supply and with increasing human population in the area continued water supply may not be assured. This study also raised the need for detailed water management plans to be drawn up for existing water sources and before any water development projects commence. To date this has not been completed for any community in the Sesfontein basin.

Water development projects at Erwee, Werda and Sesfontein, where standpipes have been provided to numerous locations within the villages, have led to an increased daily human consumption of water. A case study carried out in Erwee (Fuller, 2000a), showed the average consumption of water per person to be approximately 60L per day. This water consumption figure was supported by Jacobson *et al.* (1995) who reported that communities with readily available water also used approximately 60L of water daily. The average consumption per person in areas without a water development project (e.g. Warmquelle, Khowarib, Omuramba and Otjokovare) was only 15L per day. In addition, it appears that a great deal of water is lost through informal connections made by the communities to the pipelines carrying the water around the villages. Fuller (2000a) estimated the loss at Erwee to be approximately 20% of the total supply to the town. Fuller also found that an unknown number of people came from surrounding farms to fill water containers in Erwee. Large-scale extractions of this nature affect the amount and quality of water available to downstream users (Leggett *et al.*, 2001a). Indeed once-permanent wetlands downstream of the extraction points have now become seasonal wetlands. This has affected the lifestyles of the people who live immediately downstream of the extraction point, by forcing them to move their cattle over much greater areas in search of water during the hot dry season.

The current water use in all areas of the catchment did not exceed supply, especially over the duration of the study where above average rainfalls were recorded. All six of the focus communities have stated in public meetings (community meeting minutes on file) and during socio-economic studies that it was becoming increasingly difficult to supply sufficient water for human and domestic stock use from existing boreholes. In many areas, boreholes have been drilled close to natural permanent springs and wetlands. Extractions of water from these boreholes have led to the drying up or decrease in flow from these natural water sources affecting water availability for downstream users and wildlife. In several of the focus communities, the water table has dropped significantly and extensions have needed to be added to existing boreholes to maintain supply. There appeared to be reluctance amongst communities to deal with management issues and the solution most communities have offered to this problem was the drilling of additional boreholes to meet future water demand.

CONCLUSION

The annual rains in the Hoanib River catchment influence:

- the number and volume of flood events
- ecology of the river and floodplains
- discharge volumes from the springs and wetlands
- grazing and browsing availability
- seasonal movements of domestic stock and wildlife
- farming success of rural communities
- pressure from communal farmers for further boreholes

One of the biggest problems associated with water and water availability is the pressure on existing water sources to provide water for rural communities, domestic stock, wildlife and tourism. One of the most important issues still to be tackled by communities is the management of water points and land use options. Conservancies are now required by law to produce management plans for the natural resources in their areas and this should go a long way to answering some of these management questions. This should be given a priority before any additional water development projects commence in the catchment.

REFERENCES

Auer, C. (1997) *Water availability and chemical water quality as important factors for sustainable wildlife management in Etosha National Park and for domestic stock farming areas of Namibia.* Research Discussion Paper, No.26, Ministry of Environment and Tourism, Namibia.

Behnke, R. (1993) *Natural resource management in pastoral Africa.* Paper presented to the UNEP workshop on listening to the people: social aspects of dryland management, December 1993 Nairobi, Kenya.

Behnke, R.H., Scoones, I. and Kerven, C.(eds.) (1993) *Range ecology at disequilibrium: new models of natural variability and pastoral adaptation in African savannas.* ODI. IIED, Commonwealth Secretariat, London.

Dean, W.R.J., Hoffman, T.M., Meadows, M.E. and Milton S.J. (1995) "Desertification in semi-arid Karoo, South Africa: review and reassessment". *Journal of Arid Environments*, **30**: 247-264.

Estes, R.D. (1991) *The behaviour guide to African mammals.* Wake Forest Studium, USA.

Ellis, J.E. and Swift, D.M. (1988) "Stability of African pastoral ecosystems: alternative paradigms and implications for development". *Journal of Rangeland Management*, **41**: 450-459.

Forbes-Irving, T. (1996) *Managing water points and grazing areas in Namibia. The Cuvelai, Ohangwenga, Omusati, Oshana and Oshikoto regions.* Desert Research Foundation of Namibia (DRFN) and Ministry of Agriculture, Water and Rural Development, Namibia.

Fuller, B. (2000a) *Divided by history, united by water: Impacts of water development in the upper Hoanib catchment.* Unpublished report.

Fuller, B. (2000b) *Crops, livestock and tourists: Choices and options in the Hoanib river catchment.* Unpublished report.

Graf, W.I. (1988) *Fluvial processes in dry lands.* Springer-Verlag, Berlin, 346pp.

Jacobson, P.J., Jacobson, K.M. and Seely, M.K. (1995) *Ephemeral Rivers and their catchments: Sustaining people and development in western Namibia.* Desert Research Foundation of Namibia, Windhoek, Namibia.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L. and Cherry, D.S. (1999) "Transport, retension and ecological significance of woody debris within a large ephemeral river". *Journal of the North American Benthological Society*, **18**(4): 429-444.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L. and Cherry, D.S. (2000) "Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert". *Journal of Arid Environments*, **45**: 21-34.

Leggett, K.E.A., Fennessy, J. and Schneider, S. (2001a) "Water chemistry of selected wetlands and springs" in *Hoanib River Catchment Study, Northwestern Namibia: Water.* DRFN Occasional Paper No. 15. Windhoek, Namibia.

Leggett, K.E.A., Fennessy, J. and Schneider, S. (2001b) "The seasonal availability of grazing and browsing" in *Hoanib River Catchment, Northwestern Namibia: Vegetation.* DRFN Occasional Paper No. 17. Windhoek, Namibia.

Ministry of Agriculture, Water and Rural Development (1997) *Detailed land use plan for the Sesfontein constituency.* TRP Associates, Windhoek, Namibia.

Sandford, S. (1983) *Management of pastoral development in the third world.* John Wiley and Sons, Chichester.

Sikes, S.K. (1971) *Natural History of the African Elephant.* Eidenfeld and Nicholson, London.

Sullivan, S. (1996) "Towards a non-equilibrium ecology: perspectives from an arid land". *Journal of Biogeography*, **23**: 1-5.

Sullivan, S. (1999) "The impacts of people and livestock on topographically diverse open wood- and shrub-lands in arid north-west Namibia". *Global Ecology and Biography letters, Special issue on degradation in open woodlands*, **8**: 257-277.

Tyson, P.D. (1986) *Climate change and variability in southern Africa.* Oxford University Press, Cape Town.

Viljoen, P.J. (1982) "The distribution and population status of the larger mammals in Kaokoland, South West Africa/Namibia". *Cimbabesia*, **7**: 5-33.

Warren, A. and Khogali, M. (1992) *Assessment of desertification and drought in the Sun-dano-Sahelian Region 1985-1991.* United Nations Sudano-Sahelian Office, New York.

Ward, V. and Forbes-Irving, T. (1999) *Managing water points and grazing areas in Namibia: Southern Kunene.* Desert Research Foundation of Namibia and Ministry of Agriculture, Water and Rural Development, Namibia.

APPENDIX A

(Springs and wetlands in the Hoanib River Catchment)

Table A1: Location and the name of known springs and wetlands in the Hoanib River catchment

Springs					
Herero	**Damara/other names**	**Comments**	**Latitude**	**Longitude**	**Place**
Okombako		spring	-18.5257	14.02724	
Okozonduno		spring	-18.53798	14.03598	Kh
Otjihorongo		spring	-18.53869	14.0536	
Okapanda		spring	-18.54592	13.57863	
Okakuju		spring	-18.56426	13.58109	
Otjetjekwa		spring	-18.798	14.398	
Okauuore		spring	-18.84321	13.89461	
Okomutati		spring	-18.8662	14.34518	
Okarivizu		spring	-18.87943	14.01737	
Oruvandjei		spring	-18.91709	14.10673	
Okerada		spring	-18.97497	13.96147	
Okomupia		spring	-18.99868	13.9333	
Okomuhona		spring	-19.02066	14.17153	
Ojiheke		spring	-19.03739	13.75679	W
Otjontunda		spring	-19.0429	13.74302	W
Otjindakui-1		spring	-19.05146	13.44622	S
Otjokavare		spring	-19.06441	14.34748	K
Okapiku		spring	-19.06534	14.3459	S
Okarui		spring	-19.069	14.34	S
Otjipoko west		spring	-19.07	14.341	Om
Otjipoko east		spring	-19.071	14.342	Om
Anabeb		spring	-19.07627	13.43892	Om
Okatambi		spring	-19.07759	13.3499	Om
Ongongo		spring	-19.08355	13.49359	Om
Okomauwa		spring	-19.11167	13.73688	Om
Onguta		spring	-19.11597	14.1655	Om
Okoumbara		spring	-19.1165	13.96934	Om
Orupara		spring	-19.1165	13.96934	Om
	Sesfontein-1	spring	-19.11885	13.61984	S
	Sesfontein-2	spring	-19.11982	13.61187	S
	Sesfontein-3	spring	-19.11996	13.61166	S
	Sesfontein-4	spring	-19.12355	13.61882	S
Omutirapo		spring	-19.12367	13.93877	Om
	Sesfontein-5	spring	-19.1242	13.6191	S
Orondjombo	/Kharib	spring	-19.12978	13.2728	Om

Omaruru	/Aub	spring	-19.13095	13.32492	Kh
Otjindakui-2		spring	-19.13139	13.58901	S
Eorongava		spring	-19.13139	13.82051	
Ongongo-1		spring	-19.13207	13.82105	W
Otjipawe		spring	-19.135	14.352	W
Ongongo-3		spring	-19.13926	13.82266	W
Ongongo-2		spring	-19.13985	13.81983	W
Okondara		spring	-19.14331	13.82214	W
	Warmquelle-1	spring	-19.14944	13.82168	W
Otjomumborombonga		spring	-19.1628	14.33526	
	Warmquelle-2	spring	-19.16404	13.8138	W
Okoruhama		spring	-19.16414	13.81303	Om
Okatootoo		spring	-19.1702	13.8443	Om
	Warmquelle-3	spring	-19.17026	13.81398	W
	Warmquelle-4	spring	-19.17269	13.8153	W
Okondjou		spring	-19.17289	13.82231	Om
Omuhepue		spring	-19.173	14.357	W
Okorusu		spring	-19.1731	13.81541	W
Okandjou		spring	-19.17315	13.22489	W
	Warmquelle-5	spring	-19.17396	13.81593	W
	Warmquelle-6	spring	-19.18018	13.81742	W
Okaruikapiet	Warmbron	spring	-19.1806	13.81753	
	Warmquelle-7	spring	-19.18285	13.81724	W
	Warmquelle-8	spring	-19.18444	13.8177	W
Otjotuwe		spring	-19.201	14.357	W
Otjatjondjira	Sosos 2	spring	-19.20139	13.43893	W
Omisemayakaungu		spring	-19.21484	13.42763	S
Orondjombo		spring	-19.2163	13.45468	S
Eo rakaripo		spring	-19.276	14.338	K
Okaupehuri		spring	-19.27994	13.5418	S
Otjondumbu	/U #Nab	spring	-19.2913	13.53996	K
Okamborombonga	Tsauidis	spring	-19.31641	13.47435	W
Omburu	!Adais	spring	-19.32211	13.46546	Kh
Okongava	Aniba-#Nams	spring	-19.32598	13.49426	W
Okaruikavita	/Gamab-//Gam	spring	-19.33391	13.55296	
Oruvao		spring	-19.39922	13.63956	S
Okanaandjoze		spring	-19.502	13.625	
Okomimunu		spring	-19.52223	13.95866	
Otjiperongo		spring	-19.54144	13.88029	

Okamumu		spring	-19.55593	13.8612	Kh
Otjomenje		spring	-19.57065	13.91421	Om
Okomumdu		spring	-19.5861	14.3368	W
Omauua	Gomaku-/Aus	spring	-19.60582	13.87236	OK
Otjomumbonde		spring	-19.71839	14.13297	OK
Wetlands					
	Palmfontein middle	wetland	-19.65547	14.22954	OK
	Palmfontein upper	wetland	-19.65467	14.25043	OK
	Palmfontein lower	wetland	-19.65238	14.22279	OK
	Auses	wetland	-19.40329	12.89008	W
	Khowarib upper	wetland	-19.30802	13.95203	W
	Khowarib middle	wetland	-19.2996	13.92502	W
	Khowarib lower	wetland	-19.26705	13.89082	W
	Dubis ghoras	wetland	-19.22703	13.39094	W
	Lower Dubis	wetland	-19.22356	13.41056	K
	Dubis	wetland	-19.2162	13.45397	W
	Middle Dubis	wetland	-19.21134	13.44742	W
Other natural water sources					
Okambuku		pan	-18755	14.43	OK
		pan	-19.453	14.272	OK
Erindi otjitakana		pan	-19.44	14.257	OK
Okatupasa utto		pan	-19.421	14.304	OK
Orunguru		pan	-19.305	14.289	OK
Oromhaua		pan	-18.987	14.373	OK
Okozongumbati		pan	-18.977	14.378	OK
		pan	-18.942	14.322	OK
Erindi rongava		pan	-18.818	14.386	OK
Onaiso		pan	-18.818	14.614	OK
		pan	-18.804	14.405	OK
Erindi romurumena		pan	-18.792	14.341	OK
Ropokati		pan	-18.786	14.418	OK
Okatjetjekona		pan	-18.783	14.423	OK
Omumborombonga		pan	-18.766	14.426	OK
Omao	Sosos 1	Sossus rainwater	-19.33208	13.73219	K
Ohungujonukvena		Ground Dam	-19.14006	14.0266	
Ouguthia		pan	-19.62237	14.10852	Om

[1] Data presented in this table is a compilation of data collected by this project, community researchers, SRT, IRDNC, game guards and MAWRD (1997) report.

APPENDIX B

(Location of boreholes in the Hoanib River Catchment)

Table B1: Location, number and the year of drilling of boreholes in the Hoanib River catchment

Topographic map reference	Borehole number	Depth of borehole	Year borehole was commissioned	Latitude	Longitude
1813BD	WW3706	91.5	1953	-18.4721	13.905
1813BD	WW3785	60.4	1953	-18.4829	13.9096
1813DB	WW3798	64	1953	-18.751	13.9976
1814CC	WW3760	107.9	1953	-18.7572	14.2031
1914BC		23	1953	-19.3019	14.5779
1914AD		78	1953	-19.4438	14.4969
1914BC	WW3978	23.2	1953	-19.4708	14.5479
1914BC	WW4094	46	1954	-19.4307	14.6245
1914AD	WW4244	56.7	1954	-19.4478	14.4917
1914DA		39	1954	-19.5714	14.5841
1914AD	WW4377	72.2	1955	-19.4804	14.3679
1914CB	WW4245	49.1	1955	-19.5226	14.366
1914DA		40	1955	-19.5476	14.5184
1914DA		38	1955	-19.6003	14.6082
1914AD	WW4666	24.1	1956	-19.3189	14.3583
1914BC	WW4881	144	1956	-19.4449	14.5767
1914DA	WW4676	42.7	1956	-19.5568	14.5961
1914DA	WW4582	137.2	1956	-19.5875	14.6269
1914DA	WW4536	52	1956	-19.6195	14.6004
1914BC		35	1957	-19.299	14.5581
1914BC		37	1957	-19.3299	14.5905
1914AD	WW5221	61.6	1957	-19.3659	14.3455
1914AD	WW5213	40.8	1957	-19.4062	14.4515
1914DA	WW5228	60	1957	-19.524	14.5155
1914DA	WW5181	61	1957	-19.5877	14.6295
1914CB	WW5212	80.2	1957	-19.7316	14.269
1914CB	WW5210	87.8	1957	-19.743	14.2763
1914AA	WW5256	86	1958	-19.0026	14.0972
1914AA	WW6235	61	1958	-19.0235	14.0909
1914AA	WW5253	48	1958	-19.0324	14.0332
1913AB	WW6236	113	1958	-19.051	13.4461
1914AD	WW4408	34.1	1958	-19.3101	14.3885
1914AD	WW5229	50.3	1958	-19.3798	14.4541

1914DA		30	1958	-19.585	14.5411
1914CB		81	1958	-19.6014	14.4755
1914DA		73	1958	-19.6051	14.5405
1813DB	WW5275	125	1959	-18.5318	13.803
1813DB	WW5276	63	1959	-18.5621	13.8078
1914BC	WW6772	27	1959	-19.2654	14.5516
1914CB	WW6219	70.7	1959	-19.5165	14.3169
1914CB	WW6209	67.1	1959	-19.52	14.3644
1914DA		33	1959	-19.5685	14.5835
1914AD	WW6319	59.1	1960	-19.499	14.4606
1914AB		0	1961	-19.1646	14.4139
1914AD	WW6445	91.4	1961	-19.4084	14.4236
1813DA	WW6466	24.4	1962	-18.5671	13.6778
1813DB	WW6465	94	1962	-18.5984	13.8843
1813DB	WW6463	30.5	1962	-18.6925	13.8489
1813DB	WW6464	39	1962	-18.7495	13.8634
1813DD	WW6462	18.3	1962	-18.9254	13.8803
1813DD	WW6461	167.7	1962	-18.9331	13.8855
1914BC		24	1963	-19.3364	14.6079
1813DA	WW8233	47	1964	-18.5634	13.6788
1813DA	WW8236	107	1964	-18.6387	13.7181
1914BC		43	1966	-19.2609	14.57
1914BC		30	1966	-19.2874	14.5728
1914BC		61	1966	-19.3103	14.5572
1914AD		26	1967	-19.4352	14.48371
1914DA		37	1967	-19.5949	14.5135
1914BC		46	1968	-19.4973	14.5279
1813DB	WW9901	70	1969	-18.6695	13.9559
1813DB	WW9877	78	1969	-18.6704	13.9564
1813DB	WW9902	73	1969	-18.6711	13.9573
1914DA	WW13061	77.1	1969	-19.5537	14.552
1914AC	WW10613	90	1970	-19.3278	14.1515
1914BC	WW13065	49	1970	-19.4357	14.6169
1914BC		85	1970	-19.4682	14.6371
1914AD	WW9440	50	1971	-19.3163	14.4849
1914BC	WW13064	104	1971	-19.4479	14.6317
1914BC		55	1971	-19.4953	14.6088
1914CB	WW11586	83.1	1971	-19.6223	14.4369
1914CB	WW12912	61.3	1971	-19.6228	14.4365

1914CB	WW12925	71.7	1971	-19.6233	14.4362
1914CB	WW11587	60.4	1971	-19.6415	14.4009
1813DB	WW16377	102	1972	-18.5108	13.801
1813DB	WW16371	102	1972	-18.6387	13.921
1813DB	WW16370	52	1972	-18.6429	13.8384
1914AA	WW16345	105	1972	-19.0095	14.0258
1914AB	WW16346	55	1972	-19.2491	14.499
1914AD	WW16016	60	1972	-19.2752	14.4683
1914AC	WW16344	102	1972	-19.3155	14.0941
1914CB	WW12874	79	1972	-19.6263	14.4273
1914DA		0	1973	-19.6047	14.6236
1813DA	WW16713	93	1974	-18.5779	13.6784
1813DA	WW16724	90	1974	-18.6416	13.7175
1914AA	WW16707	84	1974	-19.1949	14.0363
1914AC	WW16706	76	1974	-19.2697	14.0117
1914DA	WW17966	91.7	1974	-19.5031	14.6045
1914DA	WW17967	67.1	1974	-19.5277	14.5448
1914AA	WW21411B	80	1975	-19.0007	14.0234
1914AA	WW21411	80	1975	-19.0053	14.0237
1914AA	WW21412	80	1975	-19.1168	14.0968
1913AB	WW5234	61	1975	-19.1533	13.2971
1914AC	WW21413	30	1975	-19.3667	14.1998
1914AC	WW21413B	80	1975	-19.3677	14.1994
1914CB	WW21303	106	1975	-19.5923	14.2917
1914CB	WW21304	72	1975	-19.5976	14.3856
1914BC	WW18724A	78	1976	-19.436	14.6595
1914BC	WW18724B	54.9	1976	-19.4418	14.669
1914AB	WW3733	27.7	1977	-19.241	14.4118
1914AD		33	1977	-19.4485	14.44889
1914CB	WW22050	96	1977	-19.5072	14.4021
1914CB	WW22051	100	1977	-19.6229	14.3526
1813BD	WW23345	121	1978	-18.4419	13.7543
1813DB	WW23342	103	1978	-18.639	13.8852
1813DA	WW22669	130	1978	-18.6499	13.6456
1813DA	WW22668	113	1978	-18.6853	13.6921
1813DA	WW23344	103	1978	-18.7483	13.5923
1813DD	WW23341C	125	1978	-18.7829	13.776
1813DD	WW23341B	15	1978	-18.7997	13.8212
1813DD	WW23341A	84	1978	-18.8011	13.82

1814CC	WW22856	72	1978	-18.8104	14.2026
1814CC	WW22857	90	1978	-18.8497	14.129
1814CC	WW23161	85	1978	-18.8512	14.1247
1914AA	WW22855	91	1978	-19.0239	14.2248
1914AA	WW22854	121	1978	-19.1165	14.0957
1914AA	WW22851	110	1978	-19.2082	14.1768
1914AD	WW22852	110	1978	-19.2988	14.2836
1914AD	WW23166	120	1978	-19.2996	14.2853
1914AC	WW22853	109	1978	-19.3655	14.1793
1914AD	WW23326	44	1978	-19.4245	14.4438
1914AD	WW23327	60	1978	-19.4324	14.4029
1914BC	WW23028	32	1978	-19.4374	14.5068
1914BC	WW23027	43	1978	-19.4755	14.529
1914AD	WW23435	80	1978	-19.488	14.4404
1914AD	WW13026	41	1978	-19.492	14.4913
1914CB	WW23434	68	1978	-19.5112	14.3967
1914CB	WW23322	80	1978	-19.5673	14.4801
1914CB	WW22773	60	1978	-19.5806	14.4779
1914CB	WW22771	90	1978	-19.5926	14.4821
1914CB	WW22662	85	1978	-19.5946	14.4712
1914CB	WW22663	73	1978	-19.5951	14.4709
1914CB	WW22774	62	1978	-19.5954	14.4696
1914CB	WW22648	85	1978	-19.5967	14.4736
1914CB	WW23319	80	1978	-19.6045	14.4785
1914CB	WW23318	80	1978	-19.606	14.4788
1914CB	WW22664	100	1978	-19.6061	14.4775
1914CB	WW22771	70	1978	-19.6065	14.4837
1914CB	WW22772	75	1978	-19.6074	14.477
1914CB	WW22795	47	1978	-19.6091	14.4827
1914CB	WW22793	80	1978	-19.611	14.483
1914CB	WW22794	59	1978	-19.6189	14.4932
1914CB	WW23203	40	1978	-19.6191	14.3485
1914CB	WW22649	80	1978	-19.6198	14.37
1814CA	WW23343	120	1979	-18.7026	14.0047
1913BA	WW24660	35	1979	-19.1211	13.6149
1913BA	WW24992	56	1979	-19.1211	13.6157
1913BA	24993	48	1979	-19.1215	13.6164
1913BA	WW24994	36	1979	-19.1247	13.614
1914AD	WW24631	66	1979	-19.4864	14.4508

1914AD	WW24821	90	1979	-19.4872	14.4444
1914AD	WW23437	75	1979	-19.4891	14.4468
1914CD	WW24577	42	1979	-19.8285	14.269
1914CB	WW25780	58	1981	-19.6569	14.2548
1914CB	WW25781	54	1981	-19.6806	14.2818
1914CB	WW24984	88	1981	-19.6864	14.2992
1914CB	WW24985	63.8	1981	-19.687	14.2996
1914CB	WW24983	70	1981	-19.687	14.2988
1913BA	WW25814	174	1983	-19.1335	13.58
1913BA	WW25815	122.5	1983	-19.139	13.5918
1914CB	WW27959	96	1983	-19.5778	14.4335
1914AB	WW27743	114	1984	-19.2301	14.4116
1914AB	WW26957	66	1984	-19.2403	14.417
1813DB	WW28599	112	1985	-18.6722	13.9356
1913BA	WW28294	100	1985	-19.0981	13.6726
1913BA	WW28293	100	1985	-19.1007	13.6726
1914BC	WW29401	43	1986	-19.3088	14.6074
1914BC	WW29216	40	1986	-19.3928	14.6373
1914BC	WW29211	40	1986	-19.3931	14.6358
1914AD	WW30238	74	1988	-19.2558	14.4493
1914AD	WW30249	85	1988	-19.2558	14.4483
1914AD	WW30253	74	1988	-19.2597	14.4517
1914AD	WW30256	53	1988	-19.2648	14.4456
1914AD	WW30241	90	1988	-19.2656	14.4453
1914AD	WW30250	75	1988	-19.2663	14.4457
1914AD	WW30248	79	1988	-19.2741	14.4396
1914AD	WW30236	81	1988	-19.2744	14.4405
1914AD	WW30235	67	1988	-19.2747	14.44
1914AD	WW30240	72	1988	-19.275	14.4696
1914AD	WW30239	72	1988	-19.2755	14.4686
1914AD	WW30237	61	1988	-19.2763	14.4373
1914AD	WW30243	49	1988	-19.2812	14.4262
1914AD	WW30254	73	1988	-19.2922	14.4817
1914AD	WW30251	74	1988	-19.3157	14.4839
1914AD	WW30252	73	1988	-19.316	14.4845
1914AD	WW30255	49	1988	-19.3641	14.493
1914AD	WW30258	49	1988	-19.3992	14.49
1914BC	WW30992	122	1988	-19.4517	14.6714
1914BC	WW30999	122	1988	-19.4579	14.6509

1917AB	WW30892	102	1989	-19.2139	14.3519
1914CB	WW31842	57	1989	-19.5775	14.3518
1914CB	WW30095	80	1989	-19.6053	14.4602
1914CB	WW30839	50	1989	-19.655	14.4087
1914CC	WW31848	30	1989	-19.8179	14.1745
1913BA	WW31879	75	1990	-19.1063	13.6068
1913BA	WW31880	76	1990	-19.1167	13.6039
1813DC	WW33961	58	1993	-18.759	13.7402
1814CC	WW33968	109	1993	-18.8898	14.2245
1813DC	WW33974	120	1993	-18.92	13.5274
1914AA	WW33970	76	1993	-19.0994	14.0912

[1] Borehole data supplied by the Department of Water Affairs, Windhoek