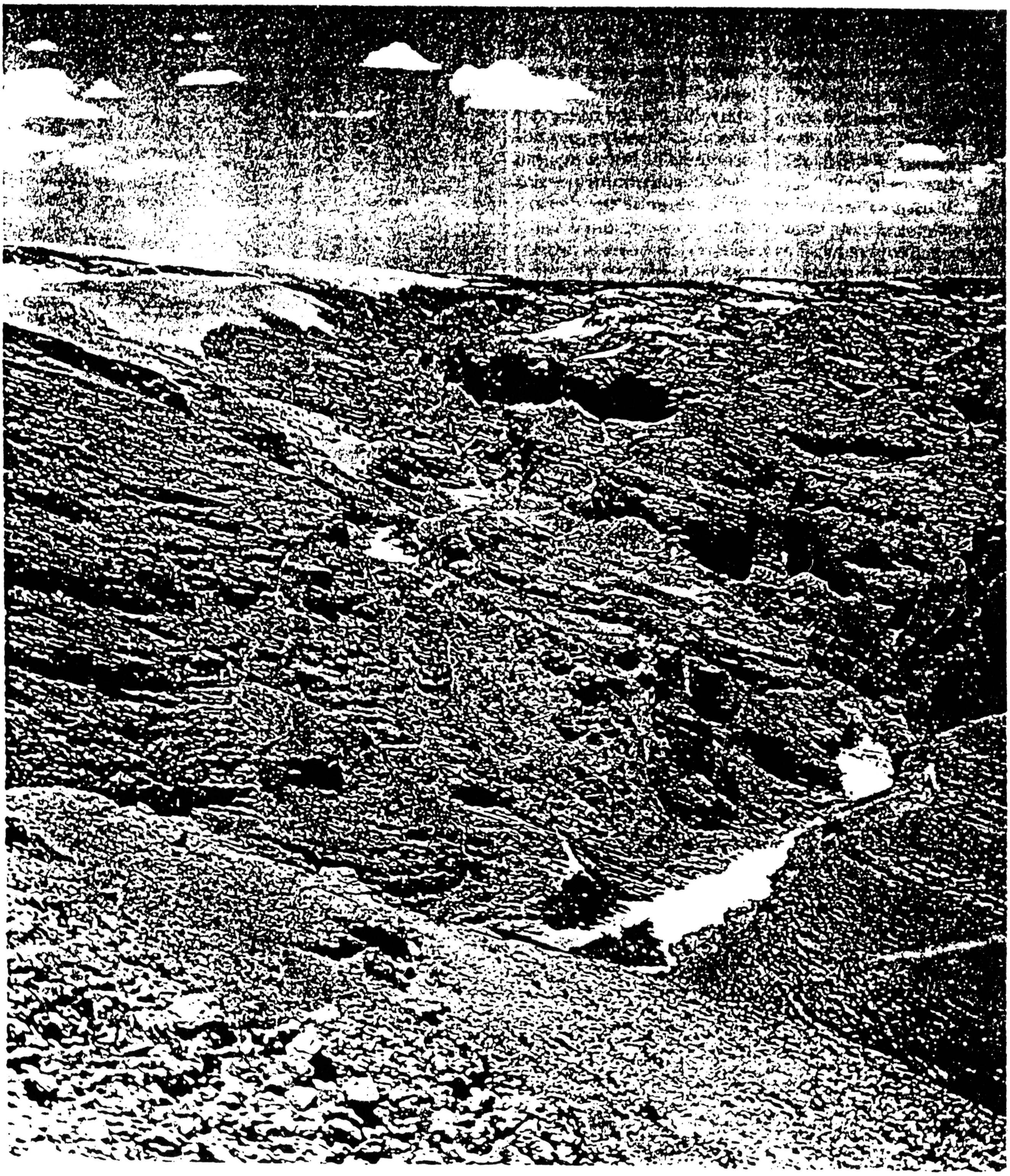
WATER IN THE DESERT SANDS

Piet Heyns



The Namib Desert is located within a narrow strip of land on the south-western coast of Africa and stretches over a distance of 1 800 km approximately from the harbour of Namibe in Angola to the mouth of the Olifants River in the Republic of South Africa. Nowhere is the desert more than some 150 km wide, lying between the South Atlantic Ocean in the west and the Great Escarpment leading to the central highlands of Southern Africa on the eastern side. The total area of the Namib in Namibia is about 130 000 km² (see Map 1).

The whole desert landscape with its dry river-beds and windswept dunes appears to be a waterless waste. Although the word *namib* (see footnote) means "place where there is nothing", closer examination reveals that this is not really the case. In spite of the arid conditions there is a relative abundance of plants, birds, reptiles, insects and other animals, whose very survival is made possible by the occurrence and availability of one of the most vital life-supporting resources in nature — water.

The Namib receives very little rain, but is often covered by a shroud of fog, which introduces moisture to the coastal belt. There are also a few places with some open water, the most significant of these being the two perennial rivers, the Cunene and the Orange, which cross the desert on the northern and southern borders of Namibia.

Since the appearance of man, the location, availability, quantity and quality of water has dictated to a very large extent where people could live. While there are areas in the world with a huge surplus of water, there are also those regions like the Namib with marginal supplies, but which contain vast natural resources and thus attract human habitation and socio-economic development.

The white, dry bed of the Kuiseb River winds through the Kuiseb Canyon, left, as it crosses the Namib Desert on its way to the Atlantic Ocean.
Picture: Clive Cowley

One of these natural resources is the fresh water available from water-bearing alluvial aquifers in the normally dry river-courses running from the interior of the country to the sea. For many millions of years these very significant water resources of the Namib were unknown to man, except for a few brackish springs which could be utilized to quench the thirst of the occasional visitor.

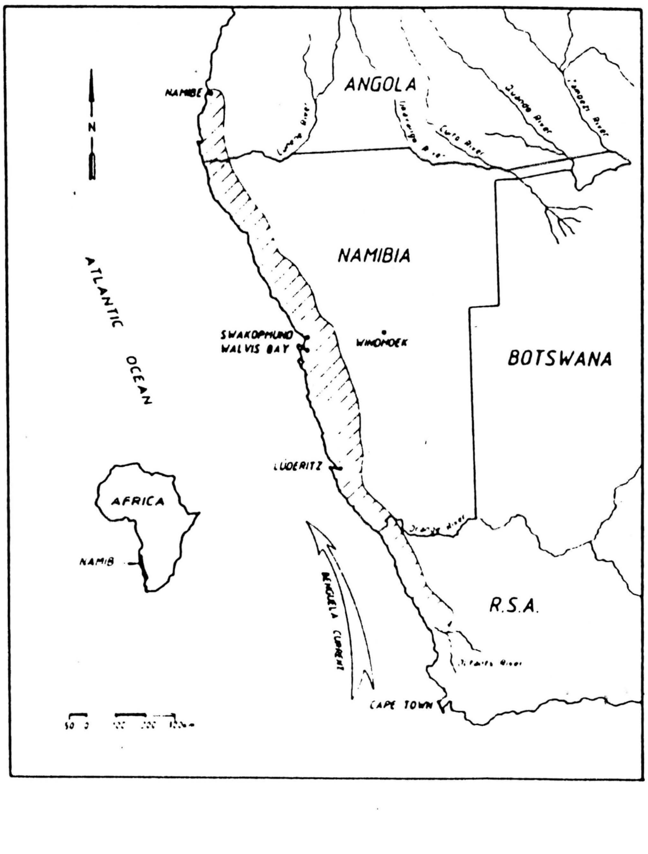
The Namib is a desirable place to live and the challenge to provide enough water of acceptable quality to sustain development has hitherto been met despite the dearth of open waters. Over the years man has mastered the techniques of harnessing water resources in areas where they occur in greater quantity and transporting them economically over long distances to sustain human, industrial and agricultural activities in places where, due to an absence of water, settlement would otherwise not have been possible. Human ingenuity to locate, tap and distribute potable groundwater from alluvial aquifers in the Namib to centres of development such as Swakopmund, Walvis Bay, Lüderitz, Oranjemund, Uis and Arandis has underpinned mining, fishing, tourism and other industries in the desert.

All this development has posed considerable challenges for the conservation and protection of the environment through comprehensive management strategies, whether in the field of mining, industry, nature conservation, urban development or utilization of water resources.

CLIMATE AND WATER RESOURCES

The water resources of the Namib are fog, rainfall, surface water run-off, groundwater and sea water, not necessarily named in order of priority, because of differences in their application and importance. However, the origin of all water in the desert is some form of precipitation and the occurrence of this vital resource is determined by important geographical factors such as climate, hydrology, topography, geology and hydrogeology.

MAP 1: LOCATION OF THE NAMIB DESERT



The climatic conditions along the west coast of Southern Africa are determined by the relative position and strength of the dry, anti-cyclonic Atlantic high pressure system in the west and the humid, cyclonic Indian Ocean high pressure system in the east, as well as the cold Benguela Current which flows from south to north off the west coast.

Summer rainfall occurs in the Namib, but the southern tip of the desert also experiences winter rainfall. In summer the rain is caused by the humid air of the Indian Ocean high pressure system moving in from the north-east, although the air mass has lost most of its moisture by the time that it reaches Namibia. Winter rains only occur if the South Atlantic low pressure system is strong enough to convey the moist air as far north as the southern extremity of the Namib. In view of these adverse conditions, both summer and winter rainfall are very low. The annual precipitation varies on average between a little more than zero at the coast to 100 mm along the eastern escarpment. Rainfall is also extremely erratic and the average deviation from the annual average varies between 50 percent to more than 80 percent.

The surface runoff in the rivers at the coast usually originates in areas of higher rainfall in the central highlands. The rainfall which occurs between October and April in the interior of the country provides the runoff which recharges the alluvial aquifers in the large rivers flowing to the Atlantic.

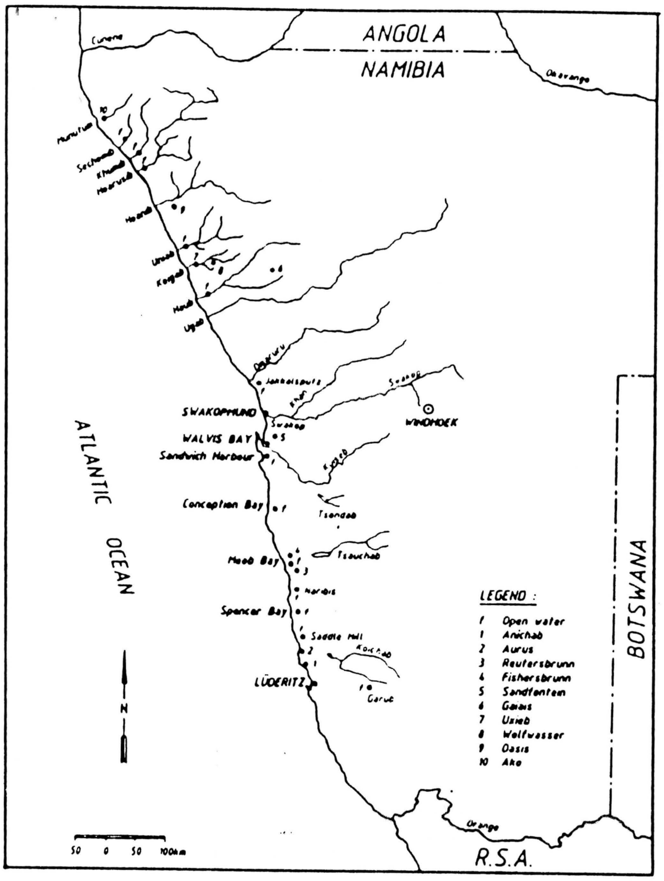
These rivers are called ephemeral because they are normally dry and only run when and if it rains enough. If the intensity of the rainstorms is too low there is either no runoff or rivers flow for only a certain distance before all the water is absorbed into the sand. High intensity rainstorms in the desert can cause flash floods which damage water-supply infrastructure and other installations.

Groundwater in the Namib rarely occurs as springs. Normally abstracted by means of wells and boreholes, it is at present the most important water resource which can be utilized economically to support urban, industrial and mining development along the coast and in the desert.

In the coastal zone the air mass directly above the cold sea is cool, but overlain by a warmer and drier mass of air, resulting in an almost permanent temperature inversion. The relative humidity is usually higher than 80 percent. All these conditions favour the formation of fog or low stratus clouds, but prevent cloud development for rainfall. There is a slightly higher occurrence of fog during winter than in summer.

Fog is an indispensable natural phenomenon because it is a vital water resource for the fauna and flora of the Namib. It can be expected between 90 and 150 days per annum, or on average eight to 12 days per month, and extends inland for 10 to 60 km from the coast. It is most dense at elevations of between 300 and 600 m above mean sea level. The fog condenses into droplets of water on rocks, plants and insects, providing a source of water which supports life in an area which is seemingly waterless. It is estimated that the condensed fog is equivalent to an average annual rainfall of about 45 mm. The relatively high humidity also provides moisture for certain plants like lichens.

MAP 2: RIVERS OF THE NAMIB



Although fog is an important water source for the natural environment, it is insignificant as a resource to sustain socio-economic development. Attempts have been made to harvest fog, but have failed to provide large quantities of water. On the coast there is mostly a cool zone due to fog, but in the interior the fog which forms overnight, is burnt away by the sun, normally by noon. Such fluctuations in temperature and humidly are most pronounced 30 to 60 km from the coast. The average daily maximum temperature for the hottest month, usually January or February, varies between less than 31°C at the coast and 34°C in the Namib interior. The average daily minimum temperature for the coldest month, mostly August, is rarely less than 7°C. The absolute minimum and maximum temperatures, as measured at Lüderitz, vary between 0°C and 40°C.

The average annual evaporation, affected by seasonal variations in wind, temperature, humidity and rainfall, varies between 3 400 mm in the central Namib and 2 600 mm in the southern and northern Namib.

The wind along the coast blows mostly from the south and south-west at an average speed of up to 30 km/h or more at places like Lüderitz. The direction of the wind plays an important role in blowing coastal fog further inland. At times a berg or east wind, similar to the *föhn* in southern Europe, blows from the interior to the coast and causes very high temperatures, extremely dry conditions and sandstorms. These very uncomfortable conditions are also referred to locally as *oosweer*.

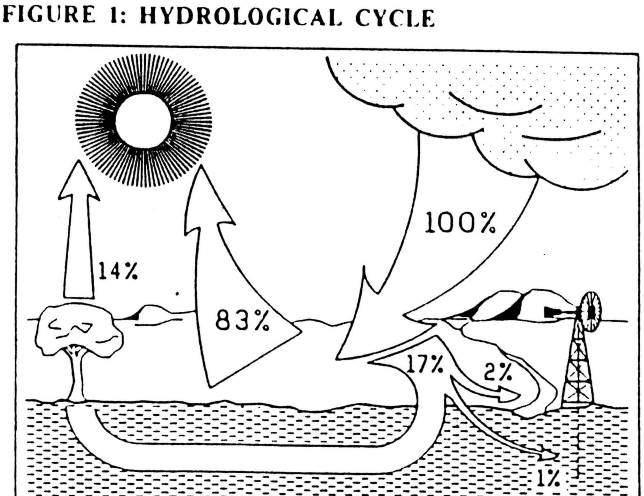
All these factors contribute to the climatic extremes and aridity of the Namib environment.

Although the limitless quantity of sea water is not normally viewed as a resource, being too salty for human consumption, it is indeed a water resource which could be used directly in some industrial processes, making it possible to conserve fresh-water reserves, or it can be desalinated to provide potable water.

HYDROLOGY AND HYDROGEOLOGY

When taking the climatic conditions in Namibia into consideration, the hydrological cycle is extremely unfavourable, as reflected schematically in Figure 1. The usual situation is that 83 percent of all rainfall evaporates virtually immediately, while only 17 percent remains as surface runoff, with about 14 percent infiltrating the soil where it is utilized by the vegetation. Of the remaining

FIGURE 1: HYDROLOGICAL CYCLE

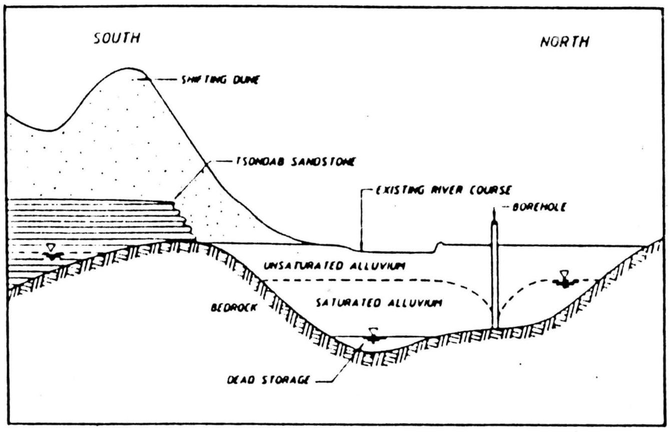


3 percent of the surface runoff, two-thirds can be impounded in dams and only one-third recharges aquifers. It is therefore important to build dams to intercept surface runoff and to drill boreholes in groundwater aquifers in order to develop available water resources.

In view of the fact that the surface runoff and groundwater aquifers in the ephemeral rivers of the Namib are at present the only economically viable sources of water along the coast, it is of critical importance to study the hydrology and hydrogeology of the resources to determine their magnitude and long-term sustainable yield.

The water-courses crossing the Namib from east to west can be divided into two major groups. They are the perennial rivers and the ephemeral rivers. The latter can be subdivided into those occasionally breaking through to the Atlantic Ocean and those that never reach the sea (see Map 2 for orientation). The most important information available on the rivers is shown in Table 1. The hydrological characteristics of all the rivers have been measured or calculated and through continuous monitoring the data base is improved to facilitate better estimates of flood frequency and mean annual runoff.

FIGURE 2: TYPICAL ALLUVIAL AQUIFER



The combination of a small catchment area and adverse climatic conditions like low rainfall, high temperatures and high evaporation rates are the main causes of the low flood frequency and relatively small mean annual runoff.

The reason why the Cunene and Orange rivers on the northern and southern borders of Namibia are perennial, is because they have very large catchment areas which are located in relatively high rainfall areas in Angola and South Africa. In comparison, the Ugab River, which has the largest catchment of the ephemeral rivers in the table, has only 37 percent of the catchment of the Cunene River. The Ugab has a mean annual runoff of only 8 Mm³ (Million cubic metres) compared to the 5 500 Mm³ of the Cunene and reaches the sea only once every two years. Namibia is therefore regarded as an arid region without any perennial rivers in the interior of the country. It also explains why some rivers are completely landlocked or smothered by the sands of the Namid Desert.

The bedrock underlying the Namib mainly comprises the late Precambrian successions and orogenic belts of the sedimentary Damara Sequence which was laid down in a shallow sea some 750 million to 620 million years ago and later extensively metamorphosed. The rocks comprise impermeable granite, gneiss, schist and quartzite. The origin of the present features of the Namib can possibly be traced back to the breaking up of the ancient Gondwanaland 200 million to 75 million years ago. This was followed by a number of ice-ages which lasted for 60 million years and persisted until about 10 000 years ago.

With the lowering of temperatures, more water froze on the high mountains and the polar ice-caps. This reduced the level of the oceans by more than 100 m and exposed up to 80 km of the western continental coastline. In the periods between the ice-ages, temperatures rose, the ice melted and sea levels at times rose even higher than the existing mean sea level.

The present Namib landscape gradually rises from sea level to about 1 000 m at the eastern escarpment. However, a combination of the formation of glaciers creeping down the mountains, techtonic activity and ancient rivers flowing during the wetter periods had a huge effect on the coastal and riverine topography. Deep valleys were carved into the bedrock and subsequently filled with alluvial deposits comprising calcareous cemented sands, conglomerates and sands as well as layers of clay and silt.

The littoral sediment transport action of the Benguela Current, which was fully developed some five million years ago, also made a contribution to the formation of the tertiary-aged Tsondab Sandstone Formation and the more recent dune sea, both overlaying the bedrock between Lüderitz and the Kuiseb River.

The alluvial deposits in the river-beds and other water-bearing formations are usually partially saturated with water. These geological features are the most important sources of groundwater in the Namib. Figure 2 shows a typical section through an alluvial aquifer adjacent to a sandstone acquifer, as found in the Lower Kuiseb.

The hydrogeological balance in an aquifer must be studied and analyzed very carefully to determine the long-term sustainable safe yield because a groundwater resource cannot supply more water than the quantity replaced by nature. This is done by developing a hydrogeological groundwater model as shown in Figure 3.

The total volume of the aquifer in Figure 3 is 1 000 Mm³, but the sand in an alluvial aquifer is usually saturated with water only to a certain level. The water level shown in the borehole is at 80 m and the volume of saturated sand is therefore only 800 Mm³. The volume of saturated sand contains a

TABLE 1: RIVERS OF THE NAMIB

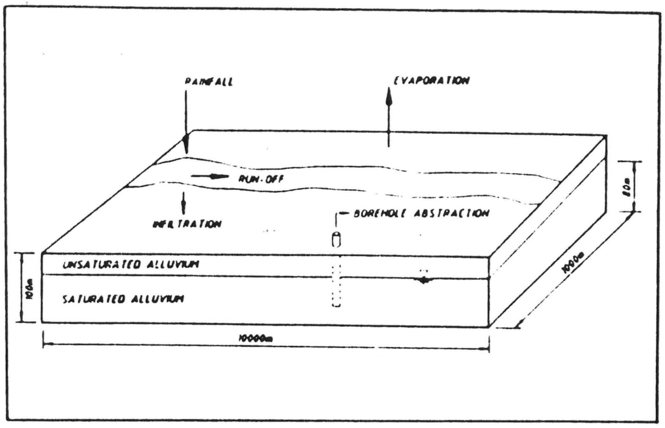
Type	Name of river	Length (km)	Catchment (km²)	Frequency of flood (years)	Mean annual runoff (Mm³/a)*
Perennial	Cunene	1 050	106 500	—	5 500
	Orange	2 250	850 000		11 000
Ephemeral (reaching the sea)	Hoanib	220	18 100	1 in 3	4.0
	Huab	265	18 100	1 in 3	4.0
	Huarusib	280	16 800	9 in 10	20.0
	Khumib	130	2 800	1 in 10	1.0
	Koigab	125	3 100	1 in 10	1.0
	Kuiseb	330	21 400	1 in 3	5.0
	Omaruru	330	15 700	1 in 2	12.0
	Swakop	385	32 600	1 in 4	6.0
	Uniab	120	8 100	1 in 5	1.0
	Ugab	400	39 100	1 in 2	8.0
Ephemeral (landlocked)	Koichab	145	5 200	1 in 4	1.0
	Tsauchab	145	4 800	1 in 3	5.0
	Tsondab	140	4 000	1 in 3	6.0

*Millions of cubic metres per year

certain percentage of water and a certain percentage of solid sand particles. The volume of the space which can be saturated with water, is called the storage coefficient. If the storage coefficient is 10 percent, then the volume of stored water is 80 Mm³. This means that if 1 Mm³ of water is abstracted from the aquifer via the borehole, the water level will drop to 79 m. If there is a flood across the aquifer and the water table rises by 1 m, the recharge must have been 1 Mm³. If the size of the flood was measured at 100 Mm³ and 1 Mm³ of water infiltrated, then the recharge coefficient is 1 percent. If the flood was measured at 200 Mm³ and it is known that the recharge coefficient is 1 percent, then it can be expected that 2 Mm³ will have infiltrated into the aquifer and that the water table will have risen by 2 m.

If all these parameters are known, aquifer behaviour can be predicted. For instance, if it is known that the long-term mean annual surface runoff for this model is 200 Mm³, it can be estimated that the annual safe yield of the aquifer is 2 Mm³, because the natural level of the water table will more or less remain the same. By measuring the water table, the runoff and the abstraction, the behaviour of the aquifer can be monitored to see if the predictions were correct and, if not, the model can be adjusted.

FIGURE 3: HYDROGEOLOGICAL MODEL



However, this rather simple model only reflects the basic parameters. There are many more complex factors which must be taken into account, such as rainfall on the aquifer, evapotranspiration by the vegetation growing on the aquifer, the underground throughflow in the river, the underground inflow from the surrounding area, the stored water reserves against the abstractable reserves and the dead storage, the rate at which the water can be abstracted, the number of production boreholes and the water demand which must be satisfied by the water scheme from the aquifer. All these parameters can also be mathematically modelled to monitor the behaviour of the aquifer and to determine the long-term sustainable safe yield.

Another important parameter is the chemical quality of groundwater. According to Namibian drinking water quality guidelines, water is divided into groups according to the chemical quality. Group A water is of excellent quality with a total dissolved solids (TDS) concentration of not more than 1 500 mg/l (milligrams per litre). Group B water is of good quality and has a TDS of less than 2 000 mg/l, while Group C water has a TDS of less than 3 000 mg/l. Group D water has a TDS of more than 3 000 mg/l. Water in Groups A and B poses no health risk, but Group C water may have a low health risk, depending on the concentration of unacceptable determinants like sulphates (cause diarrhoea), nitrates (cause methaemoglobinemia in children under the age of one year) and fluoride (causes mottled teeth).

The annual safe yields of the aquifers listed in Table 2 have been estimated according to the best available information, but the figures are subject to change due to the behaviour of the system and are under constant scrutiny as part of an aquifer management strategy which includes the monitoring of all the relevant parameters.

The stored reserves in an aquifer have no bearing on the safe yield because the safe yield is dependent on the actual mean annual runoff in the river and the estimated recharge from the runoff. However, the stored reserves provide the buffer required to bridge long periods of no recharge due to the erratic behaviour of ephemeral rivers.

The rate at which water can be abstracted from an aquifer also depends on the permeability of the alluvium, the installed pumping capacity of a borehole, the number of boreholes in the aquifer and the area which can be covered with the boreholes.

One way to enhance aquifer recharge is to increase the natural infiltration of surface runoff. This can be achieved by building a dam to store floods in order to allow the silt to settle. The clear water is then allowed to infiltrate the aquifer through infiltration beds. It is not always appropriate or practical to attempt a recharge enhancement project, but the benefits from such a project can be seen in the case of the Omaruru Delta, where the estimated safe yield of the aquifer can be increased from 4,5 Mm³/a to 8 Mm³/a (see Table 2).

HISTORIC DEVELOPMENT OF WATER UTILIZATION IN THE NAMIB

Archaeological investigations in the Namib have located a substantial number of dwelling sites, some associated with stone circles, close to the coast. This indicates that ancient peoples must have been active along the coast and in the desert. They could not have survived without water and many of the sites, referred to as "Strandloper middens", are located near water sources.

About 600 years before the birth of Christ the Egyptian Pharaoh Neco sent Phoenician sailors, who were considered the best seafarers at that time, to cir-

TABLE 2: MAJOR GROUNDWATER SOURCES

River	Aquifer	Stored reserves (Mm³)	Safe yield (Mm³/a)
Omaruru	Omdel	150	4,5
	Additional due to dam		3,5
	Total	150	8,0
Kuiseb	Swartbank	75	3,0
	Rooibank	20	1,2
	Area B	11	0,8
	Dorop	349	1,0
	Total	455	6,0
Koichab	Koichab	640	1,1
Uniab	Uniab	5	0,02

cumnavigate the "land mass of Libya" (Africa). This epic voyage started from the Gulf of Suez and it took them three years to reach the "Pillars of Hercules", the present-day Rock of Gibraltar at the western entrance to the Mediterranean Sea. This implies that the Phoenicians must have sailed clockwise round the continent of Africa, but no mention is made of their having observed or visited the inhospitable Namib coast. The reason for this may be that they avoided the treacherous coastline and waterless hinterland.

The cursory exploration of the Namib coast by early Portuguese navigators like Diego Cão, who planted a padrão at Cape Cross in 1486, and Bartholomew Diaz, who erected a similar cross in 1487 at Lüderitz, was of very short duration. They must have realized that the land could only be inhabited if adequate supplies of water were found or brought by ship and put ashore.

The next attempt to explore the coast was made two centuries later when the Dutch East India Company dispatched ships, in 1670 and 1677, to investigate the possibilities of establishing trading stations on the west coast. The seemingly desolate beaches at Walvis Bay, Sandwich Harbour and Lüderitz were visited and contact was made with local Khoi-khoi.

Little else happened until, another century later, the British surveyed the coastline in 1786. In 1793 the Dutch carried out an extensive investigation at Walvis Bay. It was also reported that a large number of whalers, representing virtually all the seafaring nations of the time, were operating in the Atlantic Ocean off the Namib coastline. According to old ships' journals the early whalers established a number of drinking water depots along the coast.

It became known that brackish water occurred in the sandy, dry river-beds and the remains of watering points were found at wells in the Swakop River, at Sandfontein near Walvis Bay, at Sandwich Harbour, at Anichab just 40 km to the north of Lüderitz and elsewhere. Of these, the best fresh water source was at Sandwich Harbour.

The establishment of the whaling industry, sealing, fishing and the discovery of rich guano deposits on Ichabo Island and other islands in about 1850, resulted in further development at Lüderitz and Walvis Bay. Needless to say, the supply of fresh water, shipped in barrels from Cape Town, became an important trade item.

In 1887 the German West Africa Company established a canning factory at Sandwich Harbour because of the availability of fresh water permeating through the desert sand along the seashore.

By 1897 Lüderitz was the first settlement in the Namib to obtain potable water from a sea-water desalination plant. After the discovery of diamonds near Lüderitz in 1908, the first industrial use was made of sea-water by pumping it through a pipeline over a distance of 28 km, from Elisabeth Bay to the diamond mining town at Kolmanskuppe.

The supply of fresh water remained problematic, but was augmented by shipping it in barrels from Cape Town to Lüderitz and transporting it by rail to Kolmanskuppe. The railway line from Lüderitz to the interior had already been completed in 1906 and water could also be transported by rail from a spring at Garub, some 100 km away on the eastern edge of the Namib.

The desalination plant at Lüderitz utilized distillation technology and was upgraded from time to time. It produced up to 550 m³/day by the time it was closed down in 1967, when the Koichab Pan-Lüderitz Regional State Water Scheme was commissioned. The Koichab Pan is some 60 km north-east of Lüderitz and the water is abstracted by means of boreholes in the alluvium of an ancient channel partially covered by sand-dunes. The capacity of the water scheme is about 0,85 Mm³/a and the water is conveyed to a terminal reservoir at Lüderitz through a 100 km gravity pipeline.

Annexed by the British, the Walvis Bay enclave was incorportated into the Cape Colony in 1884, the same year as the remainder of Namibia was declared a German protectorate, called South West Africa. As the Germans did not have free access to Walvis Bay, they constructed a pier at the mouth of the Swakop River. This stimulated development at Swakopmund and in 1902 led to the establishment of the first bulk water supply scheme in the country. The water came from boreholes in the alluvium of the Swakop River. In 1934 a huge flood in the Swakop River damaged the water scheme at Swakopmund, but although the damage to the physical infrastructure could be repaired, the increasing salination of the groundwater — as a result of runoff in the desert — could not be prevented. By 1956 when the salinity of the water had increased to 7 000 mg/ℓ, Swakopmund had to be linked to the only fresh-water sources known in the

TABLE 3: OPEN WATER SOURCES OF THE NAMIB COAST

Name of source	Origin	Water quality *Total dissolved solids* (mg/ℓ)	Potability
Anichab	Koichab Pan?	1 800 — 8 100	Yes
Aurus	—	38 500	No
Saddle Hill	—	6 000 — 10 000	No
Spencer Bay	—	1 300 — 58 400	Yes
Naribis	—	2 500	Yes
Meob Bay	Sossusvlei	5 550	No
Reutersbrunn	Sossusvlei	3 200	No
Fischersbrunn	Sossusvlei	2 900 — 3 400	Yes
Conception Bay	Tsondabvlei	7 600 — 8 300	No
Sandwich Harbour	Kuiseb River	1 060 — 13 000	Yes
Sandfontein	Kuiseb River	2 500	Yes
Gaiais Fountain	Ugab River	18 000	No
Huab River Mouth Pools	Huab River	20 000	No
Uxieb Fountain	Koichab River	20 000	No
Wolfwasser Fountain	—	4 500	No
Uniab River Pools	Uniab River	13 700	No
Oasis Fountain	Hoanib River	4 000	No
Klein Oasis Fountain	Huarusib River	65 000	No
Khumib River Pool	Khumib River	2 100	Yes
Sechomib River Pool	Sechomib River	3 300	No
Ako Fountain	Munutum River	15 000	No

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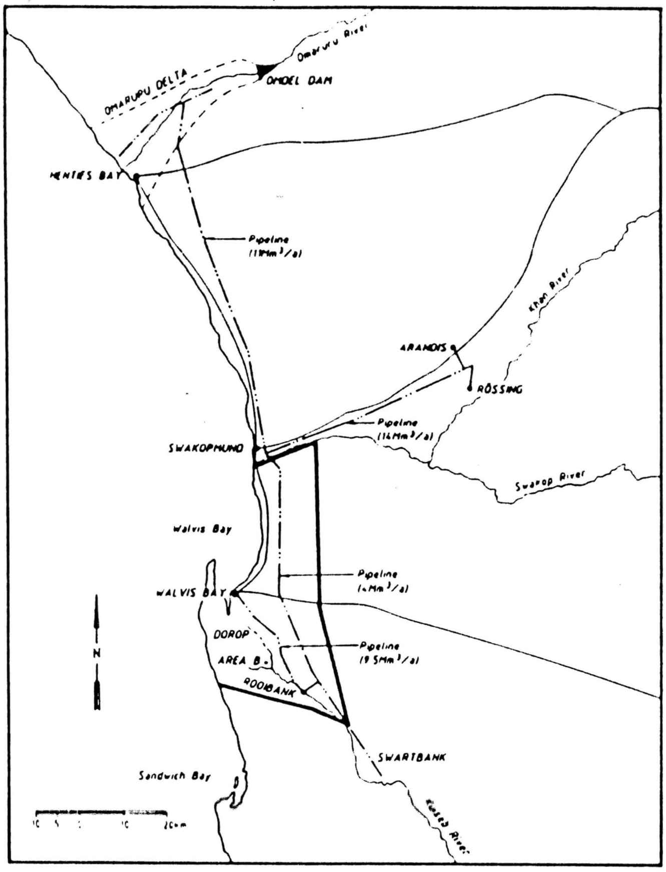
Sandwich Harbour	Kuiseb River	1 060 — 13 000	Yes
Sandfontein	Kuiseb River	2 500	Yes
Gaiais Fountain	Ugab River	18 000	No
Huab River Mouth Pools	Huab River	20 000	No
Uxieb Fountain	Koichab River	20 000	No
Wolfwasser Fountain	—	4 500	No
Uniab River Pools	Uniab River	13 700	No
Oasis Fountain	Hoanib River	4 000	No
Klein Oasis Fountain	Huarusib River	65 000	No
Khumib River Pool	Khumib River	2 100	Yes
Sechomib River Pool	Sechomib River	3 300	No
Ako Fountain	Munutum River	15 000	No

MAP 3: CENTRAL NAMIB WATER SCHEME



vicinity, those at Rooibank in the Kuiseb River, which also supplied Walvis Bay.

After the discovery of diamonds, a number of diamond mines had been developed between Lüderitz and Walvis Bay. The most noteworthy scheme to provide fresh water for these mines was a 70 km pipeline from Fischersbrunn near Meob Bay to Charlottenfelder, Hotsatia and Conception, the latter about 120 km south of Walvis Bay.

The results of various investigations into the occurrence of open water along the coast between Walvis Bay and Lüderitz were reported between 1887 and 1968 by eminent scientists like Drs. F. Stapf (1883), H. Lotz (1905), P. Range (1908), E. Reuning (1913) and H. Hellwig (1968). Further research on the quality of surface water has been done since then and some of the latest information is reflected in Table 3 while Map 2 gives the location of some of the fountains.

The end of the First World War and the allocation of German South West Africa to the Union of South Africa as a mandated territory stimulated rapid development at Walvis Bay. After further investigations into the groundwater resources of the Kuiseb River, the South African Railways and Harbours by 1923 completed a bulk water supply scheme to provide 80 000 m³ of water per annum from two wells at Rooibank, some 20 km east of the coast, via a 9-inch (230 mm) cast-iron pipeline to Walvis Bay. This water scheme brought nearly 80 years of shipping fresh water to Walvis Bay to an effective end.

From 1927 onwards diamond prospecting to the north of the Orange River mouth led to the development of Oranjemund, where water from a perennial river running through the Namib was utilized for the first time. Large-scale industrial abstraction of sea-water for diamond gravel washing also takes place at the mine. The next major development in the Namib which utilized a perennial water source was only realised in 1968 when the Rosh Pinah Mine (zinc, silver and lead) came into operation. The Rosh Pinah State Water Scheme supplies water from the Orange River by means of a pump-station protected by a concrete abstraction tower, to a purification works from where it is pumped via a 20 km pipeline to the consumers at Rosh Pinah.

After the Second World War development and the concurrent water demand at Walvis Bay increased substantially. The existing water sources could not meet the demand and by 1950 the water scheme was taken over from the Railways by the South West Africa Administration in an attempt to intensify the search for water and expedite the establishment of an adequate water scheme.

Due to a continuous increase in water demand, at both Walvis Bay and Swakopmund, additional water had to be located and supplied. Between 1960 and 1990 an extensive investigation was conducted to determine the groundwater potential of the Kuiseb River and the Omaruru River. The gradual expansion of the Rooibank aquifer since 1923, the incorporation of the Swartbank aquifer in the late sixties and the development of the Omaruru Delta in the middle seventies, led to the establishment of the Central Namib Regional State Water Scheme as it is known today. Initially the Rooibank and Swartbank aquifers in the Kuiseb River were developed and pipelines constructed to supply water to Walvis Bay and Swakopmund. By the time the Rössing Uranium Mine near Swakopmund came into operation in 1976, the pipeline from Swartbank to Swakopmund had been replaced and upgraded to supply 4 Mm³/a, while the groundwater sources in the Omaruru River Delta were incorporated by constructing a pipeline from Henties Bay to Swakopmund to supply 11 Mm³/a. A pipeline was also constructed from Swakopmund to supply 14 Mm³/a to Arandis and Rössing Uranium Mine (see Map 3).

WATER DEMAND SCENARIO

Although the water consumption figures in Table 4 have been rounded off, it can be seen that the water consumption at major centres in the Central Namib Region reached a peak of 16,58 Mm³ in 1980, but dropped to 12,36 Mm³ in 1990. This can be attributed to the reduction in water demand at the Rössing Uranium Mine, mainly due to the recycling of water. During the same period the water demand at the urban centres increased from 5,68 Mm³/a to 7,96Mm³/a at an average rate of 3,4 percent per year, implying that a reduction in water demand can be achieved without affecting normal, urban socio-economic development. However, when taking the availability of water resources into consideration, the average annual increase in water demand must be reduced. If conservation measures are successful, it is estimated that the future water demand in the Central Namib Region will increase at not more than 2,5 percent per year to 18 Mm³ in the year 2005.

The high increase in water demand between 1985 and 1990 at Lüderitz is as a result of an increase in domestic consumption, the development of a diamond mine at Elizabeth Bay, a new fishing factory and a seaweed processing factory. The annual potable water consumption at Elizabeth Bay, less than 10 000 m³, is included in the total consumption at Lüderitz.

In 1990 a new diamond mine which obtains domestic and industrial water from the Orange River, was opened at Auchas.

The annual consumption of sea water at the diamond mines at Oranjemund and Elizabeth Bay is 40 Mm³ and 20 Mm³ respectively.

In the past there were also a number of small mines which have closed down and are therefore not shown in the table. Examples are the mines at Brandberg West (wolfram, tin and lead), Goantagab (tin), Sarusas (amethyst), Terrace Bay (diamonds) and Strathmore (tin). More mineral deposits may be mined in the Namib in future, but it is difficult to estimate this additional demand.

FUTURE DEVELOPMENT

As can be seen from Tables 2 and 4, the estimated future water demand in the Central Namib Region at the coast will increase to at least 18 Mm³ a by the year 2005, while the sustainable yield of the existing water resources is estimated at only 14 Mm³ a. The picture looks better for the other water-consuming centres in the Namib and at the Orange River because the sustainable yield of the water resources will be able to meet the expected water demand.

This means that the expected water demand in the Walvis Bay - Henties Bay - Arandis triangle will be much higher than the capacity of the available resources to meet the demand. However, there are various ways of resolving this situation and they are:

1. *Conservation* of water by reducing unit consumption and wastage;
2. *Recycling* of water used in industrial and mining processes;
3. *Reclamation* of water from waste-water effluent;
4. *Substitution* of saline water for potable water;
5. *Extension* of the existing groundwater resources;
6. *Mixing* of potable water with brackish water to improve quality;
7. *Enhancement* of the recharge to the existing aquifers;
8. *Desalination* of sea water; and
9. *Importation* of water from the interior of the country.

All the alternatives need to be examined to determine their viability, affordability in terms of capital cost, the degree and sophistication of the technology involved, operational and maintenance implications, the eventual unit cost of the water to the consumer and the environmental consequences.

It is clear that water conservation measures and the reclamation of waste water should be a function of the local authorities, while the recycling of industrial effluent or the substitution of saline water for potable water should where possible be the responsibility of industry or mining operations. The expertise for the scientific investigations and feasibility studies into the extension of the groundwater resources (through drilling more boreholes in the same aquifers, developing new aquifers or enhancing aquifer recharge), the desalination of sea water, the mixing of potable and brackish water to improve the quality of the brackish water to potable levels, and the importation of remotely located water sources are vested in the Department of Water Affairs in the Ministry of Agriculture, Water and Rural Development.

The Department of Water Affairs is at present conducting a helicopter-borne electromagnetic survey into the potential of the groundwater resources under the dune sea to the south of the Kuiseb River and in the Omaruru Delta with the assistance of the German Government. This advanced technology, which is non-invasive and environmentally friendly, has been developed by the BGR (*Bundesanstalt für Geowissenschaft und Rohstoffe*) in Germany. The total area to be examined is 6 400 km² and the cost of the project is R1,5 million. The results of this investigation will determine if it is possible to extend the Central Namib State Water Scheme any further to the south of the Kuiseb River in future. This work should be completed by the end of 1993.

The Department is also constructing the Omdel Dam, some 37 km east of Henties Bay on the Omaruru River, to store floods long enough for the sediments to settle, prior to the water being decanted and led to spreading basins to enhance groundwater recharge. The dam wall will be an earth embankment floating on the underlying alluvium instead of being sited on the bedrock. The storage capacity of the dam will be 40 Mm³ and the whole scheme is the first of its kind in Southern Africa. This project should be completed by 1994 at a total estimated cost of R42 million (see Figure 4).

At the same time the Department is preparing a Water Master Plan for the Central Region of Namibia, including the west coast, with the assistance of the German Government, through the GTZ (*Gesellschaft für Technische Zusammenarbeit*) and a joint

TABLE 4: WATER CONSUMPTION AT THE WEST COAST

Consumer	Water consumption (cubic metres)				
	1975	1980	1985	1990	2005*
Central Namib:					
Walvis Bay	4 100 000	3 100 000	3 600 000	4 100 000	5 900 000
Swakopmund	1 500 000	2 000 000	2 200 000	2 700 000	3 900 000
Rössing Mine	7 000 000	10 400 000	5 500 000	4 400 000	6 400 000
Arandis	100 000	400 000	600 000	700 000	1 100 000
Henties Bay	40 000	80 000	140 000	260 000	400 000
Others	50 000	100 000	150 000	200 000	300 000
Subtotal	**12 790 000**	**16 080 000**	**12 190 000**	**12 360 000**	**18 000 000**
Southern Namib:					
Oranjemund	5 050 000	6 200 000	6 400 000	6 100 000	8 800 000
Lüderitz	350 000	370 000	390 000	620 000	900 000
Rosh Pinah	850 000	1 070 000	1 100 000	1 300 000	1 900 000
Auchas				5 500 000	8 000 000
Northern Namib:					
Uis	380 000	460 000	501 000	480 000	700 000
Terrace Bay		5 000	5 000	10 000	20 000
Subtotal	**6 630 000**	**8 105 000**	**8 396 000**	**14 010 000**	**20 320 000**
Total	**19 420 000**	**24 185 000**	**20 586 000**	**26 370 000**	**38 320 000**

*Estimated growth at 2.5 percent a year from 1990 to 2005 venture consultancy between German and Namibian engineering consultants. This study will include an evaluation of the water demand and supply situation in the area under consideration, as well as the possible development and incorporation of additional groundwater or surface water resources to meet the estimated future water demand. The feasibility of a possible link to the Okavango River on the Angolan border to augment a shortfall in demand will also be studied.

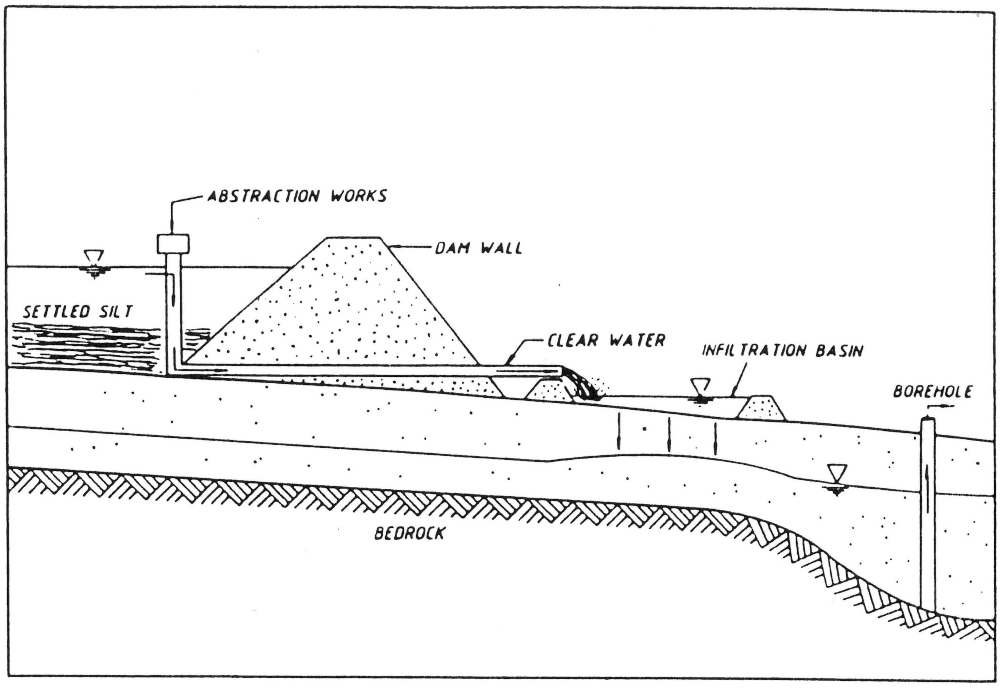
The Department of Water Affairs and Forestry in the Republic of South Africa is involved in further groundwater resource development, within the Walvis Bay enclave, in the Dorop aquifer on the Kuiseb River. It recently appointed consultants to investigate the possibilities for the desalination of sea water.

The Namibian Department of Water Affairs has already investigated the feasibility of reverse osmosis desalination technology, by operating an experimental plant at Swakopmund between 1978 and 1980, but in view of the high unit cost of the water desalination at that time it was not considered a feasible option to augment the water supply at the coast.

The desalination of sea water is expensive and can be very complicated, especially so in desalination processes which utilize membrane technologies. The sea water abstracted from the Benguela Current is very rich in nutrients and plankton and these impurities tend to clog the reverse osmosis membranes and must therefore be removed before the desalination process is attempted.

Although the estimated cost of desalinated water is between R6 and R8/m³ it might be less expensive than the importation of water from a water source like the Okavango River in the interior of the country.

FIGURE 4: OMDEL DAM PROJECT



ENVIRONMENTAL ASPECTS

The perceived exploitation and depletion of groundwater aquifers at the coast, especially insofar as the Kuiseb River is concerned, has been a matter of concern for environmentalists for a long time.

Environmental considerations in aquifer management basically centre around the conflict between the respective water needs of man and nature. Man is just as much a part of the environment as the fauna and flora existing in the finely balanced ecosystems in the linear oases provided by the ephemeral river systems running through the Namib Desert. It cannot be denied that any abstraction of water from a groundwater aquifer will lower the water table, be it temporarily or permanently, and the effect of a reduction in the water table on the vegetation in the river-bed should therefore be determined.

It is clear that the conflicts and impacts must be identified to implement an acceptable and appropriate management strategy. This might not have been done satisfactorily in the past, but the Department of Water Affairs, with the development of the Omdel Dam, took the initiative to conduct the first environmental impact study of its kind in Namibia at the time of the feasibility study.

The major commitment of the Department of Water Affairs in this regard is to conduct similar environmental assessment studies when new water projects are under investigation for future development in the Namib or anywhere else for that matter.

CONCLUSION

Water resource development in the Namib Desert has a long and difficult history. It will also remain problematic and a major challenge to those scientists and engineers who must locate, provide and conserve the scarce water resources in the face of the inevitable demands of future development.

The development of water schemes in the Namib has taken place after careful research over extended periods of time and will be continued as the need arises, technology advances and funds are made available. It is clear that groundwaters are difficult to find and it takes time to understand the natural processes that control the sustainability of those sources. At the same time all the impacts must be studied to facilitate conservation by formulating proper environmental management strategies.

It therefore stands to reason that local, regional and national authorities, as well as the general public, will have to make a combined effort to contain water demand and to ensure the most acceptable utilization of the available water resources in the Namib. ■

Piet Heyns, a civil engineer, is Director: Investigations and Research in the Namibian Department of Water Affairs.

Footnote: Translations of "Namib" vary. Among them are "shield" and "great plain", with a connotation of aridity. — Editor.

Environmental Aspects of the Eastern National Water Carrier

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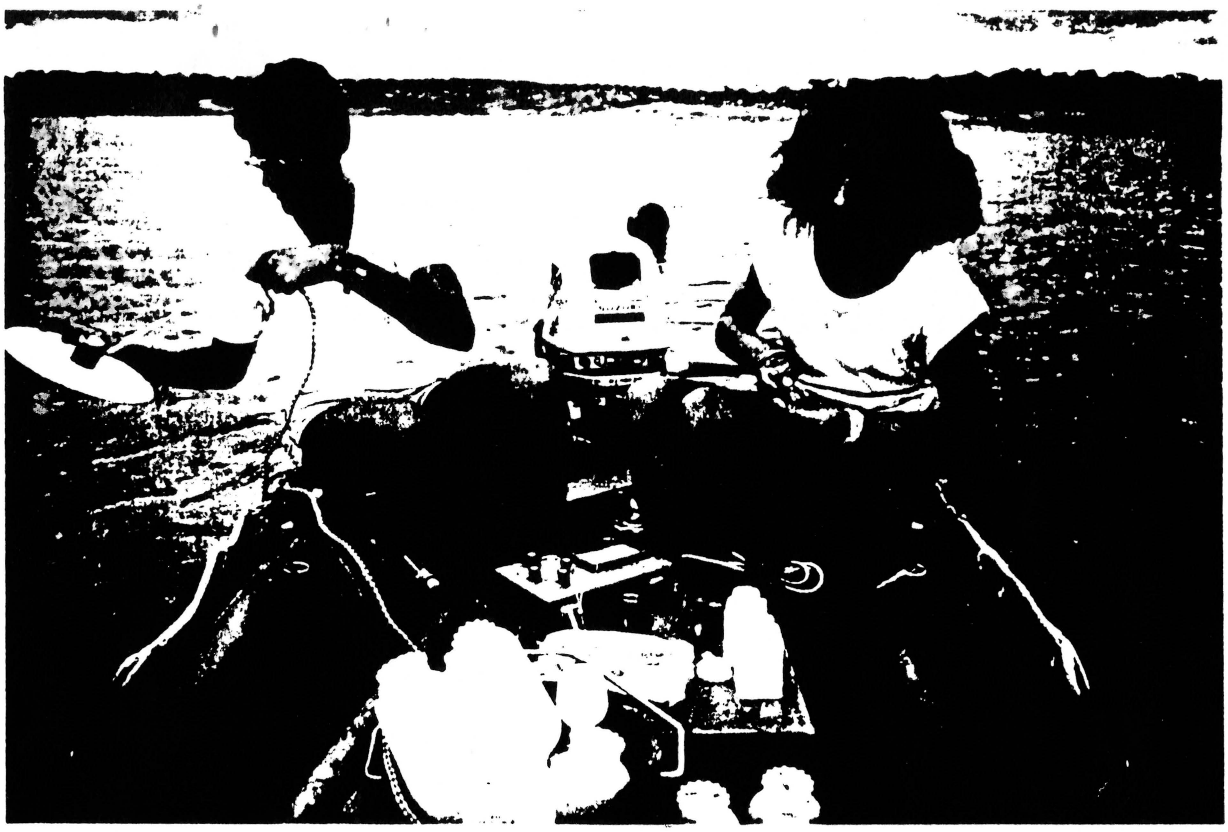
Department of Water Affairs
WINDHOEK

Swakoppoort Dam showing *Lemna*, **a free-floating plant which occurs in the impoundment.** *(Photo: S. Bethune)*



Limnologists taking in situ measurements on Von Bach Dam. *(Photo: I. Masche)*

The construction and operation of a long distance water transfer scheme such as the Eastern National Water Carrier must inevitably have environmental implications. To predict these and to select appropriate control measures, several research projects involving close consultation between researchers and engineers are being undertaken.

LIMNOLOGICAL INVESTIGATION

Limnology is the study of the physical, chemical and biological characteristics of freshwater environments. In the context of the ENWC the aims of the limnological investigation are to predict and assess the effects of both natural events and management procedures on the efficiency of the water carrier, the ecology of the storage impoundments and the water quality of the water supplied, and then, to seek appropriate solutions to any problems which may be identified.

The investigation has been preceded by a literature survey on similar projects elsewhere. The best documented studies relevant to the ENWC are on the Israel National Water System, on inter-basin tunnels in South Africa and on long distance irrigation canals; along the River Nile, in the Ukraine and in South Africa.

To establish the existing environmental conditions of the waters concerned, baseline investigations were conducted on the Von Bach, Omatako and Swakoppoort dams and on the Okavango River. The premise is that an understanding of present conditions allows any subsequent changes to be easily detected and identified so that, if necessary, timely remedial action can be taken. For a year the dams were surveyed twice a month to determine prevailing conditions and seasonal patterns. Fluctuations in water temperature, pH, oxygen concentrations and conductivity were measured, water samples chemically analysed and the aquatic plants and animals identified. Similar surveys were conducted seasonally on the Okavango River.

These baseline surveys together with the literature survey indicated that several limnological aspects required further research. These are, the possibility of introducing alien fish species from the Okavango River, the potential hazard of transmitting bilharzia, the possible excessive growth and establishment of algae in the canal and the deterioration of water quality during long distance water transfer.

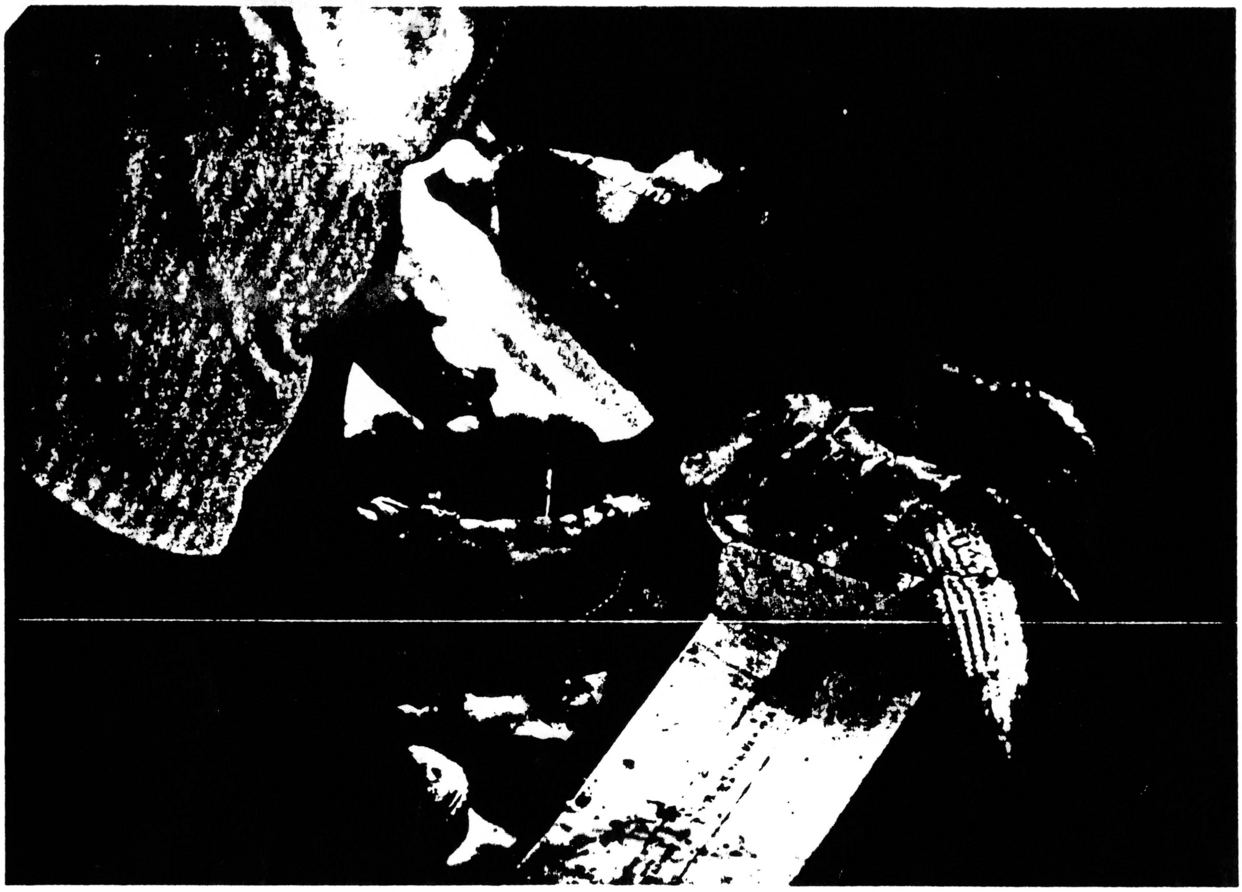
THE INTRODUCTION OF ALIEN FISH

Attention was paid to the ecological risk of inadvertently transferring fish between the relatively species-rich Okavango System and species-poor central drainage systems.

The Okavango River supports a large and diverse fish community within a wide variety of habitats. Although the ecological tolerances and preferences of most of the sixty-eight fish species found in the SWA/Namibia stretch of the river are

Popa rapids, a sampling site used during the seasonal Okavango surveys to collect current-loving (re-ophilic) fish species. These are the small, slender fish species best adapted to survive strong currents in pipelines and canals. *(Photo: S. Bethune)*

Researchers Shirley Bethune and Harald Koch, clearing fishing nets at Mkena during the March survey of the Okavango River. *(Photo: P. Skelton)*



Glen Merron measuring and determining gonad development during the Okavango fish survey. *(Photo: W.A. Smit)*

not conducive to their becoming established in the ENWC, a few could enter the carrier and possibly survive and establish in the Omatako and Von Bach dams.

Inadvertent introductions are frequently, but not necessarily detrimental to the invaded systems. Even if no detrimental consequences can be foreseen, it remains ecologically and conservationally desirable to minimize the indiscriminate transfer of organisms via the ENWC. The Department of Water Affairs operates on this premise and different methods of prevention will be scientifically evaluated before the final link with the Okavango River is commissioned.

BILHARZIA

Bilharzia, or to use the medical term, *Schistosomiasis*, is a parasitic disease which requires both a snail and a human host. It is essentially a dehabilitating disease associated with tropical waters. Both intestinal and urinary bilharzia are prevalent in the Kavango.

The free-living stages of the parasite would not survive the Rundu-Grootfontein pumping main, but the infected host snails might. It is unlikely that these snails will become established in either the canal or the dams of the ENWC. The snails require slow-flowing or quiet waters with plenty of aquatic vegetation. The flow rate in the canal is too rapid and the fluctuating water levels in the dams prevent the establishment of marginal vegetation. Furthermore, the free-living stages are unable to survive chlorination, thereby eliminating the risk of infection to the consumer once the water has been purified.

The Department is researching suitable control methods to prevent the possibility of bilharzia being transmitted to any of the components of the ENWC.

ALGAL GROWTH

A possible problem associated with cement-lined canals is the excessive growth of filamentous algae. This would not directly affect the consumer but can cause management problems. In extreme cases algae can cause physical obstructions, reduce flow rates and cause spillages at control structures such as longweirs. This problem is usually related to high nutrient levels in the source water, but in the case of the ENWC the source waters have low nutrient concentrations. If this problem should occur on the ENWC, several management options can be considered. These include chemical management e.g. adding copper sulphate and biological control using herbivorous fish.

WATER QUALITY DETERIORATION

The main cause of deterioration in water quality is the decomposition of algae and other biological material. In pipelines, biological material from the source water which cannot survive the adverse conditions inside the pipe, subsequently decomposes and causes a resultant decline in water quality.

In open canals, biological material can be introduced with the source water, with surface runoff, as wind-blown debris or terrestrial animals may drown in the canal. The decomposing biological material releases substances which can impart undesirable tastes and odours to the water and increases the concentration of dissolved organic matter. This biological pollution of the water can increase the cost of water purification.

As with the previous problems, care will be taken to minimize this introduction of biological material from the source water. The canal is designed so that surface runoff does not collect in it. There is not much that can be done to prevent wind-blown introductions, and the problem of animals possibly drowning in the canal leads us to the next project.

THE EFFECT OF THE CANAL ON ANIMAL MIGRATION AND MORTALITY

The ENWC canal is fenced off to prevent domestic stock entering the area. To some extent this fence also keeps out wild animals. Since construction began, several reports have been received of animal mortalities in completed sections of the canal. This as well as the possible influence of the canal on game migration routes are being investigated with the co-operation of the Directorate of Nature Conservation. If warranted, structures such as crossings and ramps will be built into the canal.

THE EFFECT OF GROUND WATER WITHDRAWAL ON KARSTVELD VEGETATION

The Karst Borehole Scheme consists of some seventy production boreholes spread over an area of ± 2500 square kilometres. The ground water reservoirs are located within four major dolomite synclinal areas where, due to the absence of well defined surface drainage systems, the major source of recharge results from direct precipitation. The annual rainfall is a relatively high 500—600 mm. Other factors controlling recharge include topography, thickness of soil and depth of the water table.

The aim of this investigation is to determine the possible ecological impact on the Karstland vegetation resulting from the large scale withdrawal of ground water. The findings will serve as a guideline for the most effective management of the scheme to ensure the least vegetational disturbance.

The initial investigation and short term monitoring will continue over a period of two and a half years after which a long term monitoring programme will be put into operation. This will ensure that monitoring continues once abstraction has commenced on a large scale.

The baseline study involved the classification of soil types, the identification of the main plant communities, and the mapping of groundwater levels. Using this information, investigation sites were chosen near production boreholes where the ground water level was less than 20 metres from the soil surface. Natural phenomena such as sinkholes, seepage points and springs often confirmed exceptionally high groundwater levels.

The natural water level fluctuations in the synclines and the rainfall pattern over the whole area are being monitored, so as to correlate the seasonal ground water level changes with precipitation. The moisture content in the top layers of soil is also being monitored to ascertain whether there is a correlation with the water table level. Growth and vitality of chosen indicator tree species are monitored annually at the peak of the growing season, to detect any signs of stress shown by the trees due to a lack of water, and to enable appropriate preventative action to be taken.

Ground water has already been abstracted at Berg Aukas and Kombat mines for a continuous period of 20—30 years. These sites are of particular importance since they confirm that no catastrophic effects need be anticipated. They are being investigated in order to assess and predict the possible impact on the vegetation in the other areas of the Karstveld should the water table also be lowered.

CONCLUSION

The environmental implications of the ENWC are being given careful consideration by both biologists and engineers. Together they are examining various control measures to eliminate or at least reduce to acceptable levels the potential problems which have been identified. Their recommended control strategies will be incorporated into the design and operation of the ENWC. It is hoped that this beneficial combination of biological knowledge and technological skill will ensure the best possible management of the Eastern National Water Carrier.