# SAND-STORAGE DAMS:

# AN ALTERNATE METHOD OF RURAL WATER SUPPLY IN NAMIBIA

Dissertation submitted in partial fulfilment of the requirements for the Degree of MASTER OF PHILOSOPHY in ENVIRONMENTAL SCIENCE,

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by

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# EXECUTIVE SUMMARY

With 92% of its surface area being classified as having a semi-arid to extremely arid climate, Namibia is considered a 'dry' country (Van der Merwe, 1983). A result of this climate is that water is an extremely valuable resource in Namibia. Conventional dams constructed under these conditions have a poor storage efficiency due to high evaporation losses, and a short design life due to high siltation rates. Attempts aimed at developing a more efficient method of utilising surface run-off resulted in the construction of Namibia's first sand-storage dam in 1907 (Wipplinger, 1958).

A sand-storage dam consists of a weir type structure, placed across an ephemeral water course, behind which layers of sand are deposited by successive floods. Water flowing over the surface of a sand-storage dam infiltrates into these sediments, and is stored in the voids between sand grains. Depending on the porosity and composition of the sediments, the storage volume of a sand-storage dam can be up to 25% of the volume of the storage basin (Wipplinger, 1958). The evaporative losses of sand-storage dams are small and hence water can be stored for long periods of time, while extraction can be facilitated through wells, drains or boreholes (Burger and Beaumont, 1970). The potential of sand-storage dams as a simple and efficient method of utilising surface run-off appears to have been largely ignored during Namibia's history and today, boreholes and shallow wells provide the majority of Namibia's rural water supply needs (DWA, 1991).

The costs of establishing and installing a borehole are high, ranging from R 57 000 to R 180 000 depending on the depth of hole drilled and type of pump installed (DRWS, 1996). Because of these high costs, the Namibian Government has historically taken responsibility for the provision, operation and maintenance of rural water supply. However, in accordance with the principles advocated in the country's new Water and Sanitation Policy (WASP), an emphasis has been placed on shifting this responsibility to the communities utilising these water supplies (DWA, 1993). In April 1997, the Directorate of Rural Water Supply (DRWS) implemented a programme for the "Community Management of Rural Water Supply". This programme is to be phased in over nine years and during this time rural communities are expected to gradually take over full responsibility for the operation and maintenance costs of their water supply. In the final stage of this programme it is envisioned that these communities

will be required to replace broken equipment, and provide new installations themselves (DRWS, 1996).

Expecting rural communities to pay for the full cost recovery of their water supply will result in obvious socio-economic impacts on these communities (Sekhesa, 1997). However, the present reliance of many rural communities on groundwater resources gives them little alternative but to accept responsibility for the high costs associated with boreholes. This dissertation therefore, aims at assessing the feasibility of developing sand-storage dams as an alternate supply of water in the rural areas of Namibia.

To meet this objective, information was gathered by reviewing a wide range of appropriate literature, holding informal interviews with representatives from various governmental and private organisations, and by taking personal observations in the Khorixas and Gam regions of Namibia. This information was then used to fulfil the following specific aims:

- Identify the biophysical requirements for the development of a successful sand-storage dam.
- Identify which, if any, of the rural areas in Namibia display these biophysical characteristics.
- Assess the effectiveness of storing surface water in sand-storage dams, compared with that of conventional open-storage dams.
- Compare the implications of establishing a sand-storage dam, with that of a borehole, under the concept of 'sustainable development'.
- Develop a decision-making framework to guide the evaluation of a request for a new rural water supply.

## Biophysical Requirements

The biophysical requirements for the successful development of a sand-storage dam have been identified to include:

- A hilly or mountainous topography suited to the formation of well-defined river valleys. Sand-storage dams require a suitable foundation for the wall structure and sufficient gradient for rapid channel flow (Anbroeck, 1971).

- A geological region where the predominant parent rock in the catchment area will produce a coarse sediment load. Granites, quartzites and sandstones have been identified as the most favourable rock type (Wipplinger, 1958).
- The geotechnical characteristics of the material underlying the storage basin must either compose of low permeability bedrock to prevent seepage losses, or incorporate a fracture or fault that feeds a locally utilised aquifer, hence facilitating the artificial recharge of this aquifer. In order to prevent the structural failure of the dam wall it needs to be founded on an un-weathered solid rock foundation (Nilsson, 1988).
- A suitable supply of hand-sized rocks need to be locally accessible, as this is the material which will be used in the construction of a stone masonry dam wall (Wipplinger, 1975).

## Siting and Constructing a Sand-Storage Dam

Using topographical and geological maps of Namibia, it was ascertained that the following areas in Namibia display both the topographical and geological characteristics required for the successful development of sand-storage dams:

- Karas - central areas
- Hardap - central areas
- Khomas - throughout region
- Erongo - eastern areas
- Kunene - western/central areas

Once a sand-storage dam has been suitably sited, it is constructed in a 'staged' process over a number of years. The height of each stage of the dam wall is designed such that during times of flood the velocity of flow over the wall is sufficiently high that only coarse sands will settle behind the wall. This prevents an excessive accumulation of fine silts in the storage basin (Van Tonder, 1975).

Because each stage of the wall needs to be completely silted up before the next stage can be added, the rate at which a sand-storage dam is developed depends solely on the erratic and unpredictable hydrological characteristics of Namibia's ephemeral rivers. In this study it is estimated that a three stage sand-storage dam, built to a height of between 3-5 meters will take 6-8 years to reach its full storage capacity.

## Comparing Sand-Storage Dams with Open-Storage Dams

Storing surface water in conventional open-storage dams is an inefficient method of utilising a scarce natural resource. In comparison, a well-constructed sand-storage dam provides for efficient water storage, and will produce a source of high quality water long after a conventional dam has silted up. Although the staged method of constructing a sand-storage dam results in higher construction costs, the short life expectancy of open dams results in a higher price paid per $m^3$ of water over the life time of the structure.

## Comparing Sand-Storage Dams with Boreholes

A rigorous comparison has been developed for assessing the feasibility of sand-storage dams as an alternative to boreholes. This has been done by assessing each method of water supply under a set of criteria developed from the concept of 'sustainable development'. The results of this assessment are summarised under each of the criteria below:

- **Economic Feasibility**

  Although it was beyond the scope of this dissertation to accurately compare the development costs for each method and hence provide a comparative cost per $m^3$ of water supplied, it is clear that the operational and maintenance cost of a sand-storage dam will be markedly lower than those of a borehole. In addition, sand-storage dams are expected to have a longer production life, and are constructed with a higher probability of successfully producing water than boreholes. By providing their own labour and sourcing building materials locally, rural communities should be able to develop a sand-storage dam at a lower cost than that of establishing a borehole. It is therefore suggested that sand-storage dams are a more economically feasible method of rural water supply than boreholes.

- **Technical Suitability**

  The construction and utilisation of a sand-storage dam requires significantly less technological input than is required for the establishment, operation and maintenance of a borehole. Therefore, in terms of the technical resources available to rural communities, sand-storage dams are a more practical source of water supply than boreholes. A major disadvantage does however exist, and that is the length of time required for sand-storage dams to reach full storage capacity. Boreholes can be commissioned in a matter of 1-2 months, while a sand-storage dam may take several years.

- **Social Empowerment**

  The process of developing a sand-storage dam allows for more community ownership and self determination than the highly technological process of developing a borehole. However, owing to the relative obscurity of the concept of sand-storage dams, and the length of time required for their completion, initial community perceptions are likely to be negative towards this method of water supply.

- **Environmental Impacts**

  The cumulative impact of a number of sand-storage dams will be a reduction in the downstream surface and sub-surface flow continuum. A similar impact can be expected for a number of boreholes drilled into alluvial aquifers, in addition to an expected lowering of local water table levels. However, boreholes drilled into secondary aquifers are unlikely to have any effect on downstream flow. As both boreholes and sand-storage dams are methods for providing a point source of water into Namibia's semi-arid environment, the impact of either method will depend more on the volume of water supplied, than on the actual method of supplying the water. The greater the volume of water supplied the greater the likelihood of overstocking resulting in overgrazing and soil degradation. As the volume of a sand-storage dams is expected to be lower than that of a borehole established in a well-defined alluvial or secondary aquifer, the overall environmental impacts of sand-storage dams are expected to be lower than that of boreholes.

Although sand-storage dams appear to be the more favourable method of rural water supply, they have two drawbacks which limit their ability to be developed as an alternative to boreholes. The first of these concerns is the length of time required for a sand-storage dam to reach its full storage potential. The second concern is that the fixed storage volume of sand-storage dams are likely to be smaller than that of boreholes established in well-defined alluvial or secondary aquifers, and as such may not meet the water requirements of many rural communities. These concerns point towards sand-storage dams being developed in conjunction with boreholes, as part of a long-term planning process aimed at providing sufficient water to meet the basic needs of Namibia's rural communities, without encouraging the oversupply of water.

## Conclusion

In conclusion, it is suggested that future requests for a new water supply from a rural community in the Karas, Erongo or Kunene regions will need to be assessed under a broader, more holistic set of criteria than is currently employed by the DRWS. If the DRWS intend to implementing their new "Community Management of Rural Water Supply" programme in a responsible manner, they are then obliged to consider alternate methods of water supply. One alternative to conventional methods of water supply which needs to be further investigated is the concept of storing surface run-off in sand-filled dams. An emphasis needs to be placed on the accurate identification of specific areas where sand-storage dams can be successfully established, and the communities within these areas must be informed of the additional options available to them for the future development of their water supply.

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| | |
|---|---|
| Aquifer | A rock (or sand) layer which will absorb water and allow it to pass freely through. |
| Artificial Recharge | The recharge of aquifers due to human intervention or management of the hydrological system. |
| Communal land | Land available for common use. In Namibia this land is currently owned by the State. |
| Desertification | Land degradation in arid, semi-arid and sub-humid areas resulting from various factors, including climatic variations and human activities. |
| Ephemeral river | A river which flows only periodically, for instance during periods of heavy rains in an arid or semi-arid environment. |
| Perennial river | A river which flows at all times of the year. |
| Permeability | The ease with which liquids can pass through rocks or a layer of soil. Expressed as rate of discharge per unit area, for example ($m^3$/day). |
| Porosity | The volume of water which can be held within a rock or soil, expressed as the ration of the volume of the voids to the total volume of the material. |
| Sedentarism | The permanent settlement of humans and livestock in an area. |
| Specific Yield | Denotes the volume of water that can be withdrawn from a sand medium as a percentage of the total space occupied by the particular deposit. |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| CSIR | Council for Scientific and Industrial Research |
| DET | Directorate of Environmental Affairs |
| DRWS | Directorate of Rural Water Supply |
| DWA | Department of Water Affairs |
| MET | Ministry of Environment and Tourism |
| NAPCOD | Namibian Programme to Combat Desertification |
| pers. comm. | personal communication |
| PRA | Participatory Rural Appraisal |
| RWEO | Rural Water Extension Officer |
| TDS | Total Dissolved Solids |
| UCT | University of Cape Town |
| UNDP | United Nations Development Programme |
| WASP | Water and Sanitation Policy |
| WHO | World Health Organisation |

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# CHAPTER 1:

# INTRODUCTION

# 1 INTRODUCTION

## 1.1 Background to the Project

With a mean annual rainfall of only 250 mm, Namibia is southern Africa's driest country. Low rainfall figures, combined with high evaporation rates, result in 92% of the total surface area of Namibia being classified as having a semi-arid to extremely arid climate (Van der Merwe, 1983). A consequence of this climate is that the only perennial water sources available in Namibia are rivers which run along its northern and southern boundaries, draining regions of less arid Angola and South Africa. The water requirements of the interior of country are met by capturing and storing the periodic flow of ephemeral rivers and by utilising groundwater resources. However with the high evaporation and siltation rates characteristic of Namibia's environment, conventional dams are not a very efficient method of storing water (Burger and Beaumont, 1970), and it is estimated that about 80% of Namibia's population rely on water supplies from shallow wells or boreholes (DWA, 1991).

It can be argued (UCT, 1997), that boreholes effect the whole range of components which may be included under the broad term of 'environment'- that is, the physical, ecological, social and economic components that interact and determine the integrity of the environment, and the quality of human life. This has raised concern in Namibia as historically little, or no environmental assessment is undertaken in the planning of borehole provision (Koch and Tarr, pers. comm.). In an attempt to address these concerns the Namibian Programme to Combat Desertification (NAPCOD), commissioned the 1996/97 Masters class from the Environmental and Geographical Department at the University of Cape Town (UCT), to assess the environmental impacts of emergency borehole supply in rural areas of Namibia. The objective of this assessment was to provide a 'baseline report' which highlighted the environmental impacts of these boreholes, and contributed towards the establishment of a scientific basis from which the planning process for boreholes may be informed.

The UCT project commenced in November 1996, and included a fieldtrip to Namibia from 26 January to 26 February 1997. The aim of the project was to assess the environmental impacts of emergency boreholes in the Khorixas and Gam areas of Namibia (see Figure 1.1). A draft copy of the baseline report was submitted to NAPCOD on the 7 April 1997.

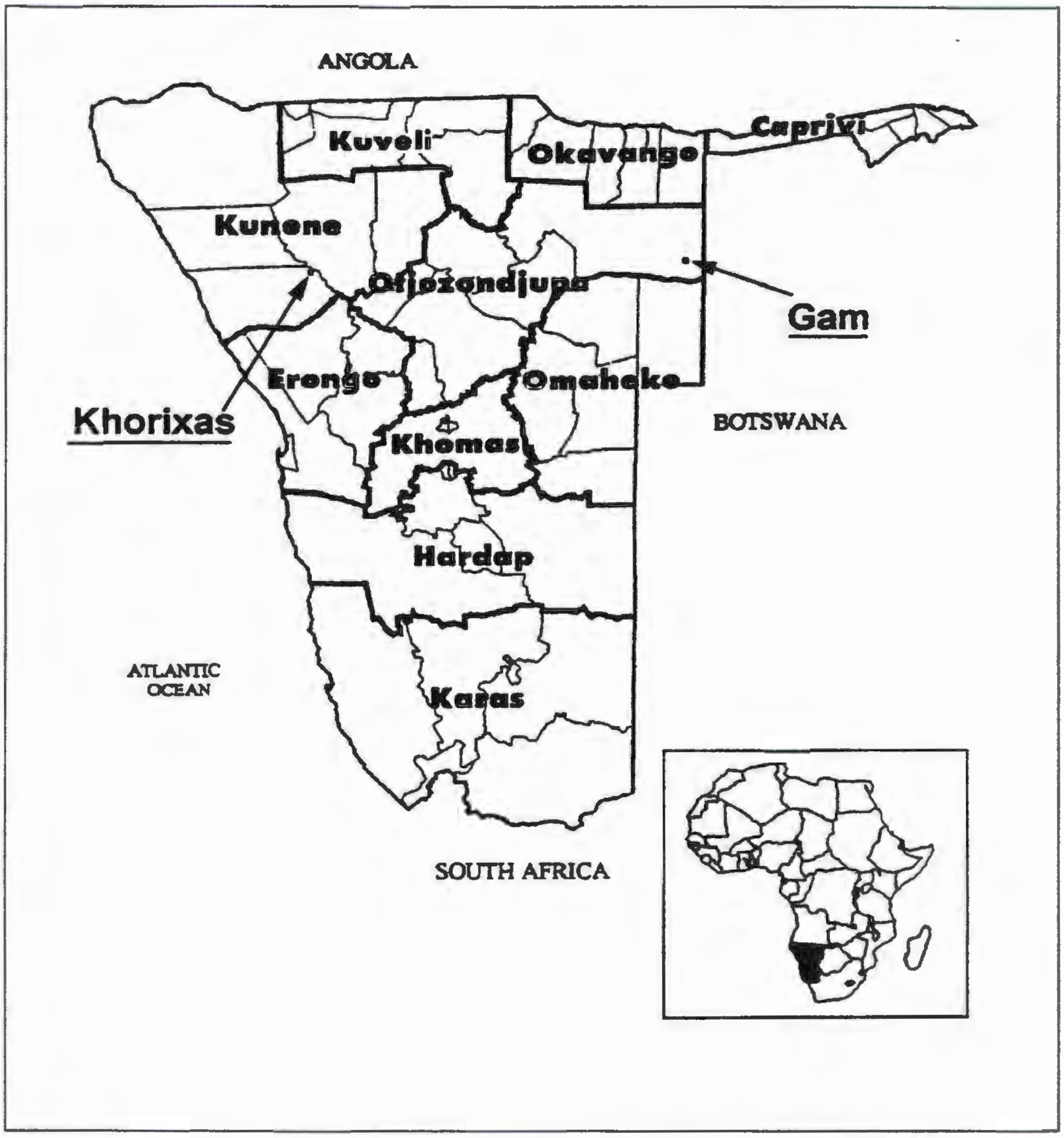



**Figure 1.1: Location of Gam and Khorixas in Namibia**

In addition to the baseline report, it was also agreed that individual dissertations relating to some aspect of this project would be drawn up by each of the students, and that these dissertations would be made available to NAPCOD. These dissertations are expected to be developed with more analytical rigour, and a greater depth of understanding than in the baseline report. While the baseline report mostly contributes information, these dissertations are intended to contribute to increased understanding of environmental aspects of rural water supply in Namibia. It is hoped that, together they will contribute to the development of natural resource strategies in Namibia.

Prior to 1997, the Namibian Government took full responsibility for the installation, operation and maintenance of water supplies in the rural areas of Namibia. However, under the principles developed in Namibia's new Water and Sanitation Policy (WASP) an emphasis has been placed on ensuring "environmentally sustainable development", and Namibia's rural communities are now expected to take an increasing responsibility for managing their own water supply (DWA, 1993). It is envisioned that over the next 9 years rural communities will be required to take full responsibility for the operation and maintenance costs of their water supply, and will also be expected to fund the replacement of broken down equipment and the provision of new installations themselves (DRWS, 1994).

This new emphasis towards implementing a policy of "Community Management of Rural Water Supply" (DRWS, 1994), motivates a review of methods of rural water supply, including the specific focus of this report on the little-known and little-used strategy of sand-storage dams, used either alone or in conjunction with open dams or boreholes.

A sand-storage dam is a dam whose basin has filled up with medium to coarse sands, deposited during the periodic flooding events associated with ephemeral rivers. Water is then stored in the voids between the sand grains (as in a primary sand aquifer). Evaporative losses are small, and the water can be recovered by means of drain pipes, wells or boreholes (Van Tonder, 1975). The concept of storing water in sand was first practised in Namibia in 1907, by the then German colonial administration, in an attempt to develop more efficient methods of storing water than was practised in conventional open-storage dams. After World War I little interest was shown by the South African administrators in sand-storage dams and with the exception of a period between 1955-1975 when the idea was revisited and a number of sand-storage dams built on commercial farms (Lau and Stern, 1990), boreholes have developed as the major source of rural water supply in Namibia (DWA, 1991).

## 1.2 Aims and Objectives

This report is one of the individual dissertations, and it addresses methods of water supply to rural communities in Namibia. The overall objective of this study is to assess the feasibility of developing sand-storage dams as an alternate supply of water in rural areas of Namibia. This interest arose out of a concern that although the concept of storing water in sand-filled dams has been periodically applied in Namibia, its potential for efficiently utlising surface run-off has been largely ignored. This study therefore aims at assessing the environmental and economic benefits of sand-storage dams, and to determine if there are any areas in Namibia where the concept might be developed as a feasible alternative to conventional methods of rural water supply.

In order to achieve these objectives, the specific aims of this study are to:

- ❑ Identify the biophysical requirements for a successful sand-storage dam.
- ❑ Identify which, if any, of the rural areas in Namibia display these biophysical characteristics.
- ❑ Assess the effectiveness of storing surface water in sand-storage dams, compared with conventional open-storage dams.
- ❑ Compare the implications of establishing a sand-storage dam, with that of a borehole, under the concept of 'sustainable development'.
- ❑ Develop a decision-making framework to guide the evaluation of a request for a new rural water supply.

With the expectations on Namibia's rural communities to take ever increasing responsibility for their water supply, it is hoped that the information and results presented in this report will help contribute towards providing some rural communities with a greater range of alternatives regarding the 'sustainable development' of their water supply.

# 1.3 Methodology

## 1.3.1 Information Gathering

The following methods were used in both individual and group efforts to collect data and general information:

***Literature Review***

A wide range of appropriate literature was reviewed for the purpose of providing a solid understanding of the theoretical background of sand-storage dams and Namibian rural water supply in general. As the concept of sand-storage dams has not been applied in Namibia for many years, much of the literature on this subject was written and published in the late 60's and early 70's.

***Interviews***

Some of the information presented in this study has been sourced from a series of informal interviews. These interviews took place both in Cape Town and Namibia with representatives from governmental and private organisations. During a four week fieldtrip to Namibia, from 26 January to 26 February 1997, Participatory Rural Appraisal (PRA) techniques were used to gather information from the members of rural communities in the Khorixas and Gam areas of Namibia (refer to Figure 1.1).

***Personal Observations***

The fieldtrip enabled direct observations to be made regarding the rural environment in the southern Kunene and Bushmanland regions of Namibia (refer to Figure 1.1). Observations in these areas were focused around rural communities regarding their dependence and utilisation of boreholes.

## 1.3.2 Analysis of Information

In order to assess whether sand-storage dams are a feasible alternative to providing rural water supply in Namibia, the information gathered using the methods described above is analysed in three stages:

i. Initially, an assessment is made of which regions in Namibia display the biophysical characteristics necessary for the successful development of sand-storage dams. This assessment is done by identifying these biophysical requirements, and then consulting maps which portray these biophysical characterises to determine which, if any, of the rural regions in Namibia are preferential areas for sand-storage dams.

ii. As sand-storage dams and boreholes both display many advantages over conventional open-storage dams regarding the efficient utilisation of Namibia's water resources, an initial assessment compares the practicality of storing surface water in sand-storage dams with that of open-storage dams. In effect, this initial assessment 'knocks out' the concept of using open-storage dams as a decentralised water supply for Namibia's rural communities.

iii. The broad environmental implications of developing a sand-storage dam are then compared with those of establishing a borehole. The methodology used in this comparison borrows heavily from the 'Framework Method' developed for environmental assessment. The Framework Method is used primarily to convey the information generated during the environmental assessment process in a non-quantitative and easily understandable method to decision-makers. In this study, sand-storage dams and boreholes are assessed individually, under a set of points developed from the concept of 'sustainable development' and these results then presented in a table that aims at highlighting the significance of the assessment. Based on the information presented in the framework table, the feasibility of sand-storage dams is evaluated in comparison with boreholes in the context of rural water supply.

## 1.4 Limitations of this Study

This study has been constrained by practicalities, and the conclusions of the study are limited by the following:

- This study focuses strictly on the supply of water rural communities in Namibia which do not have access to perennial water supplies. Although some of the information presented in this report could contribute to developing water supplies for commercial farms and urban settlements, information is not presented nor has it been processed in this context.
- It was not practical to incorporate questions regarding sand-storage dams into the Participatory Rural Appraisal (PRA) techniques which were used during the fieldwork. Fieldwork was focused on covering the basic requirements for the baseline report and as these techniques were time consuming, there was no opportunity to determine the perceptions of any rural communities regarding water supply methods.
- Sand-storage dams previously constructed in Namibia, appear to have all been developed in commercial farming areas (Wipplinger, 1958). The fieldtrip to Namibia, however, was focused primarily on collecting data in the communal farming areas. As a result there was no opportunity identify the location of any existing sand-storage dams from the Namibian Archives, nor to observe firsthand any sand-storage dams. All the information presented on sand-storage dams in this study has been sourced from the available literature.
- The data presented in the comparison sections of this study is primarily of a non-quantitative nature. Personal biases and values will, therefore, have affected the outcome of the evaluation of this data towards drawing up conclusions.

## 1.5 Structural Outline

This report consists of eight chapters. Each chapter is divided up into various sections and, where necessary, sub-sections.

In Chapter 1, the Introduction, a general overview of the report is provided. The following two chapters set the context under which rural water supply is developed in Namibia. Chapter 2 provides a brief overview of the biophysical factors affecting water supply in Namibia, while

Chapter 3 outlines the principles and objectives of Namibia's new Water and Sanitation Policy (WASP), and highlights the changes that this has brought to the provision of rural water supply.

Chapter 4 explains the principles behind sand-storage dams and identifies the biophysical characteristics which are required for the successful development of these dams. This chapter highlights the various aspects which need to be considered during the siting, design and construction phases of sand-storage dams. The final section of this chapter identifies those regions in Namibia which display the biophysical characteristics most suited to the development of sand-storage dams.

In Chapter 5 sand-storage dams and conventional open-storage dams are compared. A brief assessment is made of the practicality of each method as a form of decentralised water supply to rural communities in Namibia. This comparison is brief as it is quickly seen that open-storage dams offer little advantage for this specific context. In Chapter 6 a comparison is presented of the expected environmental implications of developing sand-storage dams and boreholes in terms of multiple criteria relevant to Namibia's rural environment.

In Chapter 7, the findings from Chapters 4, 5 and 6 are formalised in a decision-framework that is designed to help in facilitating the evaluation of a request for a new rural water supply. Chapter 8 concludes the study.

# CHAPTER 2:

# A BIOPHYSICAL OVERVIEW OF NAMIBIA

# 2 A BIOPHYSICAL OVERVIEW OF NAMIBIA

Namibia is situated on the west coast of southern Africa, between latitudes 17.5$^0$ and 29$^0$ south. With an estimated population density of 2.0 people per km$^2$, Namibia is one of the most sparsely populated countries in the world (UNDP, 1996). This low population density exists largely because Namibia is an arid country, with limited water resources. Understanding the extent of this aridity, and realising the importance of water as the principle limiting factor in Namibia is critical for any study in rural water supply.

This chapter sets the context of the biophysical conditions under which rural water supply is developed in Namibia. A brief overview of Namibia's climate is presented, and this is followed by an overview of the country's hydrological conditions and the water resources. In addition, Namibia's major topographical features and broad geological classifications are also presented, as these factors weigh heavily in determining the feasibility of sand-storage dams in Namibia.

## 2.1 Climate

Namibia's climate is governed by the country's geographic position in the southern tropics, and further influenced by the cold Benguela current running along its western coast. The high pressure conditions of the tropics, combined with the cool air masses associated with the Benguela current, result in a mean annual rainfall of only 250 mm, making Namibia the driest country in Southern Africa (DWA, 1991).

Rainfall generally originates from the Indian Ocean, is carried across by easterly trans-continental winds, and results in decreasing rainfall figures from east to west across the country, as seen in Figure 2.1 (Van der Merwe, 1983). The Namib Desert's annual mean of less than 20 mm makes it one of the driest areas in the world, while the average mean in the Eastern Caprivi is over 700 mm (refer to Figure 2.1). In broad terms then, a distinction may be made between the extremely arid coastal zone, the arid southern interior, the semi-arid central and north-western area, and the small sub-humid north-eastern zone (Van der Merwe, 1983). Table 2.1 illustrates the extent of the surface areas within the country which are associated with each of these climatic distinctions.

**Table 2.1: Surface area of Namibia's various climatic areas (after Van der Merwe, 1983)**

| Climatic Area | Annual Rainfall | Percentage Surface Area |
|---|---|---|
| Extremely arid (coastal zone) | <100 mm | 22% |
| Arid (southern interior) | 100-300 mm | 33% |
| Semi-arid (central and north-western area) | 300-500 mm | 37% |
| Sub-humid (north-eastern zone) | >500 mm | 8% |

Precipitation throughout Namibia occurs mainly during the summer months between November and April, by means of very intense but scattered thunderstorms in the late afternoon and at night. General rainfall patterns are erratic and spatially variable, with average deviations of rainfall from the mean annual average being as high as 80% in the dry south-western area, to as little at 20% in the north-east (DWA, 1991).

Namibia's potential annual evaporation rates are high, varying between 2 600 mm in the north (420% in excess of rainfall) and 3 700 mm in the central-southern area (1 750% in excess of rainfall) (refer to Figure 2.2). These high evaporation rates characteristic of the interior plateau of the country may be attributed to high day temperatures, together with prevailing lower atmospheric humidity and air pressure (Van der Merwe, 1983). The effect of these evaporation rates is compounded by the fact that the period of highest evaporation coincides with the summer rainfall season, thereby reducing the effectiveness of the low rainfall in these areas even further (*ibid.*).

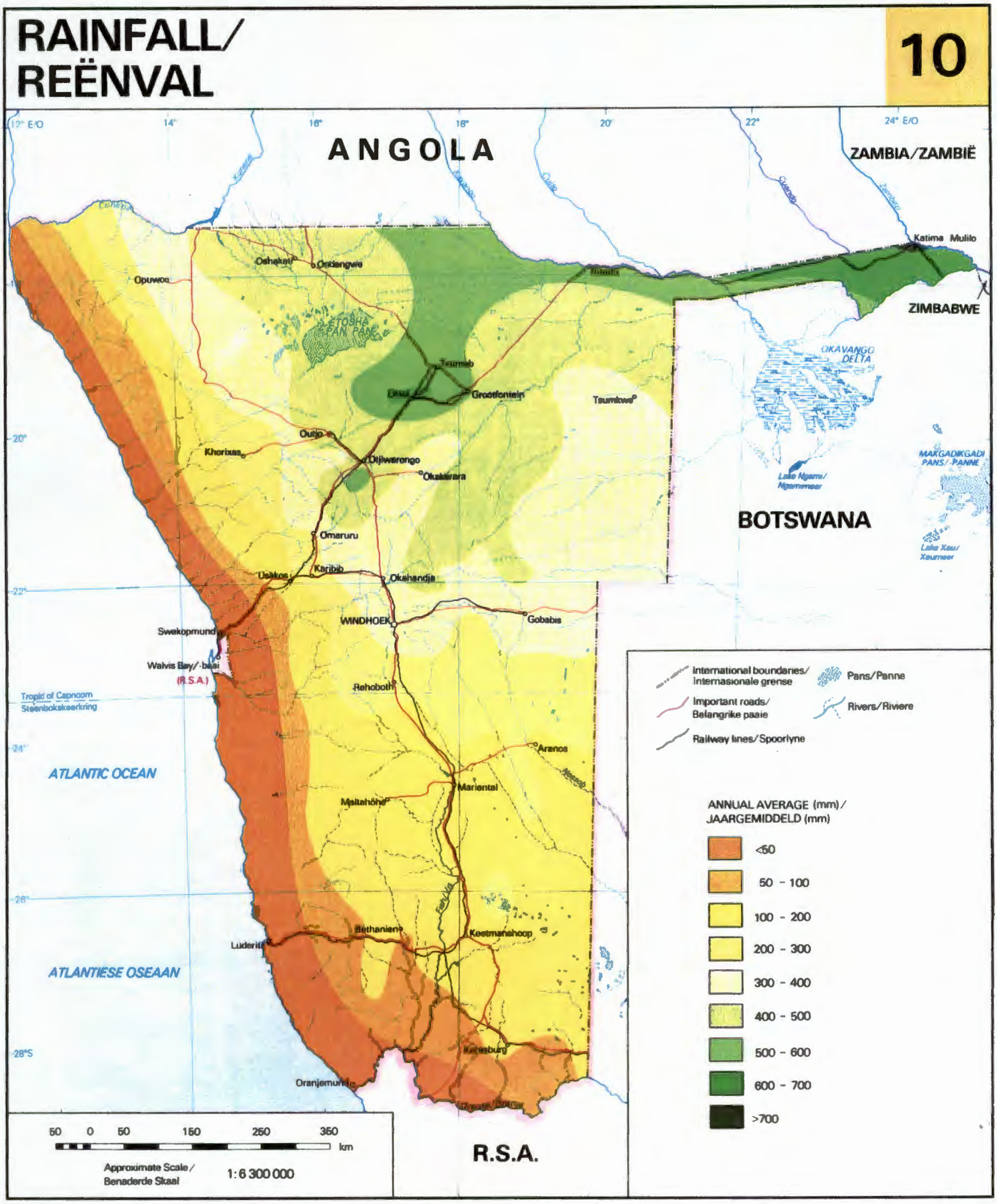



**Figure 2.1: Annual mean rainfall figures in Namibia (from Van der Merwe, 1983)**

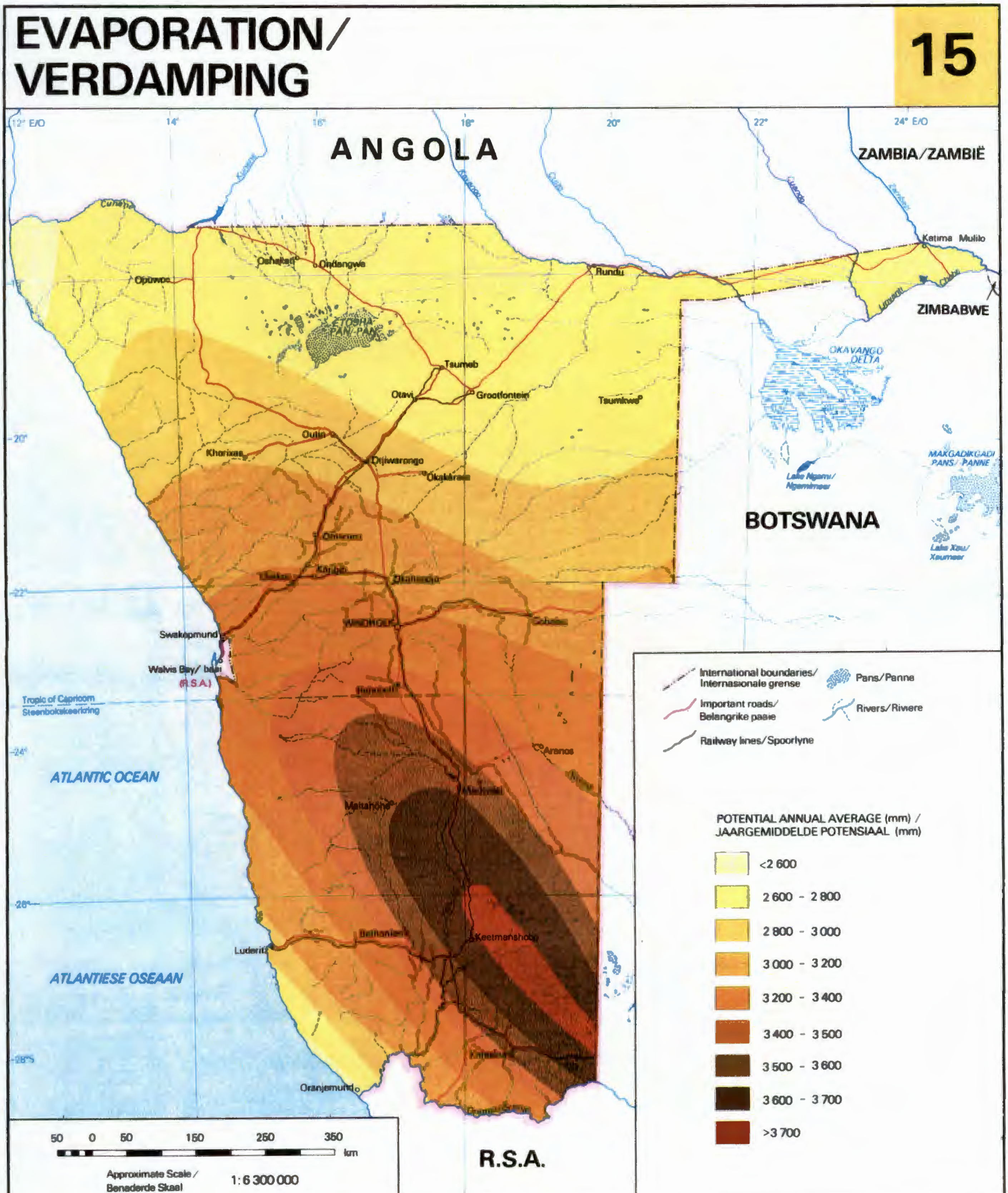



**Figure 2.2: Potential annual evaporation rates in Namibia (from Van der Merwe, 1983)**

## 2.2 Hydrology

Namibia's climatic extremes contribute to an inefficient hydrological cycle in terms of the amount of water which is available for human activities. Referring to Figure 2.3, it is estimated that on average 83% of the total rainfall evaporates shortly after precipitation, leaving 17% available as surface runoff. Of this surface runoff, 1% recharges groundwater sources, 14% is lost through evapotranspiration, and only 2% is net runoff available to supply human and environmental requirements (DWA, 1991).

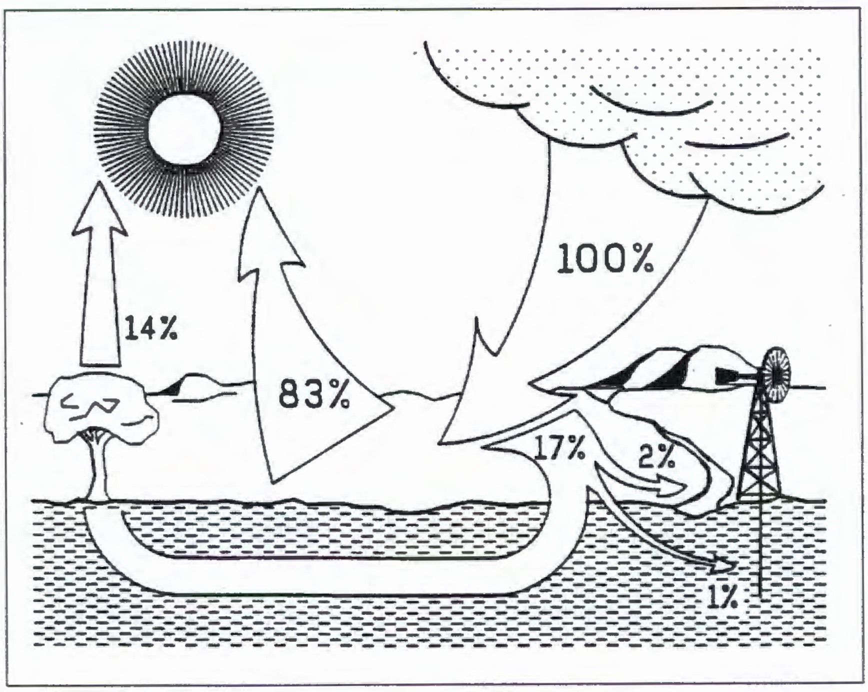



**Figure 2.3: Namibia's hydrological cycle (from DWA, 1991)**

The effects of this extreme hydrological cycle can be clearly seen in the limited availablity of perennial water resources in Namibian, and the heavy reliance which is placed on ephemeral and groundwater resources.

### 2.2.1 Perennial Rivers

The only perennial water sources available to Namibia are the Cunene, the Okavango, the Kwando-Linyanti-Chobe and the Zambezi rivers on the northern border, as well as the Orange River on the southern border. These rivers all originate in neighbouring countries where higher rainfall patterns support year-round flow. Although perennial rivers supply 23% of Namibia's water demand, this is only to villages and towns close to these sources. The majority of the country does not have access to these water resources due to the vast distances and costs involved in transporting this water to the interior regions (Bethune, 1996).

### 2.2.2 Ephemeral Rivers

In contrast to the perennial rivers along its borders, rivers which originate within Namibia are all ephemeral - flowing only after strong rains have fallen over their catchment area. For most of the year these Namibian rivers are dry, sandy channels (Jacobson, *et al.*, 1995). Studies by Davies *et al.* (1994) indicate that rivers draining semi-arid areas generally have high annual sediment loads. From Figure 2.1 it is clear that the majority of Namibia's ephemeral rivers originate in areas with a semi-arid climate, and hence carry high sediment loads. This high sediment volume results in the rapid silting up of water storage reservoirs.

Although subject to rapid silting rates and substantial evaporative losses, ephemeral surface water is stored in large, open reservoirs and which provide about 20% of Namibia's total water demand (DWA, 1991).

### 2.2.3 Groundwater

Although only 1% of the Namibia's precipitation recharges groundwater supplies, groundwater resources provide for the bulk of the country's water demand - 57% (DWA, 1991). In rural areas this reliance on groundwater is even greater, and it is estimated that about 80% of the population rely on water supplies from shallow wells or boreholes (*ibid.*). Namibia has approximately 32 000 boreholes which deliver water, with yields varying from as little as 0.5 $m^3$ per hour for rural communities and farm installations, to as high as 20 $m^3$ per hour for domestic and industrial water supply schemes (*ibid.*)

All water available as groundwater in Namibia originates from rainfall, whether recent or not. The occurrence and recharge of groundwater therefore depends on a combination of sufficient rainfall and favourable hydrological conditions. Groundwater sources in Namibia are associated with following major geological environments (DWA, 1991):

- **Secondary Structures**

  The largest part of the country is covered by geologically ancient rocks which are inherently impervious. Groundwater within these areas is found in secondary structures (secondary aquifers) along joints, bedding planes, shear zones and faults. The majority of Namibia's boreholes are sited on secondary aquifers (Simmonds, pers. comm.).

- **Carbonate Rocks**

  Carbonate rocks, including marble, limestone and dolomite which generally have solution cavities, can contain good quantities of groundwater. These cavities are formed when percolating rainwater dissolves carbonates and thus develop more readily along joints, faults and bedding planes.

- **Volcanic Intrusions**

  Throughout large parts of Namibia volcanic magma has intruded the older formations in the form of pipes, dykes and sheets. The contacts between these features are frequently water bearing.

- **Porous Sediments**

  Water bearing porous sediments are good aquifers, and the most important of these aquifers are found within the Karoo Sediments.

- **Unconsolidated to Semi-consolidated Sediments**

  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 west coast. In areas of adequate rainfall these deposits may contain groundwater.

- **Stream-bed Alluvials**

The stream-bed alluvials, or sand-filled riverbeds, are important sources of groundwater since they are periodically recharged by floods. They are usually shallow, operate as unconfined systems and are composed of unconsolidated sands and gravels. Sand-storage dams simulate alluvial aquifers by creating a structure to entice the deposition of sands and gravels.

In the stream-bed alluvials groundwater is found close to the surface. In other environments however, the depth to the water table varies considerably depending on the quantity of water abstracted, topography, geology and climate of the area and is on average about 100 m up to 200 m deep (DWA, 1991).

## 2.3 Topography

Namibia's topography is very varied. The expanses of desert, sand dunes and mountains found in the western regions contrast starkly with the flat plains which dominate the topography of the central and north-eastern regions (refer to Figure 2.6). Figure 2.4 below shows a typical topographical profile of Namibia, from Swakopmund on the west coast through Windhoek and Gobabis to the Botswana border in the east. Three prominent zones are clearly visible: a narrow coastal plain not rising higher than 500 m, an eroded escarpment reaching altitudes of 1500 - 2000 m, and an extensive interior plateau at altitudes of 1000 - 1500 m.

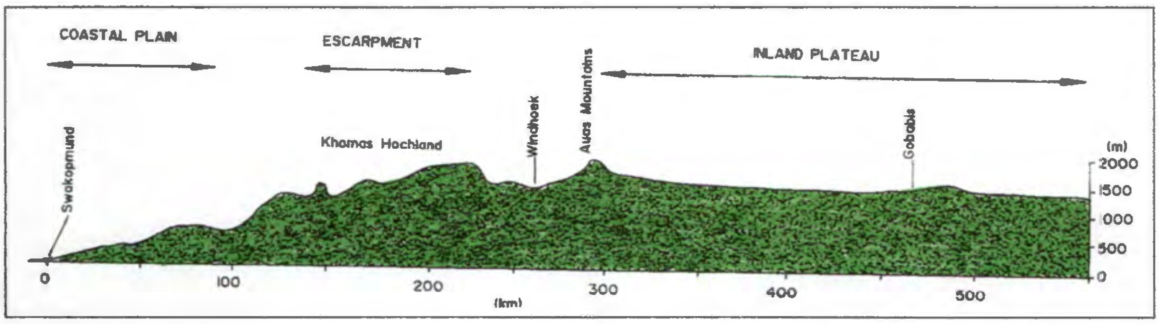



**Figure 2.4: Typical topographical profile of Namibia (from Van der Merwe, 1983)**

A topographical map is presented in Figure 2.6, and a graphical represention of the percentage distribution of these landscapes can be seen in Figure 2.5. From Figure 2.5 it is clear that more than half of Namibia's landscape is dominated by plains and dunes. The more limited occurrence of mountainous terrain is confined mainly to the escarpment region and the central interior.

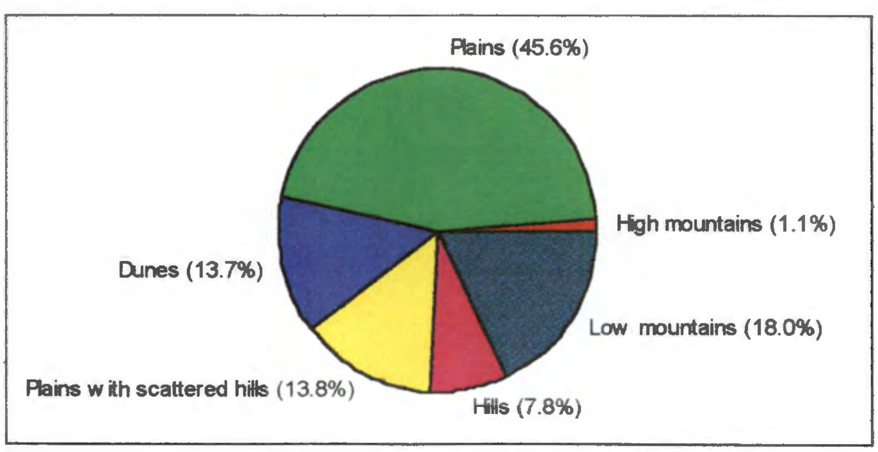



**Figure 2.5: Percentage distribution of different landscapes in Namibia (from Van der Merwe, 1983)**

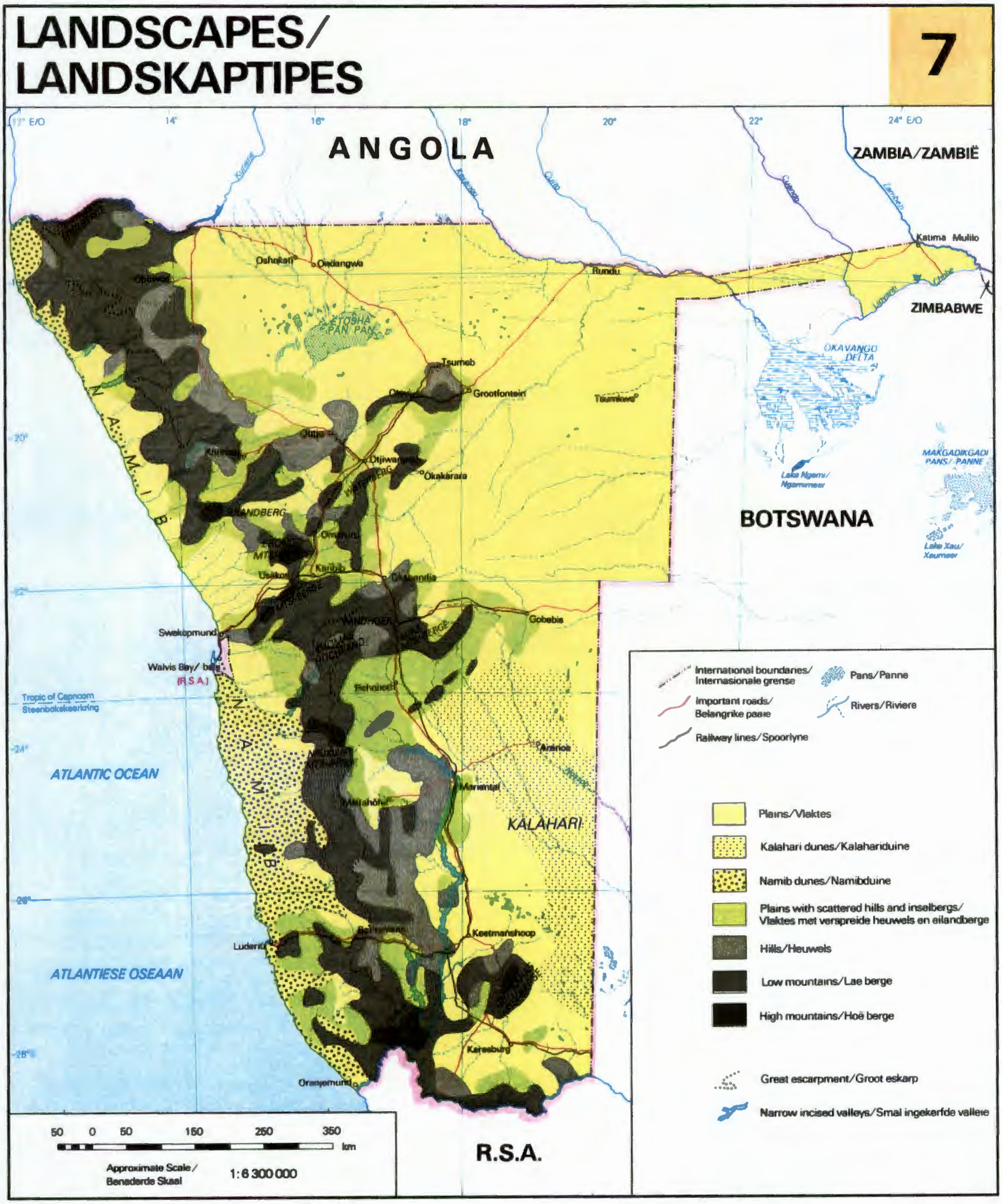



**Figure 2.6: Topographical map of Namibia (from Van der Merwe, 1983)**

## 2.4 Geology

Understanding the general geological categories within Namibia is important with regard to determining regions within Namibia which display geological characteristics suitable for the development of sand-storage dams. A summary is given in Table 2.2 of the geological categories found within Namibia and is structured according to their age, lithostratigraphic unit and rock type. The location of these geological classifications is presented Figure 2.7, and will be referred back to in Chapter 4 in order to determine areas suitable for sand-storage dams.

**Table 2.2: Namibian geological categories and associated rock types (from Van der Merwe, 1983)**

| Isotopic Age (million years) | Period | Lithostratigraphic Unit | | |
|---|---|---|---|---|
| | | Sequence | Group | Rock Type |
| ± 65 | Tertiary to Quaternary | Post-Karoo Complexes | Kalahari | Sandstone and calcrete |
| | Cretaceous | | | Granite plutons |
| ± 140 | Carboniferous to Jurasic | Karoo | | Basalt & Dolerite intrusions |
| | | | Ecca | Sandstone and shale |
| ± 345 | Cambrian | Post-Damara | | Granite |
| | | | Nama | Sandstone and shale |
| ± 570 | Namibian | Damara | Mulden | Quartzite |
| | | | Swakop | Schist |
| | | | Otavi | Dolomite |
| | | | Nosib | Quartzite |
| ± 1 090 | Mokolian | Sinclair | | Quartzites<br>Volcanic rocks<br>Intrusions |
| ± 1 500 | | Rehoboth | Khoabendus | Quartzites |
| ± 2 000 | | | | |
| > 2 100 | Vaalian | Complex<br>Epupa | Haib | Orange River volcanic rocks<br>Metamorphic basement complex |

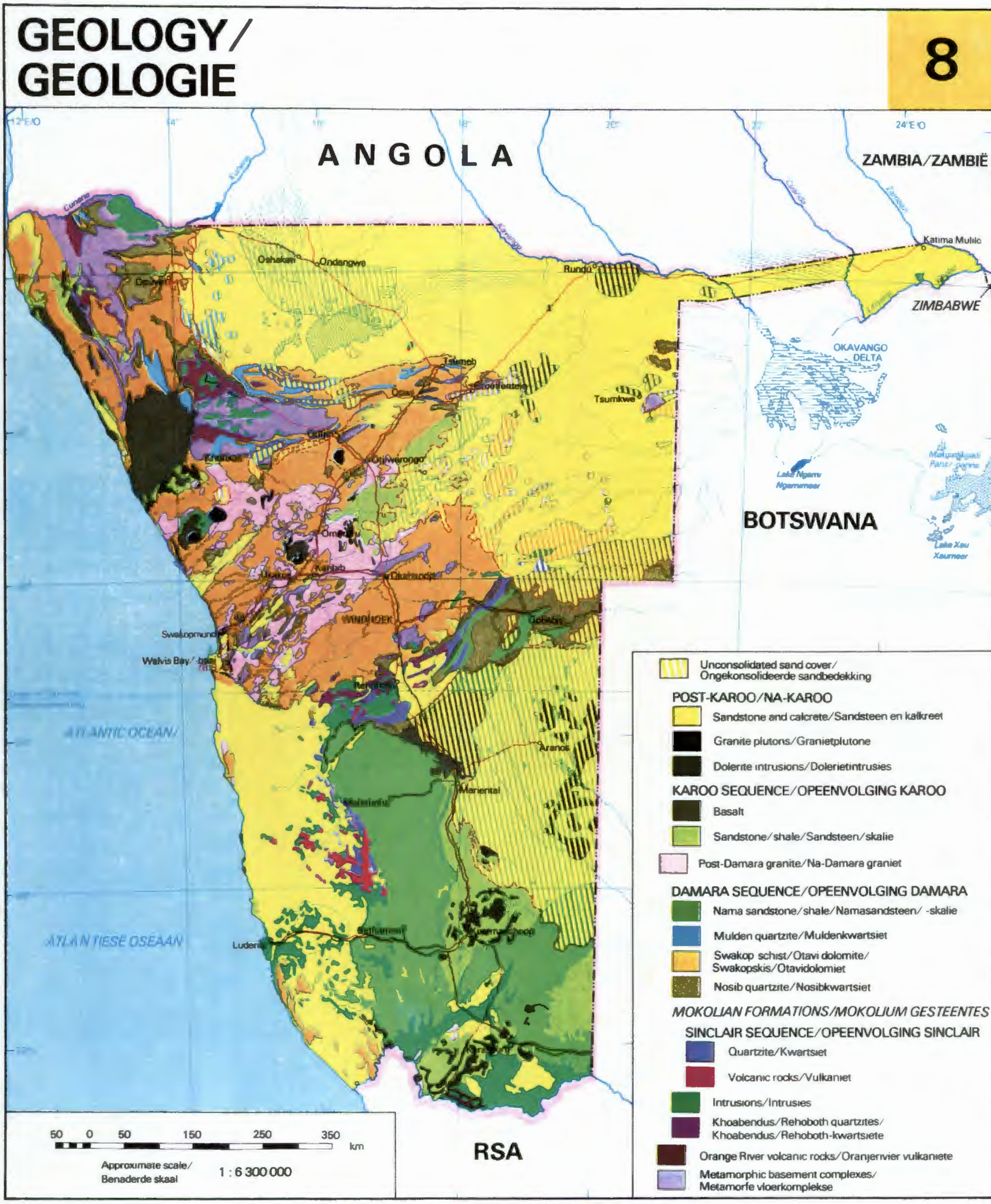



**Figure 2.7: Geological map of Namibia (from Van der Merwe, 1983)**

## 2.5 Conclusion

Rainfall is arguably the most important single variable shaping the ecological, social and economic environment in Namibia. From the climatic information presented in this chapter, it is evident that 92% of the total area of Namibia may be classified as having a semi-arid to extremely arid climate (Van der Merwe, 1983). In addition, it can be seen that in those areas of Namibia where rainfall figures are low, the potential evaporation rates and rainfall variability are at a maximum. It can thus be expected that large water deficits and periodic droughts are the norm in Namibia (Bethune, 1996).

As a result of this combination of low rainfall and high evaporation rates, no perennial water sources originate from within the country. The periodic flow of ephemeral rivers in the interior provides for 20% of Namibia's water demand, while groundwater resources provide for 57% of this demand. With more than 80% of the total rural population relying on water supplies from shallow wells or boreholes, groundwater is obviously an extremely important resource in Namibia.

# CHAPTER 3:

# RURAL WATER SUPPLY IN NAMIBIA

# 3 RURAL WATER SUPPLY IN NAMIBIA

After independence from South Africa in 1989, the Namibian Government realised that a major shortfall in water supply existed in the rural areas. It was estimated that in 1990 only 50% of the approximately 900 000 rural Namibians had reliable sources of safe water (DWA, 1993). In addition, it was realised that the overwhelming majority of existing rural water points were substandard, both in terms of the type of facilities installed, and in terms of the conditions of these facilities (*ibid.*). As a result, the Government focused considerable attention on developing future objectives and policies for the water and sanitation sector.

An inter-ministerial committee was established and this committee ultimately formulated the Water and Sanitation Policy (WASP). WASP, which was approved on 21 September 1993 defines the scope of services expected to be rendered by different sectors and provides long term principles and objectives for provision of water supply in Namibia (*ibid.*).

In this chapter, the principles and objectives which are defined in WASP will be further investigated as these are what is driving the present emphasis in Namibian rural water supply towards promoting greater community ownership of water points.

## 3.1 Namibia's Water and Sanitation Policy (WASP)

Prior to the formulation of WASP, the Namibian Government had been approaching rural water supply with a 'top-down' approach. By taking on the role of *provider*, all water-related decisions were being made by the Government and all the rural water facilities were owned, maintained and controlled by the Government. Realising that this approach was not working effectively, the developers of WASP gave due attention to the growing body of international evidence showing that rural water supply systems are neither sustainable, nor reliable, without increased user management and community control over their water resources (DRWS, 1996).

With the implementation of WASP, the Government intends to shift its role from *provider* to that of *facilitator*. As a *facilitator*, the Government will assist communities in the initial stages of the installation of new water points and where necessary, in the repairs of serious breakdowns. Over time it is hoped that the Government can focus its attention specifically on the expansion of improved infrastructure to reach all Namibians, leaving the maintenance and repairs of water points the responsibility of the community utilising that water point (DWRS, 1996). This change in focus required that the Department of Water Affairs (DWA) had to be restructured, and the newly formed Directorate of Rural Water Supply (DRWS) was given the responsibility for rural water supply, thus creating the institutional capabilities to take on the role of *facilitator* (UCT, 1997).

The following principles form the foundation of WASP (DWA, 1993):

- ❑ Essential water supply and sanitation services should become available to all Namibians and should be accessible at a cost which is affordable to the country as a whole.
- ❑ This equitable improvement should be achieved by the combined efforts of the Government and the beneficiaries, based on community involvement, participation and the acceptance of a mutual responsibility.
- ❑ Communities should have the right, with due regard for environmental needs and the resources available, to determine which solutions and service levels are acceptable to them. Beneficiaries should contribute towards the cost of the services at increasing rates for standards of living exceeding the levels required for providing the basic services.
- ❑ An environmentally sustainable development and utilisation of the water resources of the country, should be pursued in addressing the various needs.

These principles have been summed up in WASP's specific water supply objective, defined as (DWA, 1993):

> "*To supply water in sufficient quantities of acceptable quality from the available sources on a sustainable basis, by utilising affordable means to meet the reasonable demands of the consumers.*"

The principles encompassed in WASP apply for general water supply throughout Namibia, including both bulk and rural supply. However, as rural water supply operates under different conditions to bulk supply, a separate rural water supply policy has been formulated within the framework of WASP.

## 3.2 Rural Water Supply Policy

The basic objective of the rural water supply policy is that communities in the rural areas should be encouraged to participate fully in the planning, construction, management and operation of their water supply. It is believed that this is the only way in which the standard of service can be raised to acceptable levels on a sustainable basis (DWA, 1993). In order to implement this objective, it has been realised that communities need to take some form of ownership over their water supply, and in doing so they will be expected to contribute financially towards the use of this water supply.

In this regard, the rural water supply policy was formulated and is based on the following principles (DWA, 1993):

- Payment by the community should, as a general rule, cover operation and maintenance costs, although there may be cases where a subsidy may apply.
- Because of the great variations in social conditions throughout Namibia, a system should be worked out whereby the ability of each community to pay for services rendered can be evaluated, and the need for subsidisation quantified.
- An agreement between the community and the authorities, setting out the respective responsibilities and commitments, should be a prerequisite for Government support.
- Government support should be reconsidered if stipulated conditions of agreement are not complied with.

This Policy is accompanied by a set of eight Rural Water Supply Strategy Papers, which were developed in 1994 and approved for implementation in 1997. These Strategy Papers form a basis from which policy objectives can be achieved by the DRWS and community participation initiated. A brief summary of the Strategy Papers which are most pertinent to this thesis are presented below (DRWS, 1994):

**Strategy Paper 1: Ownership of Rural Water Supply Schemes and Individual Water Points**

- Effective community participation can only succeed if the community has a strong sense of ownership of the facilities they are looking after. It has been advocated that a form of ownership by the community called "user ownership" is developed. User ownership entails that the facilities of the scheme are handed over to the community for free, while the community takes on responsibility for the operation and maintenance of the scheme according to a level agreed upon between DRWS and the community.

**Strategy Paper 2: Introduction of Payment for the Services of Water Supply**

- WASP advocates that the introduction of community management be done gradually. First communities should take on responsibility for routine maintenance and operation and carry out minor repairs themselves, while bigger repairs and major maintenance jobs are still the responsibility of the Government. Over a period of time, the community's contribution should increase to include full cost recovery and all repairs. Finally, the community should be responsible for replacing broken down equipment or provide new installations themselves. Communities have been expected to start contributing towards operation and maintenance costs from April 1997, and it is expected that the final stage will be reached after about 9 years.

- WASP only describes the principle but does prescribe when the people have to take responsibility and how they are to take responsibility. It also does not dictate when the people have to pay or how much they should pay. These issues are to be addressed at a more local levels according to feedback from politicians, decision-makers, regional authorities, traditional leaders and the communities themselves.

- Tariffs shall be set such that there is a 'lifeline' block covering sufficient water to satisfy basic human and livestock needs. A minimum lifeline needed for human consumption is 15 litres per person per day, while the minimum lifeline for livestock for subsistence farming is to be set per region. Tariffs for water used above the lifeline block shall be set at such a rate that they discourage over-grazing by effectively 'taxing' excess stock numbers.

**Strategy Paper 7: Implementation of Rural Water Supply Schemes**

- The need for a new water supply scheme, or for the improvement of an existing water point must be identified by the local community. Without there being a felt need for improvement within the community, there is little chance of enthusiastic community involvement.

- A detailed procedure has been set up which stipulates the requirements for each stage during the implementation of a water supply -
  - Initiation
  - Investigation and Planning
  - Construction
  - Handover

  The steps which need to be followed for each of these stages are clearly laid out in the Strategy Paper. It is not intended to further elaborate on these requirements in this chapter, as this subject will be further explored in Chapter 7.

**Strategy Paper 8: Operation and Maintenance of Rural Water Supply Equipment**

- There has always been an informal recognition by most communities that it is their responsibility to operate the rural water point themselves. In many communities there is one individual who takes on a greater interest in the water point than others and is often appointed as a caretaker. This concept of a water point caretaker is well established in Namibia.

- The strategy paper suggests that the responsibility of a caretaker for the operation of the water point, is extended to include basic maintenance responsibilities. To facilitate this additional responsibility the DRWS undertake to provide formal training for these caretakers regarding the correct operation, and maintenance procedures to be followed for a particular type of water supply.

- As the payment strategy comes into operation, the community will become responsible for the local operation and maintenance costs. This will be a direct incentive for the community to operate the water point in the most efficient manner.

## 3.3 Conclusion

The Namibian Government are presently embarking on the implementation of a new Water and Sanitation policy (WASP), based on a partnership between Government and rural communities, to improve inadequate rural water supply standards. Central to WASP is a belief that for a water supply to be reliable, users need to be empowered to control their own water supply. It is believed that by empowering communities with the right skills, users can manage their own water point, resolve disputes regarding equitable access to water, and generally take responsibility for looking after their own water supply (DRWS, 1996).

While the WASP document reflects a vision of how this should proceed, it did not, nor did it intend to, prescribe specifically how each community should proceed. To do so would undermine the key issues underlying this policy (DWRS, 1996): "T*hat communities must own the facilities themselves, and that they must control the process leading up to the installation and continued operation and maintenance of these facilities*." The successful implementation of the policy requires that, to the fullest extent possible, communities themselves must be in charge of the decision-making process. If communities do not own the decision-making process, they cannot be expected to feel a sense of ownership over their facilities.

# CHAPTER 4:

# SAND-STORAGE DAMS IN NAMIBIA

# 4 SAND-STORAGE DAMS IN NAMIBIA

Sand-storage dams are constructed to create the effect of an alluvial aquifer. The concept is relatively unknown in Namibia at present, and so this chapter will go into some detail towards presenting and explaining these dams as a method of water supply. The first section of the chapter will define the principles behind sand-storage dams. The context of sand-storage dams in Namibia will then be set by giving a brief overview the history of these dams in the country. The major issues affecting the siting, design and construction of a sand dam will then be presented, as these issues significantly influence the feasibility of developing sand-storage dams for rural water supply. Finally, this chapter will conclude by identifying whether any rural areas on Namibia display the biophysical characteristics required for the construction of a sand-storage dam.

## 4.1 The Sand-Storage Dam Principle

In his book 'Groundwater Dams for Small-Scale Water Supply', Nilsson (1988) defines a groundwater dam as one which *"obstructs the flow of ground water and stores water below the ground surface."* He goes on to classify groundwater dams as being either:

- A *sub-surface dam*, which is constructed below ground level and arrests the flow in a natural aquifer. The general principle of a sub-surface dam is shown in Figure 4.1.
- A *sand-storage dam*, which impounds water in sediments caused to accumulate by the dam itself. The general principle of a sand-storage dam is shown in Figure 4.2.

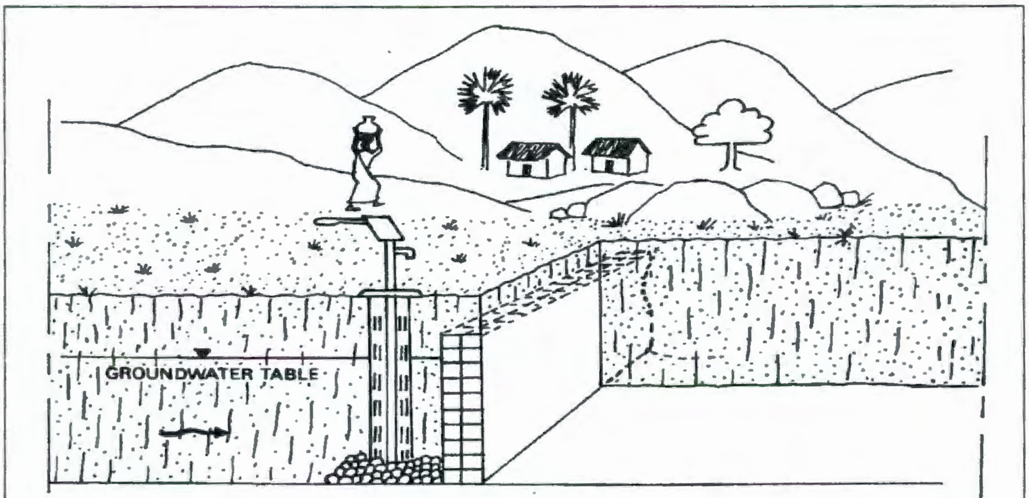



**Figure 4.1: General principle of a sub-surface dam (from Nilsson, 1988)**

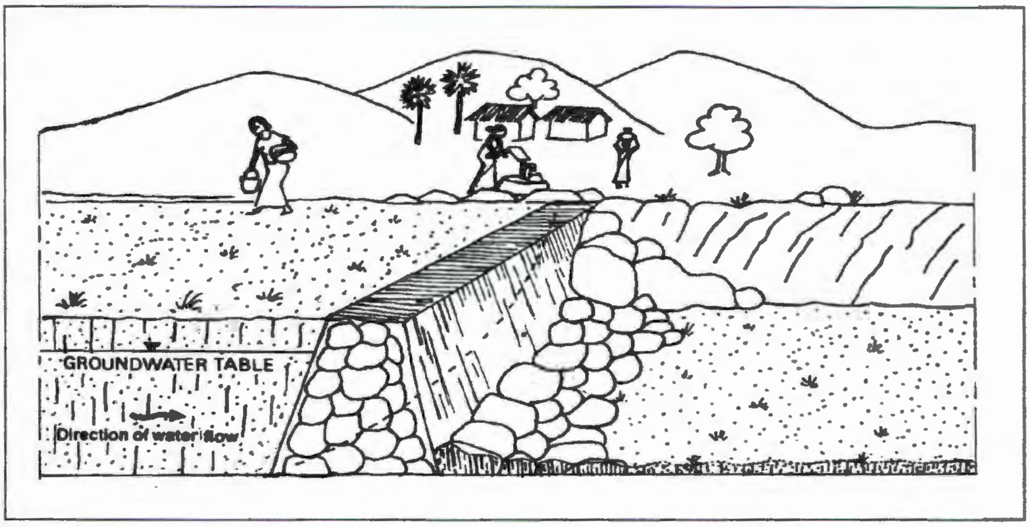



**Figure 4.2: General principle of a sand-storage dam (from Nilsson, 1988)**

Groundwater dams are often a combination of the two types. When constructing a subsurface dam in a riverbed, the storage volume may be increased by letting the dam wall rise above ground level, thus creating an accumulation of sediments. Similarly, when a sand-storage dam is constructed, it is necessary to excavate a trench in the sand bed in order to reach bedrock or a stable, impervious layer (Nilsson, 1988).

Van Tonder (1975) defines a sand-storage dam in more detail as "*...a dam whose basin has been filled up with medium to coarse sand. The water is stored in the voids between the sand grains and can be recovered by means of drain pipes, wells or boreholes. Depending upon the geological formation under the dam basin, water may also filter into the earth's crust through faults and aquifers to replenish the groundwater.*"

From Van Tonder's definition, it becomes clear that a sand-storage dam can be constructed to serve one of two purposes:

- To create an artificial aquifer in which to trap and store water. This water is then recovered directly from the dam via a well or drainpipe (Figure 4.2) or,
- To create an artificial aquifer which induces recharge of a local secondary aquifer. This water is then indirectly accessed through boreholes drilled into this aquifer (Figure 4.3).

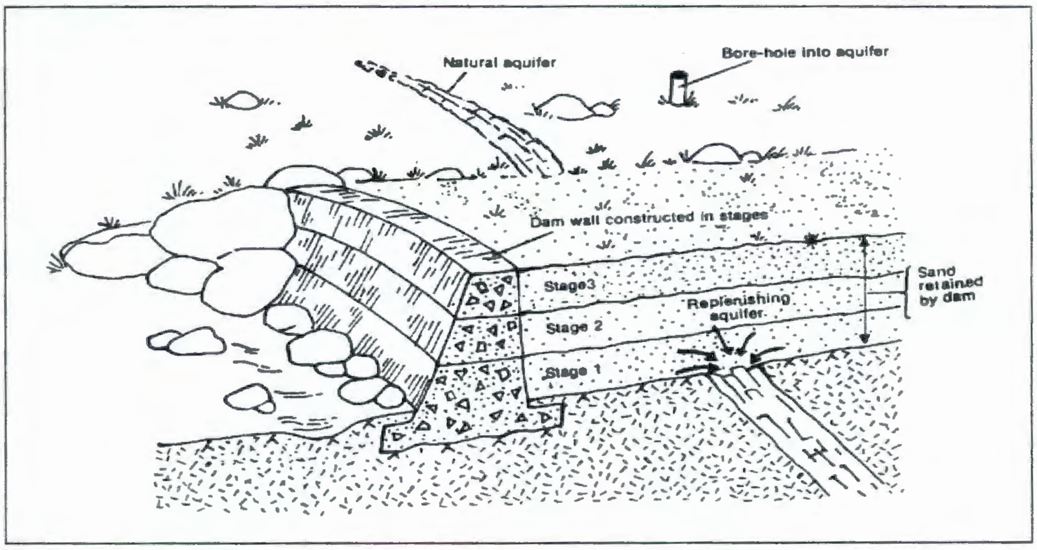



**Figure 4.3: Sand-storage dam for recharging purposes (from Sauermann, 1966)**

Regardless of which type of dam is build, the principle behind developing a sand-storage dam remain the same - that sand is intentionally enticed to collect behind an artificial dam wall, with the purpose of collecting and storing surface run-off in this sand. In this manner water is stored in a 'reservoir' which is not prone to substantial evaporation losses or siltation.

## 4.2 The History of Sand-Storage Dams in Namibia

Conserving water resources by trapping and storing it underground is not a new concept. According to Nilsson (1988), groundwater dams were constructed in Sardinia in Roman times, and the damming of groundwater was practised by ancient civilisations in North Africa. More recently, various small-scale groundwater damming techniques have been developed and applied in many parts of the world, notably in Southern and East Africa, and in India (*ibid.*).

Namibia has a long history of groundwater dams, with the first sand-storage dam being introduced in 1907 while Namibia was still under German colonial rule (Wipplinger, 1958). The German colonial policy, for the then German South West Africa, emphasised the importance of the developing a national settler economy which was self-sufficient in food and fodder production (Lau and Stern, 1990). Colonial development was implemented with a focus on (*ibid.*):

- Soil preservation and creation.
- Minimum use of non-renewable resources.
- Maximum use of local materials.

- Labour-intensive projects utilising simple technologies.
- Agricultural extension such as the dissipation of skills (especially through publications), and also the management of incomes of individuals and communities.

Under these principles the German authorities realised that the high rates of evaporation and silt transportation characteristics of Namibia's environment, combined with erratic rainfall patterns and low volumes of runoff, made it practically impossible to provide efficient perennial water supplies in semi-arid grazing lands using conventional open storage dams (Wipplinger, 1974). This led them to investigate alternate methods of water storage.

Wipplinger (1958) states that: *"In 1907 the Government Water Engineer in SWA, von Zwergen, submitted a report on water conservation methods. He described the method of conserving water in sand-filled dams, which was successfully applied in certain mountainous parts of Germany (Schwaibische Alb) and suggested that if modified to suit local conditions this method promised to solve the problem of watering places for stock.*" Action was taken on this report and in 1907 a 5m high weir was constructed at the Bacteriological Station near Windhoek. By 1913 the basin was reported to be completely filled with sediments, mostly sand, and the yield was estimated to be as high as 33% of the 18 900m$^3$ of fill retained in the dam (*ibid.*).

More sand-storge dams, sub-surface dams, and variety of other schemes to harness rainwater to enhance groundwater levels were developed by the German authorities between the period 1895-1915 (Lau and Stern, 1990). However, once Germany lost authority over the colony to South Africa after World War I, these government sponsored initiatives came to an abrupt halt (*ibid.*).

A resurgence of interest in sand-storage dams was experienced during the period 1955-1969 (Lau and Stern, 1990). During this period the Department of Water Affairs in South West Africa was under the leadership of O. Wipplinger and H. W. Stengel who actively propagated this method of water conservation and utilisation of surface run-off (*ibid.*). Old schemes and thoughts were taken from the German colonial records, researched and built upon in an attempt to develop a water resource management policy which aimed at achieving national self-sufficiency in respect of electricity, food and fodder production (*ibid.*). Sand-storage dams were researched, modelled and studied (Wipplinger, 1958; Sauermann, 1966) towards developing a design code for sand-storage dams (Beaumont, 1969; Van Tonder, 1975; Scott, 1979), and a number of successful sand-storge dams were developed during this period (Wipplinger, 1974).

This flurry of work on sand storage dams was, however, short lived. This was not because sand dams were ineffective, but rather, as stated by Lau and Stern (1990) in their historical study of Namibian water resources and their management, because: "*Stengel's and Wipplinger's approach ... was in conflict with the evolving official South African policy which took over in 1969/70, and which consisted in restructuring territorial water management to serve mines and the larger towns, especially the budding colonial sub-metropole, Windhoek. This conflict can be seen reflected most strikingly in the number of projects which were simply shelved - most prominently among them Stengel's and Wipplinger's research on and experimentation with sand storage dams.*"

Since the early 70's very little, if any, research or development has taken place in Namibia towards developing groundwater or rainwater management strategies which utilise sand-storage dams (Lau and Stern, 1990; personal observations). Towards the end of 1995/96 drought, the Windhoek municipality considered funding a pilot project to investigate the feasibility of using sand-storage dams to enhance recharge rates of the city's aquifers (Van Der Merwe, pers. com.) However, owing to a lack of funds, and record rainfall figures at the start of 1997 this project has been suspended (*ibid.*).

## 4.3 Siting a Sand-Storage Dam

Successfully developing a sand-storage dam requires that certain biophysical conditions need to met during the siting of the dam. These conditions range from area-specific, to site-specific requirements, and are categorised below:

- Topography
- Geology of the catchment area
- Geotechnical Suitability
- Accessibility of construction material

### 4.3.1 Topography

The topographical conditions of an area determine to a large extent, the technical feasibility of a sand-storage dam. The principles underpinning conventional open-storage dams, of storing water in a narrow, well-defined valley with a low stream gradient to maximise storage capacity and reduce evaporation losses, are also applicable to sand-storage dams.

Evaporation of water from a sand-storage dam usually penetrates to a depth of approximately 60 cm below the surface (Scott, 1979). To minimise evaporation losses, therefore, a sand-storage dam should ideally be constructed in a well-defined valley or river bed between steep rock banks (Aubroeck, 1971).

In less mountainous regions however, it will be difficult to site a sand-storage dam in narrow, steep sided river valleys and hence sand dams will tend to fill wider and shallower basins. The reduced storage volume of these dams, coupled with higher evaporation rates out of the wider sand medium, will result in a reduced storage capacity. Aubroeck (1971) recommends that this reduced storage capacity can be rectified by building two, three or even a series of such shallow sand-storage dams in succession.

### 4.3.2 Geology of the Catchment Area

Understanding the geology of the catchment area of a sand-storage dam is important towards predicting the type and characteristics of the expected sediments which will collect in the dam basin. Erosion in differing geological zones produces different types of material available for transportation, and eventually deposition in the dam basin. The importance of understanding the characteristics of the expected sediment load is that a sand-storage dam will only operate efficiently if it is filled with coarse sediment, displaying high porosity and permeability values.

The greater the porosity of the material filling the dam, the greater is the volume of water which can be stored in sand-filled dams. Porosity, however, only indicates how much the sand can store, and not how much it will yield, as some water will be retained by molecular and surface-tension forces (Sauermann, 1966). Specific yield is used as the term which denotes how much water is available to be withdrawn from the voids. The specific yield is dependant on grain size, shape and distribution of pores and compaction of the formation (Beaumont, 1969). Well sorted sand has a high porosity and a high specific yield. When fine materials (silt) starts mixing with coarse material, the porosity of the mixture is reduced as the finer grains fill the voids between the coarser ones (Sauermann, 1966).

The deposition of silt in a sand-storage dam, resulting in a reduction of the porosity of the storage material, adversely affects the dam's performance in two ways (Scott, 1979):

- Firstly, reducing the porosity reduces the specific yield of the dam. This results in a decreased efficiency of storage.
- The second effect is that silt reduces the permeability of the storage material in the dam basin.

Permeability is a reflection of the ease with which the water is able to travel through the voids of the material (Whittow, 1984). A reduced permeability will affect both recharge and draw off rates. Water can only enter the dam by infiltration of the dam surface, and only while flood waters flow over the dam. Recharge, therefore, is critically affected by the contact time and the permeability of the dam surface, and an emphasis must be placed on preventing a silt layer forming on the top surface of the dam (Wipplinger, 1958).

Ideally then, sand-storage dams should be sited in geographical regions where the geology of the catchment area is such that a substantial portion of the sediment load will consist of coarse particles. The most favourable parent rocks are coarse granite, quartzite and sandstones, but dams constructed in gneiss and mica-shist areas have also been successful (Wipplinger, 1958). Areas where the dominating rocks are basalt and rhyolite tend to be less favourable for sand-storage dam construction (Nilsson, 1988).

### 4.3.3 Geotechnical Suitability

The geotechnical characteristics of the material underlying the site of a sand-storage dam need to be suitable for meeting design standards for ensuring the 'safe' construction of the actual dam wall, as well as being suitable for the purpose for which the dam was developed.

According to the two types of sand-storage dams defined in Section 4.1, the dam should be sited such that the geotechnical nature of the material underlying the storage basin is either:

- Composed of un-weathered bedrock, or unconsolidated formations of low permeability to prevent excess water losses due to seepage, or;
- Straddling a fracture or fault, which surfaces in the river bed, and which feeds local secondary aquifers.

Regardless of which type of dam is most suitable to the geotechnical conditions of the storage basin, it must be realised that sand-storage dams are built to allow over-topping by floods (Beaumont and Burger, 1970). In order to prevent structural failure of the dam wall it needs to be founded on an un-weathered, solid rock foundation. Neither the footing of the dam wall, nor the valley sides can be prone to erosion, as this will undermine the integrity of the structure (Nilsson, 1988).

### 4.3.4 Accessibility of Construction Material

Suitable, locally accessible construction material needs to be available for the construction of the dam wall. Masonry or concrete is mostly chosen for construction material, in preference to clay, as it is stronger, more durable and makes it possible to increase the sand volume by subsequent stage construction (Wipplinger, 1974).

## 4.4 Design and Construction of Sand-Storage Dams

*"The development of a successful sand dam is mainly a question of time. Patience and time are the first requirements."* (Aubroeck, 1971)

Aubroeck's quote implies that developing sand-storage dams requires long-term planning. Once a suitable site has been chosen, it must be realised that the establishment of a sand-storage dam is not just a question of simply constructing a dam wall and allowing it to fill up with sand. Rather, experience has shown that the most efficient method of building a sand-storage dam is to construct the wall in stages (Van Tonder, 1975). A simple sketch portraying this staged construction method is presented in Figure 4.4. The height of each of the stages of the wall is critical to the success of the sand dam, as this affects the flow velocity, and hence the depositional characteristics of the river. Each stage needs to be designed such that the velocity of flow over the dam is sufficiently high that only coarse sands will settle behind the wall, while silt, fine sediments and floating debris are carried over the top by the flood waters. Subsequent stages should only be added once the previous stage has been completely filled with sand.

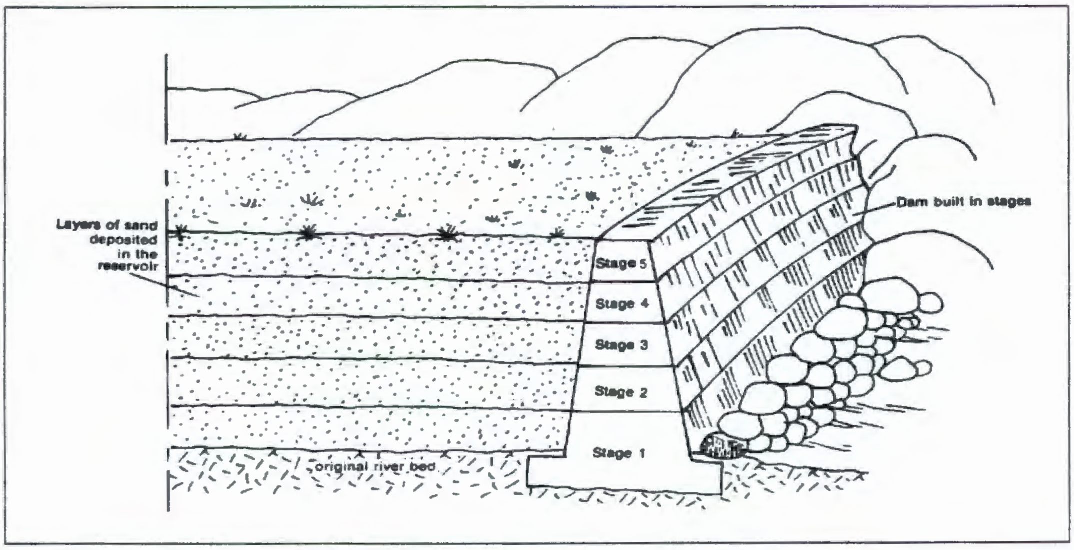



**Figure 4.4: Construction principle of a sand-storage dam (from Nilsson, 1988)**

The factors affecting the design of the height of each of the stages are the size and type of sediments expected in the river, the river slope, and the expected flood peaks and frequency of floods of the river. Determining all these factors for an accurate design of the dam wall is impractical. Nilsson (1988), recommends that a more practical design method is to roughly assess the height of each stage by studying the extent of the natural sedimentation in the stream, and by estimating the expected water velocities in the storage reservoir. After one stage has been completed the subsequent accumulation of sediments can be studied and the design of the next stage modified accordingly.

As mentioned above, the expected flow of water into a sand-storage dam will determine the design of the dam in terms of the stability and height of the wall, as well as govern the sedimentation process behind the wall (Nilsson, 1988). Consideration therefore needs to be taken of the fact that in Namibia flood flows are erratic and unpredictable, and as a result the rate at which a sand-storage dam is developed will be dependant on these erratic and unpredictable hydrological characteristics (Beaumont and Burger, 1970). The expected time for a sand-storage dam to be successfully developed can only be roughly estimated according to the average climatological conditions to be expected over a certain period of time (*ibid.*).

In a similar vain, it is extremely difficult to accurately predict the volume of water which will be available for extraction from the completed sand-storage dam. Although the expected volume of sediments to be stored behind the dam wall can be accurately calculated (Burger and Beaumont, 1970), the porosity and permeability values of the material stored in the dam basin, will be influenced by the infinite number of ways in which the particle shape, size, size distribution and type of material can be combined in a particular sediment deposit (Beaumont and Burger, 1970). As these porosity and permeability values have a large effect on the specific yield of the dam (*ibid.*), accurately determining the storage volume will only be possible once the sand-storage dam is completely developed.

The upper limit on the height of a sand-storage dam, and hence its maximum storage volume, is constrained by two conditions:

- Firstly, the dam must be able to withstand the maximum peak flow of the river which will need to be discharged safely over the wall without causing erosion to either the footing or valley sides (Nilsson, 1988).
- The second limiting factor is that the recharge of sand-storage dams only occurs while flood waters flow over the dam surface. Beyond a certain height, increasing the height of the wall will not be cost efficient as the majority of floods will not occur for a sufficient length of time to recharge the additional volume (Beaumont and Burger, 1970).

### 4.4.1 Mitigating Siltation

As mentioned in Section 4.3.2, it is desirable to prevent the deposition of any silt in a sand-storage dam. In practise however, it is acceptable and unavoidable to allow some silt to settle, as this will reduce the total filling time of the dam (Scott, 1979). Silt layers are acceptable, provided a completely silt free channel is maintained through the dam and the layers of silt are thin enough that they will be broken up by succeeding floods (Beaumont and Burger, 1970).

Maintaining a silt free channel will require that during times of low flow, the flow is confined to a relatively narrow channel in order to maintain a flow velocity at, or above its optimum value (that value of flow velocity above which the fine material is transported in suspension) (Beaumont and Burger, 1970). In times of increased flow, water will naturally overtop this channel onto the banks on either side, where silt will be deposited. The majority of this silt deposition will occur during the recession of the flood, when flow velocities are dropping back to low flow levels (*ibid.*). Auboeck and Van Wyk (1969) proposed that silt free channels can be maintained by making openings in the dam wall at selected positions. These opening can be either square or triangular (v-notch) openings, through which most of the silt laden water of small floods will be routed.

## 4.4.2 Types of Sand-Storage Dams

Although the siting of a sand-storage dam requires the fulfilment of a number of conditions, the dam wall itself can be constructed out of a number of materials. The two most common type of dam constructed are concrete and masonry gravity dams (Nilsson, 1988). These dams, shown in Figures 4.5 and 4.6 respectively, adequately fulfil the basic requirement for the dam wall - that they be sufficiently massive enough to take up the pressure from the sand and water stored in the reservoir. For larger reservoirs, consideration may have to be taken of constructing an arch dam using this material.

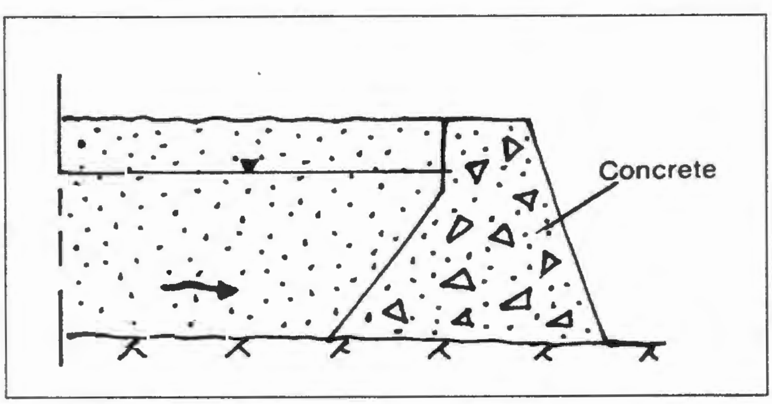



**Figure 4.5: Concrete sand-storage dam (from Nilsson, 1988)**

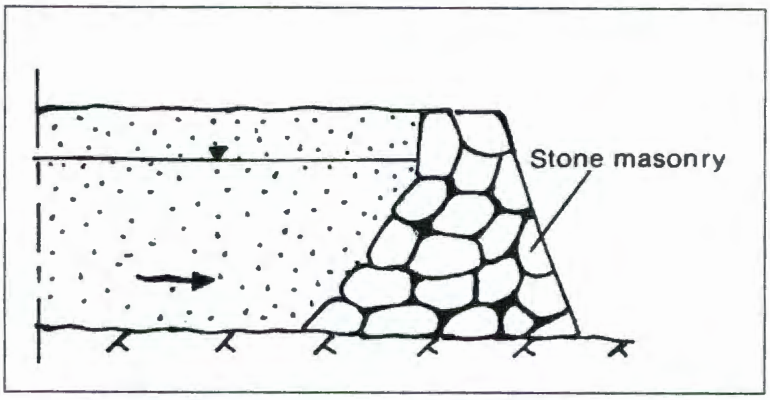



**Figure 4.6: Stone Masonry sand-storage dam (from Nilsson, 1988)**

A variety of other wall types exist, Figures 4.7 and 4.8 show examples where the pressure of the sand and water of the dam is taken up by stone gabions or large stone block. These walls are made watertight by using clay. Other combinations may utilise gabions or loose stone combined with a concrete seal to stabilise the wall. Although these structures will have less strength and durability, and hence will not be able to attain the same storage capacity as cement or stone masonry dams, efficient use is made of locally available materials, and they can be easily adapted to suit local conditions.

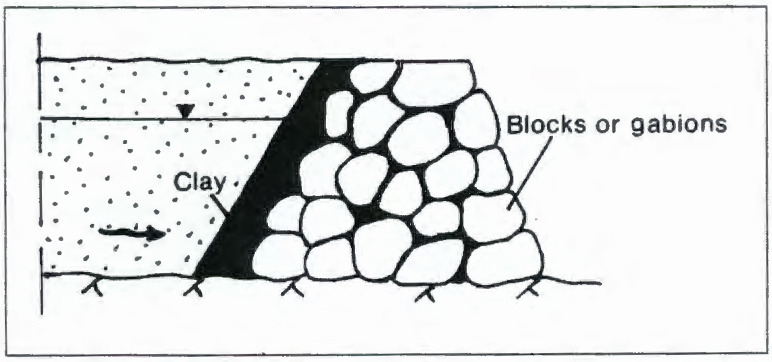



**Figure 4.7: Gabion sand-storage dam with clay cover (from Nilsson, 1988)**

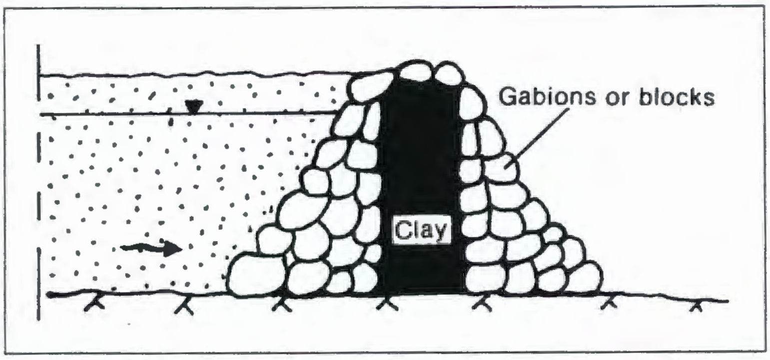



**Figure 4.8: Gabion sand-storage dam with clay core (from Nilsson, 1988)**

### 4.4.3 Methods of Water Extraction

The water stored in a sand dam can be extracted through a variety of methods. A simple and economical method is to construct a gravity fed drain along the reservoir bottom at the upstream side of the dam. This drain can then supply a well or handpump, or it can be connected to a gravity supply pipe through the dam wall. A flushing valve should be installed in the dam to facilitate cleaning of the drain if needed (Nilsson, 1988). A typical sand dam with extraction alternatives is shown in Figure 4.9.

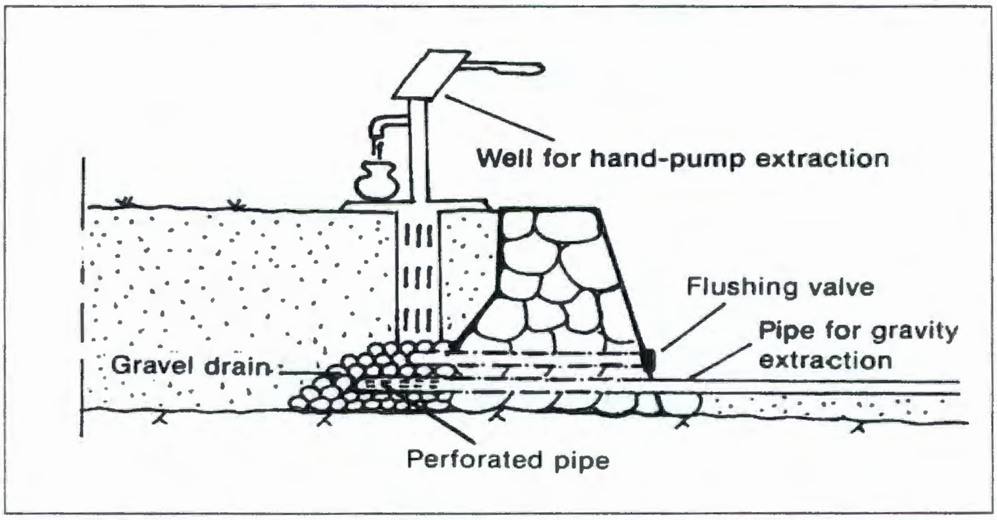



**Figure 4.9: Extraction alternatives from a sand-storage dam (from Nilsson, 1988)**

As mentioned in Section 4.1, if the sand-storage dam is purposely built to facilitate recharge of a local aquifer, then the water which infiltrates into the sand dam will be indirectly accessed through a borehole which pump groundwater from this aquifer. Figure 4.3 shows a practical example of how this can work. Sauermann (1966), states that a dike was utilised as an aquifer for the new Windhoek airport, however it was soon realised that the aquifer had insufficient supply to meet future demand. It was then decided to construct a sand dam in a river bed in which the dike outcrops. Within a year the first five foot high stage was filled with sand, flood waters infiltrated the sand deposits, recharging the aquifer and ensuring a permanent supply to the airport. At the time of writing his article, a second 3 feet high stage had been constructed, and it was anticipated that with further raising of the dam wall, water would be provided for future expansion of the airport.

## 4.5 Conclusion

Based on the requirements from Section 4.3 regarding site suitability, it can be argued that for a rural area to be suitable for the development of sand-storage dams, the following requirements need to be met:

- Topography - A sand-storage dam is ideally sited in a well defined valley, or river bed between steep rock banks in order to provide:
  - (a) A suitable foundation for a small wall structure and;
  - (b) Sufficient slope for rapid channel flow to facilitate the deposition of coarse grained sediments.
- Geology - The geology of the catchment area should be such that a substantial portion of the sediment load will consist of coarse particles. In addition, the geotechnical nature of the storage basin must either be impervious to infiltration, or facilitate the recharge of a specific aquifer.

In assessing the topographical requirements it has been assumed that suitable river channels will be found in areas displaying the following topographical characteristics (refer to Figure 2.6):

- Hills
- Low mountains
- High mountains

Similarly, it is assumed that the most favourable geological regions for producing a coarse sediment load will be found in areas where the predominant rock types are either granites, quartzites or sandstones. Sand-storage dams have also been successfully constructed in areas of mica-shist.

The predominant topographical and geological characteristics displayed in the each of the 10 regions in Namibia have been summarised in Table 4.1. From this table it is clear that sand-storage dams will be limited to the central interior in the southern half of the country, and to the western escarpment regions in the northern half. The information presented in this table has been identified by overlaying an outline of the various regions (from Figure 1.1), on the topographical map of Namibia (Figure 2.6), and the geological map of Namibia (Figure 2.7).

Many of the regions have an array of differing topographical and geological characteristics. These regions have been broadly divided into eastern, central, and western areas, and these areas have been highlighted if both the topographical and geological characteristics combine to create conditions favourable for the development of sand-storage dams.

**Table 4.1: Predominant topographical and geological characteristics in Namibia (favourable conditions combining in one area have been highlighted).**

| Region | Predominant Topography | Predominant Geology |
|---|---|---|
| Karas | •Plains and Kalahari dunes (eastern areas)<br>**•Hills & low mountains (central areas)**<br>•Namib dunes (western areas) | **•Damara sequence sandstones and shales (eastern & central areas)**<br>•Calcretes and unconsolidated sand cover (western areas) |
| Hardap | •Kalahari dunes (eastern areas)<br>**•Hills, low mountains and plains (central areas)**<br>•Namib dunes (western areas) | •Unconsolidated sand cover (eastern region)<br>**•Damara sequence sandstones and shales (central areas)**<br>•Calcrete and unconsolidated sands (western areas) |
| Khomas | **•Low mountains** | **•Damara sequence schists** |
| Erongo | **•Low mountains, hills and plains with scattered hills (eastern areas)**<br>•Plains (western areas) | **•Karoo sequence granites** (eastern areas)<br>•Damara sequence schists (western areas) |
| Kunene | •Plains (eastern areas)<br>**•Low mountains, with scattered areas of hills (western-central areas)**<br>•Plains and dunes (western areas) | •Calcrete and unconsolidated sands (eastern areas)<br>•Sinclair sequence metamorphic basement complexes (northern and central areas)<br>**•Damara sequence schists (western and central areas)**<br>•Karoo sequence basalts (south-western areas) |
| Kuveli | •Plains | •Calcretes and unconsolidated sands |
| Kavango | •Plains | •Calcretes and unconsolidated sands |
| Caprivi | •Plains | •Calcretes and unconsolidated sands |
| Otjozondjupa | •Plains (eastern areas)<br>•Plains with scattered hills and some low mountains (western areas) | •Calcretes and unconsolidated sands (eastern areas)<br>•Swakop schists (western areas) |
| Omaheke | •Plains | •Calcretes and unconsolidated sands (northern areas)<br>•Nossib quartzites (central areas)<br>•Unconsolidated sands (southern sands) |

To summarise Table 4.1, the following regions have been identified as having both the topographical and geological characteristics for the development of sand-storage dams:

- Karas - central areas
- Hardap - central areas
- Khomas - throughout region
- Erongo - eastern areas
- Kunene - western/central areas

# CHAPTER 5:

# COMPARING SAND-STORAGE DAMS WITH OPEN-SURFACE DAMS

# 5 COMPARING SAND-STORAGE DAMS WITH OPEN-SURFACE DAMS

Sand-storage dams were initially constructed as an alternative to storing water in conventional open reservoirs (Lau and Stern, 1990). The high evaporation and siltation rates which are symptomatic of Namibia's arid to semi-arid climate have a major impact on any open-storage dam. In this chapter a comparison is presented between the storage of water in sand-storage dams, with that of conventional open-storage dams. These two methods of water storage are compared under the following criteria:

- Storage efficiency
- Economic feasibility
- Water Quality
- Storage Volume

## 5.1 Storage Efficiency

The foremost advantage of sand storage dams over conventional open-storage dams is that they have an excellent efficiency of storage. According to studies done at the Swakop River by Helwig (1973), the evaporation rate from a saturated sand surface was found to be approximately 8 % less than from an open water surface. Lowering the water table by 0.3m below the sand surface reduced the evaporation rates from a fine sand to 50% of that from an open water surface. The corresponding figure when keeping the water level at 0.6m in medium sand was 10%. The relation between evaporation and depth of water table is shown in Figure 5.1. From this figure it is clear that the particle size has an influence on evaporation losses, with fine particles having a greater capillary action, and hence having higher evaporation rates than coarse particles. This further stresses the importance of avoiding the deposition of fine particles on the surface of the sand-storage dam.

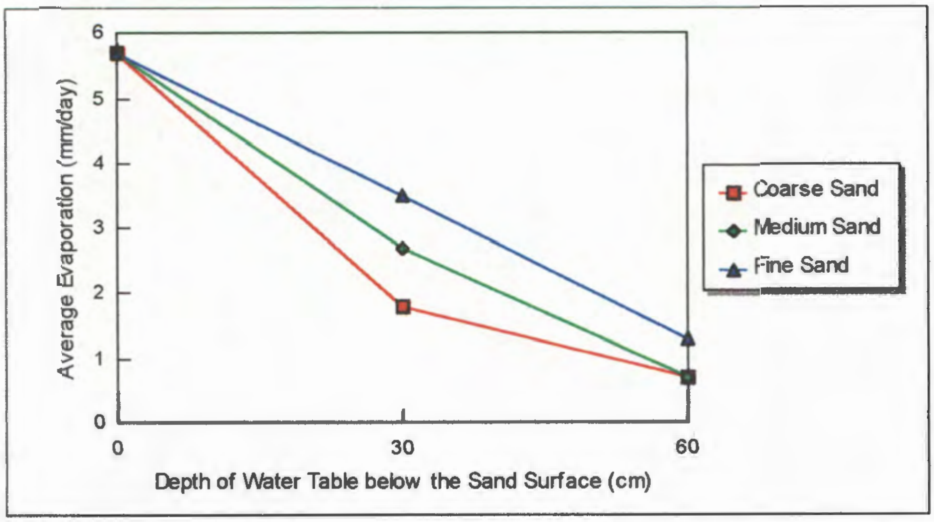



**Figure 5.1: Evaporation as a function of the depth of the water table (from Hellwig, 1973).**

Burger and Beaumont (1970) developed a theoretical case study to highlight the storage efficiency of sand-storage dams over conventional open-storage dams. In their example it was calculated that a conventional open-storage dam 12m high and 80m long in a V-shaped valley with a floor slope of 1:300 will retain approximately 575 000 $m^3$ of water. By using the depletion charts developed by Wipplinger (1958) it was estimated that over a 2½ year dry period this dam would yield 20% of the impounded water, a total of 115 00 $m^3$ or 46 000 $m^3$ per year. Similarly, a sand-storage dam with the same height, and on the same site will retain approximately 970 000 $m^3$ of sand, which at an effective porosity of 15% will contain 146 000 $m^3$ of extractable water. Over the same dry period it will yield 70% of this retained supply, a total of 102 000 $m^3$ or 41 000 $m^3$ per year. In this example the storage efficiency of the sand-storage dam makes some 400 000 $m^3$ of flood water available for downstream users, this example is summarised in Table 5.1.

**Table 5.1: Storage efficiencies of open-storage and sand-storage dams.**

| | Open-Storage Dam | Sand-Storage Dam |
|---|---|---|
| Volume impounded by structure | 575 000 $m^3$ | 146 000 $m^3$ |
| Volume lost due to evaporation ($m^3$) | 460 000 $m^3$ | 44 000 $m^3$ |
| Volume available for consumption ($m^3$) | 115 000 $m^3$ | 102 000 $m^3$ |
| Storage efficiency | 20% | 70% |

The example presented above has been developed for a relatively large storage structure. A sand-storage dam at a height of 12m would be more effectively used as a source of bulk water supply. Sand-storage dams constructed for rural water supply generally tend to be smaller. This was observed by Burger and Beaumont (1970) who found that the height of the majority of rural sand-storage dams, which were on record and were providing reliable supplies for stock watering points, were in the 2.5m - 4m range. As the efficiency of open-storage dams drops sharply with reduced depth of storage, becoming negligible for depths below 8 meters *(Ibid.)*, it becomes clear that developing open-storage dams for rural water supply would result in a highly inefficient utilisation of Namibia's scarce water resources.

## 5.2 Economic Feasibility

After showing that under conditions specific to Namibia, sand-storage dams store water more efficiently than conventional open-storage dams, Burger and Beaumont (1970) further expanded their case study by calculating the estimated costs of developing each of the alternatives as a source of drinking water supply. Although these costs are now obsolete, this comparison provides a good example of the principles on which sand-storage dams were developed. A quantitative value is given to the long-term efficient storage of water in sand-storage dams, as compared to open-storage under high evaporation and siltation rates.

For the purpose of the exercise, Burger and Beaumont (1970) assumed that similar wall structures were to be built for both options, and that the both dams are sited under the same conditions. The actual costs used in this example were taken from an example of a dam which had recently been build in the Kaokoveld, the Munemohoro No.1 dam.

An important element which needs to be considered in a cash flow analysis of a dam, especially in a sand-storage dam, is the rate of fill, and thus the total time of delay before full capacity is reached. In this regard it was accepted that the construction costs of the staged construction of the sand-storage dam would be more expensive, as the construction site would have to be re-established at every raising of the dam wall. In the example it was assumed that the sand-storage dam would be completed in four stages over 8 years, and that it would take 12 years for the dam to come to full capacity. On this basis the total capital outlay for the sand-storage dam was R 113 000 against R 95 000 for a conventional dam.

As these dams were being developed to provide drinking water, it was calculated that the water from the open-storage dam would have to be purified at a cost of 4 cents/$m^3$. The water extracted from the sand-storage dam has been deemed to have been purified during the infiltration process, and protected from pollution during storage, as such it does not require purification.

A value has also been placed on the storage efficiency of the sand-storage dam. The water which the sand-storage dam makes available for downstream users, which would otherwise have been lost due to evaporation in an open-storage dam, has been valued at 0.2 cents/$m^3$. The life expectancy of the conventional open-storage dam, under Namibian siltation conditions, was not expected to be higher than 30 years. The sand-storage dam, on the other hand, is expected to yield a constant water supply for considerably more than 30 years.

In order to prepare a cash flow analysis due regard had to be given to the cost of capital and the time value of money. For this example a rate of 6% was assumed for the cost of capital. The full cash flow analysis is presented in Table 5.2. Keeping in mind that 1970 prices are being used at a discount rate of 6% for a relatively large, commercially constructed drinking water supply, the following results were drawn:

- The cost of water for the sand-storage project is 24.7 cents/$m^3$
- The cost of water for the conventional dam is 32.4 cents/$m^3$

From this example, in which the cost of using a sand-storage dam is about 75% that of a conventional open-storage dam, it becomes clear that under Namibian conditions storing water in conventional reservoirs is not economically sustainable when costed over the expected lifespan of the dam.

**Table 5.2: Cash flow analysis for sand-storage and conventional open-storage water supply projects (from Burger and Beaumont, 1970)**

| | Year 0 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 | Year 11 | Year 12 | Year 13-30 | Year 31→ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAND-STORAGE PROJECT** | | | | | | | | | | | | | | | |
| (a) Capital expenditure | R96,500 | R60,000 | ----- | R21,000 | ---- | R18,000 | ---- | ---- | R14,000 | ---- | ---- | ---- | ---- | ---- | ---- |
| (b) Yield in m³/year | 391 000 | ---- | ---- | ---- | 1 000 | 3 000 | 6 000 | 9 000 | 13 000 | 20 000 | 27 000 | 37 000 | 41 000 | 41 000 | 41 000 |
| **CONVENTIONAL DAM** | | | | | | | | | | | | | | | |
| (a) Capital expenditure | R89,600 | R95,000 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| (b) Purification @ 4 cents/m³ | R13,200 | ---- | R1,740 | R1,530 | R1,340 | R1,150 | R1,000 | R890 | R770 | R680 | R592 | R514 | R453 | 390→0 | ---- |
| (c) Losses @ 0.2 cents/m³ | R4,400 | ---- | R600 | R580 | R540 | R510 | R480 | R440 | R410 | R380 | R350 | R330 | R300 | R270→0 | ---- |
| Total costs of conventional dam | R107,200 | R95,000 | R2,340 | R2,110 | R1,880 | R1,660 | R1,480 | R1,330 | R1,180 | R1,060 | R942 | R844 | R753 | R660→0 | ---- |
| (d) Yield in m³/year | 330 000 | ---- | 46 000 | 43 000 | 40 000 | 36 500 | 34 000 | 31 500 | 29 000 | 27 000 | 25 000 | 23 000 | 21 500 | 19 500→0 | ---- |

Cost of water for sand-storage project = R96,000 for 391 000m3 = 24.7 cents/m3
Cost of water for conventional dam = R107,200 for 330 000m3 = 32.4 cents/m3
Note: Cost of capital = 6%

## 5.3 Water Quality

Baurne (1984) states that *"Compared to with surface water, groundwater can generally be regarded as a micro-biologically unpolluted resource"*. In the case study presented above, Burger and Beaumont (1970) had obviously experienced this during their studies as they priced in the cost of water treatment for the open-surface dam, while assuming that the water quality in the sand-storage dam would be high enough not to require treatment.

Assumptions taken that water from underground storage is hygienically safe and fit for domestic use are based on a knowledge of the filtration processes which occur during the infiltration process. As water starts to infiltrate the sand impurities are filtered out, as all particles larger that the soil pores are retained on the surface (Hofkes and Visscher, 1986). In addition, many colloidal and dissolved impurities are retained by adherence to the soil particles (*ibid.*). There is a general die-off of bacteria and other micro-organisms which might have infiltrated into the sand, as most of the suitable nutrients upon which they survive are removed from the water through a process of oxidation of both organic and inorganic compounds (*ibid.*).

Clearly then, water supplied from a sand-storage dam will be of a higher quality than that of a conventional open-storage dam. As mentioned above, this has direct financial implications if it is assumed that surface water will require some form of water treatment, while water from a sand-storage dam can be utilised directly, without treatment.

## 5.4 Storage Volume

A disadvantage which sand-storage dams experience over conventional open-storage dams is that they have an upper limit to their storage volume. Recharge of the sand-storage dams only occurs while flood waters flow over the dam surface. Beyond a certain dam wall height, building more stages to increase storage capacity, will be of no purpose since flow over the dam surface will not occur for sufficient time to recharge the additional volume (Scott, 1979).

Although no information is available as to how this maximum wall height may be determined, from the examples mentioned in some of the relevant literature (Wipplinger, 1958; Aubroeck, 1971; and Nilsson, 1988), it would appear that this level would be over the 12m - 15m range.

This storage limitation is, therefore, more relevant to large bulk-water supply dams, rather than small-scale rural water supply, where the average height is 2.5m - 4m (Burger and Beaumont, 1970).

## 5.5 Conclusion

The results which have been discussed above are summarised in the following table:

**Table 5.3: A comparison of sand-storage dam with conventional open-storage dams for Namibian rural water supply.**

| | **Sand-Storage Dam** | **Conventional Open-Storage Dam** |
|---|---|---|
| Storage Efficiency | **Very efficient.** Generally evaporation losses are negligible beyond 60cm below surface level. | **Highly inefficient.** Evaporation rates for dam walls below 8m high do not make it feasible to construct the dam. |
| Life Expectancy | Once the dam reaches its full storage capacity, it is **immune to silting**. | High siltation rates result in **low life expectancies.** |
| Water Quality | **Good water quality.** Generally do not require water treatment for domestic use. | **Low water quality.** Water treatment for domestic use recommended due to high coliform counts found in open water in rural areas. |
| Cost of Construction | Due to staged construction **initial costs higher**. | Although initial costs are lower, the requirements for water treatment, low storage efficiency and short life expectancy often results in a **higher price being paid per unit of water over the life time of the structure.** |

As Table 5.3 suggests, due to the high evaporation and siltation rates characteristic of Namibia, developing conventional open-storage dams for rural water supply is not sustainable. Although the initial cost of constructing an open reservoir might be lower than that of a sand-storage dam, the low storage efficiencies, short expected life spans, and poor water quality of open-storage dams results in a higher price per unit of water over the lifetime of the dam. Sand-storage dams, on the other hand, provide an efficient method of storing and utilising surface waters. If the structure is well constructed a sand-storage dam will provide a constant source of water long after an open-storage dam has silted up.

# CHAPTER 6:

# COMPARING SAND-STORAGE DAMS WITH BOREHOLES

# 6 COMPARING SAND-STORAGE DAMS WITH BOREHOLES

Groundwater, accessed through wells or boreholes, provides water to the majority of rural Namibians (DWA, 1991). It has, however, been shown in Chapter 4 that under certain geophysical conditions, the principle of storing water in sand-storage dams may be successfully applied in the western regions of Namibia. In this chapter it is intended to explore the feasibility of developing sand-storage dams as an alternate method of rural water supply to boreholes. This will be achieved through a broad assessment of sand-storage dams compared to boreholes under a set of criteria which have been developed from the concept of 'sustainable development'.

In order to facilitate a broad comparison between the two methods of water supply, the following assumptions have been made:

- That although an existing rural community will already have some form of water supply, it is envisaged that this supply has been deemed by the community as inadequate to meet their needs. This supply is therefore to be replaced, or augmented, by developing a new, independent water supply which will not utilise any existing infrastructure (storage tanks, drinking troughs, etc.)
- That the objectives of Namibia's new water supply policy, WASP, will be implemented by the DRWS, and in approximately 9 years time rural communities will be expected to have taken over full responsibility for the operation and maintenance costs of their water supply. In addition, by this time they will also be expected to replace broken down equipment and provide new installations themselves (DWA, 1996).
- The biophysical criteria required for the siting of a successful sand-storage dam have been met.
- The sand-storage dam is constructed as a storage dam, and not developed for aquifer recharge.
- That water from the sand-storage dams will be supplied via a gravel drain using a gravity fed supply system.

Although this study has been presented as a broad comparison between the concept of sand-storage dams and boreholes in rural areas of Namibia, it is hoped that by highlighting the major factors affecting the feasibility of these water supplies, that this study may also be able to be used to guide the decision-making process of a site-specific comparison.

## 6.1 Developing a Sustainable Water Source

The concept of sustainable development has become entrenched in everyday rhetoric, and is commonly used by governments, international aid agencies, academics and practitioners alike (WCED, 1987; Gardiner, 1994; Goodland, 1995; DEAT, 1996; Hill and Bowen, 1997). Sustainable development was defined by the World Commission on Environment and Development (WCED), or the 'Brundtland Commission', in their publication 'Our common future' as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). In the decade which has followed the Brundtland Commission, many attempts have been made to further understand and define the concept of sustainability and sustainable development (Dixon and Fallon, 1989; Schultink, 1992; Toman, 1992 and Goodland, 1995).

It is not the intention of this study to further debate these varying viewpoints on the implications of sustainable development, except to quote Redclift (1991) found that the problem with referring to sustainable development is that "*its strength is its vagueness: 'sustainable development' means different things to different people*". Likewise, Hill and Bowen (1997) proposed that "*the divergence of opinions relating to the term proves that 'sustainability' is so broad an idea that a single definition cannot adequately capture all the nuances of the concept*".

The importance of the broad concept of sustainable development, within the context of this study, is that it has developed a new paradigm under which decision-making processes should be based. The economic development paradigm which tended to dominate decision-making (Schultink, 1992, citing Carpenter and Dixon, 1985) is being replaced with a sustainable development paradigm of ensuring that economic, social and biophysical sustainability is considered in decision-making (Goodland, 1995).

In attempting to apply the ideals of 'sustainability' to the concept of 'sustainable construction', Hill and Bowen (1997) identified four attributes - social, economic, biophysical and technical - which they felt *"underpin and support the attainment of sustainability"*. These four attributes have been adapted to provide the four main criteria under which sand-storage dams and boreholes will be assessed as a method of rural water supply. Each of these criteria have been divided into a number of points, and each method of water supply is assessed under these points. The four criteria which have been developed for this study are:

- ❑ Economic Feasibility
- ❑ Technical Suitability
- ❑ Social Development
- ❑ Environmental Impacts

## 6.2 Economic Feasibility

In a feasibility comparison of this general nature, comparing the direct financial implications of the two schemes cannot be done with any degree of accuracy. A direct financial comparison would require an estimation of the total cost of developing both schemes, an estimation of the expected operation and maintenance costs required to ensure a sustained supply, and to then reduce these costs to a unit price per $m^3$ of water delivered over the predicted life span of the supply. For the comparison to be accurate, due regard will also need to be taken of the cost of capital and the time value of money.

Predicting these costs also requires site specific knowledge. For a sand-storage dam, a detailed study of the potential dam site is required to determine the size of the wall to be constructed, and to provide an estimation of the expected storage volume of the dam. For a borehole, assumptions will need to be taken regarding the expected depth of the water table, and what 'down-the-hole' equipment will need to be installed.

Due to these requirements, it is not intended to attempt a direct comparison of the financial costs per $m^3$ of water delivered for both methods of water supply. Rather, the main factors which will most influence the economic feasibility of developing either method of water supply will be presented. Where possible, broad indications are given of estimated development, operation and maintenance costs. It is felt that these figures will give decison-makers a greater understanding of the magnitude of the costs involved at these stages. Unfortunately these estimations exist mainly for boreholes. As sand-storage dams have not been constructed in Namibia for over 20 years, obtaining cost estimates for their construction was not possible.

In determining economic feasible, sand-storage dams and boreholes will be assessed under the following points:

- ❑ Cost of development
- ❑ Operation and maintenance costs
- ❑ Risk assessment
- ❑ Life expectancy

### 6.2.1 Cost of Development

The cost of development is intended to cover the costs incurred during the development of the water supply. In the case of a sand-storage dam, this will include all the costs incurred until the dam reaches its maximum storage capacity, while for a borehole until the pump has been installed and is delivering water.

The main stages of the development of a sand-storage dam and a borehole are given in Table 6.1 and 6.2 respectively. For each of these tables a description if given for each stage, as well as a summary of the requirements for each stage.

**Table 6.1: The Development of a Sand-Storage Dam.**

| Stages of Development | Description of Stage | Requirements |
|---|---|---|
| Initial feasibility study | •Groundwater consultant does a desk-top study of the area to determine the feasibility siting a sand-storage dam .<br>• Site inspection, and consultation with community to determine a feasible site. | •1-2 days engineering fees for desk-top study using geological maps, topographical maps, otho-photos, satellite images, etc.<br>•Site visit by engineer.<br>•Hiring of a backactor for excavating trenches to ensure solid wall foundations |
| Design of dam | •Engineer required to design dam wall according to site conditions.<br>•Height of wall stages to be determined according to hydrological data and data gained from site visit. | •1-2 days engineering design fees. |
| Preparation of foundations and construction of 1st stage of dam wall. | •Complete excavation and preparation of wall foundation.<br>•Construction of 1st stage of dam wall using a local contractor with necessary stone masonry and dam construction skills, thus ensuring high quality of foundation and footing construction. This contractor is to provide skills only, unskilled labour is to be provided by the community. These unskilled labourers are to be trained by the contractor in masonry skills in order equip the community with sufficient skills to complete the outstanding stages of wall construction themselves.<br>•Preparation of storage basin (removal of trees, debris, organics, etc.) | •Periodic site visit by engineer to assess suitability of foundations, quality of work, and compliance of contractor with regard to using, and training of local labour.<br>•Appointment of a building contractor to provide necessary skills regarding working with stone masonry, and to provide training and supervision of local labour.<br>•Community labour to be provided according to contractors requirements.<br>•Building material - stone to be sourced locally, cement and building equipment to be purchased externally. |
| Staged construction of dam | •Construction of final stages of the wall by the local community according to input from engineer regarding timing and stage heights.<br>•Installation of gravel drain and gravity fed extraction pipes<br>•Installation of water supply infrastructure- pipe to drinking troughs, taps, etc. | •Intermittent, on-site, consultation to guide construction and assess stage heights<br>•Community to ensure a continuity of skilled labour to ensure completion of wall.<br>•Building material - stone to be sourced locally, cement and building equipment to be purchased externally. |

**Table 6.2: The Establishment of a Borehole.**

| Stages of Development | Description of Stage | Requirements |
|---|---|---|
| Initial feasibility study | •Groundwater consultant does a desk-top study of the area to determine the feasibility of drilling for groundwater. | •1-2 days consultancy fees for a desk-top study- potential water bearing geological features identified from geological maps, topographical maps,ortho-photos and aerial photographs.<br>• Drilling history of area to be assessed via old borehole logs to determine expected water levels, yields, water quality and potential success rates. |
| Siting of borehole | •Consultant required to visit site to assess geological conditions and do a hydrological exploration to identify potential water bearing geological features.<br>•Consultation with community to determine their siting requests, and borehole sited according to a conjunctive requirements of community wishes and geotechnical conditions. | •1 day site visit by consultant, use made of geophysical equipment such as electro-magnetometer, magnetometer and resistivity. |
| Drilling of borehole | •Drilling rig to be established on site.<br>•Drilling proceeds until water is reached, or until a decision is made to stop drilling if hole is deemed 'dry'.<br>•Depending on geological conditions, casing may be required to be installed to prevent borehole collapse.<br>•A blow yield test is used to determine a rough yield of the borehole. Further aquifer testing required if safe abstraction rates are required. | •Drilling contractor gets paid according to:<br>i. Fixed establishment costs.<br>ii. Drilling rate per metre.<br>iii. Casing rates per metre installed.<br>•Consultant employed to ensure quality of work of driller, and to supervise the correct construction of the borehole. |
| Installation of pump and surface infrastructure | •Pumping infrastructure is installed depending on the borehole and aquifer characteristics.<br>•Water supply infrastructure to be constructed to facilitate a constant supply of water which is not dependant on pump operating i.e. storage tanks, troughs, taps, etc. | •Installation contractor to be established on site to install pump and storage tanks. Payment made according to:<br>i. Establishment costs.<br>ii. Type of pump to be installed.<br>•Groundwater consultant usually retained to ensure correct installation procedures followed - site visit required.<br>•Local community generally able to construct the rest of the smaller infrastructure - troughs, etc. |

**Sand-Storage Dams**

From Table 6.1 it can be seen that the major costs which are expected to be incurred in the construction of a sand-storage dam are:

- Consulting fees for ensuring site suitability, design of wall, and supervision of project.
- The hiring of a contractor to provide skilled labour for the construction of the 1st stage of the wall.
- The costs of importing building material (cement, stone, tools, etc.)
- The hiring of a backactor to assist in assessing foundation suitability, and in the preparation of the foundation.

An important element which needs to be considered in a cash flow analysis of a sand-storage dam is the rate of fill, and thus the total time delay before full capacity is reached. For each project the bulk of the consulting fees, the contractors fees, and the cost of hiring a backactor will be required to be paid at the start of the contract, while the costs of materials will be incurred at each of the stages of construction. No time period is indicated for the required staged construction, however, if it is assumed that an average rural sand-storage dam will be between 3-5 meters high (Burger and Beaumont, 1970), and will be built up over 3 stages with each stage requiring 2 rainy seasons to fill up, then the expected completion time will take a minimum of 6 years.

**Boreholes**

From this Table 6.2 it can be seen that the major costs which will be incurred during the development of a successful borehole can be divided into three categories:

1. Professional groundwater consultation fees for siting of borehole, supervision of drilling process and supervision of pump installation.
2. Drilling costs including establishment, drilling rates, and casing installation rates.
3. Pump installation rates including establishment costs, the cost of the pump and the contractors installation rates.

The costs of developing a borehole will vary according to the depth drilled and the type of pump which is installed. Table 6.3 presents estimated costs, as calculated by the DRWS for installing the infrastructure required for each type of borehole pump, as well as drilling costs of varying depths of boreholes.

**Table 6.3: Estimated prices for drilling and installing boreholes (from DRWS, 1996)**

| Technology | Price per unit | Total price |
|---|---|---|
| **Handpump** | | |
| Handpump and down the hole equipment | R14,000 | |
| Cattle trough | R3,000 | R17,000 |
| **Diesel Installation** | | |
| Diesel engine and down the hole equipment | R35,000 | |
| Storage infrastructure, trough, washbasin | R20,000 | R55,000 |
| **Solar Installation** | | |
| Solar pump and down the hole equipment | R40,000 | |
| Storage infrastructure, trough, washbasin | R20,000 | R60,000 |
| **Windmill Installation** | | |
| Windmill and down the hole equipment | R25,000 | |
| Storage infrastructure, trough, washbasin | R20,000 | R45,000 |
| **Borehole Drilling** | | |
| Borehole < 50m | R40,000 | |
| Borehole 50 - 100m | R80,000 | |
| Borehole > 100m | R120,000 | |

An estimate of the cost of developing a borehole, based on the figures above, can be calculated at the feasibility stage of a project. The type of installation will be chosen according to the needs of the community, and the expected drilling depth can be estimated by assessing the geological conditions of the area, and referring to the drilling logs of previously drilled boreholes in the area.

### 6.2.2 Operation and Maintenance Costs

Operation and maintenance costs are the costs incurred to ensure the continuity of a water supply scheme once it has been developed. Operational costs will include the day-to-day running costs of machinery, while maintenance costs will be incurred to ensure a continued program of effective maintenance is maintained throughout the life of the water supply.

**Sand-Storage Dams**

A sand-storage dam supplying water via a gravity-fed drain does not require any continuous operational or maintenance inputs. An occasional flushing out of accumulated fines from the gravel drain system may be required. This would entail pumping water under pressure into the system, requiring the hiring of a small portable water pump.

With the continual recharge of a sand-storage dam, it can be expected that the porosity of the top layer of sand will decrease over time as fines and solids clog up the pores between the sand particles. This is a slow process, expected to develop over years, however it may require an occasional, conjunctive input from the community to remove this silt accumulation. Depending on the amount of silt to be removed, very simple technology can be utilised to achieve this. Strategically placing boulders or digging trenches will create turbulence to help scour out silt, or physical removal through using donkey scoops could also be used.

Sand-storage dams, then, can be considered a virtually 'maintenance free' water supply, and once they reach full storage capacity, it is not expected that any major costs will be incurred to ensure their continued and efficient supply of water.

**Boreholes**

Operation and maintenance costs will vary considerably according to the type of pump which will be installed into the borehole. Estimated borehole operation and maintenance costs, again from the Department of Rural Water Supply, have been presented in Table 6.4 to highlight the magnitude of these costs.

**Table 6.4: Price comparison of operation and maintenance costs of various borehole pumps (from DRWS, 1996)**

| Technology | Operation and Maintenance Costs | |
|---|---|---|
| | monthly | per annum |
| Handpump on borehole 50-100m deep | R84 | R1,000 |
| Diesel engine on borehole 50-100m deep | R1,000 | R12,000 |
| Solar pump on borehole 50-100m deep | R125 | R1,500 |
| Windmill on borehole 50-100m deep | R125 | R1,500 |

### 6.2.3 Risk Assessment

An important factor which will affect the financial feasibility of developing a water supply is the degree of uncertainty on whether or not a reliable water supply will be produced. The cost of developing a water supply will not be affected by the volume of water which it eventually produces. However, if this volume is smaller than expected, it will dramatically increase the estimated unit price of the water supplied. If a water supply fails to produce water all together, the costs incurred in developing this failed project will have to be 'carried over' to the next attempt, effectively doubling the unit price of water for this supply.

**Sand-Storage Dams**

Accurate calculations can be done regarding the expected volume of sediments which will be retained behind the wall (Burger and Beaumont, 1970), however accurately determining the specific yield of the dam is difficult. The factors which affect specific yield - the grain sizes of the sediments, shape and distribution of the pores and compaction, cannot be accurately assessed until the dam has completely silted up (Beaumont, 1969).

Although the precise specific yield of a sand-storage dams is difficult to calculate, Wipplinger (1958) notes that even silted up open-storage dams are capable of yielding a water supply. It can therefore be assumed that a sand-storage dam which is planned and constructed with the express purpose of trapping coarse sediments, will retain water. Conservatively calculated estimates, based on the volume of sediments expected to be stored and the expected sediment type, can be made with a high probability that they will be achieved.

**Boreholes**

Wipplinger (1958) stated that "*in certain regions/areas of Namibia, geological conditions are unfavourable towards finding groundwater reserves, and water-boring is a highly speculative venture*". Although geotechnical investigation techniques have improved since 1958, the geological nature of secondary aquifers makes accurate geotechnical predictions difficult. This is especially relevant in Namibia where, although there are an estimated 32 000 boreholes delivering water, it is noted that good groundwater sources are the exception an not the norm (DWA, 1991). Nearly

80% of these boreholes are delivering yields which are lower than the purpose for which it was drilled (DWA, 1991).

In addition to the risk of developing a borehole which produces a lower yield than required, a risk is taken that the borehole drilled will not yield sufficient water to make it worthwhile developing (a 'dry' borehole). An indication of risks involved in drilling a 'dry' borehole in the rural areas of Namibia can be seen in Table 6.5. This table is a summary of the DRWS drilling programme between 1992 - 1996 (Christelis, pers. comm.). The figures which are presented are only meant to give a rough estimate of success rates, as during this time period many 'emergency drought relief' boreholes where drilled in rural areas with little record keeping involved in some of these programmes (Christelis, pers. comm. and UCT, 1997). Results have only been presented of the drilling programmes in rural areas of Namibia where the general geology is most suitable for the development of sand-storage dams. Results from regions underlain by unconsolidated sediments (Kalahari Sands) are not presented, as it is not feasible to develop sand-storage dams in these areas.

**Table 6.5: Summary of results from DRWS drilling programme 1992 - 1996.**

| Region | Number of Boreholes Drilled | Number of Successful Boreholes Developed | Success Rate |
|---|---|---|---|
| Kunene | 144 | 87 | 60% |
| Erongo | 35 | 16 | 46% |
| Hardap & Karas | 76 | 36 | 47% |

A further risk in drilling boreholes is the uncertainty of the quality of water which will be extracted. One indication of water quality is the amount salt concentration in the water, commonly measured as Total Dissolved Solids (TDS) (UCT, 1997). The World Health Organisation (WHO) recommends that water with TDS levels higher than 1000 mg/litre is unfit for human consumption. Of the 16 boreholes tested for TDS levels for the 'baseline report' (UCT, 1997), 3 had TDS levels above 1000 mg/litre. In this report there was even mention made of one borehole which seemed to be pumping oil!

In establishing boreholes then, there is a high risk that the final yield will be lower than what is required, and depending on the geohydrological characteristics of the area, a

40-50% chance of drilling a 'dry' borehole. Concern also needs to be raised that high TDS levels may result in a water quality which is unfit for human consumption.

### 6.2.4 Life Expectancy

Although the expected service life of a structure is often discussed under technical criteria (Hill and Bowen, 1997), it is felt as the life-span of a water supply has a direct implication on the unit cost of the water, life expectancy plays a crucial role in determining the economic feasibility of a water supply. The longer the structure maintains a reliable supply, the lower the unit cost of the water, and hence the greater the chance of it being economically feasible to develop.

**Sand-Storage Dams**

Predicting a typical life-span for a sand-storage dam is difficult, with historical records showing some old sand-storage dams having extremely long life-spans. Wipplinger (1958) reports that a sand-storage dam built at the Bacteriological station near Windhoek in 1907 has "*yielded a continuous supply for gardening and stock ever since.*" From literature regarding sand-storage dams (Wipplinger, 1958; Beaumont and Burger, 1970; Aubroeck, 1971) it seems that a design life of 30 years and over can be expected from sand-storage dams.

**Boreholes**

Predicting the life-span of boreholes, especially with regard to their equipment, can be done more accurately than for sand-storage dams. Depending on whether or not a borehole is cased will affect the life expectancy of the hole, with un-cased holes tending to 'grow closed' due to root growth in the hole (personal observations). The type of pump installed on a borehole will have been manufactured according to a certain design code, and will therefore have a specified design life. Whether or not this designed life-span is achieved will depend on the handling and maintenance of the pump.

In Table 6.6 the expected life-spans of the various types of borehole installations are presented. The expected life-span of the actual hole is also given, however it is uncertain if this applies to a cased, or un-cased holes.

**Table 6.6: Expected life-spans of a borehole and various installations (from DRWS, 1996)**

| Borehole and Installations | Life-Span |
|---|---|
| Handpump | 5 years |
| Diesel Installation | 10 years |
| Solar Installation | 15 years |
| Windmill Installation | 15 years |
| Borehole | 20 years |

## 6.3 Technical Suitability

One of the requirements of a successful Community Water Supply is that the technology utilised in the development, operation and maintenance must match the resources available to sustain it (Wurzel, undated). The emphasis, therefore, which has been placed under this criteria is to assess the suitability of the technology utilised in each water supply, with regard to utilising local resources and taking consideration of local resource constraints.

Technical suitability has been assessed under the following points:

- ❑ Construction technology
- ❑ Maintenance technology

### 6.3.1 Construction Technology

Water points developed in Namibia as a source of rural water supply are effectively operating under '3rd world' conditions. If '1st world' knowledge and building standards are used to construct these water supplies, then it needs to be ascertained how much local knowledge, material and labour is being utilised, and whether or not there will there be an effective transfer of this knowledge and skills to local users and builders.

**Sand-Storage Dams**

Due to the general lack of data about the flow characteristics of Namibian rivers (Scott, 1979), it is imperative that during the feasibility stage of a sand-storage dam consultation with the local community takes place in order to obtain an estimate of these flow characteristics, required for design purposes. The construction of a stone masonry dam wall requires the use of locally available hand-sized rock, as quarrying for material or importing crushed stone and sand for a concrete mix will vastly increase building costs. In addition to requiring local materials, the construction of a stone masonry wall is also a labour-intensive process, requiring the use of local, unskilled labourers to provide assistance to skilled stone masons (Shaw, pers. com.). The skills required to building using stone masonry are not difficult to learn (*ibid.*), and during the first stage of the wall's construction these unskilled labourers should be able to develop adequate masonry skills to complete the follow-on stages of the wall by themselves. These masonry skills are highly valuable in both the local rural and an urban environment, as they are transferable skills which can be applied to any stone masonry building work.

The construction of a sand-storage dams then, can be said to make good use of locally available knowledge, materials and labour, while also facilitating the transfer of valuable stone masonry skills to members of the local community.

**Boreholes**

The process of siting, drilling and installing a borehole is a highly technical procedure. Complex geophysics are required to locate optimum amounts of groundwater (Wurzel, undated), and as a result very little effective communication appears to take place between the geotechnical consultant and the local community regarding the siting of the borehole (UCT, 1997). The drilling of the borehole is a highly specialised procedure, usually requiring 3 - 4 trained labourers who are permanently employed by the drilling contractor (personal observations). Likewise, the installation of the borehole infrastructure is a specialised procedure, with little requirement for local unskilled labour.

The highly technical process of developing a borehole therefore, is not conducive to effectively utilising local resources, or leaving any transferable skills within the community.

### 6.3.2 Maintenance Technology

Ball (1995) states that "*the only people who can sustain a rural water source are those who will use it.*" This point has been highlighted in the following assessment, which aims at determining the suitability of the technology used to provide the water, to be effectively maintained by the local community.

**Sand-Storage Dams**

As discussed in Section 6.2.2 (operation and maintenance costs), very little maintenance is required for a sand-storage dam which supplies water through a gravity-fed drain. It is felt, however, that a caretaker should be appointed, from within the community, to take responsibility of ensuring that the gravity-fed water supply system is functioning efficiently. These responsibilities will include the occasionally flushing out of the drainage system of accumulated fines, and supervising the periodic removal of silt from the surface.

The successful appointment of this caretaker will require that the potential users of the sand-storage dam are educated such that they understand the basic principles behind which the sand-storage dam works, and to outline the methods which can be employed to enhance these principles. This knowledge should be easily passed to the community, as there is no requirement for developing technological skills.

**Boreholes**

Boreholes will either be installed with a handpump, diesel engine, solar pump or a windmill. The basic maintenance required for these infrastructures will differ dramatically, from the almost maintenance free solar pump to a strict program of daily, weekly and monthly maintenance required for a diesel pump (DWA, 1996). These basic maintenance requirements can be met by a caretaker, as proposed in chapter 3 under "Strategy Paper 8: Operation and Maintenance of Rural Water Supply Equipment". The caretaker will have to undergo formal training regarding the correct operation and maintenance procedures to be followed for a particular water point.

More technical maintenance requirements, such as replacing broken solar panels or major diesel engine services, will require the hiring of external 'specialists', as these are skills which are not easily transferable to the community. Similarly, the maintenance of the borehole itself requires specialist skills and appropriate machinery. An example of the type of advanced maintenance which is required for maintaining a borehole is presented in the following quote from a report to the Department of Rural Water Supply Report (DRWS, undated) regarding the rehabilitation of a borehole: *"Lowered windmill. Pulled piping. Fished steel and rubbish from 15.0 to 18.5m. Could not fish* *further. Rubbish remains in hole.*" Removing a windmill, and pulling up the pipes which transfer water from the bottom of the hole, requires resources which are likely to be beyond the scope of a typical rural community

The basic maintenance of a borehole supplied water point can, therefore, be met by the community. This is provided that adequate skills training is given to the borehole caretaker. More technical maintenance of the infrastructure and borehole, however, will require the hiring of external 'specialist' knowledge.

### 6.3.3 Implementation Efficiency

Implementation efficiency is a measure of how quickly the water supply can be developed to its full capacity.

**Sand-Storage dams**

Owing to the staged development of a sand-storage dam, substantial delay occurs before it reaches full storage capacity. Under "Cost of Development" it was estimated that the minimum completion time for a rural sand-storage dam will be 6 years. The concept of sand-storage dams, therefore, can only be developed as a part of a long-term water supply plan.

**Boreholes**

The dependence on technical processes to site, drill and install a borehole means that it can be developed in a relatively short period of time. In the rural context a borehole should be able to be developed within 1-2 months, depending on the availability of drilling contractors and pump infrastructure. This effectively makes boreholes an 'instant' water supply.

## 6.4 Social Development

Ball (1995) realised that no matter how much the technology of rural water supply is improved, technological excellence will be undermined if the human and political factors which are peculiar to a water point are ignored. He stresses that the successful development of a new water source requires constructive engagement with the people who will be expected to benefit from it: "*listen to them, understand their concerns, and allow them to decide if they can sustain a new water supply amongst the changes it will bring.*" In a similar vain Leusink

(1992) stresses the importance of public participation and community-based management in the planning process of a water supply, stating that it is "*desirable for strengthening the awareness of the users to involve the beneficiaries at an early stage of planning and implementation and to take social issues into consideration.*"

These ideas are echoed in the Rural Water Supply Strategy Papers (DRWS, 1994) where it is stated that "*It is the cabinet's decision that rural water supply in Namibia will be implemented with a high level of community participation; the end users will be involved from pre-planning continuously through all the phases that can be recognised in rural water supply. This approach is considered the most appropriate way to establish sustainable rural water supply.*"

These ideas are especially important when consideration is given to Namibia's new "Community Management of Rural Water Supply" program (DWA, 1996). Although a community may request a new water source, if their decision to proceed with its development is not based on a full awareness of the implications inherent in this development, their ability to sustain this new supply may be jeopardised.

Assessing the extent to which it is expected that the development of a sand-storage dam or a borehole will addresses social concerns, is done under the following points:

- Community ownership
- Promotion of self determination
- Community perceptions

### 6.4.1 Community Ownership

As mentioned previously, the "Community Management of Rural Water Supply" program (DWA, 1996) is geared towards making communities fully responsible for their water supply, and in effect, encouraging them to become 'owners' of their supplies. Being an 'owner' of a water supply, however, is different to having 'ownership' over the process of its development, and ensuring its sustained use. This sense of 'ownership' will be more solidly entrenched if the community are full participants in the decision-making process of deciding what type of water supply system is the most feasible, where it is to be sited, how it is to be developed and how it will be maintained. A sense of 'ownership' will also be strengthened if the community are actively involved in the stage-by-stage development of the water supply.

**Sand-Storage Dams**

Although the concept of storing water in sand-storage dams is likely to be relatively unknown in the rural areas of Namibia, it is felt that the principles behind this idea can be fairly easily explained to these rural communities. This should facilitate a greater understanding of the implications inherent in developing this method of water supply, and allowing them the opportunity of making a more informed decision regarding its suitability according to their requirements.

The siting of a sand-storage dam needs to be done in consultation with the community, in order to best combine the biophysical requirements for a successful sand-storage dam, and the community's preference for the position of the water supply point. It is important that a concerted effort is made to ensure that the unskilled labour, provided from within the community, receive adequate training in masonry skills during the first stage of the construction of the dam wall. By transferring these skills into the community, full ownership is invested in them to ensure the successful completion of the following stages of the wall. In a similar manner, the low levels of technology required for maintaining a sand-storage dam allows the community ownership over implementing the maintenance required to ensure a sustained water supply.

**Boreholes**

Although the community can request their preferred position for a water point, usually as close to existing infrastructure as possible, the complex geophysics involved during the siting process leaves the decision of where to site the borehole largely in the hands of the groundwater consultant. This lack of understanding and involvement results in a lack of trust of the geohydrologist, and many rural communities would prefer to have their boreholes sited by a local 'diviner', whom they feel have a greater understanding of local conditions and attain higher success rates (UCT, 1997).

Once the decision has been made where to site the borehole, there is no community ownership over the drilling process. Deciding on an estimated water depth to guide the drilling process, knowing when to stop if water is struck or when to declare the hole 'dry', are decisions best taken by a groundwater consultant on behalf of the community. Simply leaving the drilling to a contractor with no 'specialist' supervision by a consultant often results in excessive expenses being incurred by the client (the community), as the contractor is paid for the depth drilled and will often drill a hole deeper than required (Hartley, pers. com.). The choice of infrastructure and borehole pump should be made by the community, again after understanding the full implications of each option. Once the choice is made however, the installation of this infrastructure requires little community involvement.

The only part of the process of developing a borehole, and its associated infrastructure, where a strong sense of community involvement is required, is to ensure the ongoing and effective maintenance of the pump. Unfortunately, this is at the end of a highly technical process which is not very conducive to community ownership or involvement.

### 6.4.2 Promotion of Self Determination

Jacobson *et al.* (1995) describe social sustainability, within the Namibian context, as "the need for a social framework which empowers self-control over resources, at the individual, regional and national level". Implicit in this description is an understanding that Namibians, at all three levels, must take on the responsibility of managing their water resources effectively.

At a water point level, individual communities need to ascertain the safe yield at which they can extract water. The concept of "safe yield" has been borrowed from a geohydrological definition of the term as "a rate of withdrawing water over a long period of time without causing an unacceptable reduction in groundwater levels (Hamill and Bell, 1986). Applying this definition to sand-storage dams simply implies a yield which will not deplete the dam's storage volume before it is recharged again.

**Sand-Storage Dams**

As mentioned previously, it is not possible to accurately determine the storage volume of a sand-storage dam. Predetermining a safe yield will require not only a estimate of this storage volume, but also a history of the flow characteristics of the river. As such, any predicted safe yield is likely to be inaccurate, and it will therefore become the responsibility of the users to determine an estimated safe yield judged on experience. This estimation will be based on assessing the strength and duration of flood events which recharge the dam, and correlating these events with accumulated experience regarding yield volumes from previous years.

Although these estimates will always be prone to variations in rainfall patterns, this method of water supply provides the community with complete responsibility for determining how to utilise the resource. A sand-storage dam obviously has only a limited volume of water available, and as such it fosters a sense of self determination as to how this water is to be rationed according to the community's requirements.

Although it is recommended that a caretaker be given the responsibility of ensuring the maintenance of the outlet structure, the low technology involved in this method of water supply means that very few 'outside' influences will affect the continuity of supply (mechanical breakdowns, lack of money for diesel, etc.). This gives all the users equal independence in determining how to utilise their water supply. Dominance over the supply by a single individual with more access to financial resources is unlikely to occur.

**Boreholes**

The complex dynamics involved in understanding underground water is not easily explained, and users often hold a misconception that there is an unlimited volume of water of underground water available to them. This misconception is compounded by the fact that it is difficult to determine a borehole's safe yield with any degree of accuracy (Hamill and Bell, 1986). The most accurate method of initially estimating the safe yield of a borehole is by doing step tests and constant rate tests (Hartley, pers. comm.). Unfortunately, due to the time and costs involved, stepped pump tests are not often done for rural boreholes in Namibia and a very rough estimate of available yield is usually calculated by the drilling contracter doing a blow yield test. (UCT, 1997).

The maximum yield of rural boreholes installed by the Namibian government has historically been set according to the results of these blow tests, or according to the estimated requirements of the community, which ever the lower volume (Van der

Merwe, pers. com.). This maximum yield would be indirectly enforced on the borehole users by regulating the size or type of pump installed, or by deliberately installing pipes which under utilised the capacity of the pump (Van der Merwe, pers. com.) Historically then, very little self determination has been given to rural communities to determine the pumping rates of their boreholes. It was obviously felt that given the opportunity they would pump a borehole to its maximum capacity, resulting in a depletion of localised groundwater levels.

One method of involving the community in regulating their water consumption is to provide them with a cheap depth meter, and educate them to monitor fluctuations in water table depths over constant time periods. By plotting these depths the community will be able to correlate water table fluctuations with rainfall events and water consumption patterns, and can be used to more accurately determine their safe yield.

The relatively high operation and maintenance costs of a borehole pump, and the reliance of the community on a caretaker who holds specialised skills required for the maintenance of the pump, may result in an unequal distribution of power within the community. Wealthier individuals within the community may dominate the operation of the water supply, while the 'caretaker' needs to be trusted by the community to maintain a high level of responsibility regarding the maintenance of the pump.

### 6.4.3 Community Perceptions

The initial perceptions which a community have regarding a specific type of water supply are likely to impact on their motivation of choosing a specific of water supply. Perceptions will be based on previous experiences from within the community, as well as from experiences which have been related from other communities. These perceptions can lead to prejudices being formed before the 'facts are on the table', and hence influence the outcome of a project at the feasibility stage. The perceptions which the community might hold will need to be addressed by the consultant who has done the initial feasibility study. This will require an impartial presentation of the implications of the both methods of water supply, which is aimed at educating the potential users of the long-term impacts and results which are likely to be experienced.

**Sand-Storage Dams**

It is likely that the initial perceptions of communities towards the idea of developing a sand-storage dam will not be positive. Some reasons for this are:

- The relative obscurity of the principles behind sand-storage dams, and the fact that this concept is likely to be unknown and untested within the community's experience.
- The long period of time required to fully develop a sand-storage dam.
- The uncertainty of how much water will be stored.

This initial negative perception is likely to change if the positive economic benefits of sand-storage dams are explained under the context of WASP requirements.

**Boreholes**

Initially, boreholes are likely to be the preferred method of water supply of rural communities. Some reasons for this are:

- Boreholes have always been the main method of supplying water to rural communities in Namibia (everybody 'knows' a borehole).
- When drilled into water bearing rock formations they produce good water.
- It is a quick process to develop a borehole and install the pump.
- Historically, rural communities never had to worry about the costs involved in developing , operating and maintaining a borehole.

The introduction of the "Community Management of Rural Water Supply" program is likely to sway the present preferation which many rural communities have towards diesel pumps (personal observations) into requests to replace them with low maintenance solar pumps or windmills. With full the implementation of full cost recovery however, it is likely that rural communities will be more willing to consider cheaper methods of water supply.

## 6.5 Environmental Impacts

The last period during which a number of sand-storage dams which were built in Namibia ended in the late 60's (Lau and Stern, 1990). Although environmental concerns were being developing in 'northern' countries at this stage, and the US government would have been busy developing their National Environmental Policy Act (Fuggle and Rabie, 1992), environmental conciousness was probably of little concern in, the then, South West Africa. With the cessation of interest in developing sand-storage dams in the mid 70's, it appears that no study of the environmental impacts of a sand-storage dam has ever been commissioned in Namibia.

Nilsson (1988) states that "If *planned and executed properly, a scheme involving damming of groundwater should have no direct negative impact on the surrounding* environment." He goes on to emphasis the importance of careful planning, as these water storage techniques are generally constructed in fragile environments where *"even a small change may have long-term physical as well as social consequences"*, and that there may be *"an effect on the groundwater conditions in downstream areas"*.

During the baseline report (UCT, 1997), it was noted that the provision of boreholes as a source of permanent water supply has enabled people to live where a lack of surface water previously prevented them from doing so. However, boreholes provided in an unplanned manner lead to inappropriate farming and land use practises being practised in marginal grazing areas. This results in environmental degradation- including soil degradation, bush encroachment and a reduction in the quality and quantity of grazing. An additional concern regarding the utilisation of boreholes is the effect this will have on water tables and downstream flow volumes *(ibid.)*

From the concerns raised above, environmental impacts have been divided into the following components:

- Downstream effects
- Resource-use efficiency
- Environmental impacts of a point source of water

### 6.5.1 Downstream Effects

A primary environmental concern regarding the development and utilisation of a water supply is the effect this will have on reducing flow volumes, and how this will impact on downstream consumers. This concern is clearly reflected by Jacobson *et al.* (1995) who state that *"when developing water resources in a region, we do not create water. Rather, we are re-distributing it across the landscape, to the advantage of some but often to the detriment of other users."*

Downstream flow is not only required for human needs, but also for environmental purposes (Walmsley, 1995). With regard to the human needs, social equity requires that all potential water consumers along the length of a river's catchment have equal access to this resource. Water required for environmental purposes has been defined by Walmsley and Davies (1991) as that volume which is required *"to maintain a multitude of ecological functioning within habitats such as wetlands, estuaries, reservoirs, river channels and riparian zones."*

**Sand-Storage Dams**

Inducing the impoundment of water in an ephemeral river will impact on downstream users (Jacobson *et al.*, 1995). As sand-storage dams effectively aim to induce surface water to recharge an artificially created alluvial aquifer, they need to be seen as a source of water impoundment. Concern, therefore, needs to be raised of the cumulative impacts a number of sand-storage dams will have on stream flow.

In this assessment no differentiation has been made between the downstream effects which are expected during the construction of a sand-storage dam, and those expected once the dam reaches its full storage capacity. This assumption has been based on the principle that the staged method of construction aims at minimising the volume of 'open' water retained behind the wall, and hence it is not expected that the total volume impounded during the construction stage will be greater than the storage volume of the dam once it reaches full capacity.

In trying to assess the cumulative effects of sand-storage dams on stream flow, it is not practical to simply try and compare the effects of a number of open-storage dams, with those of sand-storage dams holding similar volumes of water. Adams (1991) found the major effects of storing stream flow in open farm dams to be:

- A net export of water from the catchment due to increased rates of evaporation.
- An increased spatial and temporal exposure of water as it changes from a 'closed' stream state to open dam storage.
- A delay in the onset of stream flow as the dams are filled up, followed by an extended stream flow after a decline in surface runoff as the dams discharge their overflow.

Of these effects the only comparable effect which could be attributed to sand-storage dams would be a reduction in the volume of stream flow due to infiltration as it flows over the dam's storage basin. This induced infiltration is more likely to effect the stream continuum, rather than creating delays in stream flow. In this study the concept of "stream continuum" is used to represent the continuous flow, within a section of an ephemeral river, from the point where surface water starts flowing to the point where this surface flow ceases. As sub-surface flow will continue in many cases (Jacobson *et al.* 1995), a decrease in the volume of surface water is expected to correlate directly with a decrease in the volume of sub-surface flow. It seems reasonable, therefore, to extend the cumulative effect which a number of sand-storage dams will have on reducing the surface flow continuum, to also reducing sub-surface continuum.

Utilising a sand-storage dam in such a manner that it is completely 'emptied' of storage water, will not have an impact on surrounding groundwater levels. However, if vegetation has developed on, or around, the dam in order to utilise it as a source of water, this vegetation is likely to die off. However, as this vegetation is decreasing the dam's storage efficiency, it should not be encouraged to grow in the first place.

**Boreholes**

Secondary aquifers are usually found in solid rock at depths below 50m, and as such are not recharged directly from stream flow. Rather they are recharged by a slow infiltration process. As the majority of Namibia's rural boreholes are situated in secondary aquifers (Simmonds, pers. comm.), it is not expected that these boreholes will have any significant impact on reducing downstream flow.

However, boreholes which are drilled into the primary alluvial aquifers of Namibia's ephemeral rivers are abstracting water which is recharged directly from stream flow. Utilisation of these aquifers will result in similar reductions in stream flow volume as predicted for sand-storage dams, and hence in similar downstream effects of reducing surface, and sub-surface flow continuums. In addition, if these aquifers are pumped at a faster rate than their recharge by stream flow then the water table of these aquifers will be lowered. Riparian vegetation is heavily dependant on this groundwater, and if groundwater levels are lowered below the root levels of this vegetation this vegetation will die-off (Jacobson *et al.*, 1995). Lowered groundwater levels also result in the drying up of springs which might be found in the surrounding area (*ibid.*).

### 6.5.2 Resource-use Efficiency

The cause of much of the worlds environmental degradation is due to the over consumption of resources (Hill and Bowen, 1997, citing Kibert, 1994c). Although sand-storage dams and boreholes are both developed for the purpose of consuming a scarce natural resource, assessing how their development will affect the management of this resource in Namibia is beyond the scope of this study. Rather, the comparison which will be made between these two methods is to assess the extent of the resources which are consumed to provide, operate and maintain these water supplies.

**Sand-Storage Dams**

From Table 6.1 it can be seen that, during the development process of a sand-storage dam, a minimum of non-renewable resources or energy is required for its construction. The majority of the resources used in the dam wall's construction are locally available stone, imported cement, and human labour. Very few manufactured materials are used, and very little mechanised input is required throughout the development stage of sand-storage dams.

Likewise, there is very little resource input required for the operation and maintenance of a sand-storage dam. Apart from the occasional requirement to hire a small water pump to flush out the drainage supply, no technological input is required to ensure a sustained supply.

**Boreholes**

The process of developing a borehole utilises very few natural materials, most of the resource input is in the form of machinery or manufactured materials. From the geophysical equipment used in the siting process, to the process of drilling the borehole, installing steel or PVC casings, and setting up the borehole's infrastructure, there is a complete reliance on non-renewable resources.

The extent of the use of non-renewable resources during the operation and maintenance stage depends on the type of pump installed. The basic maintenance and operation of a solar pump, handpump, or windmill requires very little use of non-renewable resources, while a diesel engine requires a constant supply of diesel and oil. The replacement of parts for all of these pumps, however, requires the importation of manufactured goods, and hence a consumption of non-renewable resources.

### 6.5.3 Environmental Impacts of a Point Source of Water

A major concern which was raised in the "baseline report" (UCT, 1997), was the effects of providing a point source of water in an arid or semi-arid environment. It is not the intention of this report to revisit these effects, however it needs to be pointed out that some of the effects of placing a non-natural point water source in the Namibia's rural environment are:

- A concentration of livestock and settlements in particular locations as natural nomadism, dependant on rainfall patterns, is replaced with sedentarisation.
- Livestock concentrations around water points often results in overgrazing. This loss of vegetation cover leads to soil loss and degradation, hence a reduction of the seed bank within this soil, and it is feared that this may lead to desertification.

As sand-storage dams and boreholes are both classified as point sources of water, differentiating any difference in the degree of environmental degradation which will lead from their provision must be based on an assessment of the volume of water they will supply.

**Sand-Storage Dams**

As a water supply with a fixed volume, it is expected that the environmental impacts of a sand-storage dam will correlate directly with this volume.

If a sand-storage dam has sufficient storage volume to facilitate the development of the year round water supply, its development is likely to produce a permanent settlement. As discussed above, permanent settlement encourages unsustainable land use practises.

If the storage volume it too low to support a permanent settlement, the sand-storage dam is likely to be utilised for seasonal grazing only. Although seasonal grazing is a more sustainable farming practise in many areas of rural Namibia (Jacobson *et al*, 1995), the present lack of clear policy regarding land tenure and land use planning (UCT, 1997) makes it difficult for communities efficiently utilise this option of building low volume sand-storage dams to facilitate rotational grazing.

**Boreholes**

Boreholes in the rural areas of Namibia, tend to result in the permanent settlement of a community at this borehole (UCT, 1997). As mentioned above, these permanent settlements are promoting unsustainable land use practises which is resulting in overgrazing and soil degradation.

## 6.6 Conclusion

In this chapter, sand-storage dams and boreholes have been assessed under a number of 'feasibility' criteria. The key results from each of these individual assessments are presented in a comparative format in Table 6.7. The aim of this table is to facilitate an easily understood comparison of both methods of water supply, according to the comparison criteria developed above. Although the preferred option for each criteria has been shaded in this table (according to personal biases and values), this shading is meant to guide, and not dictate the decision-making process.

**Table 6.7: Framework Table- Comparing sand-storage dams and boreholes (Shading indicates preferred option, unshaded if no comparison can be drawn)**

| Comparison Criteria | Sand-Storage Dams | Boreholes |
|---|---|---|
| **Economic Feasibility** | | |
| Cost of Development | Major costs include:<br>•Consulting fees for ensuring site suitability, design and supervision.<br>•Hiring of contractor for 1st stage of wall construction.<br>•Importation of building materials (cement, tools).<br>•Hiring of a backactor for foundation preparation. | Major costs include:<br>•Consulting fees for hydrological exploration and supervision.<br>•Drilling of borehole- includes establishment, drilling rates and casing rates.<br>•Installation of infrastructure- includes cost of the pump, and contractors establishment and installation rates. |
| Operation and Maintenance Costs | Negligible:<br>•Basically 'maintenance free'- no major cost expected. | Depends on type of infrastructure, some estimates are:<br>•Handpump = R1,000 per year<br>•Solar pump = R1,500 per year<br>•Windmill = R1,500 per year<br>•Diesel pump = R 12,000 per year |
| Risk Assessment | Low risk of complete failure to deliver water, however accurate predictions of storage volume not possible. | Risk of drilling a 'dry' hole, and high probability that yield is lower than required. |
| Life Expectancy | Long life expectancy:<br>•In excess of 30 years. | Depends on type of Installation:<br>•Hand pump = 5 years<br>•Diesel installation = 10 years<br>•Solar installation = 15 years<br>•Windmill installation = 15 years<br>•Borehole = 20 years |
| **Technical Suitability** | | |
| Construction Technology | Low technology levels<br>•Makes good use of local resources and allows transfer of masonry skills to community. | Highly technical process<br>•Little use made of local resources, no skills left with community. |
| Maintenance Technology | No technical skills required<br>•Maintenance can be sustained by community. | Depends on level of maintenance:<br>•Basic maintenance can be sustained by community.<br>•Technically advanced maintenance requires 'specialist' knowledge. |
| Implementation Efficiency | Low efficiency<br>•Delays of 6-8 years before full storage capacity reached | High efficiency<br>•Full implementation capable in 1-2 months |

| Comparison Criteria | Sand-Storage Dams | Boreholes |
|---|---|---|
| **Social Development** | | |
| Community Ownership | **High degree of community involvement and ownership in both decision making process and in development of structure.** | Little community ownership in decision making, little community involvement in development of borehole. |
| Promotion of Self Determination | **Restricted volume of water available, therefore full independence of community to determine a 'safe yield'.** | Less restricted volume, therefore more regulation from national levels regarding utilisation of a national resource. |
| Community Perceptions | Initial perceptions likely to be negative towards sand-storage dams. | **Initial perception likely to favour boreholes.** |
| **Environmental Impacts** | | |
| Downstream Effects | Negative effects<br>•Results in a reduction of downstream surface and sub-surface flow.<br>•No effect on surrounding water table levels. | Depends on type of aquifer accessed:<br>•Secondary aquifers (the majority of rural borehole) will have no downstream effects.<br>•Boreholes in alluvial aquifers will result in a reduction of downstream surface and sub-surface flow. If aquifers are over utilised there will be a lowering of water table levels, impacting on riparian vegetation. |
| Resource-Use Efficiency | **High resource efficiency**<br>**•Predominantly utilises local resources, and little use of non-renewable resources.** | Low resource efficiency<br>•Predominantly a mechanised process utilising manufactured non- renewable resources. |
| Impacts of a Point Source of Water | Depends on volume:<br>•If high volume- will promote permanent settlement, leading to overgrazing loss of vegetation cover, and soil degradation.<br>•If low volume- will be utilised in a more temporary manner, facilitating rotational grazing. | Induces permanent settlement, leading to overgrazing loss of vegetation cover, and soil degradation. |

Under these personal biases and values then, the comparison between sand-storage dams and boreholes is summed up firstly according to each of the four main comparison criteria, and then according to the overall feasibility of sand-storage dams as an alternative method of rural water supply to boreholes. According to each of the four main comparison criteria:

- **Economic Feasibility**

  Although it was beyond the scope of this study to accurately compare development costs for each method, and hence a comparative cost per $m^3$ of water supplied, it is clear that the operational and maintenance cost of a sand-storage dam are markedly lower than those of a borehole. In addition, sand-storage dams are expected to have a longer production life, and are developed with a higher probability of successfully producing water than boreholes. Therefore, if sand-storage dams can be developed for a lower cost than boreholes, then they are likely to be a more economically feasible method of rural water supply.

- **Technical Suitability**

  The technique of storing water in sand-storage dams utilises less technology in both the development, operational and maintenance stages. As such, this method is more technically suitable to Namibian rural conditions, however a major drawback which sand-storage dams have over boreholes in this regard, is the length of time needed for their completion. Boreholes can be commissioned in a matter of 1-2 months, while a sand-storage dam may take several years.

- **Social Empowerment**

  The process of developing a sand-storage dam allows for more community ownership and self determination than the highly technological process of developing a borehole. However, owing to the relative obscurity of the concept of sand-storage dams, and the length of time required for their completion, initial community perceptions are likely to be negative towards this method of water supply.

- **Environmental Impacts**

  Although the process of developing a sand-storage dam utilises less resources than that of a borehole, comparing the downstream effects and the environmental impacts each have as a point source of water is difficult. The cumulative impact of a number of sand-storage dams will be a reduction in the downstream surface and sub-surface flow continuum. A similar impact can be expected for a number of boreholes drilled into alluvial aquifers, in addition to an expected lowering of local water table levels. Boreholes drilled into secondary aquifers are unlikely to have any effect on downstream flow. As both boreholes and sand-storage dams are methods for providing a point source of water into Namibia's semi-arid environment, the impact of either method will depend more on the volume of water supplied, than on the actual method of supplying the water. The greater the volume of water supplied the greater the likelihood of overstocking resulting in overgrazing and soil degradation. As the volume of a sand-storage dams is expected to be lower than that of a borehole established in a well-defined alluvial or secondary aquifer, the overall environmental impacts of sand-storage dams are expected to be lower than that of boreholes.

In summary then, although it appears that under the above comparison criteria sand-storage dams seem to be a more favourable method of rural water supply than boreholes, the following points need to be realised:

- The 'fixed' storage volume of sand-storage dams is likely to result in their safe yield being smaller than that of boreholes which are developed in well defined secondary aquifers. Although the yield needs to be sufficiently large enough to make its construction financially viable, if the yield is too large it will encourage overstocking, and hence unsustainable grazing practises.
- Sand-storage dams are not an 'instant' source of water, their provision requires long-term planning and foresight on the part of the community wishing to develop new water supplies.

As such, it is concluded that sand-storage dams are a feasible method of rural water supply in Namibia. However, rather than being developed as the sole, independent source of water for a rural community, it is envisioned that they are developed as part of a long-term plan to conjunctively utilise both grazing and water resources more sustainably. As a low cost water supply, requiring little operational or maintenance input, sand-storage dams can be developed by communities as additional water supplies, to be utilised on a temporary or seasonal basis, in order to lift grazing pressures from a single watering point.

# CHAPTER 7:

# DEVELOPING A DECISION-MAKING FRAMEWORK FOR RURAL WATER SUPPLY

# 7 DEVELOPING A DECISION-MAKING FRAMEWORK FOR RURAL WATER SUPPLY

It has been shown in Chapter 4 that in certain areas of Namibia it is feasible to store water in sand-storage dams, and in Chapter 6 that sand-storage dams are a viable alternative or complement to boreholes as a source of rural water supply. However, in these areas a request from a rural community for a new water supply cannot simply be answered with a decision to develop either a borehole or a sand-storage dam. Rather the following range of alternatives face decision-makers required to assess such a request:

- ❑ Rehabilitate the existing facilities.
- ❑ Construct a sand-storage dam to recharge an existing borehole.
- ❑ Construct a 'conventional' sand-storage dam.
- ❑ Establish a new borehole.
- ❑ Do nothing- a new water supply is not feasible.

In this chapter each of these alternatives are individually discussed, with an emphasis on highlighting the conditions under which they should be implemented. However, before these alternatives are presented, a brief overview is given of the process leading up to the assessment of these alternatives.

## 7.1 The Decision-Making Process

Strategy Paper 7 released by the DRWS to deal with the "*Implementation of Rural Water Supply Schemes*" (refer to Section 3.2) recommends the procedures which need to be followed for the development of a new rural water supply point (DRWS, 1994). Briefly outlined, this procedure begins with a community based local water committee filling in a standardised application form for a new water supply. This application is then assessed by a regionally based Central Water Committee (CWC), who rank the application in accordance with the perceived need of the community. As the DRWS do not have sufficient resources to support every request for assistance they will then attend to the highest ranking applications according to the budget availability.

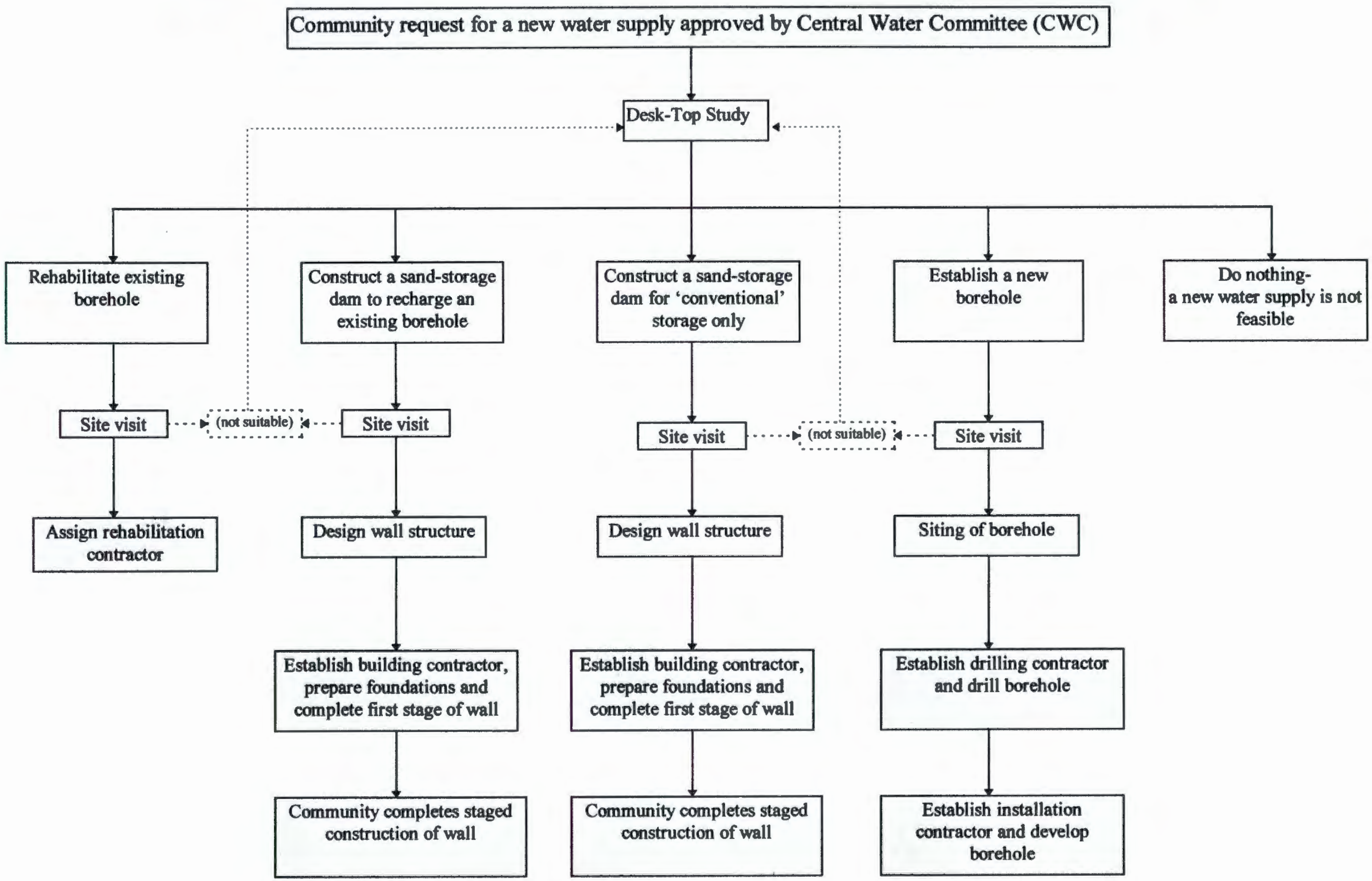
If the community's application has been successful then a DRWS construction supervisor will make a site visit to the community in order to assess the existing facilities, and meet with the water committee. The construction supervisor must then decide on what needs to be done to fulfil this request, and whether this work can be completed by DRWS staff in conjunction with the community, or whether a private contractor needs to be brought in. Further guidelines exist in the Strategy Paper regarding the construction, and handing over of the water supply to the community, however this chapter will focuses on the investigation and planning process only.

It is not the intention of this dissertation to criticise Namibia's rural water policy, however a request from a rural community to develop a new water supply will need to be assessed under a more comprehensive, and holistic, set of criteria than is presented in Strategy Paper 7 (DWA, 1994; Leusink, 1992). Simply ranking the request according to the perceived community's need, and then addressing this ranked list according to budget availability is not consistent with WASP's principles of promoting self determination and sustainable development (DWA, 1994). It is recommended, therefore, that additional factors which will need to be addressed when assessing a request for a rural water supply are:

- Conformance with WASP objectives of ensuring essential water supply and sanitation services are available to all Namibians.
- Differentiating between the volume of water required by the community to satisfy basic human and livestock needs, and water used in excess of this volume.
- Determining the community's ability to contribute towards the operation and maintenance of the water supply, and their commitment towards eventually contributing for full cost recovery.
- Ensuring conformance with relevant land use, and water resource policies.
- Determination of biophysical factors affecting the feasibility of a water supply, such as geographical location and geohydrological conditions.
- Assessing the environmental consequences of developing a new water supply.
- Promotion of the concept of demand management, rather than supply management, in order to achieve more sustainable utilisation of Namibia's water resources.

It is proposed that if the CWC approve a request for a new water point (based on perceived need), then this request needs to be further assessment in accordance with the factors mentioned above. This assessment needs to occur by a professional groundwater consultant as part of a 'desk-top study', and at this stage one (or more) of the five alternatives presented at the start of this chapter will be chosen as the most appropriate solution to the request. To finalise this decision a site visit is required in order to ascertain that the conditions 'on the ground' are suitable for the continued development of this option. If conditions are not suitable, then the request will need to be reassessed. This process has been presented in a visual framework in Figure 7.1.

## Figure 7.1: A Decision-Making Framework for Rural Water Supply



## 7.2 Rehabilitate an Existing Borehole

If a community's request for a new water supply is based on the fact that they have an existing water supply (assumed to be a borehole), however this supply no longer meets their requirements, then the following question needs to be asked - Is the borehole producing a reduced yield, or has the community developed a greater water demand?

If the indications are that the borehole is producing a reduced yield then it must be determined whether there is a mechanical problem with the existing pumping infrastructure, a blockage in the borehole, or if the aquifer is being over utilised. If there is a mechanical problem with the pump, or a blockage down the hole, then rehabilitating the borehole is a far cheaper solution than developing a new water supply - DRWS figures from a report on their 1996/97 drought programme quote rehabilitation costs at R40,000, compared to establishing a new borehole at R140,000 (DRWS, undated). If there does not appear to be a mechanical problem then it can be assumed that the borehole is being pumped beyond its safe yield, and that yields are dropping as the aquifer is being pumped beyond its recharge rate.

In the situation where the borehole is being over pumped, and where the borehole's supply has remained constant but the community's demand has increased, a decision needs to be taken whether or not to develop a supplementary water supply. This decision leads back to the concerns raised at the start of this chapter regarding the development of a new water supply, and the community's request will need to be reassessed taking these concerns into account.

## 7.3 Develop a Sand-Storage Dam to Recharge an Existing Borehole

One method of addressing a situation where an existing borehole is unable to meet increased demand, is to increase the yield of the borehole by artificially recharging the aquifer from which it is supplied. Morel-Seytoux (1983) defines artificial recharge as "*any procedure that facilitates the transformation of surface water into groundwater*." As mentioned in Chapter 4, if a fracture or fault feeding a secondary aquifer surfaces in a nearby river bed, then developing a sand-storage dam over this fault will facilitate artificial recharge of the aquifer (refer to Figure 4.3).

If this option is to be successfully pursued, then three requirements need to be met:

- The biophysical conditions of the area must be suitable for the development of a sand-storage dam.
- Geohydrological investigations during the site visit to ensure that any infiltration into the fracture or fault will be recovered by the existing borehole, and not lost to general sub-surface flow within the river bed.
- Sufficient long-term planning from within the community to ensure that their existing water supply meets their needs until the sand-storage dam begins to recharge the aquifer. Recharge will begin with the deposit of sands behind the 1st stage of the wall, and this recharge will increase until the sand-storage dam reaches its full storage capacity.

## 7.4 Develop a 'Conventional' Sand-Storage Dam

If it is determined during the desk-top study that the biophysical conditions are suitable, then a 'conventional' sand-storage dam may be developed as an independent water supply. The sand-storage dam can be developed either as a new water supply in a previously under utilised area, or developed to be used in conjunction with an existing water supply. The conjunctive use of a sand-storage dam and an existing water supply was recommended in Chapter 6 due to the length of time required to successfully develop a sand-storage dam, and the uncertainty regarding the whether or not rural sand-storage dams will supply sufficient volumes for sustaining a community.

Regardless of the purpose of the sand-storage dam, long-term planning within the community is required. This planning needs to focus on the development of future water supplies, and adjusting water demand to meet the limitations of future water supply.

## 7.5 Develop a New Borehole

If a community has requested a new water point which is required urgently, or the biophysical conditions do not suit the requirements for developing a sand-storage dam, then an assessment needs to be done on the suitability of establishing a borehole. The desk top study needs to determine whether or not the geohydrological conditions of the area are suitable for the establishment of a borehole, and ensure that sufficient finances are available for its establishment.

Any decision to site and drill a borehole needs to involve the community. If they are expected to contribute towards the establishment of the borehole, they must be informed of the risks involved of developing a borehole with lower than expected yields, and given a rough estimate of chances of drilling a 'dry' hole.

## 7.6 Do Nothing

One option which always needs to be considered is the "do-nothing" option. Developing a new water supply may not be feasible for any number of the following reasons:

- It is not within national, regional or local resource management guidelines.
- The development of the water supply will lead to inappropriate land use practices, resulting in environmental degradation.
- It is not economically feasible for the community involved to develop and sustain the water supply.
- The biophysical conditions do not suit the development of either boreholes or sand-storage dams.
- A general lack of water resources exists in the area. This could include factors such as low rainfall figures combined with an over utilisation (or lack) of suitable groundwater reserves.

## 7.7 Conclusion

Although it is appreciated that the Namibia's new policy regarding the "Community Management of Rural Water Supply" is still very new, it appears that the methods proposed in Strategy Paper 7 for approving a new rural water supply are not consistent with WASP principles. It may be necessary to utilise these existing methods during the initial implementation stage of the policy, while communities come to terms with having to take an ever increasing responsibility for the operation and maintenance costs of their water supply. However, as the DRWS moves closer towards ensuring that rural communities pay full recovery costs for this supply, a more holistic and equitable method of approving an application for a rural water point will need to be developed.

Decisions need to move away from simply assessing the community's needs according to DRWS budgetary constraints, and to take cognisance of a range of factors including:

- The community's water requirements.
- Resources available within the community to managing their water supply.
- Existing water resource policies and land-use practices.
- Environmental effects.
- Biophysical location regarding feasible water supply options.
- Adherence to demand management, rather than supply management.

# CHAPTER 8:

# CONCLUSION

# 8 CONCLUSION

Ninety years ago, in the then German South West Africa, construction started on a dam designed to fill up with sand. The German authorities believed that by encouraging the deposition of coarse grained sediments behind the dam wall they could, in effect, create an alluvial aquifer. Water, stored in the voids between the sand grains of this 'aquifer', would be subject to minimal evaporation losses, and could be recovered by means of drain pipes or wells. Six years later the storage basin of the dam was reported to be completely filled with sediments, mostly sand, and estimated to be storing about 6 000 $m^3$ of water. In 1958, fifty-one years after its construction, the dam was still supplying water (Wipplinger, 1958).

This method of storing water in sand dams seemed to provide a solution to the problems associated with conventional dams in Namibia's environment, namely high evaporation losses and excessive siltation rates. The idea, however, was short lived. After World War I the South Africa administration which took over control of South West Africa did not attempt to further this concept of sand-storage dams. Between 1955-1969 an interest in sand-storage dams was revived. During this period the concept was actively researched and shown to be an efficient and effective method of utilising surface run-off, and a number of sand-storage dams developed to supply water in rural areas. However, at the end of this period a shift in water policy towards an emphasis on the bulk supply of water to mines and towns resulted in the shelving of further work on sand-storage dams (Lau and Stern, 1990). At present the concept of sand-storage dams remains relatively unknown in Namibia, and the majority of the country's rural population rely on groundwater supplied from boreholes or shallow wells.

During a recent fieldtrip to the Khorixas and Gam areas of Namibia, it was realised that under Namibia's new Water and Sanitation Policy (WASP), the expectation on rural communities to gradually take responsibility for the full cost recovery of their water supply will have major socio-economic impacts on these communities (UCT, 1997). Concern over these socio-economic impacts, particularly for communities reliant on groundwater, prompted an interest in revisiting this concept of sand-storage dams. The specific aim of this study was to assess the feasibility of developing sand-storage dams as an alternate supply of water in the rural areas of Namibia. This final chapter draws together the information presented in this dissertation, and assesses the extent to which sand-storage dams can be applied as a method of rural water supply in Namibia.

The principles behind the successful construction of sand-storage dams differ dramatically from conventional dams. Sand-storage dams are constructed in stages to allow flood waters to flow over the dam wall, carrying with it the suspended silt load, while facilitating the settlement of coarser grained sediments behind the wall. Only once each stage has been completely filled with sediments, can the next stage be constructed. In this study it has been estimated that a three stage sand-storage dam, built to a height of between 3-5 meters, will take 6 - 8 years to reach its full storage capacity.

However, before the construction of a sand-storage dam can be considered, it must first be ascertained whether the biophysical conditions of the site are suitable. The following requirements have been identified for the successful siting of a sand-storage dam:

- A hilly or mountainous topography suited to the formation of well-defined river valleys. Sand-storage dams require a suitable foundation for the wall structure, and sufficient gradient for rapid channel flow.
- A geological region where the predominant parent rock in the catchment area will produce a coarse sediment load. Granites, quartzites and sandstones have been identified as the most favourable rock type.
- The geotechnical characteristics of the material underlying the storage basin must either compose of low permeability bedrock to prevent seepage losses, or incorporate a fracture or fault which feeds a locally utilised aquifer, hence facilitating the artificial recharge of this aquifer. In order to prevent the structural failure of the dam wall it needs to be founded on an un-weathered solid rock foundation.
- A suitable supply of hand-sized rock need to be locally accessible, as this is the material which will be used in the construction of a stone masonry dam wall.

Using topographical and geological maps of Namibia, it was ascertained that the following areas in Namibia display both the topographical and geological characteristics required for the successful development of sand-storage dams:

- Karas - central areas
- Hardap - central areas
- Khomas - throughout region
- Erongo - eastern areas
- Kunene - western/central areas

Once it had been determined that sand-storage dams could be developed in some of Namibia's rural areas, this concept needed to be compared to more conventional methods of rural water supply, namely conventional open-storage dams and boreholes. In a comparison between the practicality of storing surface water in a sand-storage dam with that of an open-storage dam, it is clear that in the Namibian environment open-storage dams are a highly inefficient method of storing water. A well-constructed sand-storage dam would provide a constant source of high quality water long after an open-storage dam has silted up.

The main comparison which has developed in this study is between that of sand-storage dams and boreholes. Under the economic, technical, social and environmental criteria developed for this comparison, it was shown that although sand-storage dams appear to be the more favourable method of rural supply, they have some drawbacks which limit their ability to be developed as an alternative to boreholes. The first of these concerns is the length of time required for a sand-storage dam to reach its full storage potential (6-8 years). The second concern is that the fixed storage volume of sand-storage dams are likely to be smaller than that of boreholes established in well-defined alluvial or secondary aquifers, and as such may not meet the water requirements of large rural communities. These concerns point towards sand-storage dams being developed to enhance, or supplement existing borehole supply, rather than replacing these supplies.

It is suggested therefore, that the concept of sand-storage dams could play an important role in the development of future rural water supplies. Although the requirement for the development of a sand-storage dam is more conducive to meeting WASP principles than for boreholes, it is recommended that sand-storage dams are not promoted as the preferred choice of water supply in these areas. Rather, sand-storage dams should be developed in conjunction with boreholes as part of a long-term planning process aimed at providing sufficient water to meet the basic needs of Namibia's rural communities, without encouraging the oversupply of water to these areas.

Under the right biophysical conditions sand-storage dams can be constructed as a simple and efficient method of utilising surface run-off. Although the potential of these dams has been largely ignored throughout Namibia's history, with the implementation of a new rural water policy emphasising the importance of community management, the Namibian government now have a responsibility to recognise alternate methods of providing rural water. The idea of storing water in sand-filled dams needs to be further investigated, with an emphasis on the accurate identification of specific areas where they can be successfully established, and the communities within these areas informed of the additional options available to them for the future development their water supply.

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