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INNOVATIVE GROUNDWATER MANAGEMENT IN NAMIBIA

By

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ABSTRACT

Water resources in arid and semi-arid regions are very scarce due to low rainfall and high evaporation. In Namibia, the most arid country in the Southern African Subcontinent, surface water sources are unreliable and often only available during the rainy season. Groundwater sources are more readily available during the whole year, but the long-term safe yield is acutely dependent on recharge from the little runoff generated by the low precipitation. This complicates the determination of the potential of the water sources, the development of appropriate infrastructure and the cost to supply of water for domestic, industrial and agricultural uses. Water managers in an arid environment must therefore have a very clear understanding of the constraints and opportunities facing them to mobilize the available water resources for the benefit of civil society. The efficient use of the water sources is of critical importance to ensure that there will be enough water support growth in all sectors of the economy.

In view of the fact that evaporation from open water is a major cause of water losses and inefficiency, the best practice to achieve surface water conservation in arid areas is the implementation of measures to reduce evaporation. The construction of sand storage dams, the conjunctive use of surface and groundwater, the artificial recharge of groundwater and water banking are effective methods to utilize the storage capacity of aquifers to increase efficiency when using surface runoff. Similarly, the sustainable use of groundwater sources can only be achieved if the potential of an aquifer is well known and when sound aquifer management is practised. Rural community participation in water supply, public water awareness about dealing with the issues of water scarcity and effective water demand management are major components of such a strategy.

The paper deals specifically with the management of groundwater resources in an arid country by elaborating the innovations of groundwater managers in the Republic of Namibia.

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1. INTRODUCTION

Namibia lies along the south-western coast of Africa, and is bordered by Angola and Zambia in the north, Botswana and Zimbabwe to the east and South Africa to the south. The country covers an area of 824 300 square kilometres (km^2), but has a population of only 1,83 million people (2001 census). The average population growth was 2,6 % per annum between 1991 and 2001. The population density is about 2,2 persons/km^2. Namibia is therefore one of the world's most sparsely populated countries in the world.

The country also has the dubious record of being the most arid country in Southern Africa. The people who originally settled in Namibia were hunter-gatherers and nomadic stock farmers. Their migration through the arid landscape was made possible because open water was available during the rainy season and in the dry winter months they could still rely on groundwater. The very survival of the early inhabitants was therefore completely dependent on the availability of groundwater resources and when their water sources dried up, they had to move to other places where water, food and grazing was available. The preferential places for permanent settlement were at the more reliable groundwater sources that had a longer term sustainability and naturally discharged on the surface. Even the capital city, Windhoek, owes its origin to the occurrence of hot water springs (85 °C). The local Herero people named the original settlement more appropriately "Otjomuise" which means "smoking water".

In areas with low rainfall the occurrence of water is extremely limited and the sustainable use of the available surface and underground water resources is a demanding challenge that calls for innovative and clever management. In the same sense, the prevention of pollution from wastewater produced by domestic, mining and industrial activities, are crucial to ensure that human health is not compromised and a very fragile, hydrogeological environment is adequately protected. The purpose of this presentation is to highlight some of the innovative achievements in groundwater management in Namibia.

2. BACKGROUND

2.1 Hydroclimate and Water Availability

Namibia receives summer rainfall and the average precipitation over the whole country is approximately 250 millimetres per annum (mm/a). The rainfall is low, unevenly distributed in space and time, highly variable and unreliable. The precipitation varies between less than 25 mm/a in the Namib Desert along the Atlantic coast to more than 700 mm in the north-eastern Caprivi Region. High daily temperatures and the dry air mass cause extremely high evaporation losses from open water surfaces. The mean annual gross evaporation is about 2 500 mm along the coast and in the Caprivi, but in the southern parts of the country it is up to 3 700 mm. The evaporation rates are significantly higher than the rainfall and this causes the environmental desiccation that is the reason why Namibia has two deserts, the Namib along the notorious skeleton coast in the west and the Kalahari in the east.

In view of these conditions, there are only ephemeral "rivers" within the borders of Namibia. An ephemeral river is a normally dry watercourse that yields runoff in the rainy season when the intensity and duration of the thunderstorms are of such a nature that a flood is generated. This means that dams must be constructed to impound the runoff during the rainy season for later use, but due to the high evaporation losses, the efficiency of the dams is very low. Only about 20 % of the stored volume can actually be used and the estimated 95 % assured safe yield from the surface water sources that can be developed on the ephemeral rivers is 200 million cubic metres per annum (Mm^3/a). Of this potential, about 90 Mm^3/a (45 %) have been developed. In the dry season the absence of surface runoff makes groundwater a very important source of water. It is estimated that the long-term sustainable safe yield of the groundwater sources is 300 Mm^3/a or 60 % of the water resources available in the interior of the country. Of this potential, about 130 Mm^3/a (40 %) has been developed. Perennial rivers form some of the borders between Namibia and its neighbouring States in the north and in the south. Although Namibia has an inalienable right to use these waters, the rivers are shared between a number of States and access to the water is not unlimited because the equitable and reasonable Namibian share must be negotiated with the other States. Although the runoff in these rivers is perennial, they are seasonal in nature and water must also be impounded during the rainy season to make it available for later use. At present Namibia has no dam in a perennial river, but the installed pumping capacity to abstract water from these rivers is 150 Mm^3/a. Although Namibia has access to about 360 Mm^3 of water per annum, water remains a scarce commodity and is still considered to be one of the most significant limiting factors to socio-economic, industrial and agricultural development in Namibia.

The water demand in Namibia was about 300 Mm^3 in the year 2000. When this demand is compared to the sources of supply, then 20 % of the needs were met from dams on the ephemeral rivers 33 % from the perennial border rivers, 44 % from groundwater and 3 % from used water that has either been reclaimed, recycled or reused. (These unconventional sources of water yield about 10 Mm^3/a.) This places the extremely high importance of groundwater in Namibia perspective.

2.2 Hydrogeological Environment

All the water that is available from groundwater sources originates from rainfall, irrespective of whether precipitation occurred recently or in prehistoric times. The potential of groundwater sources depends on a combination of sufficient, high intensity rainfall that produces runoff and favourable hydrogeological conditions that would allow the recharge and storage of water in an aquifer.

The aquifers in Namibia are associated with six major geological environments. These are secondary structures in crystalline rocks, volcanic intrusions, carbonate rocks, porous sediments, unconsolidated to semi-consolidated sediments and streambed alluvial deposits. The largest part of the country is covered by geologically ancient rocks that are inherently impervious. Groundwater is therefore found in secondary structures along joints, bedding planes, shear zones and faults. These structures are abundant in folded areas and occur in practically all pre-Kalahari formations. The majority of the stronger boreholes are located on faults. Throughout Namibia volcanic magma has intruded the older hard rock formations in the form of pipes, dykes and sheets. The contact zones between these geological features are frequently water bearing. In the south of the country more than 80% of the successful boreholes are drilled in dolerite dykes. Carbonate rocks such as marble, limestone and dolomite can contain fair quantities of groundwater, provided that karstification has taken place. This happens when rainwater that percolated through the rocks along joints, faults and bedding planes has dissolved the carbonates and created solution cavities in the rocks. Good examples of such groundwater sources in carbonate rocks are found in marble bands and dolomite Karst formations in the Grootfontein-Tsumeb area. Water bearing porous sediments are good aquifers and the most important of these occur in the sandstones of the Karoo Sequence, located in the central and south-eastern area. The water in these formations in the so-called Stampriet Artesian Basin is under artesian pressure. Two other, smaller artesian aquifers exist in the limestone and sandstone of the Nama Group to the west of the Stampriet Basin and in the basal gravel beds of the Kalahari sediments in an area to the north-west of Tsumeb. Unconsolidated to semi-consolidated deposits of aeolian sands and unconsolidated to slightly cemented sediments cover approximately 30% of Namibia. These include the Kalahari beds in the northern and eastern parts of the country, as well as the deposits of the Namib Desert along the coast. In areas where adequate rain occurs from time to time, these deposits may contain groundwater. The alluvial aquifers in the sand-filled ephemeral riverbeds are important sources of groundwater since floods periodically recharge them. The most important alluvial aquifers are in the Kuiseb, Omaruru, and Oanob rivers.

2.3 Water Master Plan

In the late sixties the South African Government, the Mandatory for the Territory of South West Africa, began with a large development programme in Namibia. At that time growth rates of up to 7 % per annum were experienced and this increased the need for water. Investigations into the availability of water resources to meet the estimated future water demand showed that most of the local water sources would be inadequate to meet large scale demands. This led to the preparation of a Water Master Plan that provided guidelines for the development of water supply infrastructure to meet the anticipated water demand. See **Figure 1**.

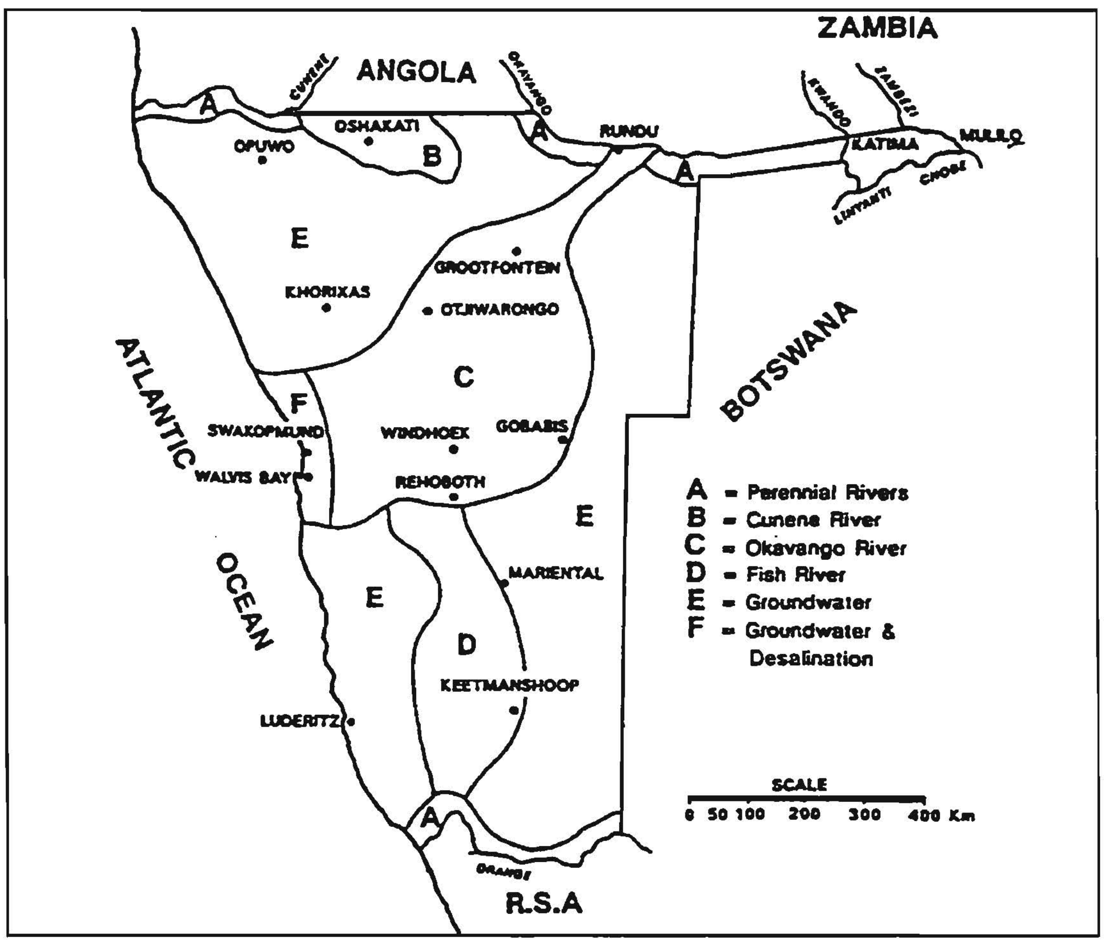

Figure 1 : Master Water Plan

According to the guidelines, the areas immediately adjacent to the perennial rivers must be supplied with water from those rivers. In order to supply the central northern area, it was proposed to import water from the Kunene to augment the local water supplies. The main reasons were that the local groundwater obtained from seasonal runoff and recharge to the shallow wells that yield fresh water would not be able to supply in the future demand. Furthermore, the hydroclimate and topography also did not allow for the construction of dams to impound the surface runoff and the deeper groundwater sources could not be used because the water is too saline for domestic consumption. In view of the fact that the ephemeral surface water and groundwater sources in the highly industrialised central area would not have been be able to meet the expected demand, it was proposed to import water from the Okavango River to augment the internal water sources. In the central southern area the master plan indicated that large water demands must be supplied with water from dams on the Fish River that is an ephemeral tributary of the Orange River. It was also proposed that the central Namib coastal area must be supplied with water from the local alluvial aquifers in conjunction with desalinated seawater to meet the future demand. The rest of the country would basically have to rely on local groundwater sources and if the demand were to exceed the supply, then more distantly located surface or underground water sources would be brought in to meet local demands. A link to the perennial water sources in the rivers on the borders of Namibia would be the ultimate solution to meet the water demand in the interior of the country. The Water Master Plan illustrates the importance of groundwater as the only water resource available to supply many small towns and a huge, sparsely populated, rural farming area.

2.4 Groundwater Development

In Namibia a shallow (up to 3 m deep) hand or mechanically dug hole in ground from which water can be removed with buckets, is referred to as a well. A water source that has been developed by drilling a hole into an aquifer and fitted with equipment, using wind, electricity, fuel or solar energy to abstract water, is called a borehole. In the stream-bed alluvial deposits the occurrence of groundwater is mostly close to the surface. In other hydrogeological environments the depth to the water table varies considerably depending on the topography and the geology of the area, but it is on average about 100 m and up to 200 m or more at some locations in the Kalahari beds.

It is estimated that more than 150,000 boreholes have been drilled in Namibia since 1900 in the search for water, but due to the poor hydrogeological conditions, only approximately 32,000 boreholes are at present utilized for water supply purposes. The safe yield of the existing production boreholes may vary between as little as 0,5 cubic metres per hour (m^3/h), mostly used for rural communities and farm installations, to as high as 120 m^3/h when used for domestic, industrial and mining water supply schemes. A successful borehole is considered to be a borehole with a long-term sustainable yield that is adequate for the purpose it had been drilled, provided that the quality of the water is acceptable for the intended use. For example, a source yielding 5 m^3/h, but where the water has a total dissolved solids content of 5 000 milligrams per litre (mg/ℓ), is not suitable for human consumption, although it is acceptable for stock drinking. More than 60% of the population rely on water supplies from shallow wells or boreholes.

3. DISCUSSION

3.1 Early innovations : Sand Storage Dams

In areas where evaporation losses from open water surfaces are very high, more efficient use can be made of the water stored in dams if the water losses to the atmosphere can be reduced. One way of achieving this objective, is to store water in a dam basin filled with sand. This objective can be achieved by building the dam embankment in small steps. Whenever the river runs, the water carries sediment and the course fraction of this sediment can be collected behind the first step while the water with all the suspended colloidal fines flows over. If silt accumulates because a small flood event did not produce enough sediment to fill the space behind the step, and to flush the silt over the top of the stepped embankment, then the silt must be removed. This can be done mechanically by either scraping the silt off or by ploughing the surface to break up the layer of silt after allowing the impounded water to infiltrate or evaporate. After the alluvial fill in the dam has reached the top of the first step, the embankment is raised by constructing a second step. This process is continued over a number of rainy seasons until the embankment reaches its designed height and the dam basin behind the embankment is completely filled with coarse sediment. The water in the alluvium behind the embankment can be abstracted from the dam by means of a collector pipe system, which had been laid in the dam basin when the first step of the embankment was built. A well can also be dug on the upstream side of the embankment to collect the water. The water collected in the well by the collector pipes can be taken through the dam wall by means of a pipe and a control valve to release the water. Sand storage dams work very successfully if the natural sediment load in the river is coarse. See **Figure 2**.

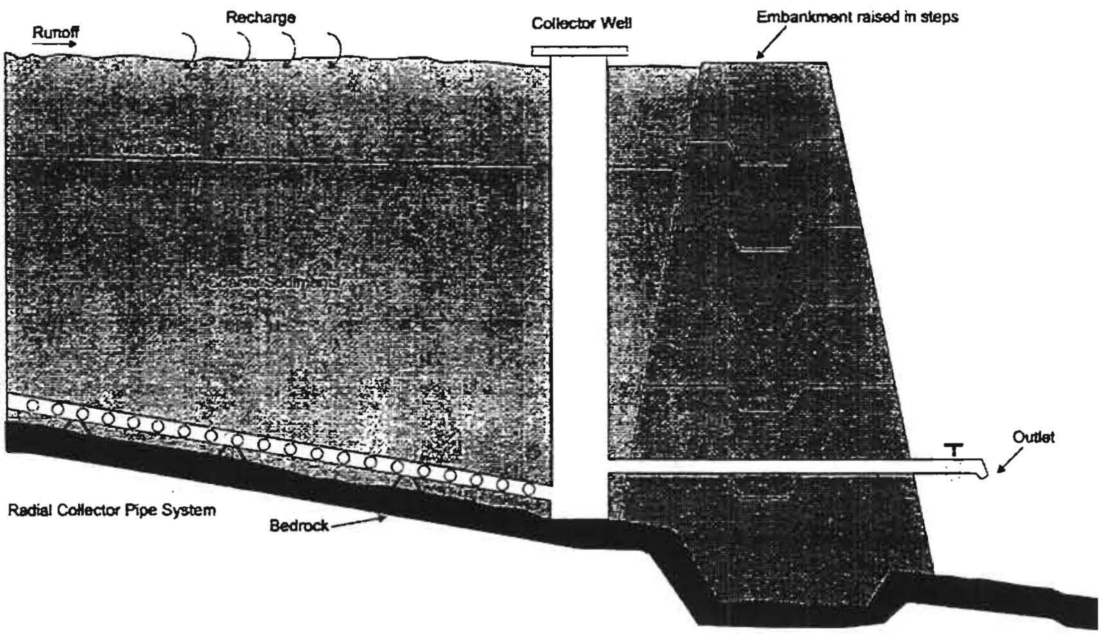

Figure 2 : Typical Sand Storage Dam

It should also be mentioned here that another variation of the same concept is the construction of a masonry or concrete wall (called a "grundschwelle") or steel wall (called a "spundwand") on the bedrock across the river. The top of this cut-off wall is always a few metres below the surface of the riverbed and this structure would then create an underground dam to impound the througflow in the river without exposing the water to evaporation at the surface.

3.2 Conjunctive Use of Surface and Underground Water Sources

The conjunctive use of different water sources is an important management tool to conserve water, mainly by reducing the loss of water due to evaporation. The Eastern National Water Carrier (ENWC) in Namibia will be used as an example to describe the concepts of conjunctive use and integrated use as part of a systems approach to increase the yield and efficiency of a water supply scheme that incorporates different types of water sources. See **Figure 3** for orientation.

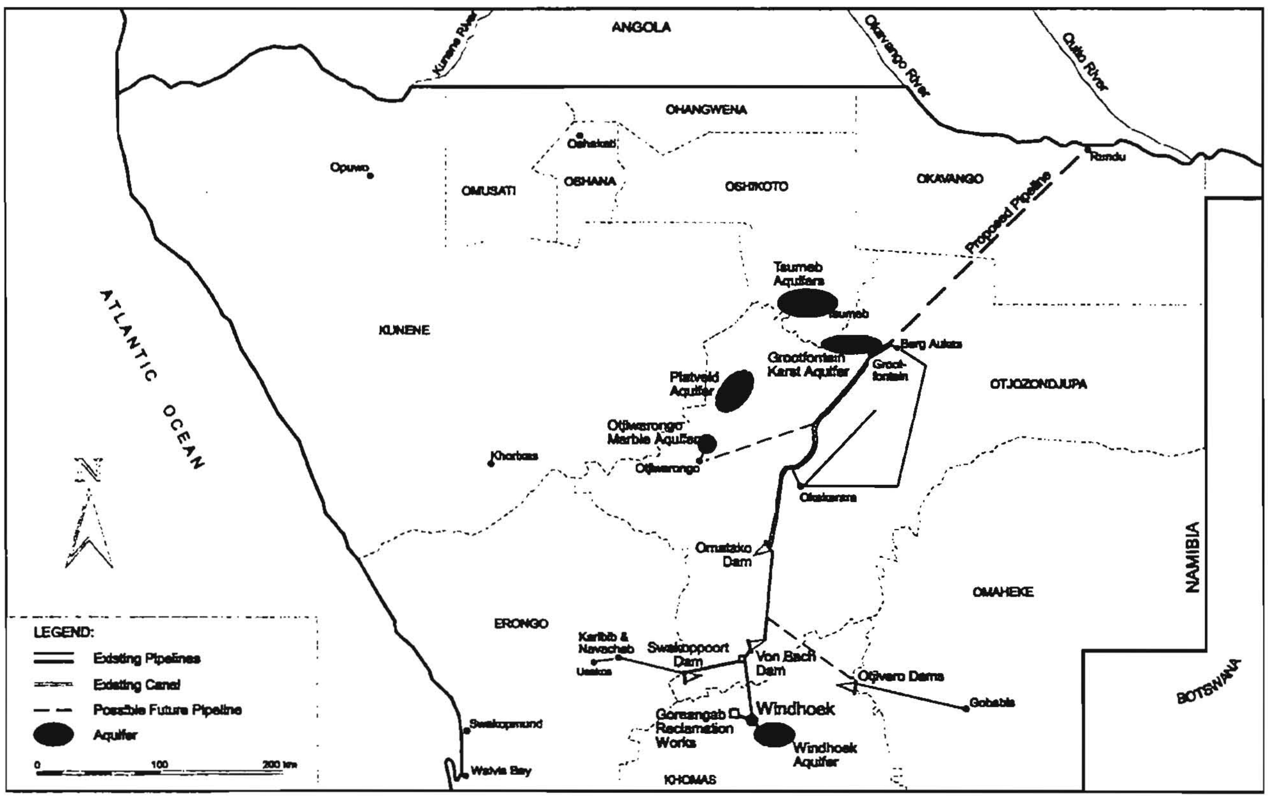

Figure 3 : The Eastern National Water Carrier

The ENWC is an ambitious water augmentation project that was proposed as part of the Namibian Water Master Plan and will eventually link dams in two ephemeral rivers, a number of aquifers and unconventional water sources in central Namibia to the perennial Okavango River. The water carrier has been under development in phases from the central area in the direction of the Okavango for the past 33 years. Three of the four phases planned are completed and each phase was an extension of the main water transfer system to connect additional water sources to meet an increasing demand. Phase one is a pipeline (60 km) between Windhoek and the Von Bach Dam, as well as links from the Swakoppoort Dam to Von Bach (60 km) and from Swakoppoort to Karibib (85 km). The second Phase is a pipeline (100 km) between Von Bach and the Omatako Dam. The third Phase is a canal (260 km) between Omatako and Grootfontein. The aquifers in the Karst area at Berg Aukas and Grootfontein are linked to the canal and those at Tsumeb will follow soon. The fourth Phase will be a pipeline (250 km) between Grootfontein and Rundu on the Okavango River.

The efficiency of a dam can be improved by reducing evaporation losses and this can be done by reducing the surface area of the water or by increasing the rate at which the water is used. Due to the fact that the three major dams of the ENWC are linked by means of pipelines, it is possible to reduce evaporation losses by using the dams on an integrated basis by transferring water from dams with less favorable evaporation characteristics to a dam with more favorable conditions. The total 95 % assured safe yield of the three dams is only 8 Mm^3/a when they are utilized on an individual basis, but by operating them on an integrated basis, the evaporation losses are reduced and the safe yield is increased to 14 Mm^3/a. When using the water in a dam as fast and as much as possible, it will reduce the evaporation losses that would have occurred if the same quantity of water were used over a longer period of time. This way of operation increases the yield of a dam in an ephemeral river, but reduces the reliability of the dam to yield water at a certain assurance of supply because less provision is made for rainy seasons with low rainfall and little runoff. This constraint can be overcome by using the surface water on a conjunctive basis with a reliable groundwater source or a perennial water source. The more reliable water source can then be used as a backup to meet the demand when there is a failure to supply water from the dam. The ENWC dams are linked to groundwater sources in the Karst Area, some 400 km to the north of Windhoek. This makes it possible to use the dams on a conjunctive basis with those groundwater sources and provides the opportunity for more alternative strategies to increase the efficiency in using the water. The Karst

Aquifers can be utilised at their normal long-term sustainable safe yield, but when there is a shortage of water from the dams as a result of drought conditions, the boreholes can be pumped at a much higher yield over a certain period of time to bridge the drought period. This unsustainable use can be allowed for a short period of time until the drought is over and the aquifer can then be rested to allow the water levels to recover. Another option is not to use stored groundwater at all. The disused mine at Berg Aukas filled up with water that cannot evaporate and is available as a backup when the surface water is in short supply. Recent studies of the potential of the Karst Aquifers show that the long term yield is in the order of 20 Mm^3/a, but up to 16 Mm^3/a can be abstracted additionally over a short period of not more than three years to serve as a backup if the dams should fail to supply. This can be done without any unacceptable adverse effects on the aquifers to recover during a rest period. When the groundwater from the Karst is used on this conjunctive basis with the dams, the 95 % assured safe yield of the dams can be increased to 25 Mm^3/a. When the ENWC is eventually connected to the perennial Okavango River, the safe yield of the dams can be even further increased to 45 Mm^3/a. By banking the surface water from the dams in the Windhoek Aquifer and incorporating the domestic sewage reclamation plant in Windhoek into the water supply system, additional security of supply has been obtained.

The ENWC project started in 1969 and should have been completed up to the Okavango River by 1983. The conjunctive use of surface and groundwater, the banking of surface water and the integrated use of the ephemeral surface waters increased the efficiency of the system to such an extent that the completion of the project can possibly be delayed until the year 2012. Another reason for this achievement is the success of a major water demand management strategy that reduced the unit water consumption and the growth in the demand. The conjunctive use of the water sources of the ENWC not only increased their yield, but conserves water, delays the need to make a new capital investment to incorporate additional water supply infrastructure at an early stage and reduces the unit cost of the water supplied by the system.

3.3 Water Banking in the Windhoek Aquifer

A cradle for the location of a city was created by an ancient rotation fault system in the metamorphic schist formations in central Namibia. Windhoek, the capital city of Namibia, is surrounded by the Khomas Hochland to the west, the Auas Mountains to the south and the Eros Mountains to the east. To the north the Windhoek basin is drained by the Aretaregas River that cut a gateway towards the north. The average annual rainfall is 360 mm and the average evaporation is 3 400 mm/a. The first settlers in Windhoek stayed in this valley because of the relative abundance of open water from the springs that owe their origin to the Windhoek quartzite aquifer. Another good reason for settlement was the cooler summers due to the high elevation of the city at approximately 1 600 m above mean sea level. At present, the population is 230 000 and the water consumption is about 18 Mm^3/a.

The existing infrastructure that delivers water to the City of Windhoek comprises separate facilities owned and operated by the Municipality of Windhoek and the Namibia Water Corporation (NamWater). The Municipality has been supplying water to the residents from the Windhoek Aquifer and two small dams in the Windhoek basin for more than a century. The natural recharge to the Windhoek Aquifer is estimated at 2 % of the rainfall and mainly takes place in the quartzites and micaceous quartzites that are largely situated in the southern part of the aquifer. These formations cover a total surface area of approximately 150 km^2. The long-term sustainable safe yield from the Windhoek Aquifer is approximately 1 Mm^3/a, but the maximum abstraction capacity of the existing groundwater supply scheme is 5,5 Mm^3/a. This allows for flexibility to use the aquifer at a higher abstraction for short periods to supply in peak demands and then to rest the aquifer. The local water sources in the city have been augmented since 1969 by the Goreangab Water Reclamation Plant and since 1971 by the ENWC scheme, described in paragraph 4.2. The capacity of the Reclamation Plant is 5,3 Mm^3/a.

It is clear that the local water sources in Windhoek cannot supply in the demand. The balance is therefore provided by Namwater. The company is the wholesale bulk water provider and operates the water supply infrastructure of the ENWC to bring water in from sources that are located far from the city. The Municipality operates the local water reticulation infrastructure to distribute the water to the consumers in the city. The Municipality can therefore be considered as the retail water provider who distributes and sells water to individual customers. The point where the bulk water supply system changes ownership from Namwater to the Municipality is at the outlet of the Namwater terminal reservoir located in Windhoek.

As stated earlier, the main sources of the Namwater bulk water supply system to Windhoek are the three ENWC dams. If the water collected in the dams after periods of good inflow, could be stored below the ground in aquifers where any losses from underground outflow would be less than the evaporation losses in the dams, the supply capacity of the surface and groundwater sources, operated as an integrated system could effectively be increased and optimised beneficially. The Windhoek quartzite aquifer can be used to store water from the central area dams in a process referred to as "waster banking." The two pipelines that supply purified water from the Von Bach water treatment plant to the city have a capacity of about 46 Mm^3/a, but the installed pumping capacity at the base station and two booster pump stations along the pipelines is only 22 Mm^3/a at present. From this it is clear that with some adjustments to increase the pumping capacity, excess capacity can be created to bank water in the Windhoek Aquifer.

One concern when banking water in an aquifer is the possibility that water may be lost if the aquifer system is not adequately confined. The Windhoek Aquifer consists of three geologic units, namely the quartzites in the southern areas, which form the Auas Mountains, the micaceous quartzites in the central, south-eastern and south-western areas, and the schists, which form the hills in the northern parts of the aquifer. To the south of the aquifer there is granitic material that has a very low permeability and in the east, west and north there are relatively impermeable schists. The aquifer is therefore bounded on all sides by these very low permeability formations and the estimated natural outflow loss from the aquifer is only in the order of 0,06 Mm^3/a. When the water level in the aquifer is kept below the level that allows for springs to start flowing, then the aquifer is acceptably confined to be used for water banking. Another issue is the compatibility of the quality of the groundwater and the water that is injected into the aquifer. Generally, the groundwater of the Windhoek Aquifer is of very high quality and complies with a Group A water according to the Namibian Guidelines for the Evaluation of Drinking Water for Human Consumption. The water from the major dams is of similar quality and the surface water is compatible with the groundwater. The Windhoek aquifer has been steadily over abstracted since 1950 at an average rate of 2,1 Mm^3/a. This has led to an average decline in water levels of 0,8 m/a. This drawdown of about 40 m relates to a depletion of about 40 Mm^3 that can be recharged by banking purified water from the major dams. In view of the suitability of the Windhoek Aquifer for water banking, a project was launched to bank water on an experimental basis. The capacity of the water infrastructure in Windhoek to transfer water from the Namwater terminal reservoir for injection into the Windhoek Aquifer is about 3,1 Mm^3/a and has been used to confirm the viability of a water banking programme. Further studies have been done on the capacity required to inject water and the injection capacity will be increased in two phases to 16 Mm^3/a over the next eight years.

The cost of banking the water is also an interesting aspect. The water company provides this water at the operating cost of N\$0,80/m^3 (1 US\$ = 10,5 N\$) and includes a small (15 %) mark-up. The water company therefore makes a profit on the sale of water which would otherwise have evaporated. The capital and operating cost of the existing bulk water supply system (N\$2,50/m^3) is recovered from water sold to Windhoek to meet the normal water demand. The Municipality who adds its costs to reticulate the water to the consumers, sells it for about N\$3,50/m^3. The Municipality banks the cheaper water and can sell it later at the consumer price when limited surface water is available during periods of drought. In this way the security of supply and the yield of the surface water resources are improved, while it is a win-win situation for all parties from a financial point of view and the assurance of supply that is achieved.

The bottom line as far as a comparison of the value of water in an arid area and the cost to supply the water is concerned, is that the value of the water increases to infinity when it is not available. At the same time, the financial cost to supply the water must be kept in check by optimizing the efficiency of the water resources already developed and by managing the demand on those resources in a beneficial way, before investing in the next, and probably much more expensive, augmentation project.

3.4 Artificial Recharge in the Omdel Aquifer

The coastal towns of Walvis Bay, Swakopmund and Henties Bay, as well as Arandis and the huge Rössing Uranium Mine some 60 km east of Swakopmund, are the main centres of economic activity in the central Namib Desert. All these developments, and a number of smaller consumers, are supplied with water from the Central Namib Regional Water Scheme. The main sources of water are the alluvial aquifers in the Omaruru River (Omdel Aquifer) to the east of Henties Bay and in the Kuiseb River (Kuiseb Aquifer) to the south-east of Walvis Bay. The well-fields in these aquifers are linked to the supply centres by means of a network of pump-stations, reservoirs and more than 200 km of pipelines. See **Figure 4** for orientation.

The existing water demand of 12 Mm^3/a is met by abstracting approximately 6,3 Mm^3/a from the Omdel Aquifer and 5,7 Mm^3/a from the Kuiseb Aquifer. The recharge to these aquifers takes place from erratic, unreliable ephemeral surface runoff and underground throughflow. In the case of the Omdel Aquifer, the average mean annual recharge is estimated at 3,5 Mm^3 and this means that the abstraction exceeds the recharge. Although the volume of water stored in the aquifer is estimated at about 150 Mm³, only half is recoverable and the steady depletion of the aquifer was considered environmentally unacceptable.

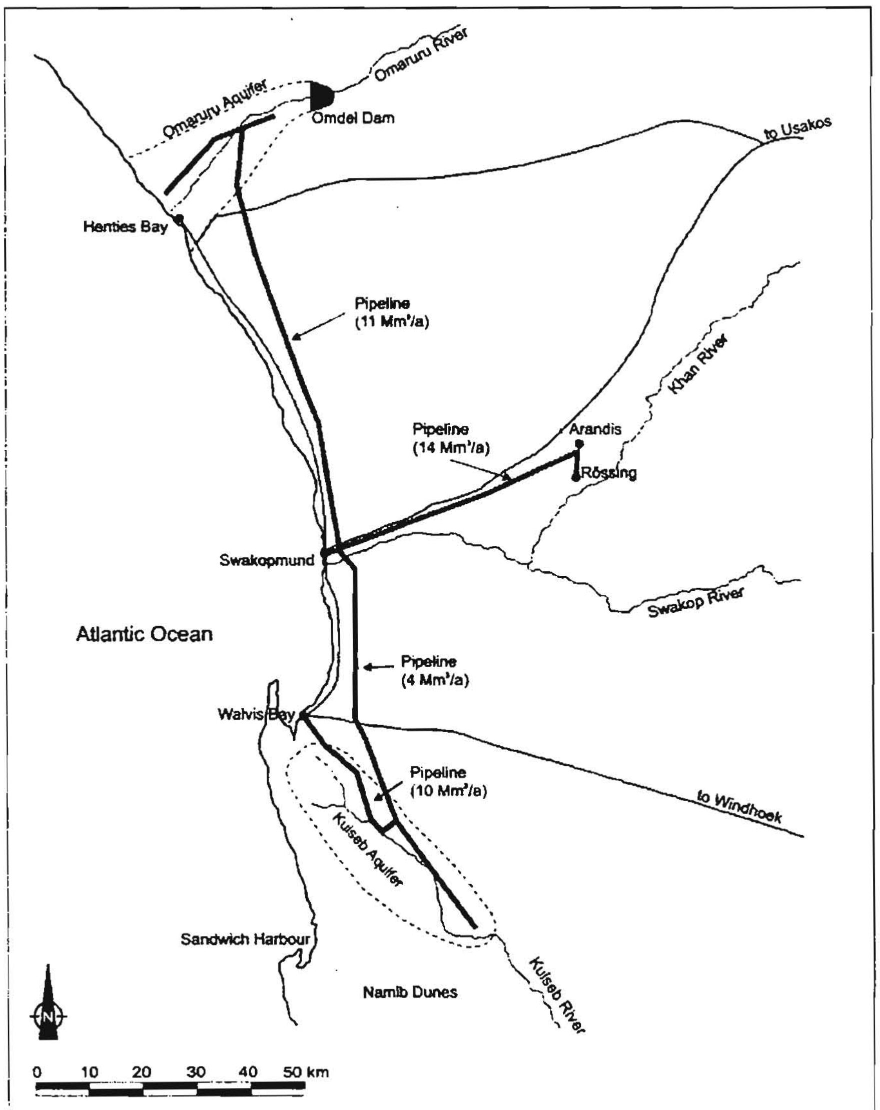

Figure 4: Central Namib Region

During the early 1980's, the Department of Water Affairs conducted a research project to determine why the natural recharge to an alluvial aquifer after a significant flood event was often less than expected in comparison to smaller floods that produced better recharge. The results of this work showed that the recharge depends on the turbulence of the flow and the clogging effect of the colloidal material suspended in the water. During less turbulent flow conditions, a layer of very fine silt or clay material is deposited on the surface of the riverbed and this reduces or completely blocks the penetration of water into the aquifer after a short period of time. In subsequent studies done on the runoff and recharge in the Omaruru River, it was found that although the aquifer sediments were relatively coarse, about 80 % of the water in a flood flows directly into the sea without recharging the aquifer. This is a common occurrence in ephemeral rivers and large quantities of floodwater just pass over the riverbed without significantly contributing to recharge. Methods to increase the turbulence of the flow in the river to enhance recharge were not successful and other methods had to be investigated.

It was also noted that shortly after the end of a rainy season, the brown colour of surface runoff impounded in the larger dams in the country starts to change to a "blue" colour. Investigations with a Secchi disk, used to evaluate the biological productivity of the water in the dams after flood events, showed that the penetration of light in the top layers of the water increases from zero to 0,5 m after three to four months. This reduction in turbidity in the upper layers of the water is caused by natural flocculation. The dissolved salts contained in the runoff in an ephemeral river is normally somewhat elevated and is enough to cause the flocculation of the colloidal material in the water. The settling of the flocks that are formed, reduces the turbidity.

As a result of the observation of these natural phenomena and the research programme to study the recharge mechanism of alluvial aquifers in Namibia, the process of artificial recharge enhancement was accepted as a viable concept. The Omdel Dam Artificial Recharge Enhancement Project was therefore proposed in 1989 to improve the recharge to the Omdel Aquifer. See **Figure 5**.

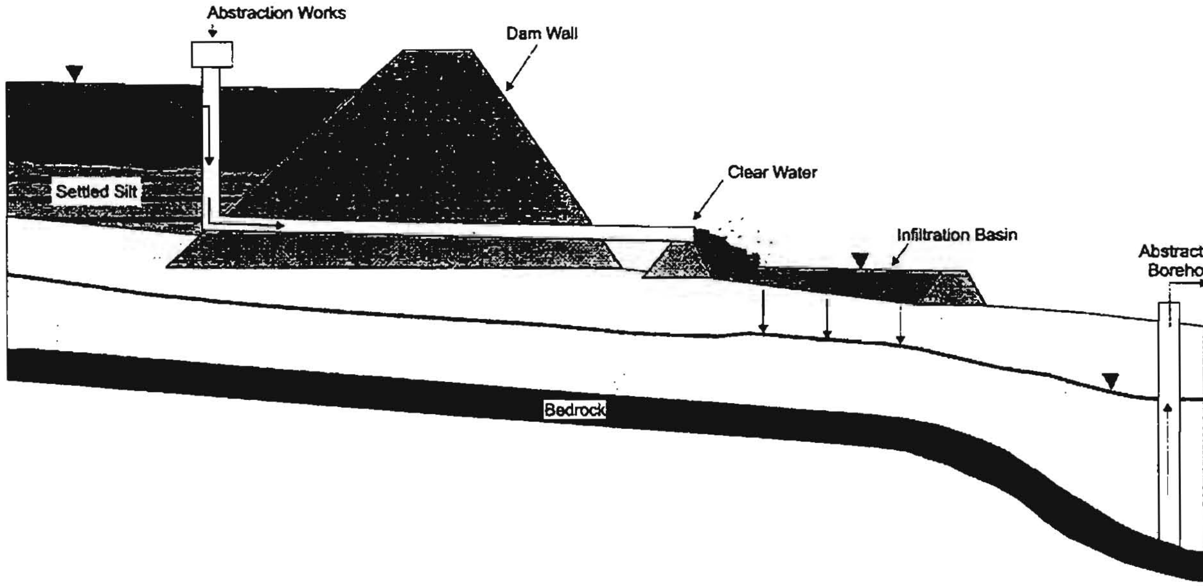

Figure 5: Artificial Recharge

The first objective was to construct a dam at a suitable site that is located upstream of the aquifer. The initial storage of the turbid runoff in the Omaruru River in this reservoir would allow the settling of the fine, suspended sediment. A clear layer of water can then be released via an abstraction tower in a controlled manner under gravity into infiltration ponds positioned across the aquifer downstream of the dam. A high rate of infiltration can be expected due to the absence of silt in the water and because the aquifer comprises coarse material. The recharge system was designed to transfer the contents of the reservoir to the aquifer during the dry season so that if there was a subsequent good rainy season with runoff, there would be storage space available in the reservoir to impound the runoff. In this way the storage potential of the reservoir and recharge to the aquifer could be maximised.

The Omdel Dam has a catchment area of 14 600 km² and the mean runoff at the dam is 15,7 Mm³. The silt load in the runoff is about 17 %. The full storage capacity of the dam is 41 Mm³ and the 95 % assured yield of the dam is 5,2 Mm³/a. The embankment of the reservoir is a unique and innovative design because it had to "float" on about 45 m of alluvial material that could not be excavated to bedrock level due to the water in the alluvium. The embankment comprises an impervious clay core and a downstream blanket of clay, supported by upstream and downstream shoulders constructed from permeable sandy soils. The control of seepage under the embankment was a major challenge and is achieved by means of a complex, multiple drainage system. The abstraction tower can accommodate the release of clear water through a number of intakes located at different levels and the maximum discharge is 7 m^3/s when the dam is full. It was estimated that a long-term recharge enhancement of between 4,5 and 6,0 Mm^3/a could be achieved.

The Dam impounded two major floods since its completion in 1995 and the results of the recharge achieved are very encouraging. After each of the flood events, about 9 Mm^3 (or 50 % of the runoff in comparison to 20 % under normal runoff conditions) could be infiltrated into the aquifer and the medium term sustainability of the Omdel Aquifer has already increased from 3,5 to 5,6 Mm^3/a.

The Omdel Dam Project was the first major infrastructure development in Namibia that was subjected to an environmental impact assessment during the feasibility study phase. In 1996 the project was the recipient of the prestigious Shell Environmental Award. The Right Honourable Prime Minister of Namibia Mr Hage Geingob, who is the patron of the Award, handed the Fish Eagle trophy to the Department of Water Affairs. Indeed a proud moment for those who participated in such an innovative and successful project.

3.5 Heliborne Geophysics in the Namib Sand Sea

The Kuiseb River catchment drains the runoff from the central highlands in Namibia in a westerly direction to the coast. The sand dunes of the Namib Desert is south of the river channel and to the north the landscape is barren because the aeolian sand from the south is trapped in the river and washed to the coast during flood events. At the mouth of the Kuiseb there is a huge fresh water alluvial aquifer that can store about 180 Mm^3. This aquifer is one of the water sources of the Central Namib Regional Water Supply Scheme as described in paragraph 3.4.

Just to the south of Walvis Bay, there is another bay called Sandwich Harbour where fresh water springs occur at the beach. A significant feature of the Kuiseb River valley is that about 60 kilometres from the coast, on its westerly course in the direction of Sandwich Harbour, the river suddenly turns in a north-westerly direction to Walvis Bay. This led hydrogeologists to believe that there may old river channels in the direction of Sandwich Harbour, hidden under the Namib sand sea to the south of the existing, active river channel. Due to the treacherous conditions in the dunes of the Namib Desert, it was never really possible to investigate this theory.

However, in view of more dynamic development at Walvis Bay after the independence of Namibia, additional water sources had to be found. Many alternatives such as dragging icebergs from Antarctica, desalinating seawater, or bringing freshwater with tankers from Cape Town or the mouth of the Congo River were considered, including an investigation of the Kuiseb River paleochannels to the south of Walvis Bay. Such an investigation would require the mapping of covered paleolandscapes, water bearing sediments, hardrock structures, coastal aquifers and saltwater intrusions in a sea of sand which covers a huge area and is difficult to access. The best method to achieve these objectives at the same time in such an inhospitable environment was to utilise airborne geophysics. The heliborne geophysical system of the Federal Institute of Geosciences and Raw Materials (BGR) in Germany was selected for this purpose. This system allows for a simultaneous electromagnetic, magnetic and natural gamma ray survey at maximum depths in the order of 150 m, depending on the background resistivity of the underground. The system is mounted in a device (a "bird") towed about 45 m below a Sikorsky 576 B helicopter and the bird is kept between 30 and 40 m above the ground level. The helicopter flies at about 90 kilometres per hour and the flight line spacing is adjusted according to the density of the measurements required.

The Kuiseb survey took eight months and covered an area of 5 300 km². The flight lines were spaced at 400 m and 1 000 m intervals to reduce the density of the survey in less important areas. The helicopter did 56 survey flights over a distance of 12 300 km along 215 survey lines. The airborne survey indeed identified the existence of the suspected paleochannels and this was followed up with a drilling programme, test pumping, groundwater isotope analysis and a groundwater chemistry survey. The groundwater reserves in the porous sandstone deposits in the paleochannels cut into the hard bedrock were estimated at 500 Mm³. About 80 % of the groundwater is suitable for human consumption. However, due to the low permeability of the water bearing sandstone aquifers, a large number of borehole installations would be required to abstract the desired quantities of water. The inaccessibility of the Namib would have complicated the development of the well-field, the construction of access roads and the pipeline infrastructure, as well as the installation of power lines. Subsequent cost calculations showed that the utilization of this water source would be less economically viable than the next best option, namely the desalination of sea water to augment the water sources at Walvis Bay.

Although the heliborne investigation did not produce positive results from a groundwater resource development perspective, the survey proved the existence of a substantial resource and gave the water development planners the opportunity to rule the resource conclusively out as a future water supply option for the Central Namib Area. Apart from this negative but useful result for the Namibians, the project also allowed the Germans to improve their airborne geophysical equipment as a result of the experience gained in the Namib Desert. In fact, the Namibian Government obtained the services of the BGR to execute another major heliborne groundwater investigation towards the end of this year in an area to the north-west of Tsumeb.

3.6 Radiaesthesia to the Rescue

The art of dowsing or the science of radiaesthesia was initially used to detect minerals, but later it was realised that dowsers can also find water. The first person to describe this ability of dowsers to find water was a French lady, Martine de Beausoleil. Her book, *La Restition de Pluton*, did not amuse the French authorities and she was incarcerated in the Château de Vincennes until her death. The riddle that has baffled people for centuries is why dowsers seemingly respond to substances as different as minerals and water. The secret lies in the ability of the dowser to detect faults, fracture zones, cracks and fissures in the crust of the earth. These geological features are often mineralised or water bearing and when a dowser finds a fracture it will appear as if the person had been able to detect a mineral deposit or a water source. Perhaps a dowser can detect magnetic anomalies, but it is mainly through experience with the results obtained from the drilling investigations at sites indicated by the dowser that he learns how to relate his response to the actual find. In this way a dowser becomes confident enough to predict the depth, yield and quality of the water source that has been sited. Thousands of successful borehole have been sited in Namibia by making use of dowsers because highly qualified hydrogeologists or geophysicists were not readily available to assist mainly the farming community to site boreholes and to developed their water sources.

Namibia experienced severe drought conditions in the early nineties and there were not enough hydrogeologists available to site boreholes in the areas where grazing for the livestock was still available, but where groundwater sources had not yet been developed. The use of dowsers was not acceptable to the Government because when public funds or financial support from the donor community is used, then the services of qualified hydrogeologists should rather be retained to ensure that an expensive borehole is drilled at a place that has been sited in a scientific way in order to obtain the aquifer parameters and to reduce the risk of drilling a dry borehole. However, in view of a lack of manpower, it was decided to make use of dowsers, provided that they had at least received some training to increase confidence in their ability to site successful boreholes. The

German Government was approached for support and a dowsing specialist was made available to assist with the project.

The first phase of the project was to establish if the dowsing ability of the expert would be successful in the Namibian hydrogeological environment. In order to make the project more scientific it was decided to combine the so-called biophysical method of radiaesthesia (or dowsing) with geophysics. In other words, the dowser would site the borehole and the geophysicist would check the result with geophysical equipment before they would jointly agree that the site could be drilled to find water. The second phase would be to train people who would be interested to receive a certificate that would allow them to practice as professional dowsers. Not everybody has the ability to dowse for water and only those who had the ability, to be a "radiaesthesiac" would be allowed on the course. These people would receive a theoretical background on hydrogeology and practical experience by siting boreholes under controlled conditions.

The project started in March 1992 and soon evolved into an interesting competition between the dowsing expert from Germany and the local hydrogeologists. The difference between a dowsing expert and a hydrogeologist is that the dowser uses only his own body as a sensitive measuring instrument. The signal is usually measured by means of a divining device such as a forked stick, or coke bottle or fanbelt or a bent wire or a pendulum to indicate his response to a water find. The fact that a dowser is able to obtain a rod response or signal is not questioned, but it is the interpretation of the signal that is a controversial issue. It appears that there is a correlation between the magnitude or strength of the rod response, the sensation the dowser experiences and the occurrence of groundwater. Some dowsers claim that they can predict the depth of the water, the specific yield and the quality of the water, but none can indicate the magnitude or potential of a groundwater resource. In many cases a dowser is useful to site a borehole when the long-term sustainable safe yield or the chemical quality of the water is of little concern, for example in the case of small-scale stock watering boreholes. However, when expensive, large-scale groundwater supply scheme infrastructure must be developed, the long-term sustainable safe yield of an aquifer must first be established, and in such cases the expertise of the hydrogeologist and geophysicist seems more appropriate. The hydrogeologist would use his knowledge about the geology and the hydrogeology of the area and he would rely on appropriate geophysical equipment to assist him in siting a borehole on a water bearing geological feature. A hydrogeologist would seldom make any claims about the yield or quality of the water, but would use test pumping techniques to determine the aquifer parameters and would analyse a water sample to determine the quality. This of course, takes time. The bottom line here is that a dowser does not have to have academic or technical knowledge about the hydrogeology, or the use of sophisticated equipment, and he can work very fast to site a borehole.

The results of the first phase of the project were rather controversial because the definition of a successful borehole was not initially agreed upon. The dowser claimed a successful siting for each borehole that yielded some water. It also did not matter what the quality of the water was and what the yield was. Just as long as water was struck, the borehole was considered successful. When the borehole was dry, the drilling crew was blamed because the drilling was not done 100 % straight (which is technically very difficult to achieve, especially for boreholes that can be up to 200 m deep). In view of the "competition" between the dowser and the hydrogeologists, as well as the fact that the hydrogeologists in the Department had to site boreholes that conform to specific requirements, the Department decided to define a successful borehole as a borehole that can be used for the purpose it had been sited for and if the borehole was dry, it will not be considered as a drilling mistake because the same drilling crews did the drilling for the sites identified by both the dowser and the hydrogeologists. At the end of the day it was conceded that the success rate for the dowser was 75 % in comparison to 67 % for the geohydrologists.

It was therefore agreed to proceed with the second phase of the project, which entailed the training of dowsers. A process was initiated to recruit persons who were interested, but had to have the ability to be a "radiaesthesiac" or dowser. The German expert then tested the "sensitivity" or the dowsing abilities of the incumbents (by holding hands!) and those that passed the test, joined the course. The trainees received a theoretical background on geology, geophysics and hydrogeology. They were lectured on the hydrogeological conditions in Namibia, familiarised to work with the Government hydrogeologists and did practical fieldwork by siting boreholes.

The Namibian project for the combined use of radiaesthesia and geophysics ran for three years when it was abruptly ended by a bolt of lightning from one solitary cloud in the middle of the Namib desert that struck the dowsing expert down. He miraculously survived the incident, but the project was never concluded as envisaged. In the final analysis one can say that the use of dowsers to find water in the Namibian hydrogeological environment with its hard rock aquifers, is an acceptable time and cost saving method to develop boreholes for small scale water schemes, but a hydrogeologist will always be necessary when it comes to the assessment of the potential of large aquifers that will be developed with expensive infrastructure.

3.7 Community Based Rural Water Supply Management

As mentioned in the discussion about the Water Master Plan for Namibia, large areas of the country will have to rely on groundwater sources. Small isolated communities, who mostly practice livestock farming and are scattered over the landscape, obtain water from rural water supply installations. These water points were provided by the State because the cost to develop a borehole installation was not affordable for the local people. The installations normally supply water to about 30 people and 50 head of cattle, but were often designed with the emphasis on livestock water supply and did not make provision for facilities to ensure that the human population had access to safe water. There was also very little or no community involvement to develop, operate and maintain the installations because of a lack of technical capacity. This absence of local responsibility, technical support and a shortage of State funds to keep the installations well maintained, led to further mismanagement and deterioration. As a result the rural water supply sector became totally unsustainable.

In 1993 the Government approved a new water supply and sanitation policy that *inter alia* made provision for an improvement in the rural water supply situation. The objectives of the policy were to provide an adequate lifeline quantity of safe potable water for human consumption and water for subsistence stock farming needs. The lifeline quantity of water was agreed upon as a minimum of 20 litres per capita per day within at least 1 000 m from a homestead in order to reduce the burden of carrying water over long distances. Another objective was to improve hygienic conditions at the water installations, to prevent the pollution of water from human and animal waste, to improve the health of the communities, to reduce water wastage, and to recover at least the operating and maintenance costs of the water installations.

In the development of the rural water supply policy, the water management practice of the commercial farming community was taken as an example. Commercial farmers were initially partially supported by the Government to drill their own boreholes through a subsidy system that was later terminated when the water supply infrastructure on the commercial farms reached an acceptable level of development. The farmers had the responsibility to pay a portion of the drilling cost and to cater for themselves as far as the development, operation and maintenance of their water installations were concerned. They were not provided with any additional technical or financial support by the Government. In the case of rural water supply the Government adopted a strategy to empower the rural communities by decentralising responsibilities to the lowest appropriate level. The local people had to accept the responsibility for the management of their own water supplies and the q*uid pro quo* for the provision of improved water supplies was that the communities would be trained to operate and maintain their water installations, including the collection of money for water sold to the community members.

This policy and the approach for the implementation of community based rural water supply management (CBM) were developed through extensive consultations at national, regional and community level. The communities and their leaders, officials of the line ministries involved and other stakeholders such as non-governmental support organisations with an interest in the water supply sector, were involved in the discussions. The communities accepted the proposals by Government to involve the users of rural water supply services as partners in the management of those services and eventually to transfer the full ownership and responsibility of their water supply installations to the local stakeholders. The proposed institutional structure to manage a water point was agreed upon and the first step would be the election of a Water Point Committee (WPC) that will manage the installation on behalf of the community. The WPC will have legal status and the right to own the installation, to use the water and to appoint a caretaker. The caretaker will be trained by Government and provided with tools and equipment to operate and maintain the installation.

In 1993 the Government established a Directorate of Rural Water Supply in the Department of Water Affairs in the Ministry of Agriculture, Water and Rural Development to implement a rural water supply programme. Although the consultative process for the development of the CBM programme took nearly four year to complete, the Government continued to provide new rural water supply installations and to renovate the old installations. The implementation of the CBM programme commenced in August 1997 and will be completed within ten years. By the year 2007 all people should have access to a reliable supply of safe water and the water committees will be fully in charge of operation and maintenance of their water points while making a contribution to recover the cost. This contribution may be in cash, in kind or in labour. Every water point is designed to provide a hygienic and secure supply of water for the people and livestock. A portion of the water pumped from the borehole is stored in an elevated tank or at ground level to provide security of supply in case there is a mechanical breakdown in the supply system. When there is a shortage of water due to drought conditions or mechanical failure, the first priority for the provision of water will be for the people. The WPC will supervise the caretaker, collect the money, pay for the services required (spare parts, fuel, materials, repairs etc), keep proper records and report to the water users about their activities. The Government will remain and an equal partner in the CBM programme by assisting with the initial development or renovation of infrastructure, establishing the local management structures and providing technical and administrative support systems. The Government will also encourage the private sector to create commercial outlets for spare parts and banking facilities in the remote areas, as well as to establish a development fund that can provide loans to the WPC to effect major repairs when necessary.

The coverage that has been achieved with the implementation of CBM and the upgrading of rural water supply facilities since the independence of Namibia in 1990 is about 67 % or 1,2 million people after about 12 years down the line. This achievement can be regarded a success, although the long-term sustainability of the CBM programme is still subject to the proverbial "proof of the pudding lies in the eating." Nevertheless, several countries in Southern Africa have studied the Namibian model and are adopting a similar strategy.

3.8 <u>Aquifer Management</u>

In Namibia nobody may abstract water from a perennial or ephemeral river for commercial purposes without a permit issued by the Government because all rivers are regarded as public streams. Similarly, certain aquifers that are shared by a large number of users have been proclaimed as water control areas and a permit is required to abstract the water. However, a person who wants to use the water for domestic purposes may abstract the water without a permit, but no borehole may be drilled in an artesian aquifer without a permit. This is to ensure that the borehole will drilled according to the drilling specifications required to ensure that there is no leakage from the artesian aquifer into other aquifers. Drilling companies must also be registered in terms of the law. The purpose of an abstraction permit is to control the equitable and reasonable allocation of water to different users, to ensure that the most beneficial use will be made of the water and to protect the aquifer against overuse and pollution. The permit application must be accompanied by a feasibility study and an environmental assessment. This must convince the Government that the most beneficial socio-economic use will be made of the quantity of water requested and that the most efficient water conservation methods will be applied when using the water. The environmental assessment is required to ensure that the soil and water are compatible, the aquifer will be protected from pollution and any desertification processes in the fragile, arid environment will be prevented. This information will enable the State to issue a permit to abstract a quantity of water that will not exceed the long term sustainable yield of the aquifer. The permit holder may not exceed the quantity of water allocated, must use the water for the intended purpose and must submit returns on the actual quantity of water used. If the user does not comply with the permit conditions, the permit can be withdrawn. The responsibility of the State is to measure the rainfall, the runoff, the recharge and the abstraction in the controlled aquifers, as well as to monitor the changes in the water levels and the water quality. This is done to determine what the magnitude of the recharge is, how the aquifer behaves under operational conditions and whether the quality of the water in the aquifer is adversely affected or polluted. If any unsustainable behaviour is detected, then appropriate measures must be taken to protect the water resource. The State therefore effectively takes charge at the upstream end of an aquifer while the consumer has to take responsibility for the sustainable and most efficient use of the water. One important strategy is to manage the demand and this can be done in many ways, depending on the type of water use. When irrigation is done, the most efficient irrigation methods should be used or high value crops cultivated. Water used in the industry and mining should be recycled. The less toxic effluents like domestic sewage could be treated to a certain, safe standard and reused as non-potable water for watering gardens, parks and golf courses. The water could also be treated in a reclamation plant to render it useable as potable water. Other means of achieving the objective of saving water through water demand management is to embark on a public awareness campaign to inform the consumer about the scarcity of water and the need to reduce the demand. The public must also be advised about the measures that could be taken to save water. Another instrument used in Namibia to control the misuse of water is the accepted policy to charge the consumer the full economic cost of the water supplied, but to make provision for those that cannot afford the water to receive a subsidy or to make a contribution in kind. The levy of water tariffs that makes provision for punitive tariffs to heavily tax water abusers has been proven as a very successful incentive for consumers to use less water.

4. CONCLUSIONS

It has been shown that the storage of surface water in sand filled dams, the conjunctive use of surface and groundwaters, the banking of groundwater and the artificial recharge of surface water can increase the efficiency in using surface water and improve the potential of aquifers considerably. The application of a very highly sophisticated airborne geophysical method and very down to earth human capabilities have been employed to determine the potential of an aquifer and to find water for small scale community water supply. The involvement of rural communities in the operation and maintenance of their water supplies as well as integrated aquifer management are crucial to ensure the optimal beneficial use of scarce groundwater sources.

5. ACKNOWLEDGEMENTS

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6. ABBREVIATIONS

a = annum

BGR = Bundesanstalt für Geowissenschaft und Rohstoffe

°C = Degrees Centigrade

CBM = Community Based Management

ENWC = Eastern National Water Carrier

m = metre

km = kilometre

M = Million

N$ = Namibian Dollar

US$ = United States Dollar

WPC = Water Point Committee

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Education	B.Sc., B Ing., Pr Eng., MEPA, MSAICE
	Piet is the Director: Resource Management in the Department of Water Affairs in the Ministry of Agriculture, Water and Rural Development in Namibia.
Professional Experience	He is a professional civil engineer and has broad experience as a water resource manager in Southern Africa. At present he directs five divisions dealing with surface water, groundwater, the water environment (quality and pollution), strategic water project planning and the administration of water legislation. In the past 25 years he has been involved in the development of water resource policy, legislation and regulations, as well as river basin management, resource investigations and applied water research.
Career	During his career in Government he obtained experience in the Construction, Operations and Planning Divisions in the Department of Water Affairs as he progressed through the ranks to his present position. He has been involved in surface water and groundwater assessments, master water planning, feasibility studies for diverse projects such as water supply infrastructure development, irrigation projects, artificial recharge, seawater desalination and institutional restructuring.
	He is a Commissioner in five Water Commissions on the internationally shared border rivers of Namibia, namely the Cunene, the Okavango, the Orange and the Kwando-Linyanti-Chobe tributary of the Zambezi River. Piet also serves in the Water Resources Technical Committee of the Water Sector in the Southern African Development Community, the Southern African chapter of the Global Water Partnership and he was a member of the Advisory Committee of the World Bank on Water Resource Management in Africa.
	His recent activities are related to major groundwater studies to determine the potential of the Kuiseb alluvial aquifer, the Tsumeb carbonate rock aquifer and the Stampriet artesian aquifer in Namibia. At present he is involved in feasibility studies on two hydropower projects, one on the Lower Cunene River and the other on the Okavango River, a study to improve the management of the Lower Orange River and the development of an integrated water resource management plan in the Okavango Basin. He is also the leader of the Namibian team participating in the negotiations to establish a water commission between the eight basin States on the Zambezi River.
Research and Teaching	Piet was involved in various water related applied research projects dealing with desalination, ecological studies, water demand management and the biological control of aquatic weeds. He has presented more than 30 papers, made contributions to several books on water matters and edited a number of publications.