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AN ASSESSMENT OF RAINWATER CATCHMENT SYSTEMS IN BOTSWANA

by

(C) John E. Gould

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NAME OF AUTHOR John E. Gould

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(SIGNED) J.E. Gould.

PERMANENT ADDRESS

85, Thanington Road,
CANTERBURY, KENT
ENGLAND.

DATED 8/3/1985

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled AN ASSESSMENT OF RAINWATER CATCHMENT SYSTEMS IN BOTSWANA submitted by John E Gould in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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Supervisor

....

....

Date......8/3/1985..........

Abstract

An Assessment of Rainwater Catchment Systems in Botswana

Botswana is a semi-arid country, with mean annual rainfall varying from less than 250mm in the Kalahari desert in the southwest, to more than 650mm in the north. Currently, the major domestic water sources in the country consist of traditional handdug pits in sand rivers and modern piped borehole schemes based on deep groundwater supplies.

The low rainfall and its highly seasonal nature are disadvantageous with respect to the development of rainwater catchment systems. Nevertheless, the low population density and the traditional triangular migration pattern between villages, arable lands and cattle posts make the provision of alternative improved water sources to all three dwelling places difficult and expensive.

Information was gathered through questionnaire and technical field surveys, structured interviews, field visits and observations and measurements , and the potential for the future development of rainwater catchment systems assessed. Rainfall data from 10 stations were analysed using a computer model developed at the University of Ottawa and roof catchment tank storage requirements and supply rates were determined. This revealed that the most effective storage tank capacity in terms of maximizing supply while minimizing costs is one which a has volume equivalent to about 40%(0.4) of the useful roof runoff. This would generally yield a supply equivalent to 70% or more of this runoff volume (with 95% reliability) To satisfy current daily household water demand in rural areas using roof runoff, an average family would require a corrugated iron roof of between $70m^2$ and $140m^2$. Since the majority of villagers do not have corrugated iron roofs, and the few that do seldom have roofs exceeding $70m^2$ or more, roof catchment is generally feasible only as a supplementary supply system.

To test the suitability of rainwater for domestic consumption an in depth survey was conducted in four villages and bacteriological analysis was done on water samples from both roof and ground catchment systems. It was found that rainwater collected from corrugated iron roofs in rural areas could, in many instances, provide a clean, safe, convenient, supplementary

domestic water supply. Although at present rainwater supplies less than 3% of the domestic water used in the villages surveyed, if all existing surfaces were exploited, roof catchments alone could provide 30% of the daily requirement, with a reliability of 95%. The lack of iron roofs and insufficient cash income in rural areas, especially in smaller , remoter locations, is currently the greatest obstacle to roof catchment development. However, a longterm trend towards increasing numbers of corrugated iron roofs is evident. Consequently, a number of ferrocement tank designs were briefly examined and possible mechanisms for implementation of roof catchment systems in Botswana were assessed.

The collection of rainwater from ground surfaces in 10-20m^3 excavated ferrocement tanks is currently being promoted by the Ministry of Agriculture in many remote lands and cattle post areas as the main form of water supply. Although it often constitutes the only viable source of water close to the point of consumption, problems exist with the bacteriological quality of this water.

Finally, it was found that a significant un-utilized potential exists for the collection of rainwater runoff from the roofs of schools and clinics throughout the country. The construction of 20m^3 ferrocement roof tanks could provide a useful fresh water supply and help to relieve the severe water shortages experienced by some of these institutions.

ACKNOWLEDGEMENTS

Close to one thousand people, most of them in Botswana, have contributed directly to this thesis by freely giving their time to be questioned or interviewed and through a host of other ways. To all these people and to others not mentioned by name, I would like to say - Ke itumetse (Thank you) and PULA! PULA! (a setswana greeting meaning rain, rain).

Fortunately, space does allow me to name most of those who have provided a major input into this study. At the University of Alberta, it is to Dr. H.J. McPherson that I owe the most graditude, for guidance throughout the research and for diligently reviewing drafts. Nevertheless, the inspiring courses of Drs. Laycock, Veeman and S.I. Smith have indirectly contributed to my understanding of the subject.

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Table of Contents

List of Tables

List of Figures

Figure Page

APPENDIX 2

APPENDIX 4

List of Plates

Plate		Page

1. INTRODUCTION

1.1 RAINWATER CATCHMENT SYSTEMS IN BOTSWANA

The collection and use of rainwater is by no means a new phenomenon in Botswana. Excavated pits, known as haffirs, have been used for centuries to collect and store rainwater runoff for human and livestock consumption. More modern type roof catchment systems have been in operation throughout this century. These were probably first built when the railway was constructed in eastern Botswana by the colonial administration bringing Europeans into the area for the first time, (figure 1.1). Today, rainwater catchment is practiced sporadically throughout Botswana and, although a number of schemes still exist for developing rainwater catchment systems, no attempt has ever been made to make a nationwide study of the practice.

The purpose of this thesis is to assess the present and potential future role of rainwater catchment systems as a method of water supply in Botswana. The justification , aim and objectives of the research and details about the study area are given in the rest of this chapter. This is followed by a comprehensive review of the literature on rainwater catchment systems in chapter 2. The purpose of this review is to trace the historical development of rainwater catchment technologies and to examine past projects both in southern Africa and elsewhere, in order to see what lessons may be learnt from them. The research findings of a number of workers in this field will be discussed including work on rainwater tank construction and design. In chapter 3 the methodology used in the present study is presented. This is followed by a presentation of the results collected in the field relating to roof catchment systems in chapter 4. Technical considerations are discussed in chapter 5. These include methods of rainwater tank sizing and construction, and the application of computer modelling to rainwater catchment systems design in Botswana. The implications of the results and economic and social considerations are discussed in chapter 6. The findings relating to ground catchment systems are presented in chapter 7 and this is followed by conclusions and recommendations in chapter 8.

Figure 1.1 ... The Republic of Botswana

1.2 JUSTIFICATION FOR THE STUDY

The rural areas of Botswana, like those of many parts of Africa, suffer due to the distant and often contaminated nature of their water sources. This leads to a great expenditure of time and energy in collecting water and exposure to water related diseases when it is used. Due to the combined effort of the Department of Water Affairs and the Swedish International Development Agency (SIDA), piped water supplies have been constructed in all of the larger villages and many of the medium sized ones during the the last 10 years, (NDP 1980). The construction of these reticulated supplies is not in itself a guarantee for improved health. This is partly due to the contamination of even improved supplies between the points of source and consumption, (Enge 1983). In some cases the lack of effective systems of operation and maintenance leads to frequent or total breakdowns of the supplies. Although the situation in Botswana is better than in many parts of Africa, (Enge 1982), the remoteness of many villages leads to problems of supplying fuel and spare parts to keep piped schemes operational. During periods of breakdown villagers usually revert to traditional sources which are often of poor quality. Any health benefits which might have resulted from the improved supply are often lost during such periods.

In recent years considerable interest has been focussed on a range of low cost "appropriate" technologies as alternatives, or complementary components, to more conventional improved water supply systems. These low cost techologies include: gravity water schemes, handpumps, shallow wells, sand dams, wind, solar and biogas powered water pumps and rainwater catchment systems. The main advantages of these technologies are their cost effectiveness, use of renewable energy resources and simplicity of operation and maintenance, (Pacey 1977). The generally flat nature of the terrain in much of Botswana greatly limits the potential for gravity flow water schemes which have been highly successful in Malawi, (Robertson 1980). Shallow wells have restricted applications due to the depth to groundwater in most of the country. Although the average depth of groundwater is 100m, some boreholes are up to 200m (Maikano and Nyberg 1981a). This may be one of the reasons accounting for the

general absence of handpumps in Botswana. Sand rivers currently provide the single most important traditional water source in Botswana. The damming of these rivers and the extraction of the water using hand, wind, solar or diesel powered pumps could provide a significant source of supply for rural Botswana in the future. According to a recent study sponsored by SIDA (Wikner 1980), the available water storage capacity in 11 sand rivers studied in eastern Botswana was estimated at between 15-59 thousand m^3 per km of river bed.

Wind and biogas powered water pumps are currently being tested by the Rural Industries Innovation Centre (RIIC) [1]. Research and development of solar powered pumps is being conducted by the Botswana Technology Centre (BTC). A comparative cost analysis of these technologies with respect to diesel pumps by Carothers(1980) indicated that all will become economically viable alternatives if long-term trends in the increasing price of oil continue.

Rainwater catchment systems have been the focus of much attention in recent years. In the 1960's, the British based Intermediate Technology Development Group conducted a ground catchment tank pilot project in Botswana, (ITDG 1969). More recently the Ministry of Agriculture has been promoting ground catchment systems throughout the country, (Whitside 1982). The role of rainwater catchment systems would seem to be limited to that of a supplementary source in Botswana due to the erratic nature and low level of rainfall in all regions, (Cullis 1984), see figures 1.2 and 1.3.

Although this thesis is primarily an attempt to treat the assessment of rainwater catchment systems in Botswana as an academic research problem, the social relevance of the topic provides immediate justification for conducting the study. Some of the findings from Botswana are likely to be of relevance to other parts of Africa and in particular the semi-arid areas which in total support more than 100 million of the continent's population. This research is also timely, since international interest in the potential for using rainwater catchment systems to supplement other water supply systems is growing. This trend is witnessed by the great

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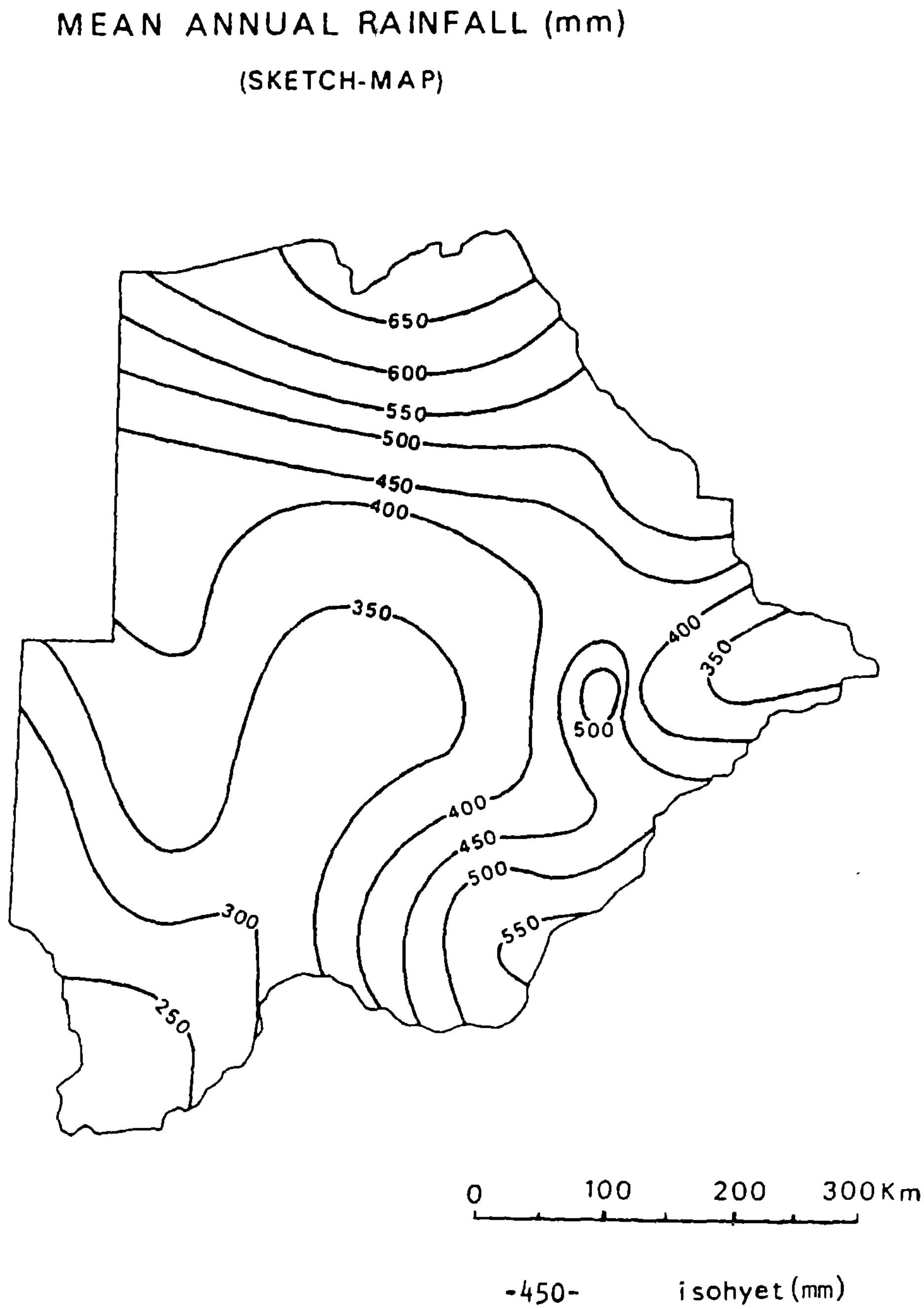
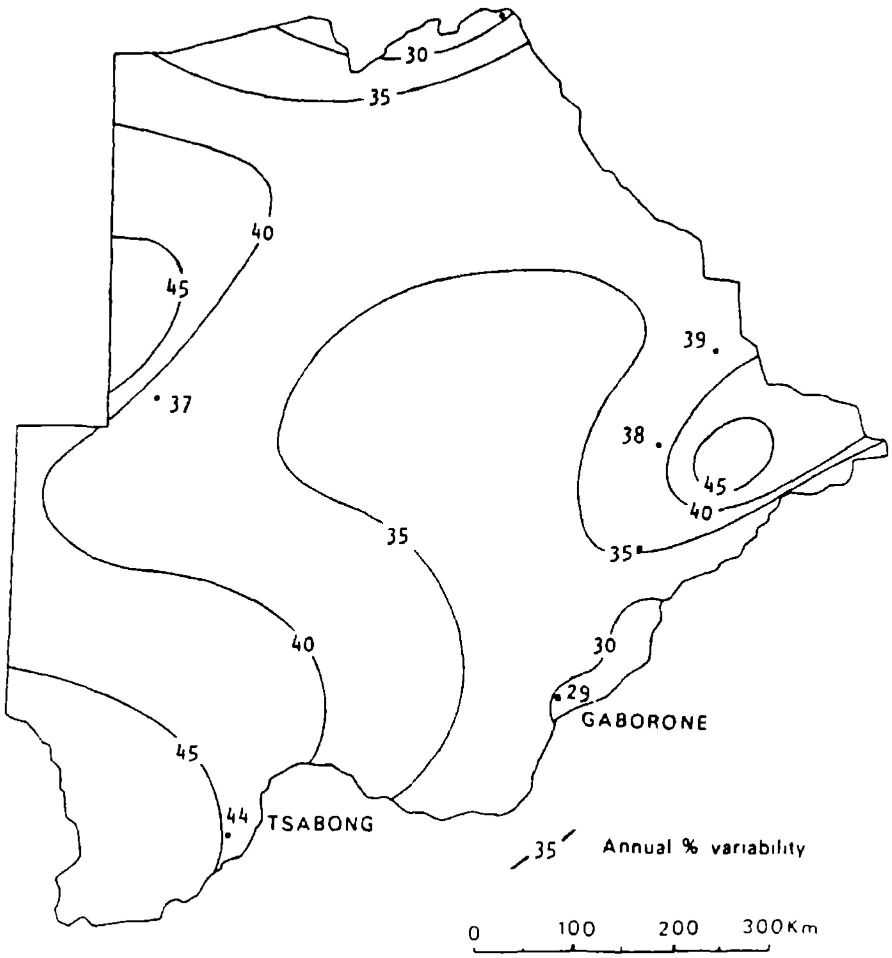
[1]Rural Industries Innovation Centre, Private Bag 11, Kanye.



Source: Bhalotra, Advisor, Botswana Meteorological Services

Figure 1.2 ... Mean Annual Rainfall over Botswana



Source: Bhalotra, Advisor, Botswana Meteorological Services

Figure 1.3 ... Annual Rainfall Variability over Botswana

number of publications and conference proceedings which are in the current literature on the subject. Among the most significant of these is a recently completed handbook by the Intermediate Technology Development Group (ITDG, in press), and a book entitled "Rainwater Catchment and Water Supply in Rural Africa" by Nissen-Peterson (1982).

The importance of rainwater catchment systems, within the context of the International Drinking Water Supply and Sanitation Decade, is another reason for conducting research on this topic. Diamant(1982), stressed the significant role that roof catchments could play in many developing countries as part of the effort to realize the goals of the decade.

1.3 AIM AND OBJECTIVES

1.3.1 Aim

The overriding aim of this research was to examine rainwater catchment systems in rural Botswana in order to assess the extent to which they are currently being used and to determine what potential role they might play in providing future water requirements. This was done through an assessment of their technical, economic and social feasibility.

1.3.2 Objectives

The specific objectives of the study were as follows :

1. To evaluate past projects and examine the general development of rainwater catchment systems in Botswana and elsewhere to gain some insight and learn some lessons from previous successes and failures.
2. To determine current water collection and usage patterns including the the use of rainwater in rural Botswana.
3. To establish the views, attitudes and desires of both the current users, and potential users, of rainwater catchment systems to determine whether such systems can provide a socially acceptable means of water supply.

4. To identify the costs and benefits of rainwater catchment systems.
5. To establish the most appropriate type and size of roof and ground catchment tanks, and to examine the possibilities for using low cost materials and technologies for their construction.
6. To determine how much household roof rainwater catchment potential is currently being utilized and how much of the unused potential could cheaply and easily be brought into operation.
7. To examine the possibility of using rainwater catchment systems at primary schools and other public buildings throughout Botswana.
8. To examine the feasibility of using ground catchment systems as a means of supply in remote localities where few other alternatives sources exist.
9. To determine the quality of stored rainwater to assess its suitability as a domestic water source in rural Botswana.

1.4 THE STUDY AREA[1]

The study area for this research is taken as the whole of Botswana. It is, however, the situation in the eastern part of the country which is of particular interest since the vast majority of the population reside there, see figure 1.4. The western half of the country is extremely sparsely populated has no tarred roads, few settlements and contains only 15% of the population (NDP 1980).

1.4.1 Location and Physiography

The Republic of Botswana is a landlocked country located in the centre of the Southern African Plateau. It has a mean altitude of almost 1000m above sea-level and a land area of 582,000 km^2, which is more than twice the size of Britain and only slightly smaller than Alberta. Botswana straddles the Tropic of Capricorn between 18°S and 27°S and shares common borders with Zambia, Zimbabwe, Namibia and South Africa (Figure 1.1).

About 75% of Botswana is covered by Kalahari sands, up to 120m thick and overlying an Archean basement [2]. Most of the country consists of a relatively featureless plain with gentle undulations and occasional rocky outcrops. In the east, however, the country is more hilly and broken, being underlain by granitic rocks. The somewhat wetter climate and more fertile soils make this area more conducive to settlement and it is here that 85% of Botswana's population reside, (UN. 1977).

In the northwest of the country, the Okavango River, which rises in Angola, drains into the Okavango Delta, a huge inland swamp from which 95% of the water evaporates. The remaining 5% flows into the ephemeral Lake Ngami. In occasional wet years, waters from the swamps may overflow into the equally extensive Makgadigadi Salt pans, 350km to the east, (Figure 1.1).

1.4.2 Climate

Botswana has a semi-arid continental climate with a marked dry season between May and October. The mean annual rainfall is 475mm, varying from more than 650mm in the north to less than 250mm in the southeast, (Figure 1.2). More than 90% of this rain falls in the summer months , between November and April, but rainfall is both erratic and unevenly distributed. The unpredictable nature of the rainfall and its seasonal variability make drought a common feature of the climate. Pike (1971) suggested that mean seasonal variability ranged from 80% in the southwest to 25% in the northwest. Reassessment of the data by Bhalotra (in press) indicates that, in fact, mean seasonal variability does not greatly exceed 45% in the southwest, (Figure 1.3). In extreme years, however, it may be more than 100% in excess of the mean, or as low as 50% or more in deficit.

Temperatures vary according to the latitude and altitude of different regions. Mean daily maximums seldom rise much above 33°C anywhere in Botswana while mean daily

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[2]Unless otherwise quoted the source of information for this section is : The National Development Plan 1979-85, Min. of Finance and Development Planning, Gaborone.

minimums seldom fall below 5°C. However, daytime temperatures up to 45°C in summer (November-January) and night-time frosts in winter (June-August) are sometimes experienced. Botswana has amongst the highest daily mean sunshine hours recorded anywhere in the world. Annual totals in excess of 3200 hours are found throughout the country,(Landsberg 1966). This, in combination with the high mean annual temperature and generally low humidity, results in high evaporation rates. In many areas, open pan evaporation rates exceed 3000mm/annum. A study by Gibbon (1975) gave actual evaporation rates of 15mm/day in extreme cases.

Rainfall in Botswana comes predominantly from convectional processes in the form of instability showers and thunderstorms. Bhalotra (in press) noted that this is the reason for the high variability of rainfall both temporally and spatially. Analysis of rainfall data from Gaborone between 1923 and 1979 has shown that only 13% of rainy days (days with 20mm or more precipitation) contributed more than 50% of the seasonal rainfall. Statistics for Mahalapye and Maun gave similar results,(Figure 1.1).

Bhalotra (in press) has also examined autographic records from Gaborone and Maun between 1958-78 in order to identify maximum rainfall intensities. It was found that maximum intensities of 162mm/hr and 120mm/hr had occurred for 5 and 15 minute intervals, respectively, during the period. The maximum hourly rainfall was 45mm for Gaborone and as much as 64mm for Maun in the north. The maximum daily recorded rainfall was in January 1963, when 231mm of rain fell over a 24 hour period at Ghanzi. Information of this type is of considerable importance when designing rainwater catchment systems particularly for sizing gutters and downpipes.

1.4.3 Vegetation and Soils

With the exception of the lush swampland of the Okavango Delta, and belts of indigenous forest in Chobe district in the north, most of Botswana supports tree and scrub savanna. This is dominated by mophane trees, accacia species and a host of other xerophytic

varieties. The vegetation becomes increasingly sparse towards the southwest due to low rainfall and sandy soils, and around the Makgadigadi Salt pans in the northeast where only grasses are supported. Much of the savanna in the east and central parts of the country is used as rangeland, although, due to the low productivity of the grasses, it supports at best, a low density of livestock. The wetter and lusher parts of the country in the north and northwest are virtually unexploited in terms of agriculture, but support great numbers of wildlife. Bamboo does not grow readily in Botswana. This is significant as it is used as a cheap substitute for commercial roof gutters in some parts of the world, and as reinforcement for cement tanks in others.

The soils of Botswana are generally sandy in nature, particularly in the west and central regions, due to the underlying Kalahari sand deposits. In some areas the soils are somewhat saline due to the deposition of evaporites. Soil erosion is a problem throughout Botswana particularly around settlements, where trees are cut for firewood; and around boreholes, where overgrazing by livestock occurs. Although the soil is highly permeable in most areas, in some regions calcrete deposits, or the formation of a "sealing" layer make the soils impermeable. The amount of fertile soil suitable for irrigation in Botswana is very limited,(NDP 1980).

1.4.4 Population

Botswana has a *de jure* population of approximately one million people, 936,000 according to the 1981 census. These are made up of people from eleven main ethnic, groups including eight Setswana speaking tribes, the Baherero in the west, the Kalanga in the northeast and the Basarwa (Bushmen) and other semi-nomadic groups. There are around 50,000 Batswana currently working in South Africa, most of them young males working in the mines. This results in a preponderance of young women at home, and one parent families often with children fathered by one or more men are the rule rather than the exception.

The most important features of Botswana's population are the following.

1. It is small relative to the size of the country. The population density is less than 2

persons/km^2 making it the second least densely populated country in the world after Mongolia.

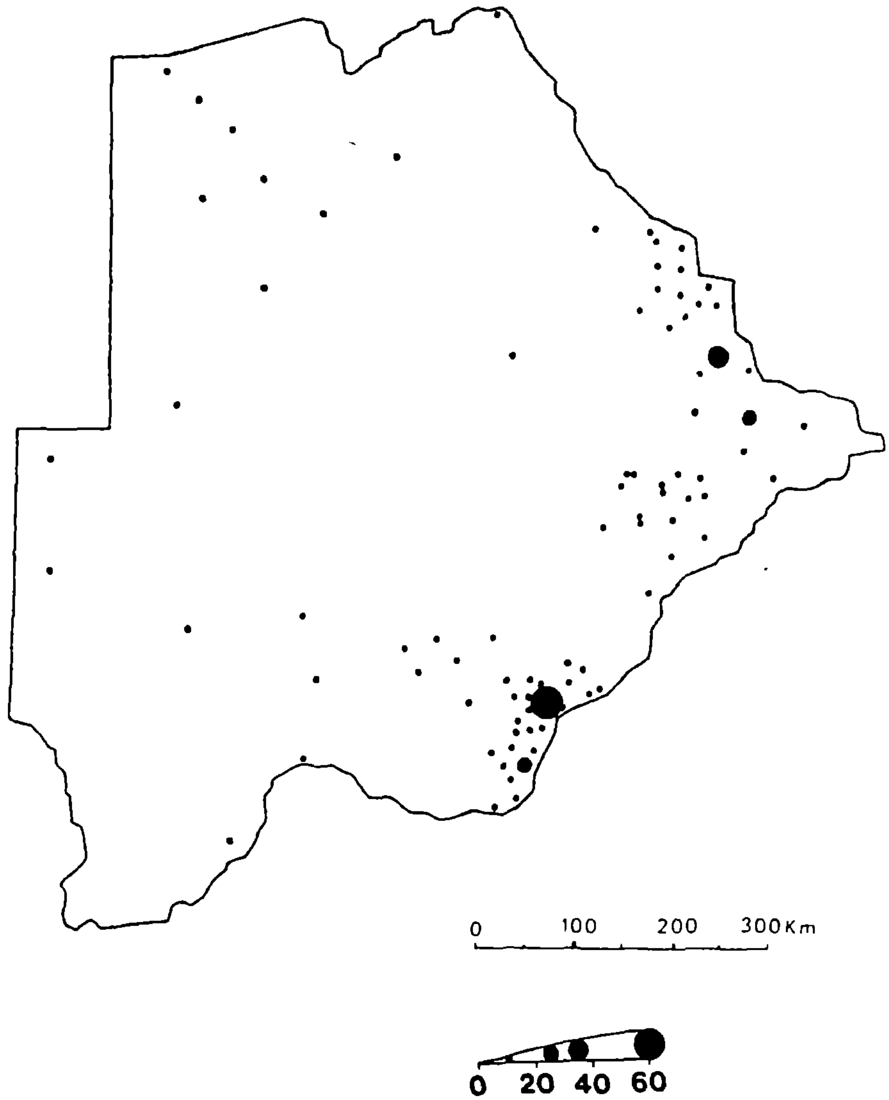
2. The population is growing very rapidly, at about 3% per annum.
3. Due to the rapid population growth there is a high proportion of young people. 33% of the total population are under 10 and 18% are under 5.
4. Life expectancy at birth is relatively low, 52 for men, 59 for women . This is mainly due to the high infant mortality, with 152 children dying per 1000 live births before reaching the age of five.

1.4.5 Settlement and Housing

The most important point with regard to settlement is the fact that the vast majority of the country's population is concentrated in the east, within 150km of the border (Figure 1.4). The two main reasons for this are: first ,the climate, soils and water resources of the area are more conducive to agriculture, and second, the Cape Town-Harare railway which runs along the eastern side of the country has attracted settlement along it, (Figure 1.1). Like most other African countries, Botswana, has a very high rate of rural-urban migration. The result of this is an urban population which has grown threefold in the last 15 years. The rural population is, however, still much larger than the urban one, making up 80% of the total,(NDP 1980). The capital, Gaborone, which was carved out of the bush shortly before independence in the early 1960's , has already reached a population of more than 60,000.

Where Botswana differs in respect to other countries on the continent is in the peculiar pattern of seasonal migration, whereby most rural families (and many urban ones too) will spend part of the year at a cattle post, part at an arable "lands" area, and part in a village. Different members of the family will spend different lengths of time at these various homes, depending on the rains in any particular year.

Housing types vary considerably within Botswana and even within single villages where, although the majority of people still live in traditional style homes, a growing minority live in



• Represents 10,000 people

Proportional circles indicating population of towns in thousands

Source: The data used for drawing this map were obtained from the National Development Plan 1979-85, table 1.4, p.9, and the 1981 census.

Figure 1 4 ...Population Distribution over Botswana

more modern type housing. The majority of people in rural areas still live in thatched huts in most villages, however, the incidence of corrugated iron roofing has been increasingly steadily since independence in 1966. Plates 1.1 and 1.2 show two contrasting housing types found in rural Botswana.

1.4.6 Economy

Mining, in general, and diamonds in particular, have transformed the economy of Botswana over the past 10 years. Previously, cattle had formed the mainstay of the economy but the development of nickel, copper and coal mining, and the discovery of some of the largest diamond pipes in the world have resulted in mining providing 75% of all export earnings, (NDP 1980). In terms of G.N.P., it has made Botswana one of the most rapidly growing economies in Africa, with an annual growth rate exceeding 13% between 1970 and 1978, (World Bank 1980). A recent depression in the world diamond market has somewhat slowed this growth, and has acted as a timely warning about the dangers of allowing the economy to become too dependent on the sale of a single commodity. Much of the wealth generated by the growing mining sector has been used for urban and infrastructural development. Although the economy in general has been lifted from a very low base level, there is clear evidence of growing inequalities between rural and urban dwellers, Johnson(1982).

As far as the domestic economy is concerned, the cattle industry still forms its backbone. The national herd has grown almost fourfold since the last major drought in the mid-1960's and cattle now outnumber people by 3 to 1 in Botswana. The 3 million cattle currently in the country are suffering the effects of the present drought and 300,000 have already died or have been slaughtered. Cattle are not only the traditional symbol of wealth in Botswana, but also provide valuable meat and hides for export and home consumption. In addition, cattle are widely used as draught power in the ploughing season. Despite the large size of the national herd in relation to the population, there are many families with few or no cattle and there are a few families with enormous herds.

Plate 1.1 ...Traditional Housing in Borolong

Plate 1.2 ...Modern Housing in Borolong

1.4.7 Hydrology and Water Resources

With the exception of the Okavango and Chobe Rivers in the north and the Limpopo in the east, which have catchment basins extending outside the country, all the rivers in Botswana are ephemeral. Some of these rivers flow for several months every year, others for only a few days every several years. Most, however, flow for several weeks every year and for the rest of the time are characterized by dry, sandy river beds. These are known as "sand rivers" in Botswana, and are probably the single most important traditional water source in the country, (Plate 1.3). Although water does not flow in these rivers for most of the year, water is generally stored beneath the sand and people dig shallow wells for collecting water and watering livestock. Almost all of the sand rivers are located on the eastern side of the country with a particular concentration in the northeast. This is one of the reasons why this region is one of the most densely populated.

In the western three-quarters of the country, deep Kalahari sands allow no rivers to flow. The high evaporation rates and the deep rooted plants result in most of the rain in the Kalahari being returned to the atmosphere. There is consequently little or no groundwater recharge in much of this region. According to Cooke(1978), the groundwater resources of Botswana are still very much an unknown quantity and there is very little information about the age or total reserves of this resource. It is only around the major mining centres that groundwater has been mapped in detail. Although there are undoubtedly some large aquifers beneath the Kalahari, the extent the water is fossil and the extent to which it is being recharged, is little known, and is a topic of some controversy. The total domestic consumption of groundwater, however, is still relatively low, although the growing national herd does consume an increasing fraction of the supply from some of the 9000 boreholes located throughout the country. It is, however, the mining and industrial enterprises which are the biggest consumers. In some cases, such as at the Selebe Pikwe mining complex , water is supplied from surface dams. Due to the high levels of extraction by these enterprises, a thorough survey of the groundwater resources of Botswana would seem in order. Such a survey should determine the

Plate 1.3 ...Traditional Water Supply for Cattle and Humans, the Sand River at Borolong

Plate 1.4 ...Improved Standpipe Supply at Selolwane

total magnitude of groundwater resources and the extent to which they are renewable. This would allow for the formulation of an effective water development strategy. Although the government recognizes that the compilation of an inventory of all the country's water resources would be desirable, it claims that the cost would be prohibitive and is not justified, (NDP 1980).

The average depth of groundwater is 100m in Botswana, but varies from less than 30m in a few isolated pockets in eastern Botswana to more than 200m in parts of the Kalahari,(Maikano and Nyberg 1981b) . Most larger villages have at least one borehole. There is currently a nationwide effort to reticulate borehole supplies and provide several standpipes in every village by 1985. Although this target may not be realized on schedule, the programme is progressing well. The small size and scattered nature of many villages and cattle posts makes the provision of an efficient reticulated supply difficult. In some areas, the periodic or total drying up of boreholes is a problem, in others, borehole supplies sometimes become increasingly saline. The maintenance of reticulated borehole supplies also presents something of a problem. This, however, is being dealt with much better in Botswana than in some parts of the continent, (Enge 1982).

The implications for future problems of groundwater supply are particularly serious for Botswana since it has been estimated that 75% of the country's human and cattle population are wholly, or partially, dependent on groundwater supplies, (Cooke 1978).

1.4.8 Water Sources

According to the National Development Plan for 1976-81, rural water consumption was estimated to have increased at 5% per annum over that period. The major sources of supply are: sand rivers, boreholes and wells, and surface dams and rivers. The current trend, however, is towards increasing dependence on groundwater supplies. Nevertheless, a large fraction of the rural community is still totally, or partially, dependent on traditional sources. Apart from those mentioned above, others include pans, which are natural depressions where rain collects

seasonally, and haffirs, which are man-made excavations constructed primarily for rainwater collection. Fortmann and Roe(1981) have defined and described these various water sources in their Water Points Survey of eastern Botswana. The result of a study of water usage in four villages by Copperman(1978) together with data collected on water usage for this study are discussed in chapter 4.

Although the governments ambitious target is (with the assistance of SIDA) to provide piped water to every village in Botswana by 1986, this would still leave many rural dwellers unserviced. Johnson(1982) noted that even if all villages had reticulated supplies, only 55% of the rural population would be served. This is due to the fact that the remainder of the population stay at the lands and cattle-post areas or are in very small settlements in remote areas. According to the National Development Plan 1979-1985, one of the most appropriate methods of water supply in the lands areas may be small scale catchment tanks.

1.4.9 Rainwater Catchment

Rainwater catchment tanks provide a small, yet significant, water source in many parts of Botswana, (Farrar and Pacey 1974). The casual collection of rainwater from the eaves of corrugated iron roofs, or from makeshift gutters, is the most common form of rainwater catchment practiced. Storage vessels include buckets, basins and 200 litre oil drums. Occasionally these are simply placed in the open to collect rainwater. More formalized roof catchment systems are found in both rural and urban areas and consist predominantly of corrugated galvanized iron catchment tanks, imported from South Africa. Water collected from roofs is a particularly important source in areas where alternative supplies are either distant, saline or unreliable. Due to the continued predominance of thatched roofs in rural areas , however, collection of rainwater in appreciable quantities is restricted to a few of the richer private households and to public buildings, such as schools. The collection of rainwater from ground surfaces in excavated tanks is currently being promoted by the government in remote lands areas and is slowly gaining popularity. By 1983, more than 350 excavated tanks collecting

rainwater from prepared surface catchments were in operation in the country, (Gaadingwe 1983). Nevertheless, to date, rainwater catchment systems have only played a minor role in the overall water supply of the country, gaining importance only at the local level, as a supplementary water supply.

1.5 SUMMARY

Botswana is a large country (582,000 km^2) with a small population of approximately 1 million people , which is concentrated mainly near the eastern border. Traditionally, people have relied on cattle (which now number around 3 million head) as their main source of livelihood and as the mainstay of Botswana's economy. Recently, however, the mining industry and diamond extraction in particular, has transformed the economy and resulted in its rapid growth. The vast majority of Botswana's population, however, still reside in rural areas where the traditional triangular migration pattern between villages, arable lands areas and cattle posts continues. Water supplies at these various dwelling places vary considerably, and although the government has installed reticulated groundwater supplies in many villages, elsewhere people still rely on traditional sources. These include sand river pits, wells and occasionally surface water. Frequently, these are distant and of poor quality, especially in remote settlements.

Rainwater catchment systems, although presently being used in Botswana, provide only a minor water supply at a few localities. It is the aim of this study to assess both the current usage and future potential of this form of supply.

2. LITERATURE REVIEW

The purpose of this chapter is to trace the historical development and current usage patterns of rainwater catchment systems through reference to the literature. The main findings of related research will be presented including similar studies from Africa as well as research dealing with rainwater tank design, construction and water quality.

2.1 TERM DEFINITION

There has been no attempt to establish a definitive terminology within the literature on this topic and many widely used terms are in fact synonomous. For example, rainwater catchment and rainwater collection are virtually interchangeable, as are rainwater harvesting and water harvesting. Rather than debate the merits of various terminologies, an attempt will be made here to simply quote some of the definitions already made within the literature. In addition, the terms used in this thesis will be stated and defined.

The term "rainwater harvesting" has probably originated from the term "water harvesting" first used by Geddes (1963), and defined by Myers (1964) as the process of collecting and storing precipitation from land that has been treated to increase the runoff of rainfall and snowmelt. The main difference between the term rainwater harvesting and rainwater catchment is that the former refers specifically to the collection of rainwater from a treated ground surface whereas the latter may include the collection of rainwater from untreated surfaces and roofs.

Latham and Schiller(1984) have defined "rainwater collection" as the process of collecting, storing and using rainwater as a primary, or supplementary, water source. This is the same definition given to "rainwater catchment" in this thesis. The only reason for choosing this term is because it is commonly used both in Botswana and in the literature on this subject

2.1.1 Definition of terms used in this thesis

1. Rainwater Catchment is the process of collecting, storing and using rainwater as a primary or supplementary water source.
2. Roof Catchment is the process of collecting, storing and using rainwater collected from a roof as a primary, or supplementary, water source.
3. Ground Catchment is the process of collecting, storing and using rainwater collected from a treated, or untreated, ground surface as a primary, or supplementary, water source.
4. Rainwater Catchment System (RWCS) is a system designed to collect, store and supply rainwater for domestic, agricultural and other purposes.
5. Rainwater Harvester is a system designed to collect store and supply rainwater for domestic, agricultural or other purposes, through the construction of a purpose-built catchment apron.
6. Runoff Coefficient is a coefficient expressed as a decimal, or percentage, refers to the fraction of rain falling on a particular catchment area which actually enters the storage facility.
7. Total Useful Runoff is the rainwater runoff which flows off a roof through the gutters and downpipes and is available for collection.
8. Storage Fraction is the volume of the storage capacity for any rainwater catchment systems expressed as a fraction of the volume of the total collectable runoff.
9. Supply Fraction is the volume of the supply for any rainwater catchment systems expressed as a fraction of the volume of the total collectable runoff.
10. Reliability is a measure of how efficiently a rainwater catchment systems yields its design supply.

2.2 RAINWATER CATCHMENT SYSTEMS : HISTORICAL DEVELOPMENT

Before dealing specifically with rainwater catchment systems in Southern Africa in general and Botswana in particular it will be helpful to examine the worldwide historical development of rainwater catchment systems.

2.2.1 Rainwater Harvesting

The earliest known record of the practice of rainwater harvesting is from the Ur civilization in the Middle East and may date back to as early as 4500 B.C., (Frasier 1975). In the Negev desert in Israel, the remnants of highly developed run-off farms, which consisted of cultivated fields surrounded by catchment areas, can still be found. Terrace walls and conduits were used to direct water onto crops and into cisterns for storage. A detailed study of these systems has been made by Evenari et al.(1961) who suggested that they may have been built from about 2000 B.C. onwards, or possibly earlier.

In North America there is evidence of less complicated rainwater harvesting systems used by the indians in the Four Corners area of the southwestern states, about 700 to 900 years ago and in Mexico evidence of similar systems exists for the same period , (U.N.E.P. 1983). In Australia, Kenyon(1929) makes reference to a 2400 m^2 "ironclad catchment" which provided adequate water for 6 people , 10 horses, 2 cows and 150 sheep in an area with a mean annual rainfall of 300 mm. In Kenya, Grover (1971) quoted in Ongweny (1979) and UNEP (1983) noted the existence of some quite sophisticated traditional ground catchment technologies along the east coast and more specifically on Wasini Island, 80km south of Mombasa. These were constructed centuries ago in response to the absence of surface and freshground water on this coral island. The traditional ground catchment systems are known locally as "djabias" and were built by constructing a catchment apron and tank, using locally produced cement mixed with pieces of coral. These were probably first introduced by the Arabs who have traded along Africa's east coast for centuries. In the late and post-colonial period more modern equivalents, built using imported cement and designed by engineers, were constructed at Wasini and Faza.

On Wasini Island, water to supplement that from the traditional "djabias" and coconut roof catchments was transported from the mainland in dug out canoes up until the 1950's. Modern ground water catchments now supply the needs of its two main villages. The second of these was constructed by Grover (1969) in the village of Mkwori. A proposed project for a major ground catchment system on Manda Island, near Lamu, has never been constructed and the island remains virtually unpopulated, despite having considerable agricultural potential. (Grover 1971 cited in UNEP 1983).

2.2.2 Roof Catchment

The earliest known reference to roof catchment systems was a plan presented to the French Academy of Science in 1703 to provide a rainwater cistern with a sand filter in every house,(La Hire 1743 cited by Latham and Schiller 1984). Roof catchment systems have, however, been used since much earlier times. Crasta et al.(1982) made reference to rainwater collection from roofs in Phoenician, Carthaginian and also early Roman times. Roman villas and even whole cities were designed to take advantage of rainwater for drinking and air conditioning purposes, (Kovacs 1979).

Although roof catchment systems have been used in Europe and the Mediterranean right up to the present, their use is now restricted to a small number of remote farmsteads or to localities with some severe water supply problems. The karst area of Yugoslavia is one such region, Gibraltar is another. Roof catchment tanks have been required by public ordinance on Gibraltar since 1869, on those parts of the penninsula which cannot be supplied from the central ground catchment supply, (G.R.W.D. 1981). Similar regulations exist on the island of Bermuda, where roof and ground catchment systems have been documented since 1628 by McCallan (1948).

2.3 RAINWATER CATCHMENT SYSTEMS : CURRENT USAGE

The current use of rainwater catchment systems has been noted on every continent by numerous workers. In N.America by by Schiller and Latham(1982) in Canada and in rural Pennsylvannia by Sharpe(1981). In Europe by Kovacs(1979) and Hofkes(1981). In Jamacia by Dedrick(1976) and in China by Jian cited in UNEP(1984).

Roof catchment is still an important source of domestic water on an individual and local scale in some parts of the more developed world, particularly in Australia, (Perrens 1975). It is mainly in the third world however, that roof catchment has the potential to be of major importance as a supplementary water supply,(Schiller 1982). Consequently, most of the major developments in the usage of rainwater catchment technologies are in the developing world.

In Thailand Latham (1984) has reported that more than 2700 tanks have already been installed since 1981 in Northeast Region alone and a total of 8900 are planned for construction by 1987. Many of these tanks are constructed by using bamboo reinforced cement. This tank construction technique is also being promoted in Indonesia and represents a good example of an appropriate technology being developed to make full use of local materials and cheap labour, (Robles-Austriaco et al. 1981). There is also considerable interest in the further development of roof catchment systems in rural Malaysia,(Malik 1982). Feachem(1973) examined the traditional use of rainwater in Papua New Guinea among the Raiapu people. Although rainwater was considered a good source, it was not generally collected from the thatched roofs of houses because of contamination by dust and small grass particles. People preferred to collect rainwater from dripping trees during heavy showers.

2.3.1 Africa

From the literature covering roof catchment systems in Africa it is evident that in many instances the full potential of this source is not being exploited, (White et al. 1972, Parker 1972 and Feachem et al. 1978). In East Africa White et al.(1972, p130) noted that:

"Only a few households without a metal roof use rainwater but the opposite is not true. Many with metal roofs do not collect water from that source"

This observation was also confirmed in the Mulago Hill area of Kampala in Uganda where all water was carried some distance from spring and standpipe sources.

"Practically every house has a roof of corrugated iron but few have gutters, other than incomplete and temporary ones- a surprising observation in view of the reliable rainfall and large cash payments so often made for water at this site." (p59)

Many rural households in East Africa do, however, use 200 litre oil drums, fed from makeshift gutters, as a wet season supplementary water supply. In a survey of domestic water use in twelve villages in Kenya, Uganda and Tanzania, White et al.(1972) found that only 7% of the households surveyed were using rainwater exclusively at the time of the survey. It was also observed that households collecting water in rain barrels used on average 25% more water than those without.

Current interest in remedying the under-utilization of roof catchment supplies in East Africa, is evident from recent research in Kenya. In a detailed survey in the humid Kisii District, Omwenga (1984) conducted a comparative cost analysis and found that the total cost of a roof catchment system is only slightly more expensive than a shallow well. He concludes his study by recommending rainwater collection as the most techically, socially and economically appropriate form of water supply for the region.

The only known published, in depth, study from West Africa was conducted by Parker (1972) in the village of Kpomkpo in southeast Ghana. This work is of particular relevance to the present study as it provides an opportunity for the comparison of results with another part of Africa. Parker examined both individual roof catchment supplies of 21 households and the possibilities for larger communal supply, based on the construction of a large excavated 70 m^3 tank below the 300 m^2 corrugated iron roof of the village school. Although the household survey sample was small, (only 21 households, for this study), as their mean size was almost 7 they did represent a significant fraction of the village's population of 420. Local water sources

consisted of pools in a river-bed within a kilometre of the village from which women spent, on average, 5 hours per week collecting water, and rainwater catchment from iron roofs.

It was found that among the 43% of households which possessed corrugated iron roofs only 20% of the total area was provided with gutters despite the fact that free bamboo guttering was available and used in a few cases. Storage for rainwater consisted of an oil drum or earthern pots and averaged 180 litres for these households. Considering that the mean area of the corrugated iron roofs was over 80 m^2 and that the annual rainfall exceeds 900 mm, the potential household rainwater supply was considerable. It was calculated that with a 12 m^3 concrete storage tank (equivalent to 59 oil drums) the mean total household water consumption rate of 135 litres per day could be satisfied. The cost of a tank of this size would, however, have been equivalent to more than 60% of the average annual cash income of a rural householder and as such could hardly be considered as a viable alternative.

Possible improvements, well within the scope of the householder, were examined. These included the purchase of an additional oil drum and increasing the amount of roof area served by guttering. Benefit/cost ratios were then calculated, based on the questionable assumption that all, or some of the time saved in fetching water would be put to productive work. The benefit/cost ratios for three possible types of improvement ranged from 1.01 to 2.99. Parker suggested four possible reasons why householders did not implement any of these improvements even though they were aware of the technology;

(i) "householders can derive greater amounts of satisfaction by putting the cash to other uses",

(ii) "the possible savings that would be derived from new systems have not been visualized by the householders"

(iii) "the benefit that is derived by those that fetch that water has insufficient influence on the householders to make them construct such a system

(iv) "the householders are not allocating their resources efficiently" (Parker 1973, p15)

The benefit/cost ratios were also calculated for larger alternative communal systems using the existing corrugated iron roof of the school as a catchment area. Ratios as high as 11.98 indicated that such projects were economically very attractive. One possible reason why no community project had been initiated in the village was that people were not aware of the concept of economies of scale. Nevertheless, large rainwater tanks still operating in surrounding villages constructed by Germans as long ago as 1910, did act as an example of both the technology and the advantages of a large communal system. Another reason, however, may have been the fact that the political authority within the village was not strong enough to organize such a project without outside leadership.

In 1971, however, work instigated by an outside agency started for excavating a large roof tank at the school. Although cement had already been purchased, the task of digging the 70 m^3 hole gradually lowered the morale of the village and there was insufficient enthusiasm to complete the project.

An interesting reference to the introduction of large roof catchment tanks among the Dogon people of Mali by Watt (1978), is of particular relevance to the present study. The annual rainfall in this area is only around 400mm, and the general climate, precipitation regime and soils of this Sahelian drought zone, are comparable in many respects, to parts of Botswana The construction of 10,000 litre ferrocement lined, traditional clay granary bins for rainwater storage was field tested by Guggenheim (1974) and was proposed for widespread implementation. The tanks are an adaption of the traditional granaries built alongside the houses for storing grain, and tanks of upto 13,000 litres were built to collect and store rainwater from an $80m^2$ roof.

2.3.2 Southern Africa

Projects related to rainwater catchment have been extremely well documented in southern Africa. This has been partly due to a running interest in the implementation of this technology in the region by the U.K. based Intermediate Technology Development Group

(ITDG) since the late 1960's. Research and observations by Farrar and Pacey (1974) in Zimbabwe, Botswana and Swaziland and by an interdisciplinary team led by Feachem (1978) in Lesotho, have also been important in this respect. ITDG were particularly involved in the construction and monitoring of low-cost, excavated ground catchment tanks made from mud, cement and polythene. These were originally developed in the Kordofan province of Sudan in the early 1960's by Ionides and Associates (1964). Projects based on the same design were initiated for the construction of 12 tanks in Botswana and 33 tanks in Swaziland between 1968 and 1971, less than half of those in Swaziland were completed by the end of the program and "people consistently baulked at the labour required" in excavating for the tanks (Pacey 1977, p33). A shortage of vehicles for use by government officers involved in the program, lack of conviction in the principle of the tanks and possibly conflicting "felt needs" among the people were other reasons given by Moody (1973) and Farrar (1974) for the slow progress of the projects. Pacey (1977) has pointed out that the provision of water at the schools, where the tanks were constructed, did not answer any of the day-to-day worries of the people. This is probably the main reason why only a few of the tanks survived more than three seasons and why there was so little replication of the technology within Swaziland. In Zimbabwe, however, replication and modification of the tanks resulted in the construction of about 30 "open" ground catchment tanks by the end of 1972, in a project initiated by Christian Care (Farrar and Pacey, 1974). In June 1983 one of these was observed to be technically sound, although no longer in use; two others were reported to be operating near Nkai and Shashani and were being used for irrigation and domestic purposes, (Gould 1983c). All of the tanks in Zimbabwe were built in Matabeleland by the Hlekweni Rural Training centre. The main work of this centre, however, has been in their construction of ferrocement roof catchment tanks, and over 200 tanks with nominal capacities of around 9000 litres have been built,(Farrar and Pacey 1974) Most of these have operated successfully for more than 10 years.

In a study conducted in rural Lesotho by Feachem et al.(1978) it was found that although 63% of the houses in one lowland village had iron roofs only 1.6% had any guttering

and even this was crude and inefficient. Rainwater was collected on a casual basis by placing buckets and other containers under the eaves of the house, or under the eaves of a neighbour's house in the case those people who only had a thatched roof. People generally regarded the turbid rainwater running off thatched roofs as unsuitable, although it was occasionally used during heavy rain. Rainwater was perceived as second only to tap water, in terms of purity, and most people regarded runoff from iron roofs as a clean source. Some householders regarded this water as unsuitable for drinking and cooking, due to contamination from leaves and bird droppings. In the highland villages of Lesotho only 1% to 5% of the households possessed iron roofs at the time of the study in 1975/6. This was probably due to the higher price in the mountains (roughly twice the lowland price) and the better insulating properties that thatch provides against the cold winter nights of the highlands.

> "When householders with iron roofs were asked why they did not install guttering they replied that they could not afford to, although guttering is cheap compared to the iron roofs and many other features of their houses. Roofing material for a typical house (5m x 6m in plan) cost about R100[3] in the lowlands compared with only a further R14 for guttering, brackets and a drainpipe. Householders with iron roofs but no guttering simply place a container, such as a metal bath, under the eaves at a place where much rainwater runs off, while those with guttering usually leave a 44 gallon drum standing permanently under the end of the guttering
>
> One reason why rainwater catchment systems are not common is that they are not reliable sources of water. Although Lesotho's average lowlands rainfall of about 2mm a day would be sufficient to supply a typical household with about 10 litres per capita per day - roughly half of its requirements - to ensure such a supply throughout the year would require 7 cubic metres of storage, costing about R200. We observed very few catchment storage tanks of this capacity, although large galvanized iron are occasionally used in the villages for grain storage" (Feachem et al. 1978, p27)

In South Africa, Alcock(1983) has recently completed research into the feasibilty of using community rainwater harvesting systems to provide potable water to villages in the Vulindlela district of Kwazulu. It is postulated that due to the low quality of water in the springs, currently used as the major source of drinking water, the introduction of community rainwater harvesters will result in an improvement in the quality of potable water in the region. Fog interception and individual household rainwater tanks are also being examined as possible

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[3] 1 Rand=US$ 1.15 (1978)

drinking water sources. Fog interception is, however, limited only to the highest parts of the Vulindlela study area. In the case of individual rainwater tanks, it is suggested that due to the storage volumes required, financial constraints do not make this a feasible option. This is partly because state funding is more readily available for community, as opposed to individual, projects. Another problem is "a fear of poisoning by pernicious neighbours" and the fact that although many households collect rainwater from their roofs "gutters are either absent or poorly installed and the common household rain storage capacity is simply one or two 210 litre drums", Alcock, (1983, personal communication).

2.3.3 Botswana

Until the commencement of the present study no material dealing specifically with roof catchment systems in Botswana had been published. An occasional reference had, however, been made to the topic in a number of internal circulars and consultancy reports. At the African regional meeting of the U.N. Water Conference in 1977 it was stated that:

> "Roof catchments are being occasionally used in towns such as Gaborone but ought to be given more attention" (U.N., 1977, p13)

In a study on the impact of improved water supplies on four villages, Copperman(1978) suggested that before a borehole is reticulated it should be checked that the water taste is acceptable. If not, rainwater should be investigated as an economic means of supplying sweet drinking water. Fortmann and Roe (1981) recommended that both the government and intermediate technology groups in Botswana should be approached concerning the feasibility of constructing low cost rainwater catchment tanks. These should be suitable for collecting water from the thatched roofs of huts in the lands areas, and would provide a convenient source of domestic water. The collection of rainwater from thatched roofs was also proposed by Carr (1978), who suggested that the roofs should first be covered with polythene. The introduction of cement jars as an alternative to galvanized iron ones was also mentioned with reference to Botswana.

In contrast to roof catchment systems, the collection of rainwater from ground surfaces has been reasonably well documented in Botswana and major steps have been taken in the development and implementation of this technology. The first publication followed a pilot project in the late 1960's when low cost excavated rainwater catchment tanks of an "open" design were first introduced at 12 primary schools in eastern Botswana, (ITDG 1969). A second report, (ITDG 1971), gave an assessment of the project after three years of operation. These two reports have led to two totally conflicting misconceptions.

On the one hand is the idea that the technology has been widely adopted in Botswana and that subsurface catchment tanks of the "beehive" design are quite common throughout the country. This misleading impression resulted from the wide circulation afforded by the first report and the inclusion of the ITDG "beehive" tank design in a number of popular texts. In fact, only 2 tanks of this design were ever built in Botswana and neither of them is operating today,(Gould 1984). On the other hand some of those who read the second report, which was less widely circulated deemed the project as a complete failure, (Farrar and Pacey 1974). This was due to the fact that it reported that only 7 of the 12 primary schools participating in the pilot project ever completed the tanks and of these only two were operating successfully three years later.

In the 1970's, there was some very limited replication of the work done in the late 1960's, but also considerable interest in modifying and developing ground catchment tanks to make them more practical and appropriate to the needs of the people, (Cullis 1984). Experiments in the use of P.V.C., chickenwire and cement, for lining excavations, were conducted with some success in Morwa, where rainwater stored in an open tank of around $100m^3$ with a natural catchment apron was used to water eucalyptus seedlings. The use of butyl rubber for lining tanks was also experimented with, (Cullis 1984). In Serowe one such tank was constucted for collecting rainwater from a natural hillside for providing irrigation water for the forestry brigade. The $600m^3$ tank was still functioning in 1983. Since 1980, the Ministry of Agriculture has initiated a program of ground tank construction in arable lands areas through

the Arable Lands Development Programme. A number of workers including Classen(1980), Maikano and Nyberg(1981a), Gaadingwe(1983), Ainley(1984) and Gould(1984) have discussed this project which has resulted in the construction of more than than 400 tanks to date. A detailed discussion of this project will follow in chapter 7.

2.4 RAINWATER CATCHMENT SYSTEMS : DESIGN, CONSTRUCTION AND WATER QUALITY

Three aspects of rainwater catchment systems which are of particular significance when examining the feasibility of this technology are design, construction and water quality. These are each addressed in detail with respect to Botswana in chapters 4 and 5. It is useful at this point, however, to briefly review the findings of other researchers.

2.4.1 Design

The biggest problem facing the rainwater catchment systems designer is to determine the most appropriate storage volume for any given catchment area and rainfall regime. The storage has to be large enough to allow a constant rate of supply, sufficient to satisfy the required needs, throughout the longest dry period likely to be experienced. At the same time, however, Schiller and Latham(in press) have noted the necessity for trying to make the best use of the available rainwater runoff at the lowest cost. Since cost is directly proportional to tank size, the problem becomes one of trying to maximize supply while at the same time minimizing the storage tank volume.

One of the earliest methods for determining such storage requirements was developed for reservoir sizing in general by Rippl(1883). This method, known as mass curve analysis has been applied to rainwater tank sizing by a number of workers including Grover(1971). Although it is relatively straight forward to carry out, this method which is normally done graphically, can be time consuming and only operates for a reliability of supply of 100%. A simplified version of this approach directed towards applications in the rural parts of the Third

World was developed by Watt(1978) and is shown in figure 2.1. A similar method based on using values equivalent to two-thirds of the mean monthly rainfall was used by Keller(1982).

Ree et al.(1971) developed a more involved method which, although still based on mass curve analysis, requires the ranking of rainfall totals for fixed periods in order to determine the probability (or reliability) of a given level of supply. This method is very slow and laborious unless a computer is used.

Apart from greatly speeding up data analysis and rapidly producing graphs which may be used to determine appropriate storage capacities for a given location and catchment, a computer allows for easy comparison of storage capacites and associated supplies, at a number of reliability levels. In recent years a number of different computer based methods for rainwater tank storage determinations have been developed. These include a method developed by Perrens(1975) to investigate collection and storage strategies for rainwater catchment systems design in Australia, and a method based on the "the yield after spillage" used by Jenkins et al.(1978) to examine the feasibility of rainwater collection in California.

One of the most recently developed methods is that by Latham(1983) and is referred to as the Ottawa Model. This method involves a calculation midway between the mass curve method adapted by Grover and Perrens, and the Jenkins method. Although this model uses monthly rainfall data, Latham(1983) noted that agreement with the daily situation is good. A brief description of the workings of the Ottawa Model and its comparison with other methods of rainwater tank sizing is given in Appendix 2.

All the methods examined here are based on the use of actual past mean monthly rainfall data and the identification of critical dry periods within the data for which stored rainwater would be needed to supplement any pre-determined minimum supply. The most critical or driest period in the data will determine the storage requirement. Where the methods differ from each other is in their treatment of tank spillage, rationing and stocking procedures.

Perrens' method based on mass curve analysis uses a "yield before spillage" calculation, this has a tendency to somewhat under-estimate storage requirements. The approach used by

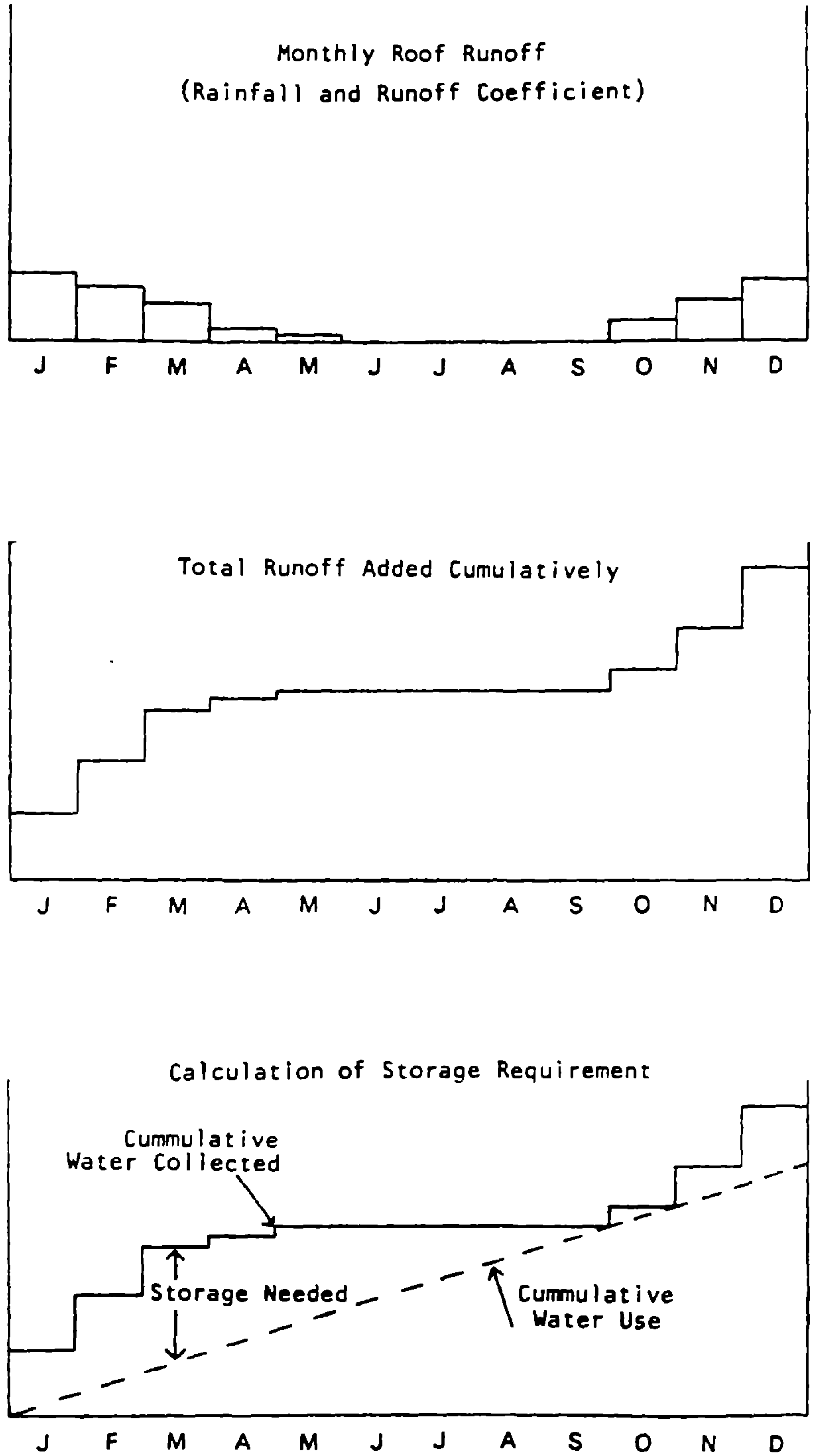

Figure 2.1 ...Simplified Mass Curve Analysis for Determining Rainwater Tank Storage Requirements, (adapted from Watt 1978)

Jenkins on the other hand, is based on an assumption of "yield after spillage" which tends to over-estimate storage needs. Because the Ottawa Model uses a calculation midway between the two it would seem more likely to produce a closer estimate of the true situation. This is one of the reasons why this model has been used in preference to others for analysing the rainfall data used in this study. more detailed discussion of the model and of its applications to rainwater catchment systems design in Botswana is given in chapter 5.

2.4.2 Construction

There are numerous construction methods for building rainwater storage tanks. However, only a few of them can produce durable , low cost, easy-to-construct tanks. These are necessary if rainwater catchment systems in developing countries are to provide an attractive, viable alternative to other forms of water supply. Two basic methods developed, relatively recently, which show considerable promise for the future, are ferrocement construction techniques described by Watt(1978) and IWACO(1982) and bamboo reinforced cement construction techniques described by Rolloos(1979). The bamboo reinforced cement tanks are a slightly lower cost modification of the ferrocement construction method using bamboo reinforcement instead of wire Bamboo reinforced tanks are particularly appropriate for many parts of southeast Asia where bamboo is ubiquitous. The use of both bamboo reinforced and ferrocement tanks in Indonesia and Thailand has been described by Latham(1984). Bamboo can also be used to make gutters and downpipes, (IRW 1982).

The relatively limited distribution of bamboo in Africa makes ferrocement construction a more practical alternative in most areas. The advantages of constructing storage tanks on site over using transported corrugated iron tanks have been stated by several researchers working in Africa. Nissen-Peterson(1982) points out the high cost, susceptibility to corrosion and limited capacity of corrugated iron tanks as compared to tanks built on site. This view is supported in reference to southern Africa by Farrar and Pacey(1974) who have noted, that :

"The most common type of roof catchment tank in southern Africa is a cylindrical

tank made of corrugated sheet steel with a galvanized finish. Apart from their initial cost these tanks have a limited life because seams open up and corrode. Better installation can overcome this to some extent, but 5 years is accepted as a reasonable life by European farmers who have the knowledge and capital to ensure that all possible precautions are taken."(p5)

Consequently, they draw attention to the benefits of the more durable ferrocement tanks which can be constructed for about 60% or less of the price of installing a factory made galvanized one, if self-help labour is used in their construction.

According to Watt(1978) ferrocement tanks have been in constant use in some areas since at least the early 1950's. The construction of the tanks basically involves the erection of an iron formwork on a concrete base, wrapping it with chicken wire, reinforcing with fencing wire and plastering it with cement. The formwork is removed and the inside of the tank is plastered. This basic design has become the standard approach for the construction of ferrocement rainwater tanks of this type, (see figure 2.2).

Kenya is a country where a number of innovative roof catchment tank technologies have been recently developed. There are probably more rainwater catchment tanks in Kenya than in any other African country. This is partly due to the efforts of UNICEF and other NGO's (Non-Government Organizations) who have introduced and promoted a number of these new designs. The five most significant of these are the cement jar[4] , the ghala basket, the concrete ring tank, the concrete block tank and the weld mesh ferrocement tank. Four of these are shown in figure 2.3.

1. The cement jar is constructed by using a stuffed cloth or hessien bag as a mould, placing this on a pre-cast base and plastering on the outside. When the mortar has set the mould (bag) should be emptied and removed. Thousands of these jars with volumes of between $1m^3$ and $10m^3$ are already in service. The larger ones are reinforced using both wire mesh

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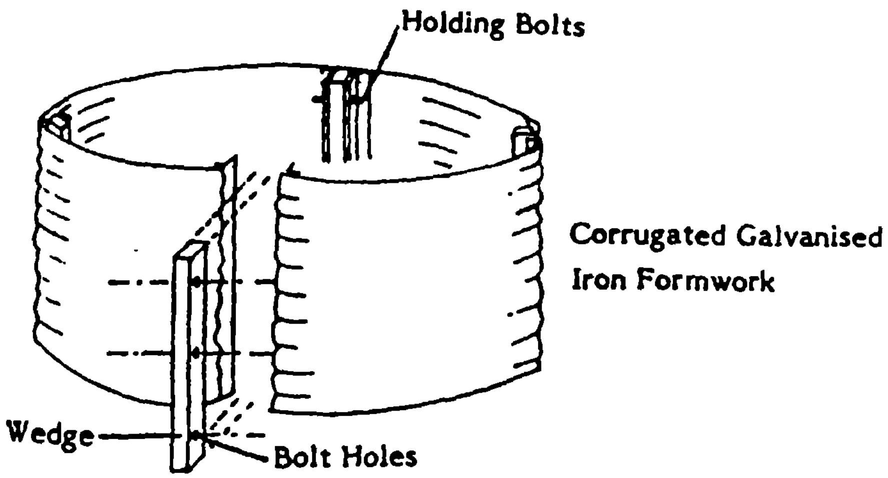
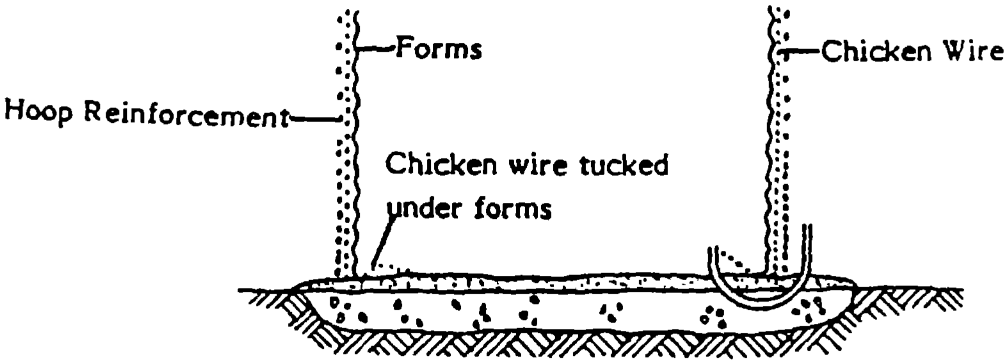
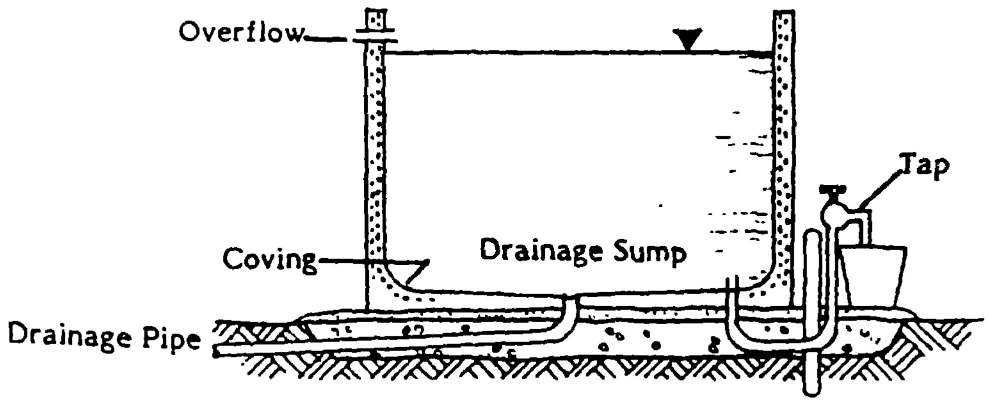
[4]During a two week course in 1979 at the Denman Rural Training Centre near Gaborone a group of farmers were trained how to build these tanks. Although demonstration cement jars were regularly displayed at agricultural shows in Southeast district, no evidence that anyone actually built their own tank could be found.



Assembing the Formwork

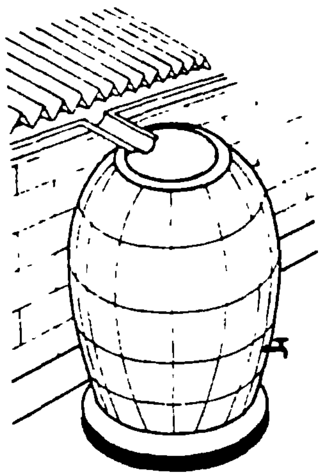


Erect Formwork and Wind on Reinforcing Wire

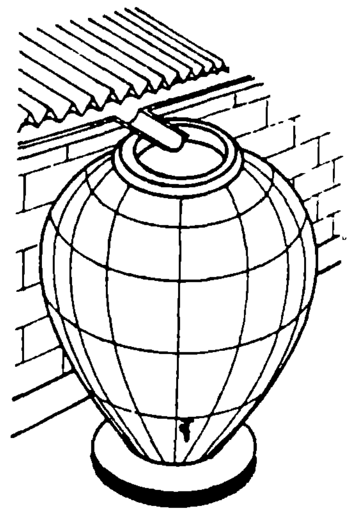


The Completed Tank

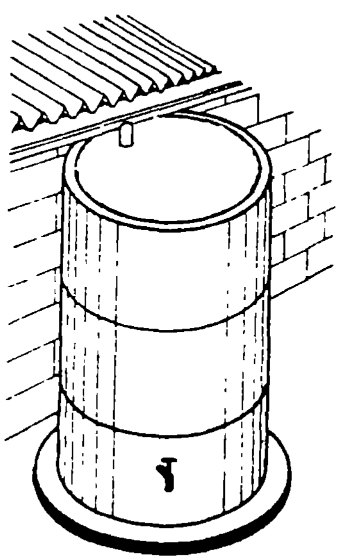
Figure 2.2 ...The Stages of Construction of a Ferrocement Tank (Adapted from Watt 1978)



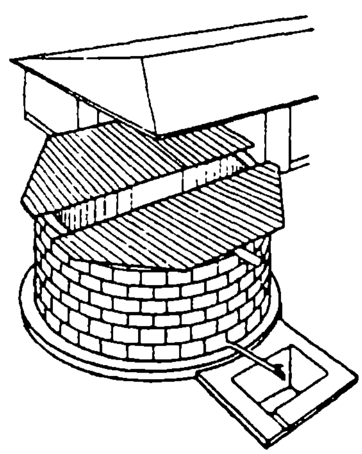
Large Cement Jar



Ghala Basket Tank



Concrete Ring Tank



Concrete Block Tank

(Adapted from Nissen-Peterson 1982)

Figure 2.3 ...Four Types of Low-cost Rainwater Catchment Tanks found in Kenya

and fencing wire and are known as ferrocement jars. At the Utoomi Development Project in Kola, three jars per household were planned, and 150 have already been constructed (Byrne 1983). In the water-short region of North Kitui around Mwingi where ground water is generally either saline or unavailable altogether, one builder alone working for the Inter Church Group has been involved in the construction of at least 167 cement jars for rainwater storage, Gould(1983a).

2. "Ghala Basket" tanks built in Karai (25 km west of Nairobi), have, however, been very sucessful . More than a thousand have been constructed by a local community group who were originally assisted by UNICEF . The tanks use a basket work frame onto which mortar is applied, tanks up to 6 m^3 have been built using this technique. Early technical problems were overcome by plastering the tanks on both the inside and outside. A detailed review of the project is given by Molvaer(1982) and more recently by McPherson et al.(1984).

3. The Concrete Ring Tank has only been built in large numbers in Kenya since 1983, when a project was initiated in Machakos District. The design consists of the casting of concrete rings on top of each other on a concrete foundation using corrugated iron moulds. The moulds are removed as the rings set and mortar applied to both the inside and outside of the concrete . Wire is used to reinforce these tanks which so far have been built upto volumes of 13m^3 ,(Thiadens, personal communication 1984).

4. The Concrete Block Tank design and construction technique for a 23 m^3 is described in detail by Nissen-Peterson(1982). Basically it consisted of simply making concrete blocks using a home made wooden mould and laying these on a circular reinforced concrete base. Barbed wire is used to reinforce each course of blocks. Finally the tank is plastered on the inside and a corrugated iron roof placed on a wooden frame.

5. Weldmesh Ferrocement Tanks are currently being developed by AMREF (African Medical Research Foundation) and are based on the use of a weldmesh frame onto which shuttering is attached and mortar applied. Initial indications are that this construction

technique is both cheap and effective, (Greenacre, personal communication 1984)[5].

Some innovative work in ground catchment tank design has also taken place in Kenya. Nissen-Peterson(1982) describes the construction of a 50m³ semi-spherical design using ferrocement. However, probably the most important work regarding ground catchment tank design and construction has taken place in Botswana. Apart from the ITDG design (ITDG 1969) already mentioned, two recently developed designs for excavated cylindrical tanks are described by Whiteside(1982) in which a standard volume of 10 m³ is suggested. The more common of the two designs is a ferrocement tank with a corrugated iron cover. This is constructed by simply pegging chicken wire to the smoothed sides of a cylindrical hole and carefully plastering over it. For unconsolidated soils a brick tank with a brick dome cover has been designed.

The first tanks built at Pelotshetlha were rectangular in shape but Classen (1980) suggested using a cylindrical design for reasons relating to strength and more efficient use of materials. Tanks of up to 25 m³ were proposed due to the economies of scale associated with large tanks.

All of these tanks have been designed to collect rainwater from traditional threshing floor catchment aprons made by plastering a compacted surface with cow dung and mud. The floors normally used at harvest time for threshing millet are upto 150 m² in area, (Maikano and Nyberg 1980a) and are found in most of the rural parts of Botswana.

2.4.3 Water Quality

Although a great many workers have made statements regarding the quality of stored rainwater, there have not been many detailed studies on this topic. However, according to Watt(1978), the long history of their use suggests that the water can be drunk with few health risks. Schiller(1982) stated that the quality of rainwater can normally be assumed to be good, except in industrialized areas, where aerosol pollutants may contaminate the rainwater before it

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[5]AMREF, PO Box 30135, Nairobi, Kenya.

reaches the surface.

A detailed study of rainwater from 12 cisterns on the U.S. Virgin Islands by Lee and Jones(1972) was conducted to examine the chemical quality of this form of supply and its suitability for drinking and domestic use. The study concluded that supplies were generally satisfactory in terms of chemical water quality and that there was no significant contamination from materials used to construct the cistern or paint the roof tops. Although no tests were conducted, some concern was expressed regarding the bacteriological quality of the water.

Studies in Thailand by Vadhanavikkit et al(1981), in Balau by Romeo(1982) and in Nova Scotia by Waller and Inman(1982) have, however, all indicated that the bacteriological quality of stored roof rainwater generally falls within acceptable limits. A similar conclusion was reached by Stenstrom and de Jong(1982) based on the results from five samples from roof catchment tanks in Botswana.

Watt(1978) has noted that the process of storing rainwater can in itself assist in improving its' bacteriological quality, due to the intolerance of cholera, typhoid and diarrhoeal pathogens to prolonged storage exceeding a few days. In Thailand , Vadhanavikkit et al(1981) have observed that the bacteriological quality of rainwater is markedly improved after a few roof washes by rainstorms at the advent of the dry season. They also noted that rainwater from thatched roofs, although coloured and turbid, was still within allowable limits for drinking once roof washing had occurred. This finding supports the belief of Hall(1982) that the collection of rainwater from thatched roofs is a feasible means of water supply. Fortmann and Roe(1981) have also suggested the possible suitability of this form of supply in Botswana. There is, however, considerable controversy over this issue. Feachem et al.(1978) found that in Lesotho rainwater from thatched roofs was "turbid and generally regarded as unsuitable". The suitability of rainwater from thatched roofs in Botswana is therefore one of the topics addressed in this thesis.

References to the quality of water from ground catchment systems are few and only hard data relating to chemical quality could be found,(Classen 1980, Maikano and Nyberg

1981a). In both these studies, however, concern was expressed over possible bacteriological contamination of water from ground catchments in Botswana. particularly as the catchment apron for the Arable Lands Development Programme (ALDEP) tanks examined consisted of plastered mud and cow dung threshing floors. Whiteside(1982) stated, that although water from the tanks "should be fairly clean", boiling is necessary to make sure it is "absolutely safe". The results of bacteriological analysis conducted on similar tanks are presented in chapter 7.

2.5 SUMMARY

The collection of rainwater from roofs and ground surfaces has been practiced since ancient times. Examples of this form of domestic supply can still be found in almost every country in the world. It is in developing countries, however, that rainwater catchment systems are most numerous. Evidence from Africa suggests that although widespread, the full potential of this form of water supply is far from being realized.

In Southern Africa a number of projects to encourage both roof and ground catchment construction have been attempted since the 1960's. The largest of these were the ferrocement roof catchment tank project in Zimbabwe in the early 1970's and the on-going ALDEP ground catchment tank project in Botswana. Although these projects are large in comparison with others which have been attempted in the region, they have only accounted for the construction of around 200 roof tanks in Zimbabwe and 400 ground tanks in Botswana, respectively

The design and construction of rainwater catchment tanks involves an attempt to keep costs and hence tank volumes as low as possible while at the same time trying to maximize the rainwater supply from a given roof area. The earliest design methods for rainwater tank sizing were based on graphical techniques. Faster, more sophisticated computerized methods are now available. One of these, the Ottawa Model, is used for the analysis of rainfall data in this thesis.

Among recent roof tank construction methods which have been developed as alternatives to galvanized iron tanks, the ferrocement design described by Watt(1978) and five

others recently developed in Kenya are prominent. These include the cement jar, the ghala basket, the concrete ring and concrete block and a weldmesh/ferrocement technique. In Botswana two designs for ground catchment construction have recently been developed, one involves ferrocement while the other involves the use of a brick dome construction technique.

A number of studies on the quality of water from roof catchment systems have indicated that it is generally good. Less information exists regarding the quality of water from ground catchment systems and some concern regarding its suitability is expressed in the literature on this subject.

3. METHODOLOGY

3.1 FIELDWORK

The fieldwork for this thesis was conducted in Botswana between June 1st and November 28th 1983. It consisted of the major task of collecting primary data and the comparatively minor task of secondary data collection. Almost all of the primary data collected were from locations in the east of the country where the rainfall is highest and where the vast majority of the population live. The remote arid western part of the country was not visited, although some data from this region were obtained through secondary sources (such as rainfall data from the Department of Meteorological Services) and a postal questionnaire.

Six major components of the fieldwork can be identified; these consisted of:

1. A village survey in which several villages were studied, and an in-depth oral questionnaire and technical field survey conducted in four of them.
2. A schools survey, which was administered predominently through a postal questionnaire which was sent to 200 primary schools, and supplemented with observations and measurements at six of these schools and visits to a number of others.
3. A ground catchment survey, which consisted of interviewing government officers involved in the implementation of the Arable Lands Development Programme rainwater catchment tank project, as well as observations and measurements of both ALDEP and other similar tanks.
4. An investigation into the quality of stored rainwater compared with other sources.
5. Field observations and measurements supported by information gleaned from discussions and interviews with various officials politicians, planners, engineers, technicians, health workers extension staff and villagers.
6. The collection of medical, climatological, economic, social and technical data.

3.2 PRIMARY DATA COLLECTION

3.2.1 Sampling and Selection Criteria

The main aim of the fieldwork was to obtain a clear, unbiased view of the extent to which rainwater catchment systems are being used in rural areas and the potential for the further implementation and expansion of this technique for providing a supplementary, reserve or interim water supply. It was, therefore, necessary to collect technical, economic, social and attitudinal information from a series of representative locations. In all, about a dozen villages were visited for periods of a day or more. The majority were located in the northeast and four of these were selected on the basis of their size, accessibility and type of water provision for detailed surveys. Another village surveyed was Mathangwane (30km north of Francistown) . This was chosen as the site for the pilot study. During the pilot study the questionnaire and technical field survey were pre-tested at 10 households and subsequent minor alterations and improvements made before the main survey was conducted.

Apart from the observations and surveys in villages in northeastern Botswana, a number of villages in the southern part of the country were also visited. Of these Morwa, Pitsing and Mogonye were examined the most extensively, (Figure 1.1). Although no questionnaire surveys were conducted in these villages informal interviews were carried out and some measurements taken. The purpose of these was to establish whether the findings from northeastern Botswana also held true in the southeast, as this is the only other major population centre in the country, see figure 1.4. Most of the people in Botswana reside in areas where the mean annual rainfall is between 350mm and 550mm, (see figures 1.2 and 1.4). All the villages selected also fell within this range.

Due to the fact that time and resources could only allow for the in-depth study of four villages, it was decided that rather than choosing them at random, it would be better to select villages that were each different in character yet were each representative of a major group of similar type villages throughout Botswana. The main single criteria used to differentiate the

villages was the type and level of provision of water. The four villages chosen, Borolong, Selolwane, Thini and Nata were all similar in size, had similar precipitation regimes, but varied markedly in their water supply provision, (figures 1.1 and 1.2).

Borolong and Selolwane both had reticulated borehole supplies connected to a number of standpipes but while the supply in Selolwane was very reliable, only one of four standpipes in Borolong occasionally yielded water. Thini had no improved water supply at all, and the major water source was a sand river on the northern side of the village. Because the settlement was very scattered some people had a return journey of 3.5km for each bucket of water. Those who could afford them used bicycles for water collection. At the village of Nata attempts to provide a borehole supply had been thwarted by the fact that the groundwater in the area is highly saline [6]. The only improved water supply consisted of a tank containing a comparatively small amount of water transported to Nata from freshwater boreholes between 40-50 km away. The main water source in the village was a highly contaminated river which was shared with the village livestock. Nata represents an extreme case, both in terms of the poor quality of traditional water sources and due to the difficulty and expense of providing an improved water supply. Rainwater catchment systems represent a particularly attractive alternative under these conditions. A detailed case study of Nata is presented in Appendix 4.

Factors other than water provision also influenced the choice of the four villages in which in-depth studies were conducted. The villages had to be small enough for a detailed study to be feasible and of similar sizes to make comparisons justifiable. The four villages chosen had populations between about 1000 and 1850. Small villages of this size are of particular interest because some have reticulated supplies while others do not. Most of them have their own primary schools, shops and at least several private homes with corrugated iron roofs, offering potential for rainwater collection. The location of the villages relative to major centres influences the cash incomes of the households, the price of various building materials and hence

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[6]Nata is one of many villages in Botswana which suffer from saline groundwater supplies; others include Orapa, Kang, Ramotswa, Mopipi, Letlhakane, Kedia, Bodibeng and Tsabong.

the number of corrugated iron roofs. The four villages chosen for detailed study all were north of Francistown. Borolong was closest at just 22km, while Nata was at a distance of 198km to the northwest,(figure 1.1).

3.2.2 Village Questionnaire and Technical Survey

The selection of households on which the questionnaire and technical survey were conducted, was random. A crude map was drawn up for each of the villages and all of the households numbered, 50 households were then selected using random number tables. In cases where nobody was home, the household would be visited later, if there was still nobody there, the nearest neighbouring household would be chosen. The response rate for the survey was 99.5%, only one respondent out of 201 refused to answer the questionnaire, The purpose of this survey was to get a deeper understanding of the economic, technical, political, cultural and attitudinal factors which affect water supplies in Botswana; and to use this information to determine what role ,if any, rainwater catchment systems might play in future water provision. Due to the wide range of information required, data were gathered using a dual approach.

A standard oral questionnaire was completed in Setswana through an interpreter at each household, for obtaining personal, attitudinal and economic data. A technical field survey was then conducted through observation and measurement to collect the complementary technical information required for assessing the potential for installing any form of roof or ground catchment system. Information such as the roof type and area, the existence of gutters and the presence and volumes of any existing collection vessels were documented. A copy of the household questionnaire and technical field survey are presented in Appendix 3. The questionnaire is divided into three sections A, B and C. Sections B and C were completed for households with iron roofs and/or some form of rainwater catchment systems. Section A, which was answered by all interviewees is also divided into three parts. The first part is concerned with the collection of data relating to water supply. This included questions about the location, nature and distance to water sources in both wet and dry seasons, the cost (if any)

and reliability of improved supplies. Attitudes towards improved supplies were determined by asking the interviewees about their feelings towards the convenience, cleanliness, maintenance and taste of these supplies. Similar questions relating to the collection, purity and taste of rainwater were also asked. Information about the supply and demand for water was obtained by asking questions about the amount of water collected each day (normally the number of buckets), and also by asking about the quantities of water used for various activities. Apart from water for regular domestic purposes, such as cooking, drinking and washing, water is also used for brewing beer, watering vegetables and livestock, washing clothes and repairing the huts and the veranda area (lolwapa) around each compound. Information on these activities was obtained in the second part of section A. In the third part, socioeconomic data for each household were collected, the number of people, age groups, occupation and education of the head of the household, and the number of family members living or working elsewhere were recorded. Personal information about cattle ownership and the health of the family was also requested. The questions relating to wealth although giving an indication of the true situation , were not expected to yield an accurate picture. For this reason observations of "indices of wealth" were conducted as part of the technical field survey. These probably acted as a better indicator of the economic state of each household. Other observations relating to health were also made in this survey. The presence of a latrine and its type, for example , as well as a subjective estimate of the general level of hygiene in each compound. In section B, householders with at least one metal roof (which were a minority in most villages), were asked questions on the perceived cost of gutters and tanks and the ability to pay for these. In addition, householders were asked whether they had considered, or would now consider, installing a roof catchment system. For the few households already using a rainwater catchment systems, however crude, Section C was completed. Questions relating to the permanence, volume and frequency of cleaning of the storage vessel were asked, as well as the time of year when rainwater was used and for which purposes. The owners of the catchment tanks were also asked what they thought was the greatest advantage of rainwater. Finally all the respondents of

the questionnaire were asked if they had any comments or questions.

In addition to the 50 household questionnaires and technical field surveys conducted in each village, two other information sheets were used for data collection. The first of these consisted of a short form which was used for collecting data from every public building in the village. Private shops and bars were included among these. The second, was a village technical field survey in which general information relating to the physical, infrastructural, social, political, medical, and administrative nature of each village was gathered. In addition to this, a catalogue of both improved and unimproved water sources was compiled in which general data concerning water use and the nature of water sources within each village were gathered, these are included in Appendix 3.

3.2.3 School Questionnaire Survey

The purpose of the school questionnaire surveys was to establish the types of water supplies currently being used by the schools, as well as the reliability, quality and distance to these supplies. The extent to which rainwater is currently being collected and used as well as the potential for using this source was also determined. This was done by asking the headteachers at each school to provide information about the size and type of roofs and rainwater catchment tanks currently being used. Unlike the village questionnaire survey which was conducted orally in Setswana through an interpreter, the school questionnaire was a postal questionnaire written in English and sent to the headteachers of 200 primary schools through-out Botswana [7]. A copy of the questionnaire and the introductory letter which accompanied it can be seen in Appendix 5, along with the addresses of the 64 schools which responded. Six schools were also visited at Morwa, Borolong, Nata, Mogonye, Thini and Selolwane, and detailed observations and measurements of roof areas and existing tanks were made. Figure 3.1 indicates the location of all the schools included in the survey.

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[7] This survey was conducted in cooperation with the Botswana Technology Centre.

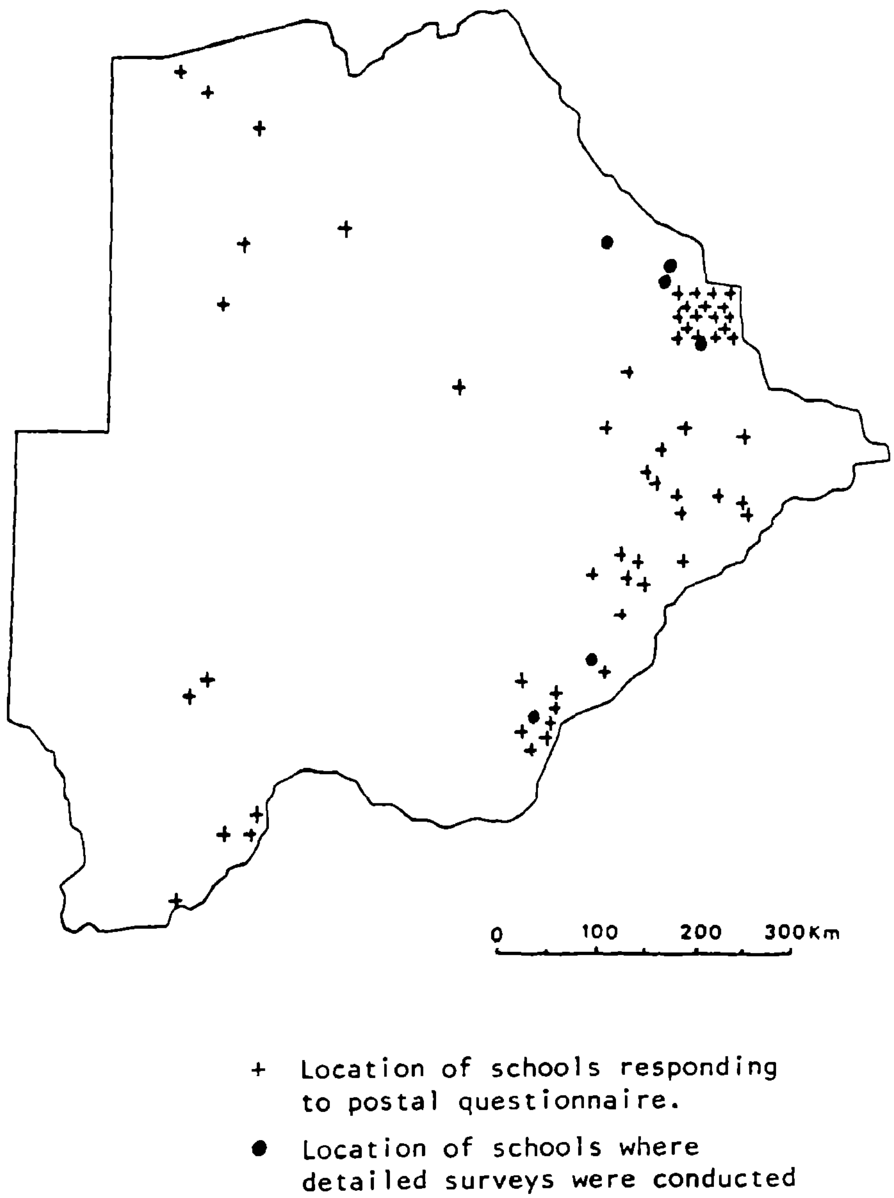

Figure 3.1 ...Location of Primary Schools which Participated in the survey

The decision to conduct this postal questionnaire on primary schools was not made during the initial planning phase of the fieldwork, but came as a response to the obvious potential shown for the wide spread use of large rainwater catchment tanks at primary schools in a number of the villages visited during the initial reconnoitre.

It was the realization that at many schools with extreme water shortages, the use of rainwater was either being grossly under-exploited or being ignored altogether, which acted as the major motivating force for conducting a nationwide survey of schools. The main aim of the postal questionnaire was to determine whether there was a demand for the installation of rainwater tanks and how much water might feasibly be obtained in this way. It was thus necessary to ask questions relating to the size of the school, both in terms of the number of students and in terms of total roof area. In addition questions relating to the nature, location and quality of current water sources, as well as the number , size and condition of any existing rainwater catchment tanks, had to be asked, see Appendix 5.

The response rate to this questionnaire survey was more than 35%. This is a high response rate for a postal survey conducted in a Third World country and may have reflected an interest in any possibilities for water improvement by the schools staff.

3.2.4 Ground Tank Survey

The main purpose of the ground tank survey was to evaluate the success of the ALDEP rainwater tank project to date, in order to determine the overall potential of small scale ground catchment tanks as a supplementary water source in remote lands and cattle post regions. A map showing the location of existing tanks can be seen in figure 7.2.

Two main approaches were used to gather information in this survey. The first consisted of a structured interview with the District Agricultural Officer, in which the number, location and type of tanks in each district were determined and more importantly the problems which had been encountered. These included not only technical problems but also problems relating to the implementational aspects of the ALDEP tank scheme. The second main

approach consisted of visits to 30 ground catchment tanks. Only 23 of these had been implemented by the Ministry of Agriculture. At each tank visited information about the size, type and condition of both the tank itself and the catchment apron was gathered, see Appendix 6. In addition to this, questions relating to the uses of the stored rainwater, the number of people relying on the source, the approximate withdrawal rates and the distance to the nearest alternative water source were also asked. Economic data relating to costs and arrangements for loan repayments were collected as well as information about the the occupation and indices of wealth of the recipient of each tank. Finally a sketch was made of every tank and catchment apron visited on which all measurements taken were included. An outline of both the structured interview and the survey sheet used for collecting information at each tank visited is presented in Appendix 6.

3.2.5 Water Quality Analysis

To determine the suitability of rainwater for domestic consumption and its quality relative to other sources, water quality analysis was conducted. Although there has been widespread sampling and quality analysis of many different water sources in Botswana, there has been very little research with respect to rainwater supplies. It was therefore necessary to collect and analyse a series of samples from both roof and ground catchment tanks to supplement the existing sparse information. Bacteriological analysis of all of the main water sources at Nata were also conducted as no previous information on this could be found.

In all, 20 samples were collected from different types of catchment tank (the results and the location of the sites are given in tables 4.9 and 7.1). These included covered corrugated iron roof tanks, covered and uncovered brick and cement roof catchment tanks and a number of ALDEP type sub-surface ground catchment tanks. In most cases only bateriological analysis was done, as generally rainwater does not suffer from serious chemical contamination in non-industrialized regions. In addition, it is in regard to the bacteriological analysis of stored rainwater that the existing data were most deficient.

The collection of water samples for bacteriological analysis requires extreme care to avoid contamination. All precautions were taken and the instructions issued by the Department of Water Affairs in relation to their sampling procedure followed. Samples were taken to the laboratory for analysis as soon as possible and in the intervening period they were stored in a cooler box or refrigerator. Specific details of the water sample collection and analysis procedure is not be dealt with here, however, the most important points are :

1. Once the samples had been collected and delivered to the laboratory, 5ml and 50ml extracts were filtered through a very fine paper to collect the bacteria. This paper was then placed on a pre-prepared agar and left in an oven at a carefully controlled temperature for either 24 or 48 hours, depending on which agar was used.
2. Three different agars and two different temperatures were used for developing the cultures of three indicative bacterial types for determining the presence of Faecal Streptococci, Faecal Coliforms and Total Coliforms.
3. The number of cultures which grew on each plate was equivalent to the number of bacteria present in the sample and using a straight forward calculation the number per 100ml sample was determined. In some cases the numbers even for a 5ml sample would be too numerous to count (TNTC) this normally meant over about 1000. In other cases, when the cultures were very numerous they would grow together resulting in a confluent growth(CG).

The three different bacteriological indicators used for the water analysis are each indicative of a certain type of contamination. Faecal streptococci generally indicate contamination from some form of animal source. This is commonly present in catchment tanks due to contamination by birds, lizards and other small animals. Although any form of bacteriological contamination is obviously not desirable, faecal streptococci in low concentrations are not indicative of a major health hazard. Faecal coliforms, nevertheless, indicate contamination of a human origin and represent a health hazard, even at relatively low

concentrations. Total coliform counts show the general presence of bacteria of a variety of types.

In addition to the direct analysis of water samples, data were gleaned from other sources and in particular from the Department of Water Affairs in Gaborone. It was here also, that half of the water samples were analysed, the other half being done at the Jubillee Hospital's laboratory in Francistown. To check that the samples were not contaminated during collection and that the analysis was being done effectively, Two control samples from the town water supply were included. These proved to be free of any bacteria.

Finally, data on the water quality of covered and uncovered corrugated iron roof tanks was taken from a draft report on the Botswana-Water Quality Surveillance Programme, Stenstrom and de Jong (1983).

3.3 SECONDARY DATA COLLECTION

Apart from water quality data, a number of other secondary sources were used to gather information for this study. Health statistics were obtained from the Regional Medical Officer (RMO) of the area in which the in depth village surveys were conducted. A series of informal interviews both with the RMO and with nursing staff at Nata clinic also yielded important information about waterborne diseases and general levels of health in the region The 1981 census results were used as the major source of base data. Birth rates, death rates, population growth rates and village populations were obtained from this source.

Maps of two of the four villages for which an in-depth study was conducted were obtained from the Department of Town and Regional Planning in Francistown. For the other two villages Nata and Borolong areal photographs obtained from the Department of Survey and Lands in Gaborone were used to draw maps. However, because the scales of the original photographs were very small, 1 to 70,000 and 1 to 29,000, the photographs were enlarged to 1 to 10,000 for Nata and 1 to 5,000 for Borolong, respectively. Crude working maps were then traced from these photographs.

3.3.1 Rainfall Data Analysis

The most important secondary source data used for this study was rainfall data. Fortunately, Botswana has a reasonable record of rainfall with continuous measurements dating back to the early 1920's at several stations. At present, their are more than 25 weather stations and data storage is now being computerized. Mean monthly rainfall data were obtained for 10 stations from the Department of Meteorological Services in Gaborone. The location of these are shown in figure 3.2. These data were run using the Ottawa Model a storage-demand supply computer model which is discussed in chapter five. The use of this model produces graphs relating storage and supply volumes (at varying levels of reliability) for each rainfall station. These graphs provide powerful design tools which are used for determining the most appropriate storage tank volumes at any locality. In chapter six these results are used for producing maps which provide an estimate of the most appropriate storage volumes and associated rainwater supplies per unit area of catchment for any point in Botswana.

3.4 SUMMARY

The main components of the methodology for this study included:

1) - an oral questionnaire and technical field survey conducted in four villages, and backed up by observations and measurements in several others.

2) - a postal questionnaire sent to 200 primary schools and support by detailed surveys at six of these.

3) - a ground tank field survey including visits to 30 tanks and interviews with every district agricultural officer in Botswana responsible for ground tank implementation.

4) - survey of the quality of stored rainwater conducted through the bacteriological analysis of 20 roof and ground tank samples.

5) - the collection of secondary data from various sources.

6) - the application of a computer model for rainfall data analysis.

Figure 3.2 ...Location of the 10 Stations for which Rainfall Data was analysed

4. ROOF CATCHMENT SYSTEMS : RESULTS

In this chapter the results of the village questionnaire and technical field surveys are presented, along with those of the primary school postal questionnaire survey, and the results of the bacteriological analysis of roof rainwater samples. These results illustrate the nature of water sources and water usage in the study villages and provide basic physical and socio-economic data about these locations. The attitudes and perceptions towards water sources in general and rainwater in particular are presented, as well as data relating to the current use of rainwater and the cost of roof catchment tanks. Through an examination of this information and that relating to the quality of rainwater it is possible to assess the potential for using rainwater as a means of supply.

4.1 RESULTS OF THE VILLAGE SURVEYS

A great deal of data were collected during the four village questionnaire and technical field surveys. Although the vast majority of the information was found to be of direct relevance in assessing the potential for rainwater catchment systems, it is far too voluminous to all be explicitly included in this section. An attempt will therefore, be made to summarize the most important data in table form, and refer specifically to other results where they are needed to elaborate the overall findings. The results of certain portions of the questionnaire and technical field survey (Appendix 3), are not referred to explicitly. This is because either the findings were inconclusive or that they were of only minor significance and have been included implicitly in some of the more general statements in this section. Tables 4.1, 4.2, 4.3, 4.4, and 4.5 deal with basic information relating to the four villages, their inhabitants, their attitudes and perceptions and their water sources. Table 4.6 deals with current rainwater collection practices.

4.1.1 Description of Villages

Details of the location (figure 1.2), population, infrastructure water supply and estimated rainfall for the study villages are summarized in Table 4.1. The most important facts to note are that whereas none of the villages had electricity, all of them had a primary school. These are generally new , with relatively large corrugated iron roofed buildings. Nata, the largest of the four villages and an important district centre, also has a clinic, police station, road maintenance depot and a Botswana Agricultural Marketing Board warehouse, as well as shops, bars, bottlestores , a garage and other service and government premises. Thini at the other extreme had only a few shops and a chibuku (traditional beer) depot. However, like Nata, Thini's main water source is provided by a river. At Nata the lack of a reticulated village supply is due to the very high salinity of groundwater in the area, owing to its proximity to the Makgadigadi Salt pans. The residents of Nata are thus forced to rely on a dirty river, which flows through the centre of the village as their main water source. Thini, on the other hand , although located in an area of good groundwater supply, simply has not had a reticulated supply installed at the time of this study. The dispersed and scattered nature of this village which covers an area of over 20 km^2, results in long journeys to collect water, the mean distance to the river being 1.3 km,(Table 4.3). It also makes the provision of piped water to within 400 metres of every household a daunting task.

Both settlements (Nata especially), are growing rapidly mainly due to in-migration . The residents of these two villages are generally poorer than the residents of the other two study villages (Borolong and Selolwane) . This is inferred from the lack of corrugated iron roofs in Nata and Thini (Table 4.5) and the low incidence of radio ownership, 22% and 28% of the households owning radios in the two villages , respectively, compared with 64% in both Selolwane and Borolong,(Table 4.2). The high incidence of car and bicycle ownership in Thini, 14% and 76%, respectively, do not reflect general wealth in the village; but rather the reponse of a few wealthy individuals (in the case of the cars) and the majority of poorer ones (in the case of the bicycles) to the remoteness of their homes from stores and water supplies, (table 4.3).

Table 4.1 ...Basic Facts about Study Villages

VILLAGE	NATA	THINI	SELOLWANE	BOROLONG
Location relative to Francistown	190km NE	95km NE	100km NE	22km East
Rainfall (estimate)	550mm	520mm	520mm	480mm
Population 1983	1850	1150	970	1050
SERVICES				
Electricity	none	none	none	none
Medical	Health Centre	none	none	none
Educational	Primary	Primary	Primary	Primary
Water Supply	-River -Bowser -Saline borehole	-Sand river supply only	-Piped borehole supply to standpipe -Sandriver	-Piped borehole supply to standpipes -Sandriver

Table 4.2 ...Indices of Health, Wealth and Education

VILLAGE	NATA n=50	THINI n=50	SELOLWANE n=50	BOROLONG n=50	MEAN n=200
Cattle per household	21	17	14	10	16
Range	350	130	200	50	
% of households with no cattle	50%	22%	22%	46%	35%
Indicies of wealth					
- car	6%	14%	10%	12%	11%
-bicycle	0%	76%	76%	38%	57%
-radio	22%	28%	64%	64%	45%
-donkey cart	2%	4%	4%	22%	8%
as % ownership					
Education schooling years of the most educated adult	4.1y (3.8)	2.6y (3.2)	4.7y (3.6)	4.1y (3.3)	3.9y
Mean household size	6.5 (2.6)	7.5 (3.0)	7.1 (4.2)	6.9 (2.7)	7.0
Children born per woman	4	6	5	7	5.5
Children lost	0.5	1.1	1	0.5	0.8
% of households with latrines	18%	6%	12%	12%	12%

Standard Deviation shown in brackets

Table 4.2 provides other general information relating to indicies of health, wealth and education. The data presented includes infant birth and death rates , the incidence of latrine ownership and information regarding the number of years of schooling received by the most educated adult in each household.

The reason for the relative wealth of the households in Borolong is probably due to its close proximity to Francistown 22 km away. Apart from employment opportunities, Francistown also offers goods at somewhat lower prices than in rural areas. This is probably the main factor accounting for the high incidence of iron roofs in Borolong (see table 4.5) . Selolwane and Borolong both have several shops and chibuku depots, but Borolong also has a road maintenance depot and a church which doubles as a nursery school during the week.

Although, Borolong and Selolwane both have reticulated water supplies, Borolong has only one of it's four standpipes operating with regularity, whereas all of Selolwane's standpipes operating continuously. However, as the reticulated supply ended at Selolwane Primary School, a number of households beyond the school are as far as 1200 metres from the nearest standpipe. Most of these households chose to use the more convenient sand-river as their main source of water supply. Thus despite a clean, reliable reticulated supply 20% of the households in Selolwane still chose to use the river as a source. Where the river was the closest source, it was generally chosen in preference to the improved source even if a standpipe is only slightly further away. One primary school teacher in Selolwane who was fully aware of the benefits of using water from an improved supply, still fetched water from the river bed 250 metres from her home rather than walking 650 metre trek to the nearest standpipe. This case demonstrates that an awareness of the benefits of using an improved supply is not necessarily sufficient to encourage people to use improved water sources, if traditional sources are still more convenient. Another problem discouraging the use of improved reticulated borehole supplies is that some villagers mentioned that they preferred the taste of their traditional river water supply as compared with the often somewhat saline groundwater.

4.1.2 Water Usage

The total mean household water usage for the 200 households interviewed in this study was 107 litres per day. This result is close to the figure of 128 litres determined by Copperman (1978) in her study of water usage among 70 households in 4 villages in Eastern Botswana. The lower value for the present study is probably attributable to the severe drought experienced since 1982. Figure 4.1 shows a comparison of the total and specific water usages documented during the present study as well as those from Copperman's study which was conducted during a much wetter period. The biggest difference between the two patterns of water consumption is in the vastly decreased amount of water used for beer brewing. This is directly attributable to the drought as apart from the shortage of water, the sorghum and millet normally used for making traditional beer were in very short supply at the time of the survey. The amount of water used for smearing the lolwapa and huts was also considerably less than that determined during Copperman's study. This follows logically as building and repairs would seem the most obvious activity where conservation of water in times of shortage could be made, besides which, huts are normally repaired in the rainy season. The demand for drinking, cooking and washing water is far more inelastic. This is confirmed by the closer relationship between the quantities of water used for these purposes in the present study and Copperman's study, than that used for other purposes,(figure 4.1).

It is important here to make a clear distinction between the daily household water consumption and the total household water consumption per day. The daily water consumption is the amount of water collected by householders on a daily basis and used for drinking, cooking and washing purposes. The mean value for the four villages was 67 litres, (see table 4.3), which is coincidentally exactly the same amount obtained by Copperman(1978) for daily water collection in her study. However, whereas this figure was derived from direct questioning of householders about the number of buckets collected in the wet and dry season, (see appendix 2), for the present study, Coppermans figure incorporated standpipe observation.

Table 4.3 ...Household Water Usage in the Study Villages

VILLAGE	NATA	THINI	SELOLWANE	BOROLONG	MEAN
n	50	50	50	50	200
Mean distance to nearest improved water source in metres	535 (communal tank)	1776**	421	257 (seldom working)	747
(Standard Deviation)	(295)	(603)	(307)	(170)	
Mean distance to nearest unimproved water source in metres	422	1285	498	433	659
(Standard Deviation)	(248)	(606)	(309)	(198)	
Total household water consumption* in litres per day	125	90	96	115	107
Mean daily household water consumption in litres	84	68	57	59	67
(Standard Deviation)	(41)	(33)	(25)	(26)	
Mean daily consumption per capita (litres)	13	9	8	9	10

*Includes water used for building, watering livestock and gardens and other water not collected on a daily basis

**Nearest improved source are standpipes in neighbouring Selolwane

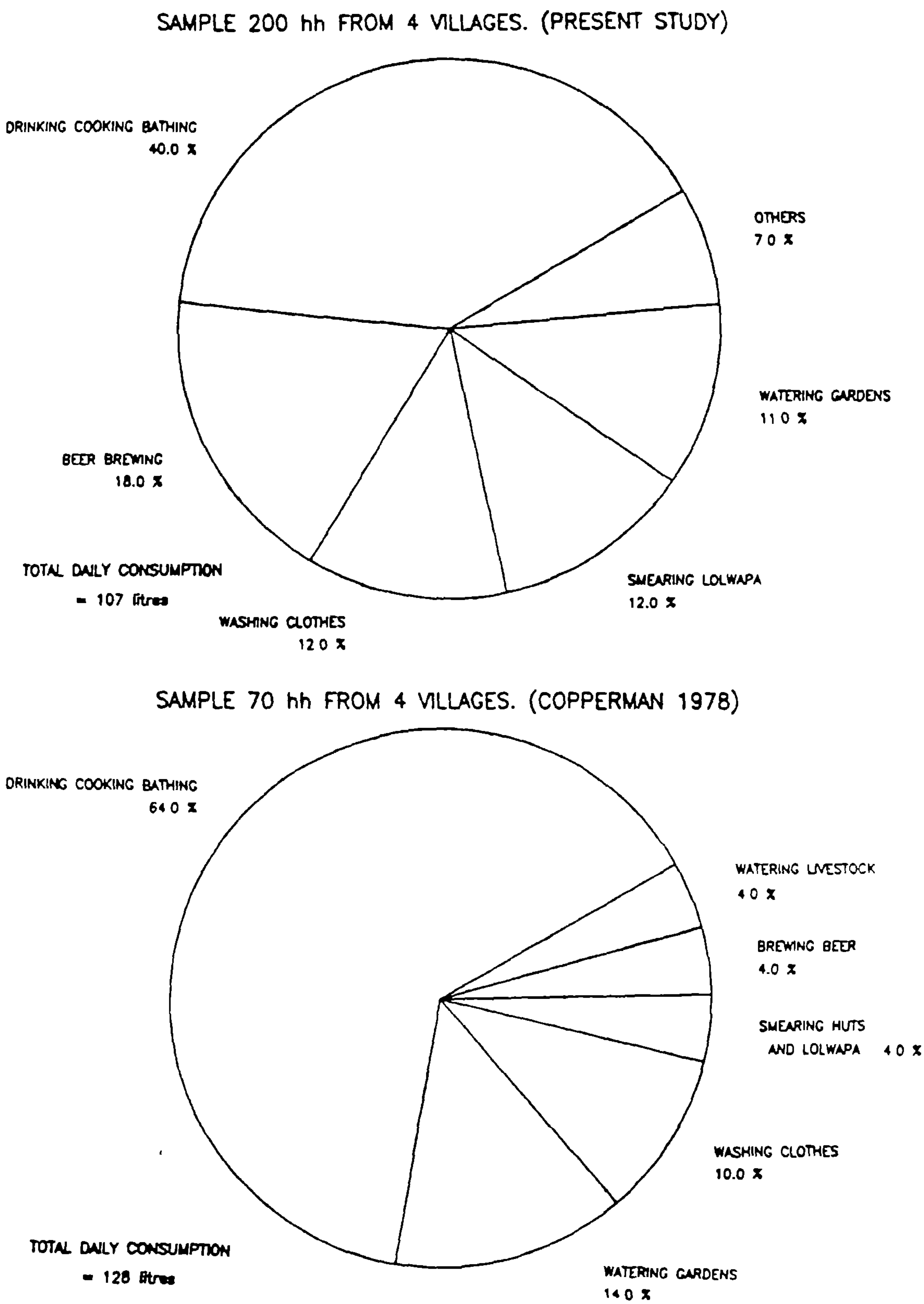

Figure 4.1 ...A Comparison of the Domestic Water Consumption Findings of the Present and a Previous Study

Table 4.3 summarizes much of the basic water data for the four study villages. Some of the results here can be logically explained, others are less clear. For example, the relatively low total household water consumption for Thini is not surprising since people there have to go three times as far to collect water than in the other villages. However, it is less clear why the total consumption and daily consumption of water is also relatively low in Selolwane which has a reliable reticulated supply as well as a sand-river within easy reach of most households, (table 4.3). It is also unclear why both the daily consumption and total consumption of water is highest for Nata. Although, the river there provides a convenient water source the whole year round, it is also one which is highly polluted and generally regarded as such. An analysis of variance was conducted on the mean daily household consumption rates (table 4.3) and no significant difference between the data for the four villages was found. In determining the potential for rainwater to provide a domestic supply it is this figure (67 litres/day/household) which is used. This is because the total water consumption per day (107 litres), includes the use of water for occasional activities such as building and repairing huts and lolwapas, brewing beer, watering gardens and livestock, and washing clothes. Many of these activities do not require a high quality water supply and some can be conducted when water is in plentiful supply in pools or ponds which fill in the rainy season near to the household. For these reasons it was not considered necessary to include this water as part of that which a rainwater catchment systems would necessarily be required to supply in order to satisfy daily domestic requirements. Further, with activities such as washing clothes and watering livestock householders have the option of either carrying water to their homes or taking their livestock or washing to the water source.

4.1.3 The Current Usage Patterns of Rainwater and Other Sources

The current usage of water sources in the study villages is shown in table 4.4.

The main source of water for 63% of the villagers was the nearest sand-river and only 30% of residents used the nearest standpipe as their main source. Dongas (small streams filled

Table 4.4 ...Current Usage of Water Sources in the Four Study Villages

VILLAGE n	NATA 50	THINI 50	SELOLWANE 50	BOROLONG 50	MEAN 200
SAND RIVER	85%	85%	20%	60%	63%
DONGA	-	10%	-	-	2%
STANDPIPE	0%	0%	77%	35%	28%
RAINWATER	5%	1%	1%	5%	3%
TRANSPORTED WATER	8 %	1%	-	-	2%
OPEN POOLS	2%	3 %	-	-	1 %
PIPED TO HOUSE	3%*	-	2%	-	1%

*SALINE not included in total.

in the wet season), open pools and transported water each accounted for less than 3% of the total domestic supply. Less than 1% of the total population of the four villages had water piped to their homes. These mean figures are calculated from the data for each of the villages shown in table 4.4. Obviously there is enormous variation from village to village especially as only two of them Selolwane and Borolong had reticulated supplies.

Although almost half of the households (46%) in the four villages collected rainwater for domestic use, (see table 4.5), it was estimated based on the corrugated iron roof areas of each village and the number and size of catchment tanks used, that rainwater probably accounts for less than 3% of the overall water consumed by the villagers. Observations in other villages including Morwa, Mogonye and Pitsing in the south, (see figure 1.1), confirmed that this figure is probably typical for other parts of Botswana. Table 4.5 indicates the percentage of households in each of the study villages which collected rainwater and the various means used to do this. It can be seen that 64% of the residents of both Nata and Borolong collected rainwater for domestic consumption. The figures for these two villages are explained by the fact that Nata suffers from an acute water shortage due to the saline nature of the groundwater in the area, while in Borolong, only one of the village's four standpipes was operating. The high incidence of metal roofs in Borolong is also a contributing factor.

Despite the popularity of collecting rainwater the total quantity collected is relatively low, this is mainly due to the very inefficient way which most of it was collected. At about three-quarters of the households where rainwater was collected, the only containers used to do this were buckets or small containers. In many cases these were simply placed in the open, sometimes even at households possessing a corrugated iron roof. Most often, however, the containers would be placed under the eaves of metal roofs or in some cases when these were not available, under thatched roofs, see table 4.5. Table 4.5 also shows that only 33% of households had any metal roofs and only about 5% had any kind of gutters. Even in Borolong where 70% of the households had corrugated iron roofs only 8% had any form of guttering installed.

Table 4.5 ...Current Rainwater Catchment Practices in the Study Villages

VILLAGE n	NATA 50	THINI 50	SELOLWANE 50	BOROLONG 50	MEAN 200
% OF HOUSEHOLDS WHICH COLLECT RAINWATER	64	34	22	64	46
Containers used: a) Permanent catchment tank	10	0	2	2	3.5%
b) Temporary catchment tank (e.g oil drum)	6	4	8	12	7.5%
c) Buckets	18	14	8	34	19%
d) Containers put in the open	30	16	4	16	16.5%
% OF HOUSEHOLDS WITH :-					
a) Atleast one metal roof	14	18	30	70	33%
b) Metal roof and gutters	10	0	4	8	5.5%
c) Only thatch for roofing material	86	82	70	30	67%
% collecting rain from thatch roof	14	4	4	0	5.5%
RAINWATER AS A % OF TOTAL VILLAGE WATER SUPPLY	5	<1	<1	5	<3%

Only 11% of the households in the four villages had catchment tanks and only 3.5% had permanent ones and these tended to be on government houses. The other catchment tanks found at 7.5% of the households were temporary in nature and generally consisted of an oil drum, barrel or basin which was put underneath a downpipe or gutter during times of rainfall, (see Table 4.5).

The vast majority of households had exclusively thatched buildings (67%) yet only in Nata was there any significant collection of rainwater from these roofs (14%), see table 4.5. This was probably due to the very desperate water situation in Nata, although even there the runoff collected from the thatch was generally used for domestic purposes other than cooking and drinking.

4.1.4 Attitudes and Perceptions

Attitudes and perceptions are not as easy to monitor or express in a quantitative form as physical or climatic factors. Nevertheless, an attempt will be made here to demonstrate some of the the more predominant feelings towards both rainwater and its use, as well as towards several facets relating to improved water sources. For the residents of Nata, the only improved public water source operating during the study period, was a communal tank at the school, which was usually filled daily from a bowser with a limited freshwater supply of about 5 m^3 per trip. In Thini there was no improved water source, the nearest one being provided by the standpipes in neighbouring Selolwane, 2 km away.

With the exception of Nata where the traditional and main water source was particularly polluted, people did not generally show great concern for the quality of traditional water sources. In Selolwane for example 20% of the villagers preferred to use traditional sources closer to home than walk a little further to draw water from a clean reliable standpipe supply, (Table 4 4). Providing a water source appeared relatively clean, the major factors determining attitudes towards it were convenience (i.e. the distance to it) and its taste. Traditional and rainwater sources were generally preferred over any improved source that was even slightly

saline,(table 4.6).

The popularity of reticulated water supplies seemed to stem mainly from the perceived convenience of the supply associated with them. People were, however , generally unwilling to walk much further to draw water from a standpipe in preference to a closer traditional supply.

Table 4.6 summarizes the results from the questionnaire survey relating to attitudinal information regarding water sources It can be seen that almost all people perceive improved water sources as being clean, most perceive them as being tasty and well maintained, but less than half consider them to be close by. Perceptions of convenience vary greatly from village to village and individual to individual this is clearly seen from table 4.6. For example, where as almost everybody in Nata, where present water sources are saline and contaminated, considered rainwater to be clean and tasty, not everybody in the other study villages felt this. Generally, however, most people perceived rainwater favourably (table 4.6), although, some preferred the taste of river water. When asked about the collection of rainwater from thatched roofs the vast majority of people stated that the runoff from grass roofs was discoloured, dirty and unhealthy, consequently few people used this source, see table 4.5 This is a particularly important finding in the light of suggestions encouraging the use of thatched roofs for rainwater catchment by Hall(1982) and for Botswana specifically by Fortmann and Roe(1981). Clearly any attempt to try to implement rainwater catchment systems using grass roof catchments are unlikely to succeed in Botswana.

When asked about metal roofs most of those not living in compounds with exclusively thatched huts expressed a desire to own a hut with a corrugated iron roof. Lack of money was the most common reason given as to why a metal roof had not been installed. Although many of those households lacking metal roofs recognized the potential for using them for rainwater collection not everybody with metal roofs realized their full potential as a water source.

This is well illustrated by referring specifically to actual instances encountered. One old man living in a thatched household in Borolong, complained that his neighbour, who had a corrugated iron roof did not allow him to collect water from it At the other extreme was a

Table 4.6 ...Attitudes and Perceptions about Water Sources

VILLAGE n	NATA* 50	THINI** 50	SELOLWANE 50	BOROLONG 50	MEAN 200
% OF HOUSEHOLDS WHO FEEL THAT:-					
1) The improved supply is:					
a) Clean	88%	90%	88%	98%	91%
b) Tasty	78%	54%	64%	96%	73%
c) Maintained properly	62%	86%	72%	70%	73%
d) Closeby	54%	8%	46%	70%	45%
2) Rainwater is:					
a) Clean	98%	90%	74%	68%	83%
b) Tasty	94%	64%	66%	74%	75%

* For Nata the improved supply refers to the bowser transported water.

** Refers to standpipes in neighbouring Selolwane

village councillor in Mathangwane, where the pilot study was conducted, who owned a tractor, several hundred cattle and a large farm. He lived in a compound which included two large metal roofed buildings. Yet, despite the fact that the nearest standpipe was almost 2 km away, he only collected very small amounts of rainwater from one of his roofs in an oil drum, even though he already had well constructed gutters in place. The councillor normally drove to the standpipe in one of his three vehicles and filled 6-8 oil drums every one to two weeks. When the idea of catchment tanks was put to him, however, he did express considerable interest. It must be realized that this second example is an extreme case, as the majority of people live in compounds consisting of only thatched huts and even those who do have small iron roofs could probably not afford a catchment tank without making what they would perceive as a major sacrifice such as selling cattle.

4.1.5 Actual and Perceived Costs

The collection of information relating to the perceived cost of corrugated iron roofs and catchment tanks met with only limited success as most people said they had no idea of the cost. For those who did attempt to estimate the price, most tended to under-estimate it, yet claimed that even this was very expensive The actual cost of an average sized corrugated iron roof, 46 m^2 would total almost P 200 (US$ 150), and gutters , brackets and drainpipes might cost P 50 (US$ 37.50) more. The most appropriate storage volume for a roof of this size would be a tank of around 8 m^3. No corrugated iron tanks of this volume are commercially produced, but the cost of a 9 m^3 tank would be around P360 (US$ 270), see table 4.7. Thus the cost to a householder to build a roof catchment system is in excess of P600 (US$ 450). When it is considered that the per capita G.N.P in Botswana is around P800 (US$ 600), (NDP 1980), and in rural areas the average is far below this, it is not surprising that it is only a few rich people who install sizable catchment tanks in rural areas Table 4.7 shows a comparison of the costs of various types of catchment tanks available in Botswana.

Table 4.7 ...Actual Costs of Rainwater Catchment Tanks in Botswana (1983 Prices)

TANK TYPE	VOLUME (M^3)	COST IN PULA* (1983)	COST IN PULA* PER M^3
OIL DRUM	0.2	30 - 60	150 - 300
CORRUGATED IRON	2.25	137 - 160	61 - 71
	4.5	200 - 209	45 - 47
	9.0	342 - 384	38 - 43
FERROCEMENT	20.0	850 - 1250	42.5- 62.5
SUB-SURFACE FERROCEMENT	20.0	400 - 600	20 - 30

*In 1983 1Pula was worth approximately 0.75 US dollars.

Sources of information : Gantron Suppliers Ltd, Gaborone
Haskin's Ltd, Francistown
Botswana Technology Centre, P/Bag 0082, Gaborone.
Ministry of Agriculture, P/Bag 003, Gaborone.

Most people who collect and store roof runoff for domestic water supply have to manage with one or more 200 litre oil drums, see table 4.5. Although, these are insufficient to store more than 2 or 3 days supply they do provide a useful supplementary water supply in the wet season. The cost and quality of oil drums varies considerably. New purpose built galvanized drums sell for up to P60 (US$ 45) and these will last up to 20 years, see table 4.7. Although second hand oil drums can be purchased for as little as P5 (US$ 3.75) these normally rust through within a couple of years. Many people were unsure of the price of an oil drum but the majority had a reasonable idea. Those who could afford it preferred to invest in galvanized drums and in a few cases in large plastic barrels

4.2 RESULTS OF THE PRIMARY SCHOOL SURVEY

The survey which was restricted to primary schools consisted of a postal questionnaire distributed to 200 of more than 400 primary schools in Botswana,(Appendix 5). In addition to the 64 responses received 6 schools were visited and detailed surveys carried out at each. Table 4.8 summarizes the findings of the postal and site surveys. Although these results indicate that only 22 of the schools did not have water piped to their site (table 4.8), a number of schools with piped water complained of frequent breakdowns or of water too saline to drink. In fact less than half of the schools had clean, relatively reliable, convenient improved supplies.

Among the 28 schools which already had catchment tanks (table 4.8), the average number per school was 4 each having a mean capacity of 4.5 m^3 Most of these were corrugated galvanized iron tanks. A number of teachers and headmasters commented on their relatively short life expectancy generally less than 10 years, and often less than 5 years. This probably accounts for the fact that almost half of the existing catchment tanks, 52 out of a total of 121, were reported as leaking. The average usable corrugated iron roof area was $901m^2$ per school indicating that even among those schools which had installed catchment tanks the mean total storage capacity of 18 m^3 was totally inadequate when compared with the potential useful runoff. A storage capacity of $100\text{-}200m^3$ would have been far more realistic at an average sized

Table 4.8 ...Summary of Primary School Survey

NUMBER OF SCHOOLS SURVEYED	64	(100%)
NUMBER OF SCHOOLS USING PIPED WATER (Generally a standpipe supply)	42	(44%)
NUMBER OF SCHOOLS USING LOCAL BOREHOLE	11	(17%)
NUMBER OF SCHOOLS USING RIVER BED PITS OR POOLS	8	(12%)
NUMBER OF SCHOOLS USING WATER TRANSPORTED BY BOWSER	3	(3%)
NUMBER OF SCHOOLS WITH CORRUGATED IRON ROOFS	64	(100%)
NUMBER OF SCHOOLS WITH ROOF CATCHMENT TANKS	28	(44%)
- Total Number of Tanks 121		
- Tanks Reported as Leaking 52		
MEAN SCHOOL ENROLLMENT	403	(Standard Dev. 203)
MEAN ROOF AREA (m^2)	901	(Range 126-2260)
MEAN ANNUAL RAINFALL FOR ALL THE SCHOOLS SURVEYED (mm)	469	(Standard Dev. 79)

Mean Annual Runoff for a Typical School in Botswana

= ROOF AREA x RAINFALL x RUNOFF COEFFICIENT

$$= 901m^2 \times 0.469m \times 0.8 = 338m^3$$

school as a means of supplying as much of the approximately $338m^3$ (table 4.8) of useful runoff it would be economically feasible to collect, at least at those schools suffering from acute water shortages. Although, a supply of only 3-4 litres per day per capita would be possible at most schools, this would suffice as a drinking and cooking water supply.

At schools with a piped supply the installation of a few storage tanks might be considered as a means of providing a reserve supply during periods of breakdown. This would prevent the return to traditional sources with all the associated health risks. Where groundwater supplies are saline, rainwater could provide a sweet fresh drinking water supply. The very desperate water situation at a number of schools is emphasized by quotes from the headteachers of the following primary schools.

Maunatlala

"We do not have enough water in this school, the bore hole is 8 km away... we sometimes stay without water for the whole week."

Kedia

"Water is very scarce, water from pits too salty, tractor doesn't give us enough water from Mopipi village 24 km away."

Mmashoro

"The school encountered the problems of not having rainwater catchment tanks because during the rainy season water is wasted ...... Sometimes the children spend the whole day without drinking due to the shortage of water especially when the engine is not in good order"

Letsholathebe

"The school urgently needs more catchment tanks because of the great distance to the river."

The following plates 4.1 and 4.2, show two of the schools which were visited as part of the

primary school survey. The first school, at Borolong is typical of many schools in rural Botswana. Despite having no water supply and a number of large corrugated iron roofs no rainwater tanks are present. The second school, at Morwa in southern Botswana (see figure 1.1), shows a school which is self sufficient in terms of water supply and immune to the problems resulting from the frequent breakdowns of the local borehole. The reason for this is the existence of almost 80 m^3 of roof tank capacity at the school. When the school was originally built in 1967 one 40 m^3 tank provided the schools only supply. Although this tank is still functioning perfectly the presence of a standpipe close to the school means that the rainwater tank is mainly used as a reserve supply. Rainwater is, however, used at all times for drinking due to the slightly saline tasting nature of the ground water supply The school also has a 100 m^3 ground catchment tank built in the 1960's which is still successfully being used for irrigating a small garden.

4.3 RESULTS OF WATER QUALITY ANALYSIS

The quality of water from both traditional and improved water sources are of direct relevance to the present study. Although, a wealth of data exists on the quality of a wide variety of water sources in Botswana , relatively little information has been collected regarding the quality of rainwater supplies. In a study conducted by Stenstrom and de Jong (1983), a comprehensive summary is given of the quality of potable water from a wide variety of sources. In total 450 bacteriological and 250 chemical water analyses were carried out most of them on borehole, standpipe and traditional water sources. The results indicated that around 50% of borehole and standpipe supplies did not satisfy WHO guidelines in terms of bacteriological quality, (see table 4.9). Even when the more lax but realistic guidelines used by Botswana's Department of Water Affairs, (Brynolf 1983), are applied, almost 20% of the supplies had water of an unacceptable quality for human consumption. The quality of improved supplies was, however, significantly better even in some of the worst cases than that of all the traditional sources sampled in the study. Stenstrom and de Jong(1983) found the median value

Plate 4.1 ...Un-utilized Roof Catchment Potential at Borolong Primary School in Northern Botswana

Plate 4.2 ...Roof Catchment Tanks at Morwa Primary School in Southern Botswana

for faecal coliforms per 100 ml for traditional sources to be 610 for 16 river and dam samples and 1190 for 14 well and waterhole samples, respectively.

In terms of chemical quality the water sources in Botswana leave less cause for concern. Although WHO guidelines for nitrate and fluoride levels are exceeded in around 20% of the groundwater supplies sampled,only in relatively few instances were the concentrations at a serious level. The most common reason for groundwater being below standard in Botswana is salinity. Aarsse(1981), examined the records of 1867 boreholes for which chemical data was available and found that 482 or 26% had total dissolved solids in concentrations greater than 1500 mg/l the WHO recommended upper limit for human consumption. Saline groundwater is a particular problem in the north and southwest of the country and also around the Makgadigadi Salt pans In the village of Nata on the edge of the pans(figure 1.1) borehole water has total dissolved solids of 22,000 p.p m making it unsuitable for virtually every purpose. This is an extreme example, more commonly the levels of salinity are much lower. However, values are often high enough to make the water taste salty and this often discourages people from drinking it. In these localities rainwater provides an attractive alternative source for drinking water.

4.3.1 Bacteriological Analysis of Roof Tank Water Quality

Table 4.9 shows the results of bacteriological analysis conducted on water samples from 8 roof tanks during the present study and 5 conducted for the Stenstrom and de Jong(1983) study. The results of both studies are in close agreement with each other, and in only one case was there some cause for concern about the quality of the water . In this case both the Total and Faecal Streptococci counts, exceeded WHO guidelines although, the coliform counts did not exceed Botswana's own recommended guidelines. This tank, however, was not covered and this probably is related to the presence of coliforms which are normally indicative of contamination from human origin Although, faecal streptococci are present in numbers exceeding WHO guidelines in 8 cases. The appropriateness of such guidelines to rural Botswana is questionable

Table 4.9 ...Results of Bacteriological Analysis Conducted on Roof Catchment Tanks in Botswana

LOCATION OF TANK	TOTAL* COLIFORM	FAECAL* COLIFORM	FAECAL* STREPTO-COCCI	DETAILS OF TANK
TUTUME	0	0	0	Covered corrugated iron tank
NATA	0	0	0	" "
FRANCISTOWN	0	0	0	" "
FRANCISTOWN	0	0	0	" "
TLOKWENG	0	0	46	" "
MORWA	0	0	84	Partially covered brick tank
MORWA	0	0	158	" "
MORWA	0	0	164	Covered brick cement tank
NOT KNOWN**	0	0	44	Covered
NOT KNOWN**	0	0	75	Covered
NOT KNOWN**	0	0	90	Covered
NOT KNOWN**	1	0	1	Covered
NOT KNOWN**	29	6	62	Not covered

	MAXIMUM PERMISSIBLE CONCENTRATION		
WHO RECOMMENDATION	<10	<1	<1
BOTSWANA GUILDLINES	<100	<10	<10

*Per 100 ml calculated from analysis 5 ml and 50 ml samples.

**Source of information: Stenstrom and de Jong (1983).

Table 4.10 ...A Comparison of Water Quality from Household Containers and Borehole Sources

SITE	TOTAL COLIFORMS	FAECAL COLIFORMS	F.STREPTOCOCCI
OODI			
Borehole	0	0	0
Household	2120	700	900
PITSANE			
Standpipe	8	0	0
Household	2500	460	68
OTSE			
Standpipe	16	0	0
Household	2000	2000	720

Source: Water Hygiene Campaign Botswana. Final Draft Report
Enge, M. (1983)

In any case the faecal streptococci are probably indicative of slight contamination from birds, lower animals and plant debris.This does not pose a serious threat to human health. Koplan et al.(1978) did, however, postulate that roof water heavily contaminated by bird droppings may have been the cause for the outbreaks of a rare form of salmonella in northern Trinidad. Stenstrom and de Jong(1983), nevertheless, concluded that their results indicate that if "correctly constructed rainwater catchment tanks could be a realistic and hygienic drinking water alternative ",(p12). From the investigations conducted in the present study it was found that water from covered corrugated iron roof tanks was of particularly good quality, even in cases where the tanks and gutters contained organic debris.

Although the provision of clean water sources is extremely important, one should not assume that this alone is sufficient to guarantee an improvement in the health of the community. The relationship between the provision of clean water and health is a complicated one. Table 4.10 illustrates one of the major problems, even if the water supply is clean at source, contamination during collection and storage is very common. If true benefits are to be achieved through improvements in water supply it is clear that hygiene education programs should be run concurrently with the construction of any new water supply system. This applies equally to reticulated borehole supplies as to rainwater tanks.

4.4 SUMMARY

A questionnaire and technical field survey were conducted at 50 households in each of the four study villages, Nata, Thini, Selolwane and Borolong. The results revealed that:

1. - the village populations were between 970 and 1850 (mean 1255) and the mean household size was 7.0
2. - few people owned cars (11%) or latrines (12%) and although cattle outnumbered people in every village by up to 3 to 1, many households (35%) owned none.
3. - the mean distance to the nearest water source varied from 255m in Selolwane to 1285m in Thini, and was around 700m overall.

4 - the mean daily domestic water consumption varied from 57 litres to 84 litres and averaged 67 litres (10 litres per capita) for all four villages.

5. - only in Selolwane did more than half the households (77%) use piped water as their main source, while sand rivers provided the major source of domestic supply for 63% of the households surveyed.

6. - only in Borolong did more than half the households (70%) have at least one corrugated iron roof. Of all of the households sampled only 33% have at least one corrugated iron roof while the remaining 67% have exclusively thatched roofs.

7. -mean annual precipitation varied from 480mm in Borolong to 550mm in Nata.

8 - although 46% of the households collected rainwater most people simply placed containers in the open. Only 11% of the households have any form of temporary or permanent catchment tanks (a 200 litre oil drum being the most common type).

9. - rainwater was perceived by the majority of villagers to be clean (83%) and tasty (75%). The cost of installing large commercially available galvanized catchment tanks, however, priced at P137 - P384 (US$103 - 288) for $2.25m^3$ to $9m^3$ tanks, was considered even by of those who already own corrugated iron roofs to be beyond their means.

10. - although about 5% of householders collected rain from thatched roofs the vast majority of people perceived this source of water as dirty and unsuitable for consumption.

A postal questionnaire sent to 200 primary schools resulted in 64 reponses These revealed that while all the schools had corrugated iron roofs (mean area $901m^2$), only 28 (44%) had roof catchment tanks (average total capacity $18m^3$ per school). The mean annual rainfall at the schools was 469mm (Standard Deviation - 79mm) , thus an average runoff of $338m^3$ ($0\ 469m \times 901m^2 \times 0.8$) could be expected at a typical school. Although 42 (66%) of the schools in the sample had piped water, this did not always provide a fresh or reliable supply.

Bacteriological analysis conducted on rainwater taken from 13 different roof tanks indicated that water from covered storage tanks is of good quality and generally acceptable for human consumption.

5. ROOF CATCHMENT SYSTEMS : TECHNICAL CONSIDERATIONS

The results in chapter 4 indicated that although, rainwater was perceived favourably by most people, and was collected in varying amounts by almost half of the households surveyed , the full potential for roof catchment supplies is far from being realized. In chapter 6 calculations are presented to show what the current potential roof catchment supply might be. In order to conduct these calculations the level of supply from any given catchment area, rainfall regime and storage capacity needs to be determined.

The purpose of this chapter is to show how the storage requirements and associated supply can be determined for any roof catchment system in Botswana. This will be done by demonstrating the applications of a computer model for assisting in roof catchment systems design The production of maps which can be used as design tools for estimating roof catchment storage requirements and associated supplies are also demonstrated [8] A number of methods for rainwater tank construction are also included in the final section.

5.1 DESIGN

The main purpose of the design phase is to establish the most appropriate storage capacity for any given rainwater catchment system. In order to do this information relating to rainfall supply and consumption rates (demand) is required. If the demand cannot be satisfied then the design should aim at maximizing the supply while minimizing the storage capacity and thus providing the maximum supply for the minimum cost.

5.1.1 Supply

The determination of the mean annual runoff from a given catchment area is not difficult to estimate. Nevertheless it does require a reasonably good record of the rainfall for the locality over a number of years and an accurate approximation of the catchments runoff

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[8]It should be noted that although the design methods are demonstrated for roof catchment systems in this chapter the techniques can just as easily be applied to ground catchment systems

coefficient [9]. If these are available the values can simply be multiplied together to give the runoff as follows:

RUNOFF = Runoff Coefficient x Precipitation x Catchment Area (R = K x P x A)

This basic calculation could be subject to considerable error if the amount of precipitation or the runoff coefficient is wrongly estimated. The most serious danger in terms of rainwater catchment systems design is an over-estimation of the total runoff. For this reason care was taken in this study to to under-estimate rather than over-estimate any unknown values (for example a runoff coefficient of 0.8 was used when in many instances it may have been closer to 0.9). Although the catchment area could be determined very accurately, the runoff coefficient and rainfall totals were less precisely known Interpolation using mean rainfall values was necessary between the network of 35 government meteorological stations providing regular rain gauge recordings. Where a locality was very distant from the nearest stations a somewhat lower than likely rainfall estimate would be used for runoff determinations to avoid the danger of over-estimating the possible mean rainwater supply.

Although the runoff coefficient is sometimes difficult to estimate for ground catchment aprons it is easier to generalize about them for corrugated iron roof catchments. This is particularly useful as far as Botswana is concerned because corrugated iron is almost the only material used for improved roofing in rural areas. An empirical investigation by Ree(1976) in Oklahoma found that on average 92.5% of rainfall ran off a sloping roof, 96% on the windward side and 89% on the leeward side. These findings suggest that roof runoff could be slightly increased if buildings were constructed with single slope roofs facing towards the direction of the prevailing wind. This would be easy to determine in some parts of Botswana since people in windier localities traditionally build the entrance to their hut facing away from the prevailing

[9]The Runoff Coefficient represents the fraction of rainwater which when falling on a surface, is not absorbed but flows over it and can thus be collected. For example a roof with a runoff coefficient of 0.8 will allow 80% of the rainfall to flow off the roof through the gutters and into a storage tank

wind.

Although it might not seem unrealistic to expect a runoff coefficient of 0.9 from well constructed rainwater catchment systems in Botswana, leaking roofs and gutters, and under-designed gutters and downpipes (subject to overflow during occasional high intensity rainfall events, see chapter 1, section 1.4.2), make a value of 0.8 a more realistic estimate. This is the figure used for all the calculations of roof runoff in this thesis and it is in close agreement with an estimate of 0.7-0.9 for corrugated sheets by Hofkes(1981) and values for corrugated iron roofs suggested by Keller(1982) and Latham(1983).

The following diagrams of roof catchment systems (Figure 5.1 and Figure 5.2) serve to demonstrate that the catchment area provided by any roof is equivalent to the area of the roof when projected onto a horizontal plane. The second diagram (figure 5.2) , shows that the cost of guttering can be reduced using a single pitch roof. If possible it should be pitched towards the prevailing wind to maximize rainwater runoff.

5.1.2 Demand

The demand for water is difficult to estimate empirically In rural areas where traditional sources are relied upon, seasonal variations in supply often lead to adjustments in consumption. Just as the quantity demanded of a product is subject to variations according to price, so the quantity demanded of water is subject to variation according to the distance to the water source. Studies by Feachem et al. (1978) in Lesotho, and White et al. (1972) in East Africa have demonstrated the rather loose relationship which exists between water consumption and the distance to the water source. Up to a distance of a mile (1.5km) no relation could be found. However, for water sources at more than a mile from the point of consumption, a decline was noted in the amount of water collected.

One of the major questions posed when planning the implementation of rainwater catchment systems and in particular roof catchment systems, is what effect the provision of water at the point of consumption will have on total consumption Very little work has been

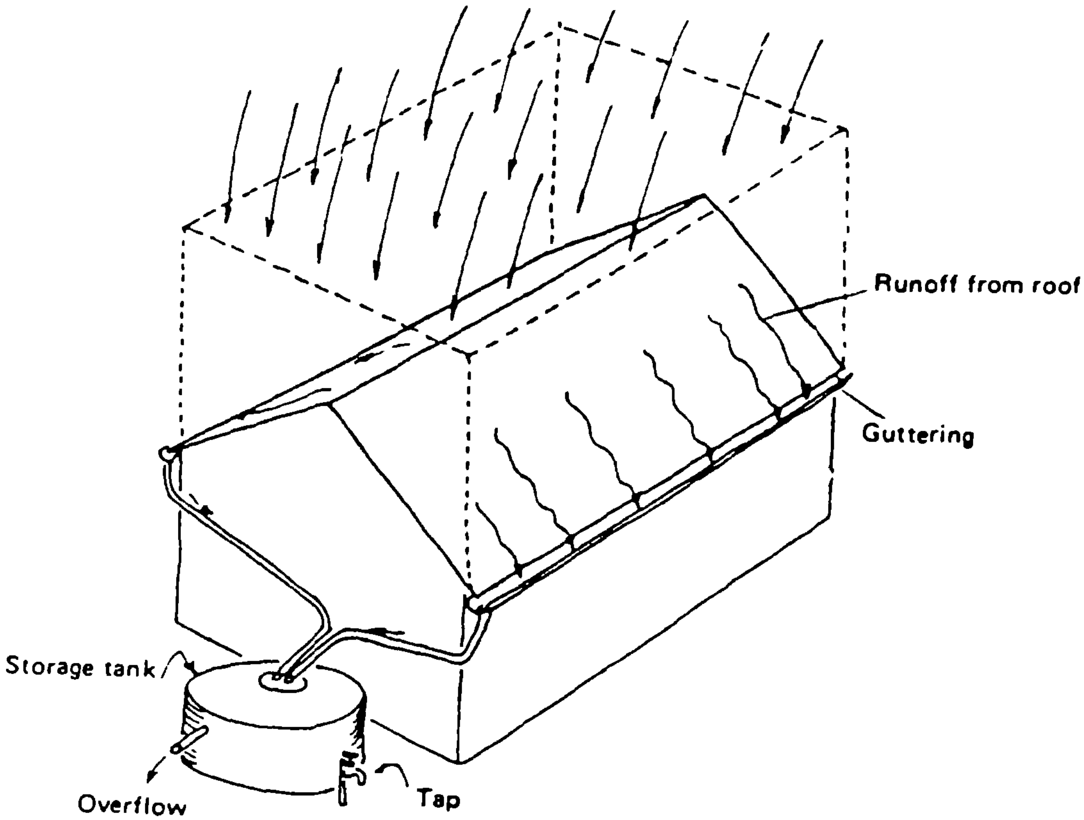

Figure 5.1 ...Simple Roof Catchment System (Adapted from Watt 1978)

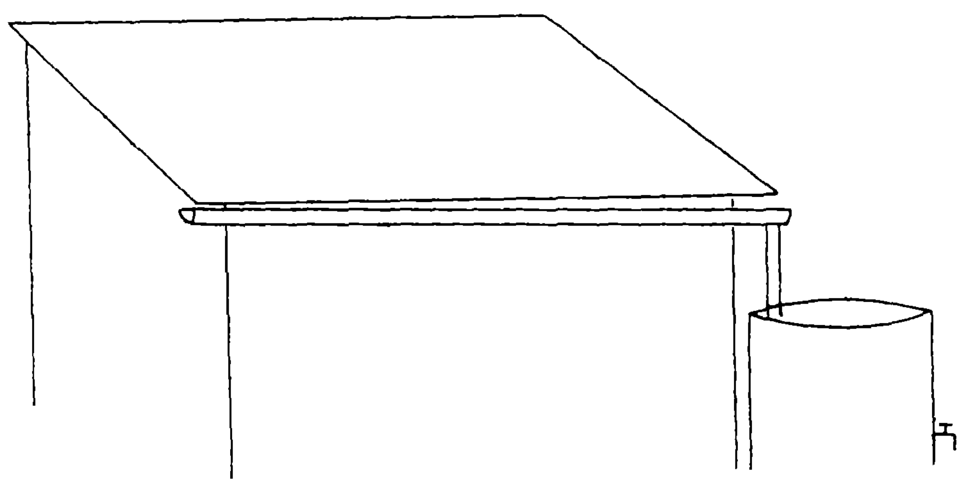

Figure 5.2 ...Single Pitch, Single Gutter Roof Catchment System

done to study the effect of installing catchment tanks on patterns of consumption. White et al.(1972), however, noted that the per capita consumption of urban households with roof catchment tanks was 25% more than that of adjacent households totally reliant on standpipe water 0-400m from their homes.

Assessments of the rural water consumption and the effect of distance on the amount of water collected have been attempted in a number of previous studies in Botswana. The most notable of these was a study by Copperman(1978) on four villages in Eastern Botswana. The results of this indicated that water consumption fell slightly when the distance to the standpipe increased beyond 200m. For people living more than one or two kilometres from the supply, water usage decreased considerably among those without access to drums and some animals or motor powered vehicle for transporting water. For these remote rural dwellers, daily per capita water consumption of less than 4 litres is common. In the villages, however, Copperman found that per capita daily water consumption ranged from from 5-20 litres with the mean at around 10 litres per day. This is in agreement with the mean figure of 10 litres per capita obtained in the survey of the four study villages,(table 4.3).

5.1.3 Storage

The determination of an appropriate storage tank volume is the most critical part of any rainwater catchment system design. In areas where rainfall is heavy and spread evenly throughout the year a relatively small tank may suffice to satisfy demand as it will constantly be refilled. In regions with marked seasonal variations in precipitation, a much larger tank will be required in order to guarantee that a supply can be maintained throughout the dry season. The required storage volume for any system is a function of the rate of inflow, which is a random variable and the rate of consumption which is comparatively fixed.

STORAGE TANK VOLUME = f (Rate of Inflow , Rate of Consumption)

The function of the storage tank is to provide the means of matching a random inflow with a fixed outflow. In order to model this system, information about both the inflow (rainwater runoff) and outflow (rate of consumption) is required. The outflow once determined can be dealt with easily provided the assumption of a fixed consumption rate is used. The inflow is more difficult to determine and requires knowledge of the runoff coefficient and a long period of historical rainfall data from a nearby station.

In regions where rainfall is very high and catchment areas are moderately large, the storage tank volume may be determined by the minimum volume required to satisfy the water requirement. In Botswana, however, rainfall is relatively low, highly seasonal and unpredictable; in addition to this, catchment areas are generally not very large. Consequently, the emphasis in almost every case is on maximizing the supply. In order to maximize tank volume while at the same time minimizing the marginal storage costs, a high efficiency in the unit volume of supply per unit volume of storage is required. If a tank is over-designed scarce resources will be wasted with little benefit to the user, if a tank is under-designed the catchment system will not operate at its full potential and valuable water will overflow and run to waste. If an optimal design size is to be achieved, the rainwater runoff (inflow data) has to be analyzed over a long period of time in order to determine what rate of supply can be achieved at different levels of desired reliability. This hydrologic analysis then has to be combined with economic considerations in order to determine the most appropriate tank size.

5.1.4 Rainwater Tank Sizing

Although numerous methods for determining catchment tank volumes based on the analysis of rainfall data have been proposed, some of which were discussed in chapter 2, only two will be considered here. These are the mass curve analysis technique, originally developed by Rippl(1883), and the Ottawa Model - a computer based approach which has recently been refined by Latham(1983). Although these two methods are strikingly different in their execution, both are based on the same principle of critical period analysis. This involves the

analysis of a long rainfall data series in order to determine the most severe (critical) period of water shortage and hence derive the required storage capacity to over-come this.

Mass curve analysis is a statistical approach which although requiring many repetitive calculations, can be handled using a calculator. Schiller (1982) suggests that this approach may thus be more feasible for developing countries, than methods requiring computer facilities. The approach basically involves plotting the cumulative monthly runoff totals for a given catchment area for a period of, preferably, at least 20 years. If the tangent to the resulting curve is then drawn the greatest vertical distance between the tangent and the curve represents the storage capacity required to overcome the driest period in the data without allowing the tank to run dry, (figure 5.3) In other words, this represents a 100% level of reliability for the total supply of all roof runoff. Due to the very large storage volumes required to provide this high level of supply, it is normally desirable, especially in arid and semi-arid environments where rainfall is generally erratic, to accept a somewhat smaller roof runoff supply in order to reduce the storage capacity requirement. To determine the storage volumes needed to satisfy these smaller levels of supply an array of supply curves should be drawn, see figure 5.3. If the line representing a given supply requirement such as 70% or 90% of the total runoff is drawn tangentially at various points above the cumulative mass curve, the greatest distance between the curve and the tangent will represent the storage requirement to satisfy that level of supply, (figure 5.3). The main disadvantages of the Mass curve analysis approach is that it is slow and laborious if graphs for many stations have to be drawn, and it can only produce results for a 100% supply reliability.

In contrast to mass curve analysis, the Ottawa computer modelling approach not only produces rapid accurate results but offers the user considerable flexibility. Latham (1983), provides both a full explanation of the workings of the model and a comparison with other catchment tank sizing techniques , a summary of this is given in Appendix 2. It is, however, the application of the technique that we are most concerned with here. The data input required for the model consists of monthly rainfall values for at least 20 years and preferably 30 years.

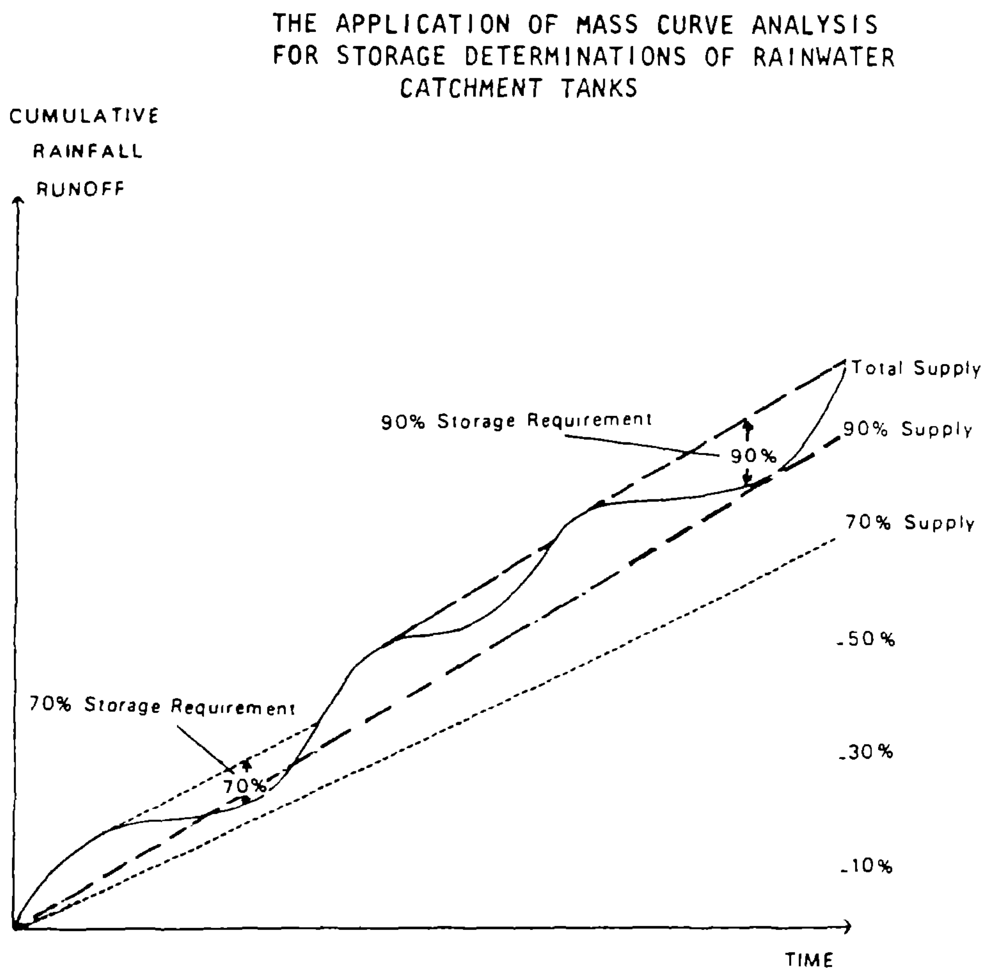

Figure 5.3 ...Mass Curve Analysis : Storage Determination

What the model effectively does is determine various rates of supply which can be satisfied by different storage volumes at various levels of reliability. This is illustrated by figure 5.4, which shows the storage-supply curves for Ghanzi 1923-1983.

Essentially the computer conducts an analysis of past rainfall data and, by identifying "critical periods", calculates the minimum fixed guaranteed supply which can be maintained at any chosen level of reliability for different storage capacities, (see Figure 5.4) In order to use these curves an important first step is to decide what level of reliability is most appropriate for our needs. In most situations where rainwater catchment supplies are used in Botswana or are likely to be used in the future, their primary function will be that of a supplementary supply, (Cullis 1984). For this reason it is not absolutely essential for rainwater catchment systems to be designed to provide supplies with 100% reliability. Even where rainwater catchment systems are used as the only source, for example as a drinking water supply, if reliabilities of below 100% are used, drought periods can be overcome by either stocking the tank with water transported from some external source or by adopting a rationing schedule.

The biggest advantage of designing a system with a reliability level somewhat below 100% is that the same level of supply can be maintained for almost all of the time using a much smaller storage capacity. This point is illustrated in figure 5.4 which shows the storage-supply curves for Ghanzi at 90%, 95%, 99% and 100% reliability levels. It can be seen that using the 100% reliability curve a storage fraction equivalent to 0.4 of the total annual runoff would provide a constant year-round supply equal to 0.39 of the annual runoff. However, using the 95% reliability curve a storage fraction of 0 4 yields a supply equivalent to 0 71 of the total annual runoff, for 95% of the time. This essentially means that if a constant supply fraction of 0.71 were maintained throughout the life of the tank, (in other words, an even withdrawal rate equivalent to 71% of the total useful runoff), then the tank would be dry for a total of 12 months during every 20 year period (5% of the time) This would occur during the severest drought periods and if rationing or stocking were not implemented an alternative source would have to be sought in these months.

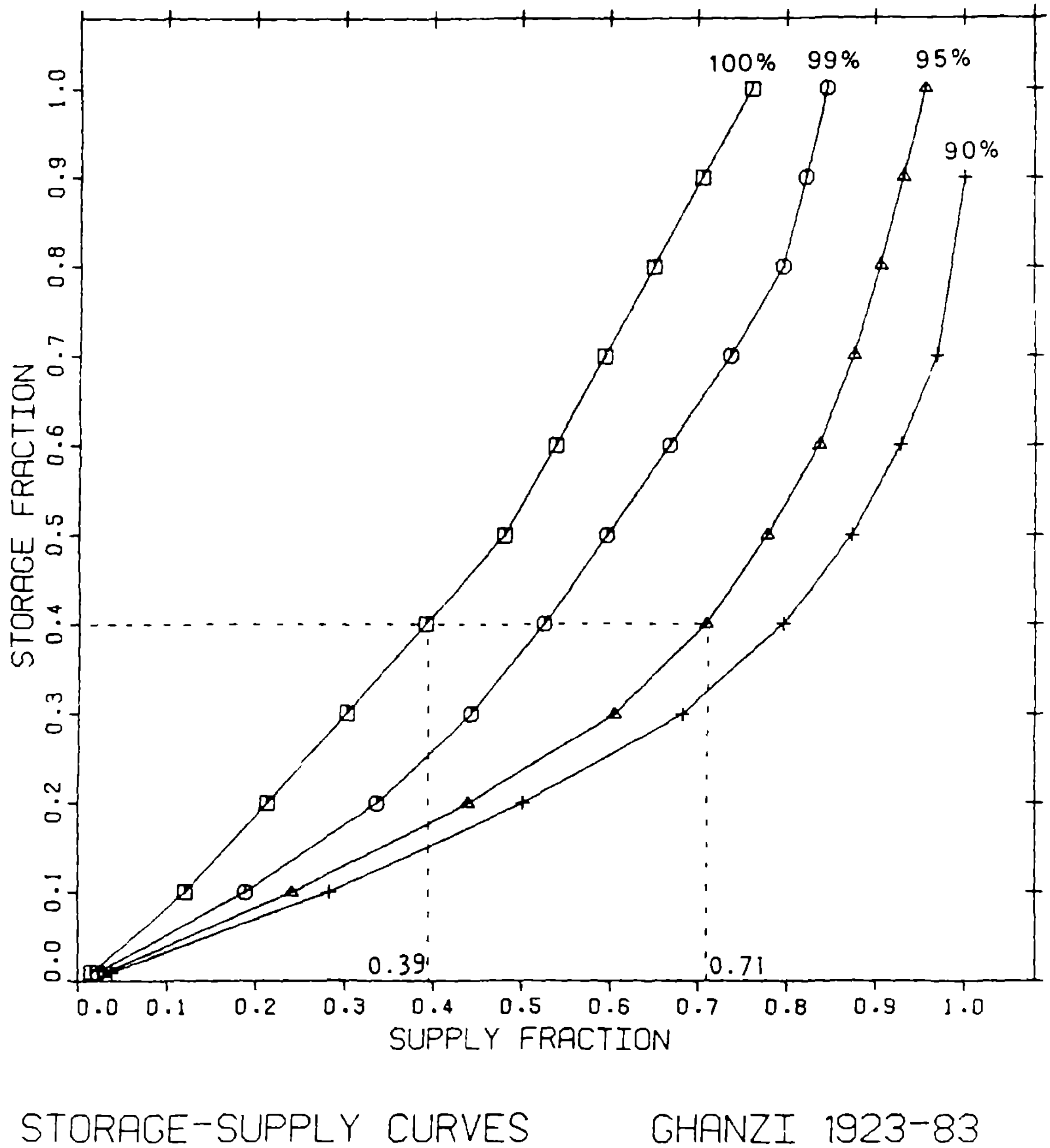

Figure 5.4 ...Storage-Supply Curve for Ghanzi Botswana 1923-83 at 90%, 95%, 99% and 100% levels of Reliability

Despite the disadvantage of the tank occasionally running dry, the cost savings associated with only having to build a tank of about half the volume for a 95% reliability supply, as compared with a 100% reliability supply provide immediate justification on economic grounds for choosing a supply based on the lower reliability level. The 95% reliability level is therefore used for the rainwater catchment system designs discussed in this thesis. It should be stressed, however, that in countries with greater and more regular rainfall than Botswana, much higher levels of reliability may be appropriate.

5.1.5 An Example of Computer Model Application to Tank Design

The application of Ottawa model (Latham 1983) to rainwater catchment tank design problems is best illustrated by an actual example. The primary school in the village of Thini near Tutume and 90km north of Francistown provides an interesting test case. The school, like the rest of the village, has no improved water supply and despite the fact that the school buildings have a total roof area of 862 m^2, no roof catchment tanks have been installed. Currently, the only water source available is a sand river and the children have to make a round trip of more than one kilometer to collect water in tins for drinking and cooking the school dinner

The problem then, is what should the total volume of the roof catchments be, bearing in mind the wish to minimize costs, and hence tank volumes, while at the same time maximizing supply. The solution to this problem is demonstrated using the following steps.

1. Calculate Annual Roof Runoff

   Using rainfall data from Sebina 35km to the south;

   Mean Annual Rainfall (P) = 0.473 m

   Runoff Coefficient (K) = 0 8

   Roof Area (A) = 862 m^2

Annual Roof Runoff = P x K x A = 0.473 x 0.8 x 862 = 326 m^3

2. Determine the Storage and Supply Fractions

Using the Storage-Supply curve which is produced by running the computer model with mean monthly rainfall data for Sebina 1960-1979, an appropriate storage and corresponding supply fraction can be chosen, (Figure 5.5) The graph shows the storage supply curve at the 95% reliability level. A storage fraction of 0.4 is chosen because beyond this value each unit increase in storage is not matched by an equivalent unit increase in supply. In other words it represents a case of diminishing returns. The storage fraction of 0 4 corresponds to a supply fraction of 0.73.

3 Calculation of the Actual Supply and Storage Volume Requirements

The Storage volume required is found by simply multiplying the storage fraction (0 4) by the runoff.

$$0.4 \times 326 \text{ m}^3 = 130 \text{ m}^3$$

The supply which will result with a 95% level of reliability from this storage is equal to the supply fraction multiplied by the runoff.

$$0.73 \times 326 \text{ m}^3 = 238 \text{ m}^3$$

Thus, the installation of catchment tanks with a total volume of 130 m^3 could yield a supply of 238 m^3 per year or over 1190 litres per school day[10]. In practice the preceding calculations

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[10]Assuming 200 school days per year

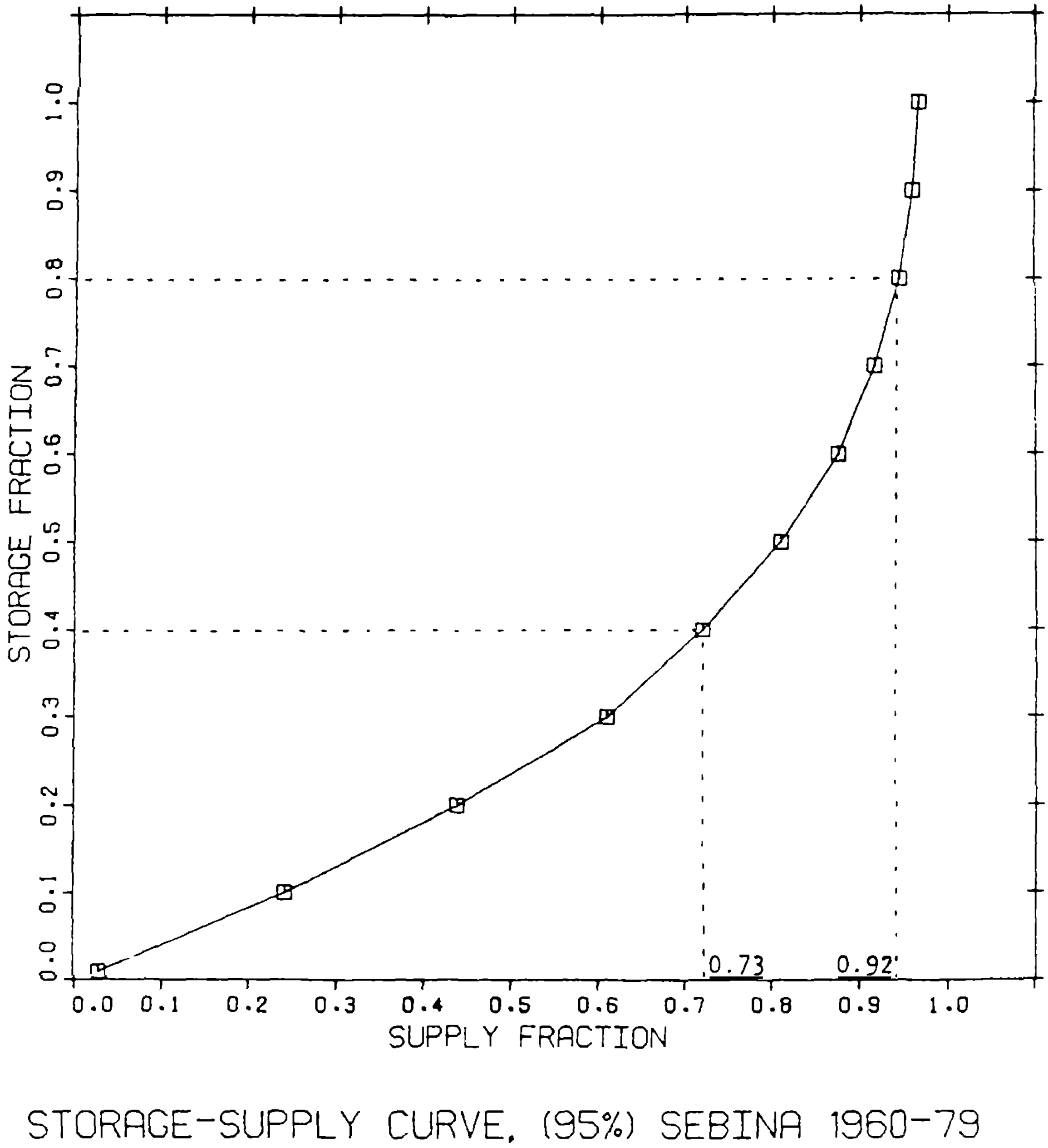

Figure 5.5 ...The Storage-Supply Curve for Sebina, Botswana (1960-79) at the 95% Reliability Level

would have to be conducted for each of the six school buildings so that catchment tanks of an appropriate size could be matched with each.

5.2 APPLICATION OF THE COMPUTER MODEL TO BOTSWANA

Using the Ottawa computer model, rainfall data covering similar 20 year time periods were analysed and storage-supply curves at 95% and 100% reliability levels produced for 10 stations. The ten stations were selected as they had continuous rainfall data for between 17 years (1960-1976) and 71 years (1912-1982). In addition the stations were spread over the whole country enabling a general picture of the overall situation to be established. The 95% reliability curves for four of these are plotted in figure 5.6. These include the curves for Kasane and Tsabong the wettest and driest stations in Botswana, respectively. Tsabong in the southwest is also the station with the highest annual rainfall variability (figure 1.3) , 44% according to Bhalotra(in press). This is much lower than earlier estimates of over 80% by Pike(1971). The uniform pattern of rainfall variability for Botswana was also confirmed by the results of the computer model. This was reflected by the storage-supply curves which were remarkably similar for all the stations tested. Even the curve for Gaborone which has one of the lowest rainfall variabilities in Botswana at 29%, was not The curves for the other six stations all fell within the region between the Tsabong and Gaborone curves, (Figure 5.6).

What is of particular significance in terms of applying the storage-supply curves is the fact that the curves for all the 10 stations analysed steepened sharply once the storage fraction exceeded 0.4. In the case of Gaborone and Tsabong the slope appears to steepen beyond 0.3 according to figure 5.6. What is of most significance here, however, is the value at which the curve exceeds 45°. In the case of all 10 stations examined this occurred between storage values of 0.35 and 0.45, with an average value close to 0.4. What this essentially means is that for storage capacities exceeding a fraction of about 0 4 (40%) of the volume of the average annual runoff, increases in the associated supply diminish rapidly. Figure 5.5 illustrates this point quite clearly, it can be seen from the graph that a storage fraction of 0 4 will yield a supply

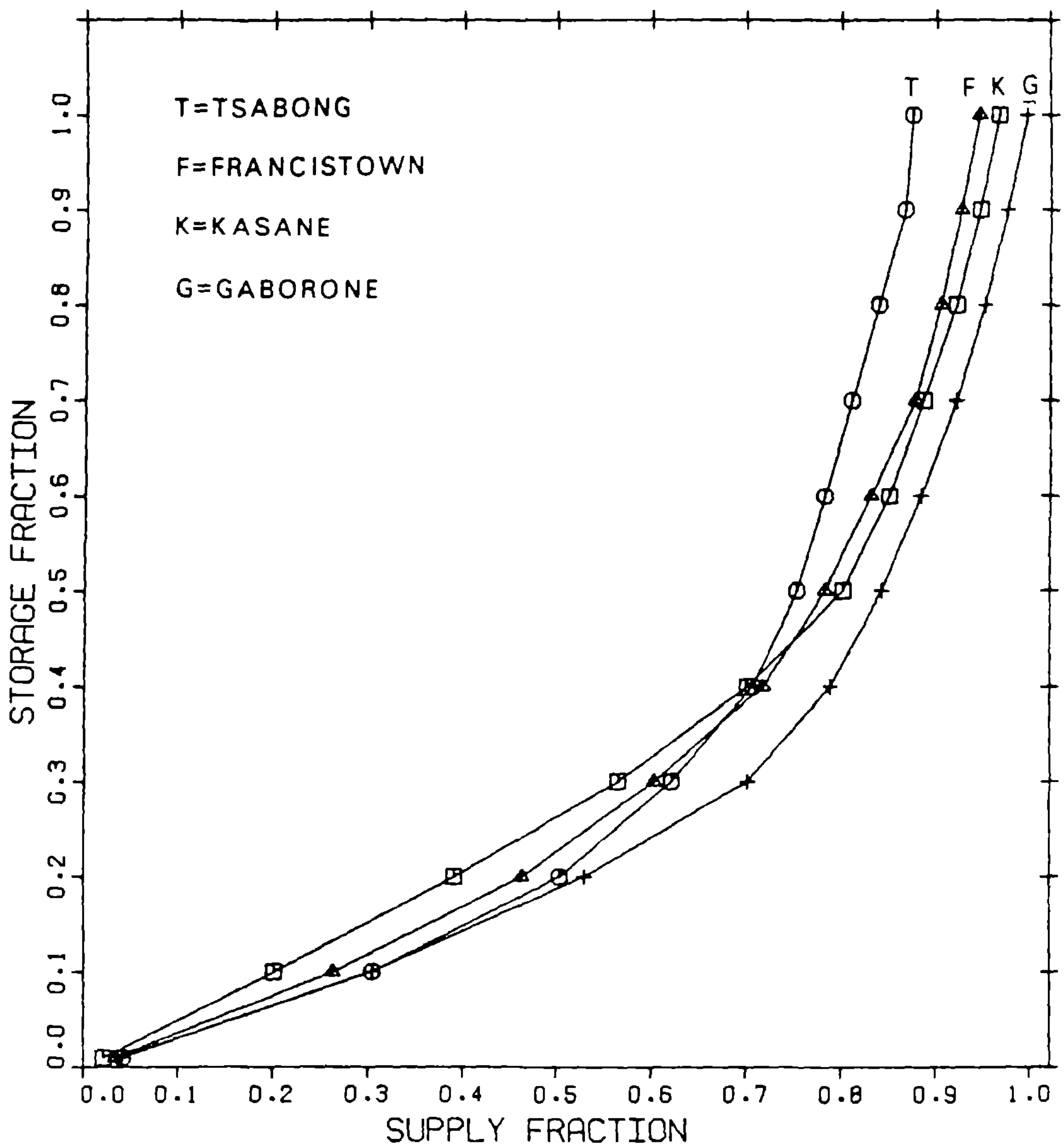

Figure 5 6 ..Storage-Supply Curves (95% reliability) For 4 Stations in Botswana

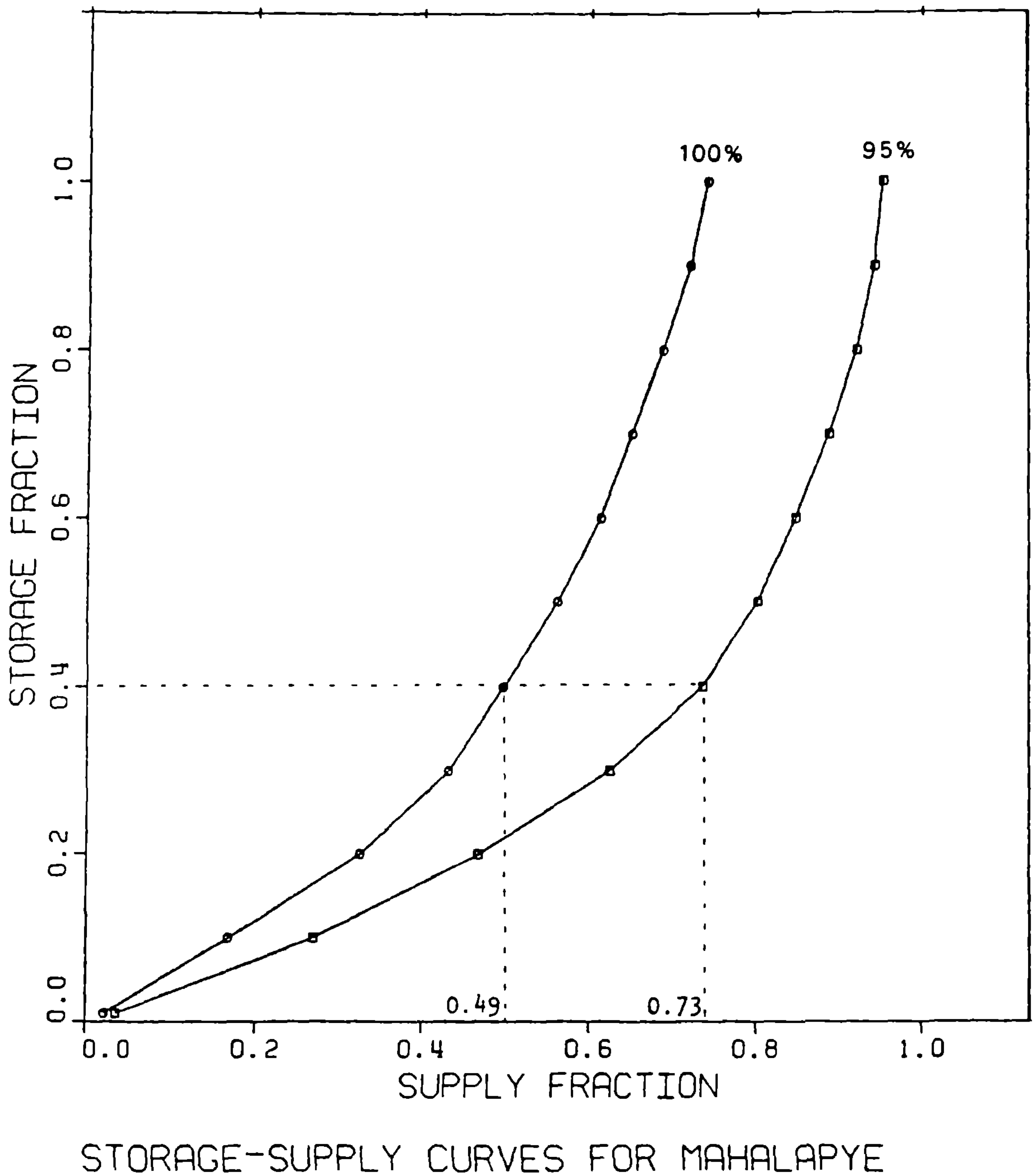

Figure 5.7 ...Storage-Supply Curves (95% and 100% reliability) for Mahalapye Botswana

fraction of 0.73 or more, while a storage fraction of 0.8 will only yield a supply fraction of 0.92. Thus a doubling of the storage capacity will only increase the rainwater supply by 19%. Due to this situation of diminishing returns for larger storage capacities, a storage fraction of 0.4 thus appears to be an appropriate estimate for determining the best (largest and most cost effective) storage volumes for all the stations tested in Botswana.

The relative uniformity of rainfall variability throughout Botswana and the resultant similarity between the Storage-Supply curves for all the stations examined suggest that a reasonable estimate of the most appropriate storage volume and its associated rainwater supply can be obtained using a single generalized curve for the whole country, (compare 95% curves in figures 5.4, 5.5, 5.6 and 5.7). Since a storage fraction of approximately 0.4 appears to represent the most efficient determinant of catchment tank capacities through-out Botswana, the actual storage volume required at any particular locality will depend on the mean annual rainfall, the area of the catchment and its runoff coefficient. For roof catchment systems a runoff coefficient of 0.8 can be assumed (as discussed in 4.1.1) and the tank volume can thus be determined as follows:

$$\text{Tank Volume} = \text{Storage Fraction} \times \text{Runoff Coefficient} \times \text{Rainfall} \times \text{Catchment Area}$$

$$\text{Tank Volume} = 0.4 \times \text{Runoff Coefficient} \times \text{Rainfall} \times \text{Catchment Area}$$

$$\text{Tank Volume} = 0.4 \times 0.8 \times \text{Rainfall} \times \text{Catchment Area}$$

$$\text{Tank Volume} = 0.32 \times \text{Rainfall} \times \text{Catchment Area}$$

This can then be generalized for any roof catchment area :-

Tank Volume (litres) per m^2 of Roof Area = 0.32 x Rainfall(mm)

5.2.1 Mapping Rainwater Storage Requirements and Associated Supplies

Using the above approach it is possible to relate required catchment tank storage volumes to the rainfall pattern throughout the country. The map in figure 5.8, shows this relationship [11]. This approach can be used to determine the most appropriate roof catchment tank volume in litres for a roof anywhere in Botswana. This is done simply by finding the relevant value from figure 5.8 for the locality and multiplying this by the roof catchment area in square metres. This is best illustrated through an example. At Mahalapye, where mean annual rainfall is 462mm (Table 5.1) this depth per m^2 of catchment is:

$$0.462\text{m} \times 0.32 = 0.148\text{m}$$

This value can be found along with those for nine other localities in table 5.1 and figure 5.8. In order to calculate the most efficient and cost effective storage capacity for a $50m^2$ catchment area straight forward multiplication is all that is required

$$0.148\text{m} \times 50\text{m}^2 = 7.4\text{m}^3 \text{ (7400 litres)}$$

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[11]Due to the lack of stations accurate interpolation between known values is difficult, to compensate for this the mean annual rainfall map (figure 1.2) was used as a general guide to the overall pattern for the isolines drawn on following the maps. This was possible due to the high correlation between mean annual rainfall and storage and supply capacities at all of the stations.

Table 5.1 ...Storage Requirement and Minimum Supply in Litres per square metre of Catchment Area at 95% and 100% Reliability Levels (assuming constant demand) for 10 Stations in Botswana

LOCATION	RAINFALL (mm)	STORAGE	RELIABILITY 100%	95%
GABORONE	554	177	281	354
TSABONG	296	95	86	169
KASANE	643	206	261	360
GWETA	483[a]	154	179	255
FRANCISTOWN	471	150	171	263
GHANZI	409	131	128	180
PALAPYE	382[b]	121	165	218
SEBINA	474[c]	152	213	278
MAHALAPYE	462	148	180	270
MAUN	495	158	204	283

*Mean Annual Rainfall calculated from Dept. of Meteorological Services Data from 1954-1983.

a) 1960-1976, b) 1959-1982, c) 1959-1979

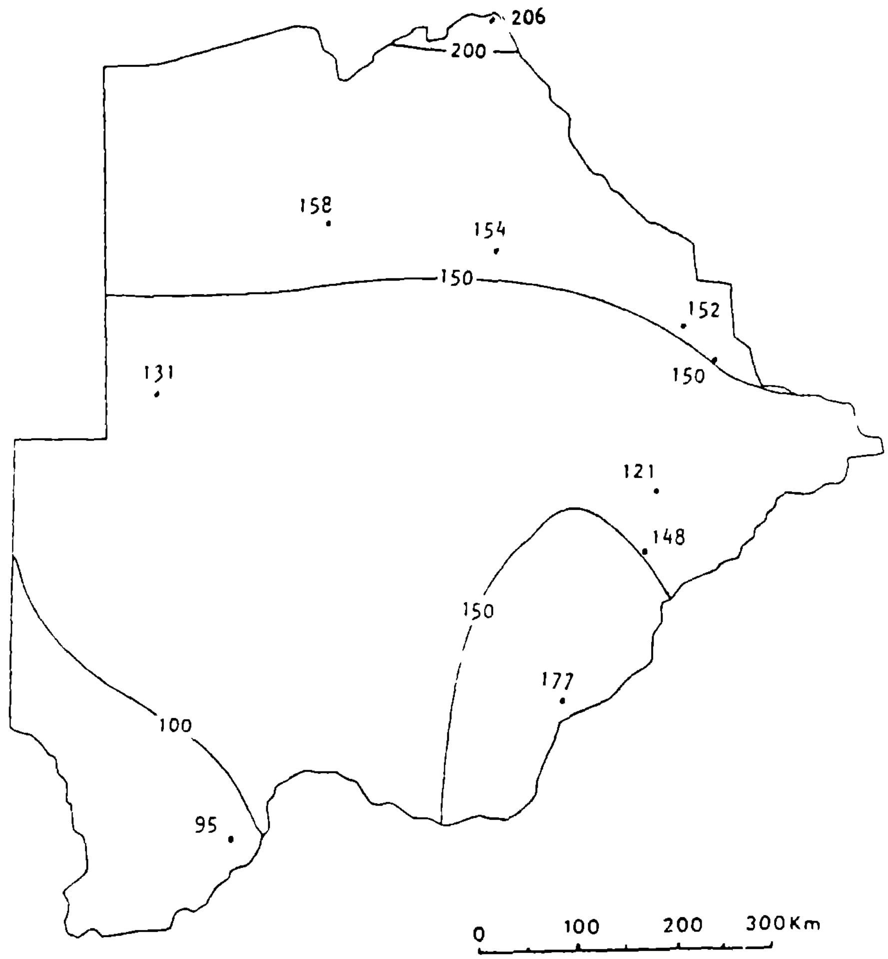

Figure 5.8 ...Map Showing the most Appropriate Rainwater Catchment Tank Volumes given as the Depth of Rainwater(mm) per Unit of Roof Area for Botswana. (The values correspond to the number of litres of storage required per square metre of roof area.)

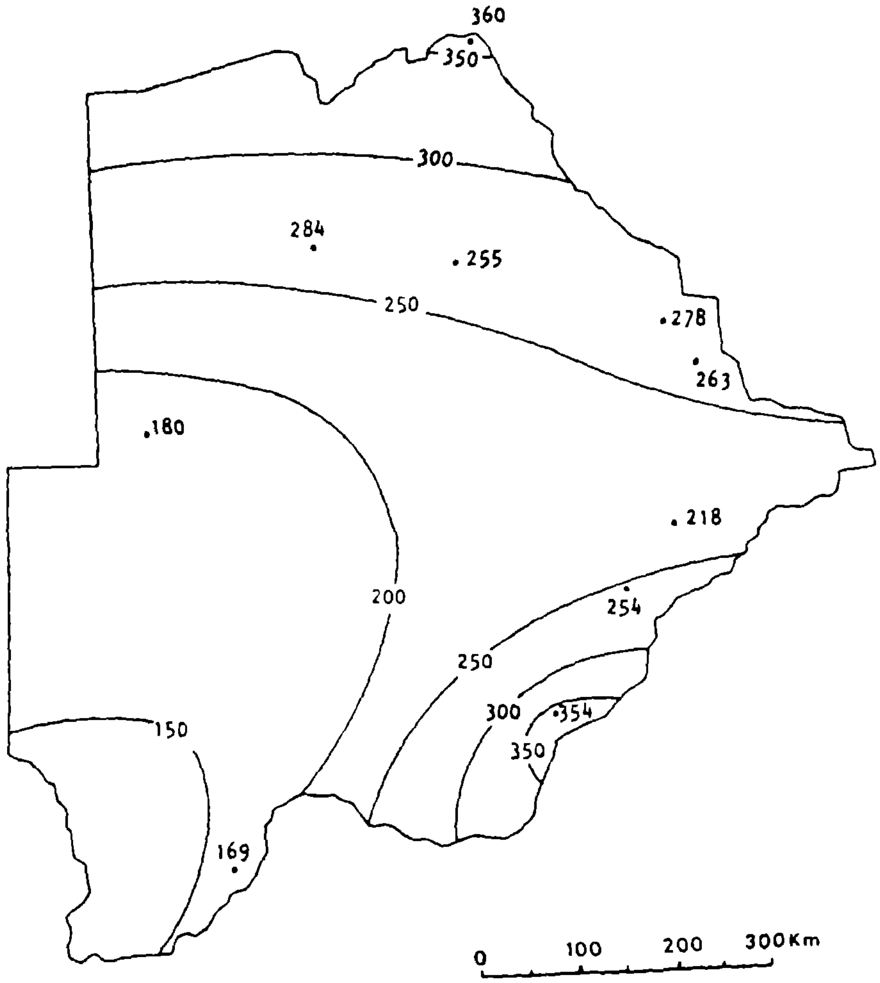

Figure 5.10 ...Map Showing the Minimum Annual Rainwater Supply for Botswana in Litres per m² of Roof Area (or depth in mm per unit area) with 95% Reliability Assuming Constant Demand

To calculate the supply which such a storage volume could yield it is necessary to use the storage supply curves for Mahalapye ,(see figure 5.7) It can be seen from this graph that a storage fraction of 0.4 will yield a supply fraction of 0.49 with a 100% level of reliability or 0.73 with a 95% level of reliability. Thus the respective supplies are calculated as follows:

$$0.49/0.4 \times 7.4m^3 = 9.0m^3$$ ...for 100% reliability supply

$$0.73/0.4 \times 7.4m^3 = 13.5m^3$$ ...for 95% reliability supply

The results of these calculations are shown for Mahalapye and four other stations in table 5.2. It can be seen that in general for stations with higher rainfalls larger storage capacities are required and significantly greater levels of supply are possible. It will be noticed, that Kasane, despite having a significantly higher mean annual rainfall and larger storage than Gaborone has predicted levels of supply which are comparable. In fact in the case of the 100% reliability supply for Kasane it is even smaller than that for Gaborone. This is explained by comparing the rainfall regimes of the two stations. The dry season is more marked in Kasane than in Gaborone When monthly rainfall records from 1922-1983 were compared for the two stations it was found that where as Kasane had experienced periods of total drought (zero precipitation) for 6 months or more, in 11 different years, Gaborone had never experienced a total drought of more than 4 months. Figures 5.9 and 5.10 show the minimum levels of supply which could be expected per m^2 of catchment area for the given storage capacities (figure 5.8), at 100% and 95% levels of reliability, respectively, for all 10 stations (see table 5.1). Thus, in order to calculate the supply for a $50m^2$ roof in Mahalapye, for example the values from the maps are simply multiplied by the area.

Thus for a 100% reliability supply :-

$$0.180m \times 50m^2 = 9.0m^3$$

Table 5.2 ...The Most Efficient and Appropriate Tank Volumes for 50m² Roof Catchments and Associated Minimum Levels of Supply at 95% and 100% Reliability Levels for Five Stations in Botswana

LOCATION	MEAN ANNUAL RAINFALL* (mm)	TANK VOLUME (m^3)	SUPPLY RELIABILITY OF (100%)	SUPPLY RELIABILITY (95%)
KASANE	643	10.3	13.1	18.0
GABORONE	554	8.8	14.1	17.7
FRANCISTOWN	471	7.5	8.6	13.2
MAHALAPYE	462	7.4	9.0	13.5
TSABONG	296	4.8	4.3	8.5

N.B. All figures rounded off to 1 decimal place

*Mean Annual Rainfall Calculated from Dept. of Meteorological Services Data from 1954-1983.

For the 95% reliability supply :-

$$0.270m \times 50m^2 = 13.5m^3$$

These two maps thus provide a simple yet powerful tool for the rainwater catchment systems design in Botswana. Using them it is possible to estimate the most efficient storage capacity for maximizing the supply while minimizing the storage requirement for any catchment area in the country

5.3 CONSTRUCTION

A number of the possible construction methods maybe used for building the storage tanks required for any rainwater catchment systems. One of these cited by Watt(1978) is a ferrocement design which has already been successfully implemented and tested in Matabeleland,(a region adjacent to the study area) in Zimbabwe where more than 200 tanks have been built , (Henson 1972, Gould 1983d). The biggest advantage of using this method in Botswana is that the technique has already been introduced and is currently being promoted by the Botswana Technology Centre, although to date only about 20 tanks have been constructed The method involves the use of a corrugated iron formwork, which is bolted together, wrapped with chicken wire and plastered both inside and outside with mortar. The three main stages of construction are shown in figure 2.2. The main disadvantage of this design is that its volume is fixed by the size of the moulds available and it cannot be built to any specifications. This makes it hard to match a particular roof catchment area with the most appropriately sized tank. [12]

A number of alternative tank designs also deserve consideration. The cheapest of these is an excavated ferrocement tank of the type built in the Arable Lands Development Programme ground catchment tank project, (Whiteside 1982). This tank can be built to

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[12]A detailed description is given by Watt(1978), chapter 7.

virtually any specifications up to at least 60m^3. A 20m^3 tank of this design would cost around P500 (US$375) less than half the price of a surface ferrocement tank. However, some means of extracting water would be needed and if a handpump were not used the quality of the water could suffer seriously. The problem of contamination of the stored water supply or of needing a handpump could be overcome if a design based along the lines the of one suggested by Farrar and Pacey(1974) were adopted. This design illustrated in figure 5.11 , consists of a partially excavated concrete block tank. This could be constructed to virtually any required volume and water could be drawn off by gravity flow The cost relative to a ferrocement tank is not known, but this could be considerably reduced if the excavation were done through self-help efforts and if the blocks were made locally. Among other possible tank designs which might be suitable for household catchment tanks are the four Kenyan designs mentioned in chapter 2

The advantage of these designs is that the tanks can be constructed to virtually any specifications, although 10 m^3 may be the limit for ferrocement jars. The concrete ring design is probably the cheapest and most robust of the three designs but it does require the use of aggregate. In many parts of Botswana particularly towards the north and west the surficial geology is predominantly sandy. For this reason ferrocement designs might be more appropriate in these areas as it does not require much aggregate for construction.

The proper installation of gutters and a simple filter, sedimentation chamber or first flush device is important in the construction procedure. An example of a simple low cost sedimentation chamber and filter is shown in figure 5.12. A simple yet effective way to improve the quality of rainwater entering the tank is to place some wire mesh at the top of the downpipe. The top of the downpipe can be elevated slightly above the top of the gutter as illustrated in figure 5.13 to prevent runoff from light showers, which only manage to wash the dirt off the roof, from entering the tank,(Omwenga 1984). A detailed summary of a number of devices for disposing of the initial foul flush from roof catchment systems is given by Michaelides and Young(1984). Covering the tanks is also essential to prevent both evaporation and contamination. Any trees with over-hanging branches above the roof catchment surface

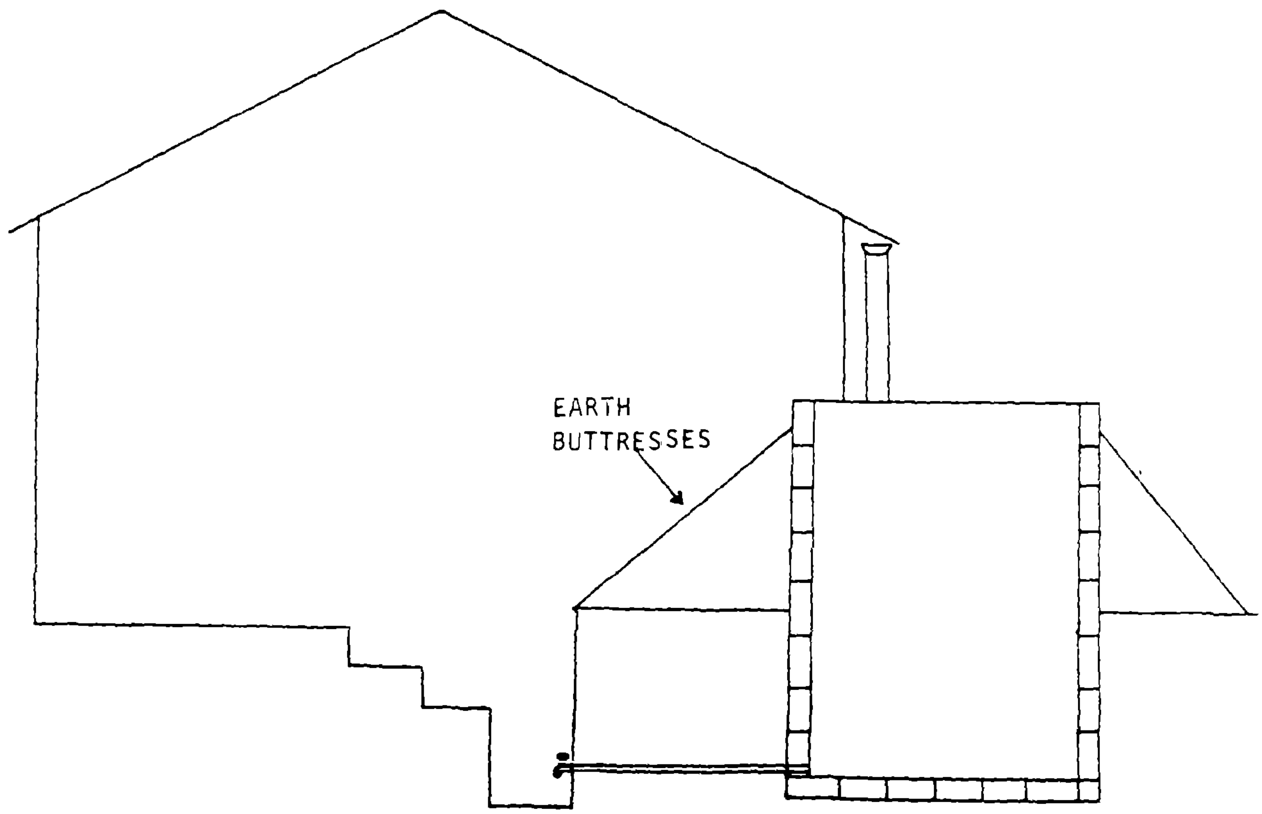

Figure 5.11 ...Partially Excavated Concrete Block Tank

need to be cut down or pruned back as leaves from such trees clog gutters and birds frequenting the the branches contaminate the roof surface.

5.4 SUMMARY

The design and construction of roof catchment tanks are the two most important technical considerations which have to be dealt with before roof catchment systems can be implemented. In Botswana, the design of a rainwater storage tank generally involves an attempt to both maximize the rainwater supply while at the same time minimizing costs. Using a computer the laborious calculations required in the analysis of rainfall data, which are needed for accurate tank sizing can be done extremely rapidly The Ottawa computer model used in this study also allows considerable flexibility whereby different levels of reliability can be attached to rainwater supplies. Storage-Supply curves for 95% reliability of supply were produced for ten stations in Botswana. These revealed that on average, a storage capacity equivalent to about 0 4 (40%) of the total useful runoff, provides a reasonable estimate of the most appropriate tank size for providing the greatest amount of water at the least cost. This will generally supply at least 0.7 (70%) of the total useful runoff in all but the driest years. Maps showing estimates of optimum storage volumes and associated supplies provide a useful tool for the rainwater tank designer in Botswana.

At the present time the only roof catchment tanks being installed in Botswana, other than the imported galvanized tanks, are ferrocement tanks built according to Watt's design. Other tank designs and construction methods which deserve consideration in Botswana are the five Kenyan designs discussed in Chapter 2 and the partially excavated block tank shown in figure 5.11

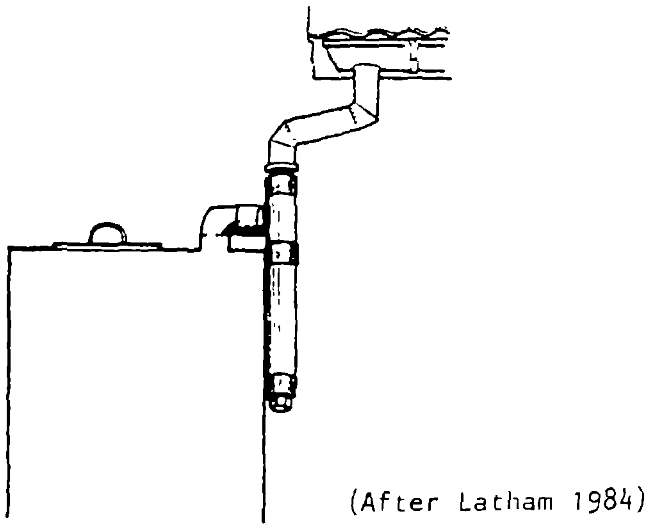

Figure 5.12 ...Simple Low Cost Sedimentation Chamber/First Flush Device

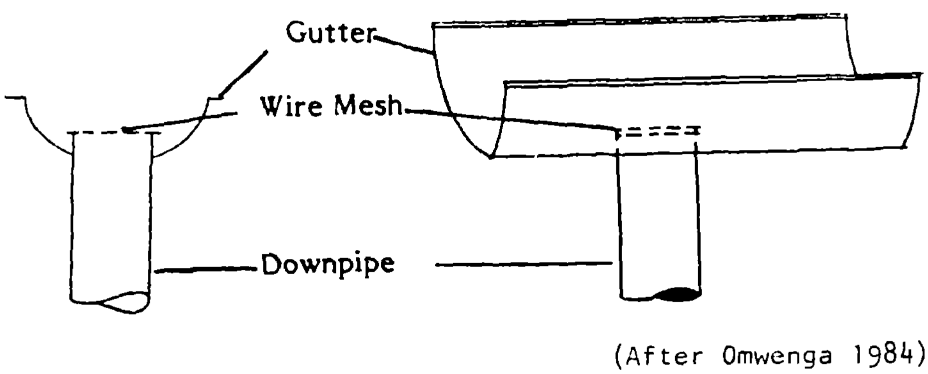

Figure 5.13 ...Downpipe and Gutter Configuration for Reducing Dirty Water Entering the Tank

6. ROOF CATCHMENT SYSTEMS : DISCUSSION

In this chapter the results from the surveys presented in chapter 4 and the findings from the last chapter will be tied together and their implications with respect to rural water supply in Botswana discussed.

6.1 FEASIBILITY

The fact that roof catchment systems are already widely in use throughout Botswana implies that in certain circumstances at least, they do represent a feasible form of supply. The operation and maintenance of roof tanks by private individuals indicates that they already satisfy the "felt needs" of their owners and provide an appropriate water supply solution for at least a small group of Batswana. However, those currently owning large roof tanks tend to be among the wealthy minority who are living in corrugated iron roofed households For the majority who lived in households with no metal roofs (67% for the four villages surveyed) only 5.5% collected roof runoff , see table 4.5, and at only one household (in Nata) did the occupants claim to drink it. This was due to the fact that most people perceived the runoff from thatched roofs as being dirty and not suitable for consumption, (an attitude shared by villagers in Lesotho, Feachem et al. 1978).

Although, household roof catchment systems may not be a feasible alternative for the majority of rural households, a significant and ever increasing proportion of households (33% according to the survey) do possess at least one metal roof [13]. It is therefore worth determining what contribution rainwater could make to the total water supply of both individual metal roofed households and entire villages.

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[13]Examination of aerial photographs from 1978 and 1981 revealed a significant increase in the number of metal roofs in every village.

6.2 POTENTIAL RAINWATER SUPPLY FOR METAL ROOFED HOUSEHOLDS

A useful starting point in determining the potential supply which could be yielded from an individual metal roofed household is to calculate the mean supply from such households for the study villages. Table 6.1 indicates that the average corrugated iron roof area among households with at least one metal roofed building was 46m² and that this could supply (with 95% reliability) over 13m³ of water per year equivalent to 54% of the annual domestic consumption of 25m³. It is thus easy to calculate that in order to provide a total supply a roof area of 85m² would be required, (46m² x 100/54). Since the mean household size in the study villages was 7.0, (Table 4.3), a per capita roof area of just over 12m² would be required to provide a total domestic roof catchment supply. Only a very small number of the households in the study villages had sufficient roof area to provide a total supply Thus even for metal roofed households, the vast majority are only able to provide a supplementary supply. Among the few households observed which did have roof areas sufficient to provide a total supply, none of them had the required storage capacities to provide such a supply. A few households were, however, totally dependent on rainwater for drinking and cooking purposes, particularly in Nata due to the lack of acceptable alternative sources.

In order to make easy determinations of the extent to which rainwater could be used to supplement domestic water consumption, it is useful to construct a map showing the minimum corrugated iron roof area required to provide a total supply at any locality in Botswana. Figure 6.1 shows such a map based on the storage supply curves for the 10 stations discussed in chapter 5. This map was constructed by determining the supply per m² for each station on the basis of maximizing the supply while at the same time minimizing costs. The area required per capita to satisfy a daily consumption rate of 10 litres (figure 4.3) was then calculated. A reliability of supply of 95% is assumed . It can be seen that the per capita roof area requirement varies from less than 10m² in Kasane to more than 20m² in Tsabong. Thus in Kasane an average household of 7 persons would require a minimum roof area of about 70m² to provide a total domestic rainwater supply, whereas in Tsabong a roof area exceeding 140m² would be

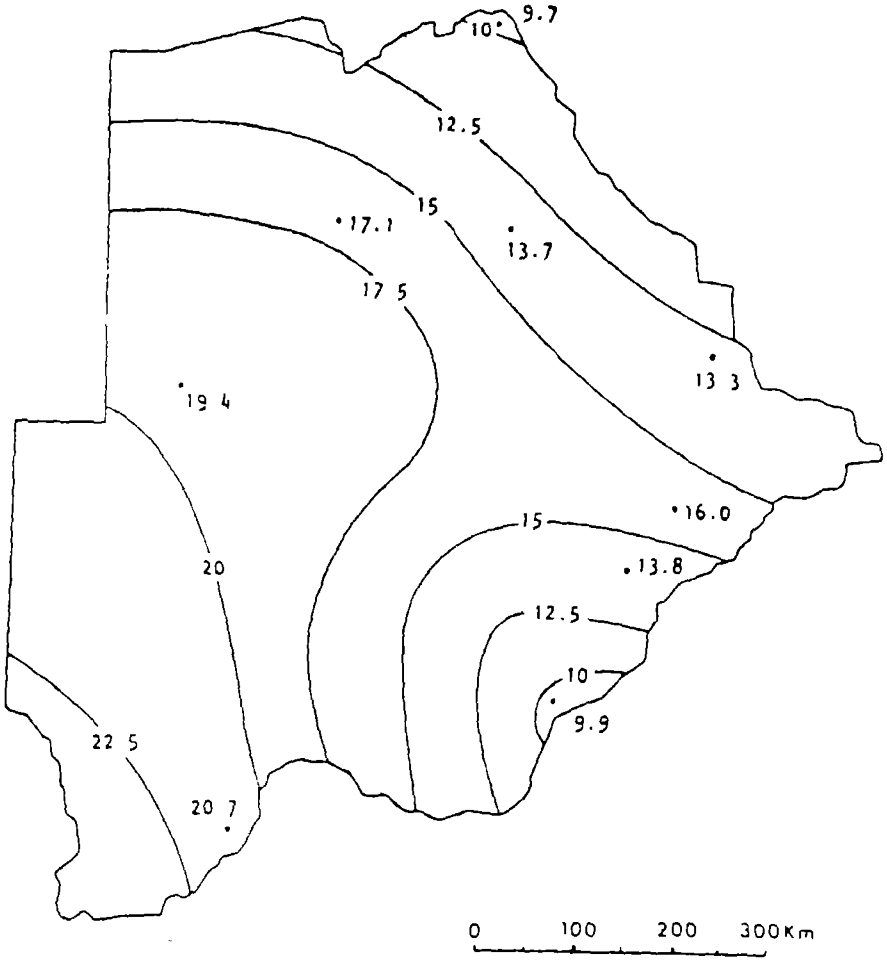

Figure 6.1 ...Map Showing the Minimum per Capita Roof Area Required in m² to Provide a Total Domestic Rainwater Supply in Botswana

required.

In order to calculate the extent to which a particular metal roofed household at any locality could supplement its domestic water requirements, simply divide the actual corrugated iron roof area per capita by the per capita roof area required for a total supply at that location, shown in figure 6.1, and multiply by 100%. This will give the percentage of the supply which could be provided by rainwater.

Example. A family of 5 living in a $40m^2$ metal roofed household in Mahalapye where $16m^2$ of roof catchment area per capita is required for a total supply, (Figure 6.1).

$$\text{Actual Available Roof Area per Capita} = 40m^2/5 = 8m^2$$

$$8m^2/16m^2 \times 100\% = 0.5 \times 100\% = 50\%$$

Thus a supplementary rainwater supply of 50% could be obtained by such a household through the installation of a properly designed roof catchment system.

Clearly if a figure of more than 100% is obtained a total supply is possible. In this instance the storage requirement should be calculated on the basis of the required supply, using the storage-supply curves for the nearest station, see chapter 5

6.3 POTENTIAL RAINWATER SUPPLY FOR THE STUDY VILLAGES

The present low level of roof rainwater supply is clearly not due to lack of interest in the use of rainwater which is currently being collected by almost half of the population, (table 4.5). It seems to stem more from the lack of metal roofs and more especially the lack of gutters. Furthermore, the containers used to store the rainwater frequently consist of buckets and small basins which are totally inadequate to store the vast quantities of roof runoff available for use in drier periods. Even oil drums can only provide a few days storage and these provide a convenient supply only in the wet season. In the few cases where catchment tanks

were observed, they were generally much too small to store more than a fraction of the total roof runoff and often did not collect rainwater from the whole roof area.

It is obvious from these observations that the rainwater catchment currently being practiced in rural Botswana is conducted in an extremely inefficient manner and that the potential supply from this source could be greatly increased. A useful starting point for trying to determine the maximum potential of a roof catchment supply is to calculate the total available useful roof runoff for each of the villages and compare this with the total rate of consumption. Table 6.1 presents this information (the mean annual rainfall values have been estimated from figure 1.2 by interpolating between the isohyets). A runoff coefficient of 0.8 is used in the calculations which are outlined in the table. All the other data used are from the results of the village survey. This includes frequency of occurence and mean size of metal roofs, as well as the mean annual household water consumption

The results of the simple calculations shown in table 6.1 show that even for those households with metal roofs, the roof areas are too small and the annual rainfall too low to provide more than about 54% of the total household water requirements. Due to the fact that less than a third of the households in the four villages had any metal roofs, the mean maximum potential household rainwater supply for the four villages is around 17.5% of the total requirements, although it is 35% in Borolong due to the large number of metal roofs. If the potential roof runoff yields from public buildings e.g. schools, clinics, shops, etc... are included in the calculations, then the average potential roof rainwater supply for the four villages increases to 29% of the total requirements, and 47% for Borolong, see table 6.2. This table also shows the mean storage capacities that would be required by households in each village and the associated level of supply, if an overall mean rainwater supply of 29% of current daily domestic consumption were to be achieved

Table 6.1 ...Calculation of the Potential Rainwater Supply for the Study Villages

	NATA	THINI	SELOLWANE	BOROLONG	MEAN	Calculation
MEAN ROOF AREA (m^2)	52	45	45	42	$46m^2$	a
MEAN RAINFALL (mm/year)	550	520	520	480	518mm	b
RUNOFF COEFFICIENT	0.8	0.8	0.8	0.8	0.8	c
USEFUL ROOF RUNOFF (m^3/a)	23	19	19	16	$19m^3$	d d=axbxc
FEASIBLE POTENTIAL SUPPLY (m^3/a)	16	13	13	11	$13m^3$	e e=dx0.7
PRESENT DOMESTIC (m^3/a) CONSUMPTION	31	25	21	22	$25m^3$	f
HOUSEHOLD RAINWATER SUPPLY AS % OF DAILY CONSUMPTION	52	52	62	50	54%	g g=e/fx100%
% OF HOUSE-HOLDS WITH IRON ROOFS	14	18	30	70	33%	h
POTENTIAL RAIN-WATER SUPPLY AS % OF DOMESTIC CONSUMPTION FOR WHOLE VILLAGE.	7	9	19	35	17.5%	i i=gxh

Table 6.2 ...Maximum Potential Roof Catchment Supply in the Study Villages (when public buildings are included)

VILLAGE	NATA	THINI	SELOLWANE	BOROLONG	MEAN
MEAN STORAGE CAPACITY REQUIREMENT IN m^3	9.2	7.6	7.6	6.4	$7.7m^3$
POTENTIAL ROOF RAINWATER SUPPLY FOR AVERAGE METAL ROOFED HOUSEHOLD IN m^3	16.1	13.3	13.3	11.2	$13.5m^3$
HOUSEHOLD ROOFS POTENTIAL RAIN-WATER SUPPLY AS % OF PRESENT VILLAGE DOMESTIC WATER CONSUMPTION	7%	9%	19%	35%	17.5%
POTENTIAL RAIN-WATER SUPPLY INCLUDING ROOFS OF PUBLIC BUILDINGS	16%	16%	36%	47%	29%

6.4 THE IMPLICATIONS OF THE FINDINGS

Although, an average roof rainwater supply of 29% of the total daily domestic water requirements of the study villages may seem low, (figure 6.2), it is very important to examine the potential for utilizing even this quantity of water before dismissing roof catchment technology as being inappropriate as a method of water supply in rural Botswana. Clearly, in terms of overall water supply in rural areas , and for the vast majority of individual households, roof catchment provides a technology for only supplementing domestic water requirements

Due to the high quality of roof runoff, however, its use even as a supplementary source, could be highly beneficial The frequently poor quality of alternative traditional sources makes the use of rainwater exclusively for drinking, cooking and brewing beer, an attractive option. Traditional sources being left for uses such as washing and building where good quality water is not so essential. If rainwater were used to supplement a traditional supply in this way by replacing the use of the poorer quality water for human consumption, the possibility of bringing about health benefits for the community would be very real. This would, however, be contingent on an effective health education program being conducted in conjunction with the implementation of roof tanks.

Even in villages already served by high quality water supplies, such as Borolong and Selolwane, where ground water is reticulated to several standpipes, roof catchment systems can still play a vital role in the overall village water supply There are two main reasons for this. First, in most villages with standpipe supplies the coverage is incomplete; the mean distance to standpipes in Selolwane and Borolong being 498m and 433m, respectively, (figure 4.3). Second, none of these supplies are fail-safe and in many villages breakdowns of one or all of the standpipes are frequent. In Borolong, for example, only one of the four standpipes, installed in 1981, was working during the study period and even this one functioned for only about half of the time. Consequently, most of the villages used the sand river as their main water source. In Selolwane, although the reticulated supply was operating effectively almost all of the time a

large number of households in the village (about 40%) were in excess of 400m from the nearest standpipe and in many cases, where the sand river was closer, this was used as the main supply in preference to the standpipe, (table 4.4). In Mathangwane, where the pilot survey was conducted, the reticulated supply frequently broke down and people often had to revert to using the sand river as their only alternative source for several days until the reticulated supply was repaired. Plates 6.1 and 6.2 show the alternative means used for collecting household water when the improved supply breaks down. It is during periods like these that roof catchment systems could act as invaluable reserve water supplies, which would prevent people reverting to traditional water sources when improved supplies breakdown. This would help reduce the exposure to pathogens found in the unimproved sources and thus assist in overall health improvements. Roof catchment tanks would also provide a convenient, clean, freshwater supply at the point of consumption and act as a supplementary supply both in villages with and without standpipes. For villages with reticulated groundwater supplies, roof catchment systems would greatly increase the reliability of overall supply through providing a fall-back improved supply which can be used at times when the main supply might be broken down. Even in times of drought when rainwater supplies are low, the rainwater tanks could be filled with water from the standpipes to provide an additional reserve supply for times of breakdown.

Despite many other benefits, convenience is probably the greatest single benefit which results from the use of roof catchment tanks as a form of supply in rural Botswana. For example, in Thini the mean return trip to the nearest water source, a sand river, is 2.6km and although many villagers collect water using bicycles, there are some who walk up to 10km per day collecting water. The advantage of having even a partial water supply in the form of a roof tank would save these people an enormous amount of time and energy which might potentially be put to better uses.

At the present time Thini has relatively few households with corrugated iron roofs, but if present trends continue the number of metal roofs will increase rapidly in the near future and

Plate 6.1 . .Donkey Bowser being used to collect water while the pumped reticulated supply awaits repair in Mathangwane

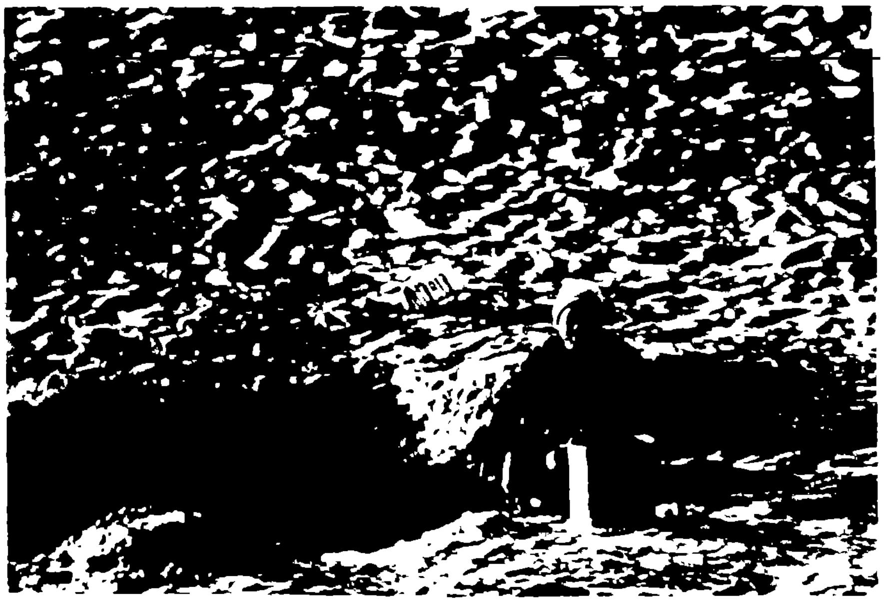

Plate 6.2 ...Water collection during a period when the improved supply is temporarily out of action in Mathangwane, Botswana

the potential for roof catchment systems will increase accordingly[14].

Although an accurate determination of the economic benefits and time-saving value of catchment tanks is difficult due to the existence of many unknown variables such as the marginal product of labour and what uses saved time might be put to, it is, nevertheless, possible to estimate the time and effort that could be saved through the installation of a catchment tank.

In chapter 5, (figures 5.5 and 5.6) it was shown that the most efficient storage capacity for maximizing supply while minimizing volume is equivalent to approximately 0.4 (40%) of the useful roof runoff. From table 6.1 it can be seen that the mean runoff for iron roofed households in the four villages is $19m^3$. Thus, a storage tank with a volume of $7.6m^3$ ($19m^3$ x 0.4) would be ideal, (see chapter 5). This would supply around $13.9m^3$ ($19m^3$ x 0.73) annually, according to figure 5.5 which shows the storage-supply curve (95% reliability) for Sebina the rainfall station most centrally located relative to the study villages.

Based on the information in table 4.3, it can be seen that the mean distance to the nearest reliable water source is in excess of 400m in every village (except Borolong) and that daily water collection averaged 67 litres, equivalent to about 4 buckets. Thus, a mean return trip of 800m x 4 or 3200m per day would be typical. It can therefore be calculated that an annual roof supply of $13.9m^3$ would save 663.9km (3.2km x 13,900/67) of walking (or in some cases cycling) for water. This is equivalent to 57% of the distance, time and effort currently expended.

6.5 RAINWATER CATCHMENT POSSIBILITIES AT SCHOOLS

The primary school at Borolong serves as a good example of one locality where the potential for the installation of roof catchment tanks was obvious. Although Borolong has a reticulated water supply, the distance from the primary school to the nearest standpipe was

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[14]According to village officials the first metal roof appeared in the village in 1972, examination of aerial photographs from 1981 revealed 6 metal roofed buildings, by the time of the survey in 1983, 15 existed and two more were under construction.

650m. However, as only one of the four standpipes in the village worked on a regular (albeit discontinuous basis) the actual distance to the nearest functioning standpipe was over 1100m.

The school had no water source of its own, so in order to provide water for drinking and cooking the midday meal, students were asked to collect water from the nearest convenient source which, for most of them, meant a sand river 800m away. Each child brought water to the school in containers which were seldom clean and had volumes of between 2 and 5 litres , see plate 6.3. This resulted in a daily supply of between 300-500 litres, enough for cooking and some drinking.

Although, the school had a corrugated iron roof area of 690m^2 and was in an area with a mean rainfall of 470mm, no catchment tanks had been installed,(see plate 4.1). The maximum potential mean annual runoff, assuming a runoff coefficient of 0.8, would be:

$$690 \times 0.470 \times 0.8 = 260 \text{ m}^3$$

Even if only half of this water could be collected and stored, by the installation of catchment tanks with a total volume of 100m^3, it would still be possible to provide a mean supply of about 150 m^3 (150,000l) or 400 l/day. This amount is equivalent to that currently being collected by the children.

Lack of water was not the only problem being faced at Borolong Primary School. Plate 6.4 shows one of five classes at the school which had no classroom.Despite the shortage of classrooms, however, the Headmaster (G.B. Wally) still stated "that the main problem is water, classrooms comes second".

The school at Borolong was just one of a number visited in the early phases of the research that were in a similar predicament. Nevertheless, there were also a number of schools which did possess rainwater catchment tanks These tanks, however, tended to be small. A school with several hundred square metres of corrugated iron roof area would typically have about 4 rainwater catchment tanks, with a total volume of around 18m^3. When it is considered

Plate 6.3 ...Water Supply for Borolong Primary School (Collection vessels filled by the children at a sand river 1km away).

Plate 6.4 ...Children at Borolong Primary School - "Lack of Water is the Main Problem".

that something in excess of 200m^3 of water was running off these roofs annually, this represents a case of severe under-utilization of this water source.

6.5.1 Plan for a Hypothetical School

The following diagrams, Figure 6.2 and 6.3, illustrate possible improvements which could be made to a typical primary school suffering from water supply problems through the construction of rainwater catchment tanks. Although the diagrams show a hypothetical situation they are based on an actual school visited.

The construction suggested in this case consists of eight 20m^3 ferrocement tanks and some additional guttering, as well as a ground catchment tank for irrigation purposes. The ferrocement design is based on that described by Watt(1978) using iron formworks of fixed volumes,(figure 2.2) Tanks of this type and size have already been constructed in Botswana. The current price is around P1000 (US$750). Although this may at first sight seem expensive when compared with galvanized iron tanks the shorter life expectancy of the latter makes the ferrocement tanks the more economic alternative , see table 6.3. During the 1950's and 1960's good quality galvanized iron tanks were manufactured (some of which are still functioning today) in recent years, however, their quality has deteriorated considerably and the life expectancy of the tanks has been reduced. Another major disadvantage relating to the purchase of corrugated iron tanks is that as they are produced in South Africa, their importation results in an outflow of valuable foreign exchange from Botswana. The construction of ferrocement and other locally constructed designs thus helps to conserve foreign exchange as only some of the required materials have to be imported. In addition, they provide employment opportunities and encourage the development of new skills. Investment in locally produced tanks can thus assist the rural economy directly as well as indirectly. Among the indirect benefits that a schools rainwater tank program may bring about are through the improved health of students and the saving of time and energy previously spent fetching water. The positive demonstration effect of rainwater catchment technology is also a further benefit. The construction of an open ground

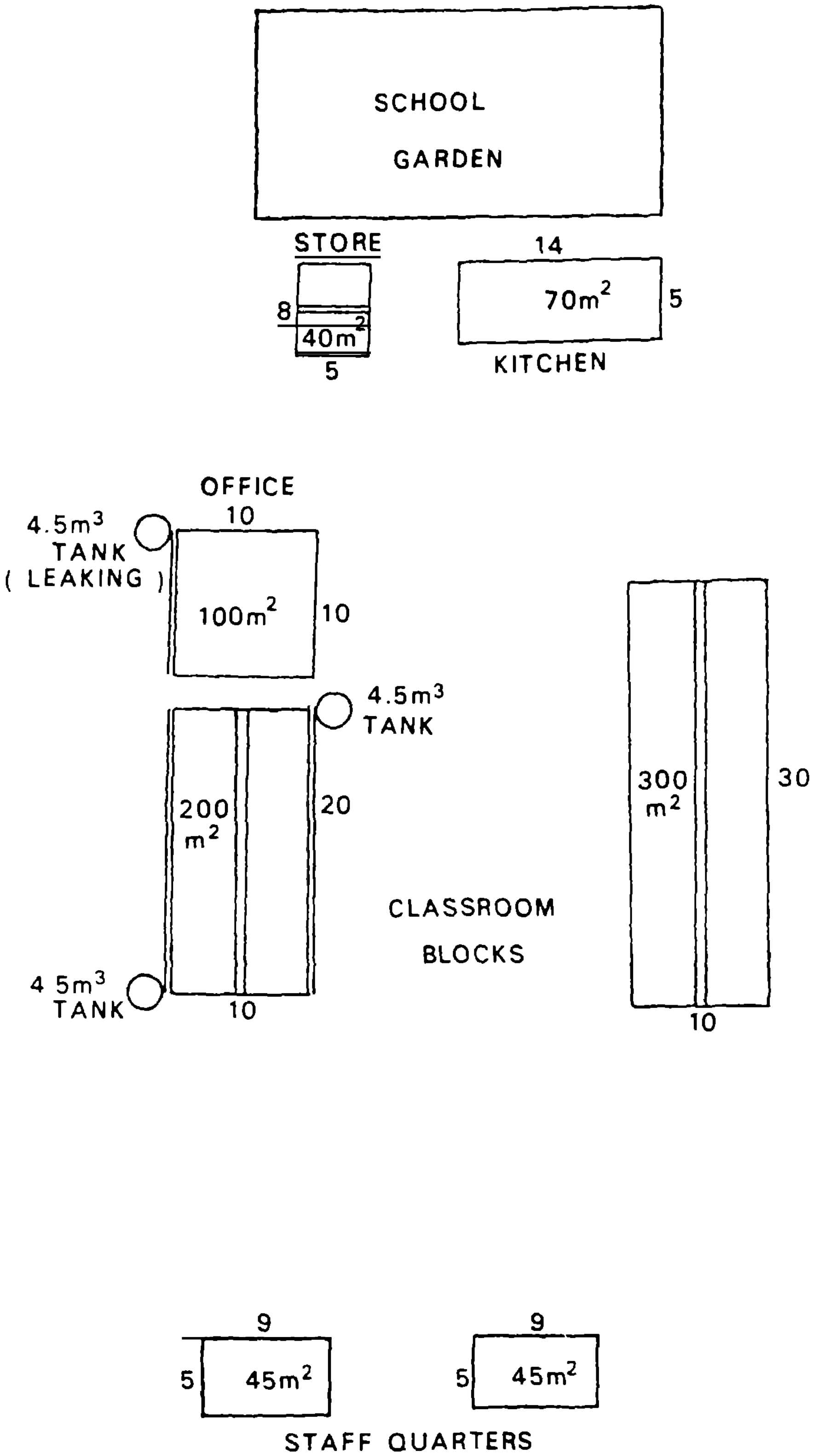

Figure 6.2 ...Plan of a Hypothetical Primary School Before the Installation of Ferrocement Rainwater Catchment Tanks

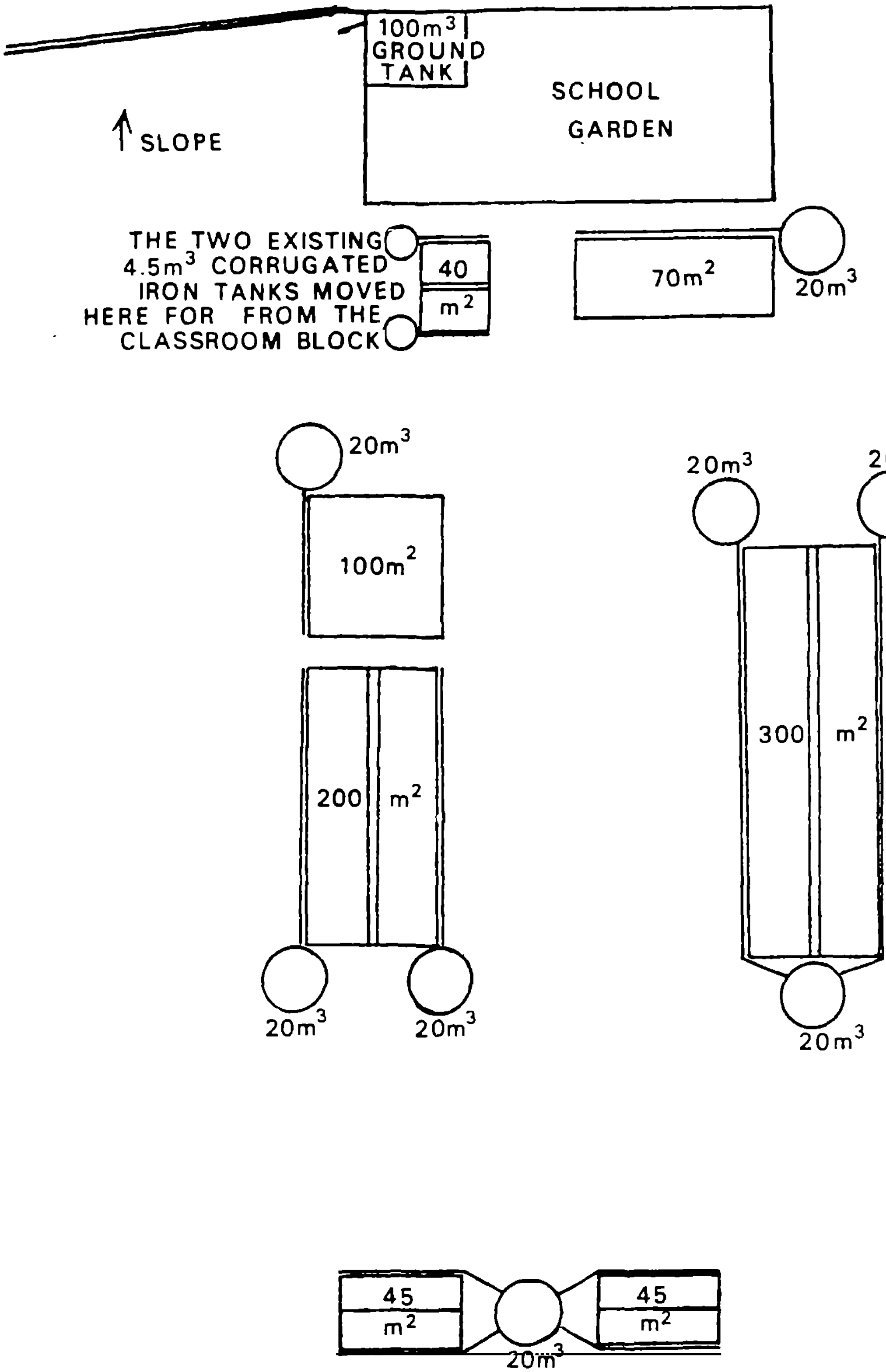

Figure 6.3 ...Plan of a Hypothetical Primary School After the Installation of Ferrocement Rainwater Catchment Tanks

catchment tank for providing water for irrigating the school garden would also have a positive demonstration effect on the local community as well as assisting in improving the diet of the children. The educational benefits of having a properly run school garden may also be considerable. An open ground tank with a capacity of 100 m^3 is neither difficult nor expensive to construct. If the excavation is conducted by self help labour the tank could probably be built for under P1000 (US$750). Although a cover for the tank would reduce the evaporation losses considerably it would also add to the costs appreciably. The danger posed to the school children should also be considered. A child was drowned in an uncovered, unfenced tank of this type in Tamasane (30km northeast of Palapye) quite recently. The area around any ground tank should always be fenced and if the tank cannot be covered properly some form of ladder or notched pole should be placed in the tank so if somebody falls in they can climb out easily.

The idea of using ground catchment tanks for irrigating school gardens in Botswana was first introduced by ITDG in the mid-1960's, (ITDG 1969). The failure of the project to stimulate widespread adoption of this technology was probably due to the fact that the domestic water needs of the schools and villages were ignored . In addition, the design used, although extremely low cost, made excessive demands on the use of self-help labour,(Pacey 1977). A more effective, if somewhat more expensive, design consists of the lining of an excavated pit with ferrocement (chicken wire and mortar).

6.6 ECONOMIC AND SOCIAL CONSIDERATIONS

6.6.1 Economic Considerations

Any assessment of the potential for using one form of water supply as compared to any other, would not be complete without some attention being given to the relative costs of the systems under consideration. Due to the great variations in the costs of schemes from one locality to another and due to the wildly varying estimates concerning the life expectancy of different technologies it is difficult to make accurate reliable calculations of the relative unit

costs of water for different methods of supply. It is, nevertheless, useful to try to work out rough estimates of how the technologies compare in terms of the unit cost of water provided. Table 6.3 provides such a comparison for various types of roof catchment tanks, a bowser supply and an approximation of the mean cost for a reticulated supply.

It can be seen from this table that while rainwater catchment tanks are considerably more expensive than hand-dug wells or piped groundwater supplies, they do provide a cheaper source than distant transported bowser supplies. Although hand-dug wells appear the most attractive option in economic terms, there are technical problems as only in a few areas are groundwater sources close enough to the surface to enable wells to be dug Boreholes provide the main source of groundwater supply in Botswana. The high cost of drilling and the fact that some of the boreholes yield little or no ground water while others produce saline or unreliable supplies, mean that the capital cost of installing a reticulated groundwater supply (shown in figure 6.3) may not in reality reflect the average cost for the exploration and development of a high yielding borehole since the cost of failed exploratory drilling is not included. Nevertheless for larger settlements, where groundwater supplies are plentiful these provide the best alternative. Even more difficult than determining the relative unit costs of water is trying to determine what value or economic benefits it might provide. Economic techniques such as benefit-cost analysis require the use of assumptions relating to unknown variables such as the life expectancy of different water supply technologies and the value of the time saved by these technologies. As a result of this, the findings of economic studies on this topic tend to be controversial. For example, Parker(1973) in his benefit-cost analysis of roof catchment tank installation in a village in Ghana made the highly debatable assumption that either 100% or at least 57% [15] of the time saved fetching water would be put to productive use. In addition, this time was ascribed a value based on the average return to labour for women. Even if Parker's assumptions were valid for Ghana, which seems improbable, it is even more unlikely they would hold true in Botswana. The long dry season, the lack of opportunities for productive

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[15]This is the percentage of a womans' 12 hour day normally devoted to productive labour (equivalent to 6.8 hours)

Table 6.3 ...Comparison of Unit Cost of Water for Various Supplies

TYPE OF SUPPLY	LIFE SPAN (years)	COST Recurrent	COST Capital	SUPPLY m^3/y	COST PER M^3
Hand-dug well[1]	20	--	714	336	P0.11
Reticulated[2] groundwater standpipe supply	20	1750	109,400	30,315	P0.24
	10	1750	109,400	30,315	P0.40
$20m^3$ Ferrocement[3] ground catchment tank	20	--	615	30	P1.03
$20m^3$ surface[4] ferrocement roof catchment tank	20	--	1000	30	P1.66
$4.5m^3$ surface[5] corrugated iron roof tank	10	--	210	7	P3.0
Transported[6] bowser supply (Nata)	--	35,000		1750	P20

N.B. Prices have been adjusted to 1983 level (At that time P1 = US$0.75)

Sources of Information :

1. Classen(1980)
2. a) Carothers(1981)
   b) Water Engineer, NE District
3. Ministry of Agriculture, ALDEP Team
4. Botswana Technology Centre
5. Haskin's Ltd, Francistown
6. District Office, Tutume

employment in the informal sector and crop production geared primarily towards subsistence, mean that for most of the year, at least, time per se is of very limited value particularly in rural areas. The major sources of household income are from the sale of cattle and remittances from family members working in the formal sector either in Botswana or South Africa, many of them in the mines.

Standpipe water for domestic use is provided free of charge by the government in those villages in Botswana with improved supplies. Due to the significant revenues from the sale of diamonds and considerable assistance with its rural supply program from SIDA (the Swedish International Development Agency), the government is probably in a better position to fully subsidize the cost of water than the people of Botswana are to pay for it If the government did try to impose some kind of revenue it seems likely that some of the poorer sectors of the community might revert to using traditional sources. This situation was observed in the village of Nata where households had to pay P0.25t (US$0.18) per month for water brought by a bowser from a borehole 43km away. The revenue raised in this way would have totalled around P30 (US$22.50) while the cost of operating the bowser was around P3000 (US$2250) per month. Due to large government subsidies for rural water supplies in general, it is assumed that any roof catchment tank implementation program would be considered eligible for considerable government support. Without the assistance of some external agency the average rural household in Botswana could not to afford a roof catchment system without selling some cattle. About half of the households in Botswana own cattle and there is a strong cultural and emotional attachment to them. Persuading Botswana's men to sell their cattle so that their women don't have to walk so far for water would not be an easy task. Due to such traditional cultural complexities, the complications introduced by government subsidies of water supplies and the dubious economic value of time saved and health benefits resulting from the implementation of improved water supplies, no attempt will be made here to conduct a detailed economic analysis.

Roof catchments tanks involve high capital costs and may be difficult to justify on purely economic grounds using the methods of economic analysis generally used by governments and contractors. These seldom take into account the frequency and length of break down of diesel powered supplies and generally accept the design life of the system rather than the actual life. Feachem et al(1978) found that only 25% of the diesel powered piped water schemes visited in Lesotho were functioning. In such cases larger scale schemes are unlikely to be economically viable. The reason for the frequent premature breakdown of large scale rural water supply schemes is often that only the technical aspects of the supply have been given sufficient attention and many very important complementary inputs such as user education in operation and maintenance have been ignored. Lack of community participation results in the community not feeling they own the system and thus are unwilling to maintain it or even use it with care.

The main advantage with roof catchment tanks as a means of supply is that despite the high initial capital costs, the recurrent costs are extremely low. Due to the fact that the tanks are owned by individual households, the people are totally responsible for their own water supply, if they maintain it they will benefit, if they abuse it they will suffer. From the perspective of the individual this is not always the case with communal water schemes.

When considering the cost of a roof catchment system it is important not to forget the cost of the roof Where this has already been installed the total price of the system is considerably reduced but elsewhere it may add significantly to the price of a system. The cost of a 50 m^2 corrugated iron roof is around P 200 or P4/m^2. Surprisingly the real cost of smaller thatched roofs is around P120 or P6/m^2, if the bundles of grass needed for their construction are purchased. Most people cut and bundle their own grass and thereby effectively reduce the cost of the roof to virtually nothing. For those people working in the formal sector who have no time to cut grass it is cheaper for them to install a corrugated iron roof. This may be one of the major factors accounting for the rapid transition to corrugated iron as a building material. A trend which is of great significance to the present study as it will result in the increasing

feasibility of using roof catchment systems in rural areas.

One very important concept which should be carefully considered when assessing the feasibility of implementing roof catchment systems is that of affordability. If no subsidy is available, only the few rich people already installing catchment tanks in many cases will be able to participate. If a total subsidy is offered, people may feel not recognize the value of the roof catchment system, they don't feel they own it and hence are less likely to maintain it. What is required is a subsidy which makes the tanks affordable to the vast majority of the people, and makes use of any labour input or local materials they may be able to provide to help reduce the cost of the tank.

6.6.2 Social Considerations

A major social obstacle to providing efficient rainwater catchment supplies is the problem of impressing upon the users the importance of rationing, especially during the driest periods when the prudent use of water could prevent the tank from running dry. This is particularly important where rainwater provides the only safe drinking water supply, as if the supply is not carefully rationed and dries up, people will be forced to return to contaminated traditional sources and any health benefits associated with the roof catchment tank supply will be lost. The introduction of rationing schedules, however simple, is bound to require considerable inputs relating to community education.

Hygiene education should also be an essential part of any new water supply scheme. Research has shown that efforts to improve water supplies are often ineffective at improving health (Feachem et al. 1978). unless a rigorous program which is well organized and constantly evaluated is introduced.

Simply employing a community health officer is, however, unlikely to be sufficient. This point is well illustrated by reference to an interview with the Family Welfare Educator in Nata, who's main job was to advise the community on improved hygiene practices. Amongst the advice she gave to women concerning the village's major water source a polluted river

which was generally recognized as such, was that they should boil their water before drinking it. When asked if people took her advice, she replied that they didn't, and even admitted that she herself did not boil her water as she was too lazy ,(at least she was honest). The problem in Nata is that firewood is becoming increasingly scarce close to the village and this discourages people from using it for anything unless they have to. This illustrates the complex nature of the social factors that have to be considered. Clearly detailed investigations and close participation with with the community are essential if any project and especially a roof tank project is to have any chance of success.

6.6.3 SUMMARY

Analysis of the results shows that at the present time roof catchment systems can generally provide a supplementary water supply in Botswana. Even in the wettest areas an average household would require a corrugated iron roof area of about $70m^2$ to provide a total domestic rainwater supply. Since the majority of rural dwellers do not own corrugated iron roofs and for the minority who do, roof areas are generally less than $70m^2$, total domestic roof catchment supplies would only be possible in a few exceptional cases. For the study villages where an average of 33% of households had at least one corrugated iron roof (mean size $46m^2$) household catchment tanks (mean volume $7.6m^3$ supplying $13.5m^3$ on average) could potentially provide 17.5% of the village domestic water requirements, compared with less than 3% at present. If rainwater was also collected from the roofs of public buildings a mean domestic supply equivalent to 29% of that currently used in the villages could be obtained.

Despite only being able to provide a supplementary supply, roof catchment tanks could nevertheless be highly beneficial due to the good quality, convenient supply they provide at the point of consumption. If roof catchment potential was exploited to the full, households with tanks in the study villages would on average save 57% of the time and effort currently expended on domestic water collection.

The increasing proportion of corrugated iron roofed buildings also mean that a greater potential for rainwater collection will exist in the future. The collection of rainwater at rural primary schools which have large corrugated iron roofs could provide a useful source of clean, fresh water available at the point of consumption for the staff and students.

The cost of stored rainwater varies from about P1.0 to P3.0 per m^3 which although being considerably more expensive than ground water supplies, is much cheaper than some of the transported bowser supplies currently being used at a number of schools and villages throughout Botswana.

7. GROUND CATCHMENT SYSTEMS

Simple ground catchment tanks known as haffirs have been used in Botswana for generations. These consist of large man-made excavations strategically placed to collect water in the rainy season for supplying both humans and livestock. In recent years more modern ground catchment tanks have been introduced and various other ground catchment systems explored. This chapter examines their use in Botswana and assesses projects which have attempted their implementation. Three basic types of ground catchment systems can be identified. These are :-

1. Ground catchments, which use treated or untreated ground surfaces as catchment aprons and excavated tanks as storage cisterns.
2. Rock catchments, which use natural or cleared rock surfaces as catchment areas and generally store the collected rainwater behind concrete dams, see figure 7.1
3. Micro-catchments and Runoff farms. These are systems which direct and concentrate rainfall into small areas in order to allow rainfed agricultural practices to take place where this would not normally be possible, see figure 7.2.

Among these three types of systems, it is the ground catchments which have played the most important role in Botswana to date. This is partly due to the initiation of projects relating research and development of ground catchment systems in Botswana in the late 1960's by the Intermediate Technology Development Group, (ITDG 1969,1971). More recently, the Ministry of Agriculture has been active in a major project involving the implementation of hundreds of ground catchment tanks through the Arable Lands Development Programme (ALDEP). This is the largest project of its type in Africa and its assessment provides the main focus for this chapter.

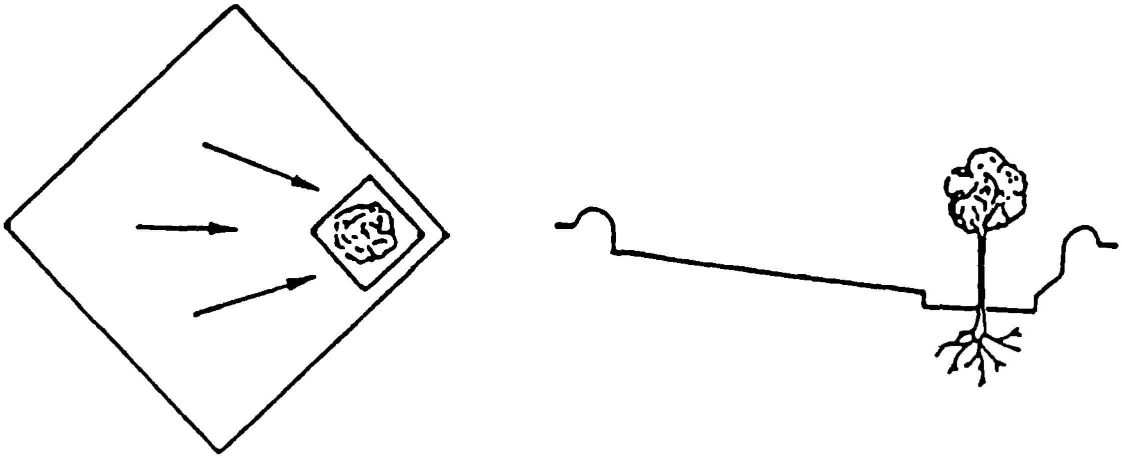

Figure 7.1 ...Plan and Cross-Section of a microcatchment(Adapted from N.A.S. 1974)

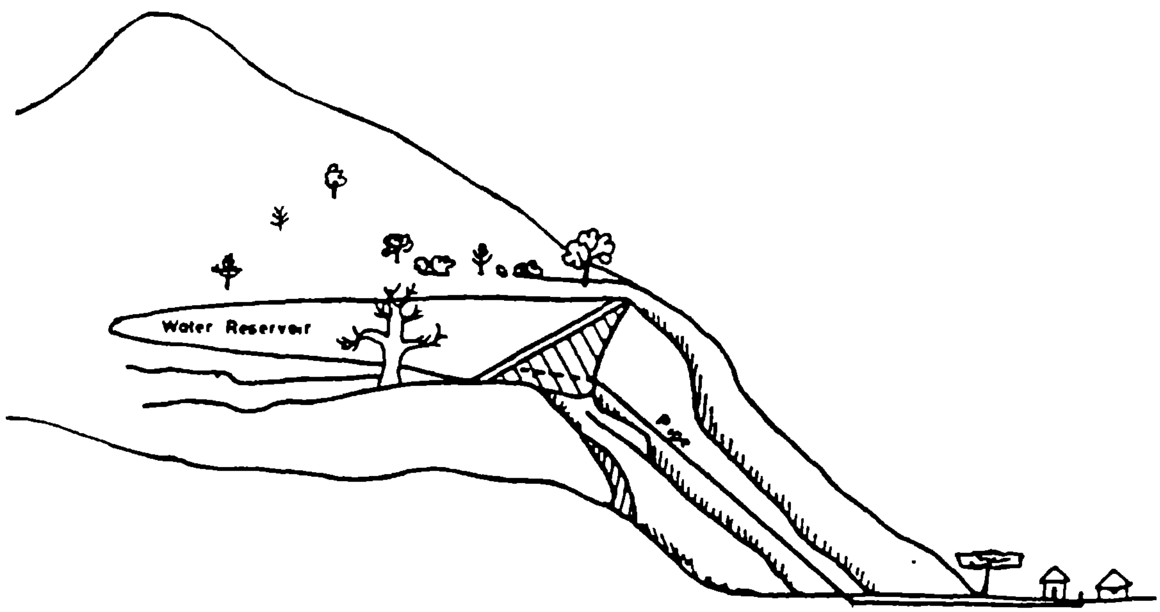

Figure 7.2 ...Diagram of a Rock Catchment (Adapted from Nissen-Peterson 1982)

7.1 GROUND CATCHMENT PROJECTS

7.1.1 ALDEP Rainwater Catchment Tanks

Since 1979, the Ministry of Agriculture through their ALDEP (Arable Lands Development Programme) has been the main force involved in the development and construction of sub-surface ground catchment tanks in Botswana. Two basic tank designs have been adopted,(Whiteside 1982). One is a ferrocement design, suitable for consolidated soils, in which chicken wire is pegged to the sides of an excavated hole in which a concrete foundation has been laid and three layers of mortar applied. The other is a brick-dome design, suitable for areas with unconsolidated soils. Both of these designs are shown in figures 7.3 and 7 4. It is likely that these designs would not be effective in humid and temperate environments, due to the effect of frost and of high soil pore water pressure acting on empty tanks. In the semi-arid tropics these problems are absent as the temperature seldom drops below freezing point, and pore water pressures are high only after periods of heavy rain (when the tanks would contain water); consequently the forces resulting from high soil pore water pressure acting on an empty tank are absent. Since the dangers resulting from a failure of the design are minimal, it can thus be concluded that the tank designs are an appropriate low cost solution for the Botswanan environment.

7.1.2 The Arable Lands Development Programme

The Arable Lands Development Programme in Botswana provides subsidies for purchasing fencing, donkeys, agricultural implements and labour for the destumping of fields as well as financial and technical assistance for the construction of rainwater catchment tanks. The original rationale behind the programme was that, if certain bottlenecks restricting agricultural development could be removed, productivity would rise considerably. One of the bottlenecks identified was the lack of water at the very beginning of the wet season. This prevented people from moving to the arable lands areas, watering their oxen and starting to

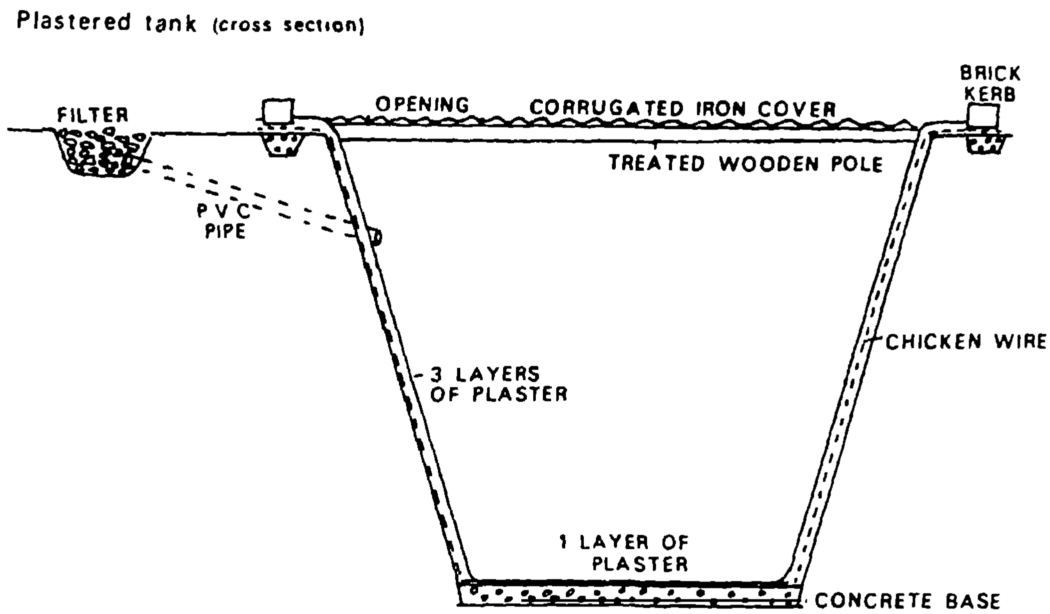

Figure 7.3 ...The Ferrocement Sub-surface Rainwater Catchment Design

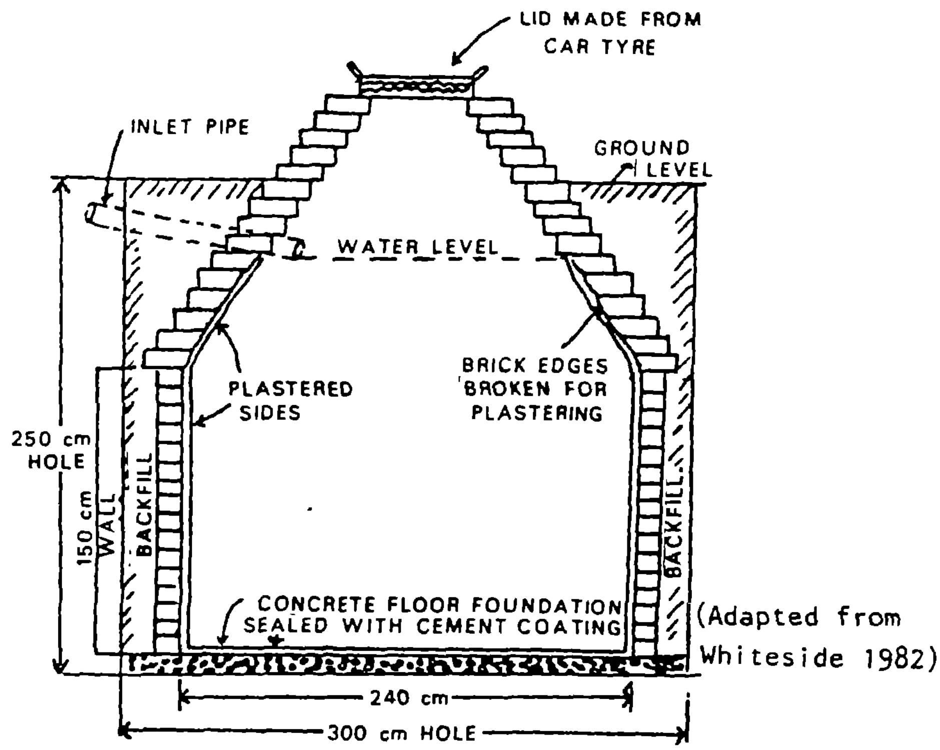

Figure 7.4 ...Brick-dome Sub-surface Rainwater Catchment Design

plough early, thus improving the chances of a good crop yield. It was hoped that by constructing ground tanks collecting rainwater from the first showers using traditional threshing floors as catchment areas, water might be provided for consumption by both oxen and humans and earlier ploughing would result. Trials to test the viability of this technology were conducted at the Integrated Farming Pilot Project at Pelotshetlha by the Ministry of Agriculture where a number of different designs were tried out. Initially, rectangular tanks were built, but following a consultancy recommendation by Classen(1980), circular tanks were built as these use less material per unit volume of storage.

7.1.3 Assessment of the ALDEP Rainwater Catchment Tank Project

The overall assessment of the ALDEP rainwater catchment tank project presented here is based on extensive field visits to more than 30 ground catchment tanks throughout Botswana. Structured interviews were also conducted with District Agricultural Officers in every area where ALDEP ground catchment tanks had been constructed. Details of these interviews and of field survey are given in appendix 6 and a summary of the findings from each district given in appendix 7. Information about the observations, measurements and interviews was given in chapter 3.

Following the success of the initial feasibility study at Pelotshetlha in 1980, (Maikano and Nyberg 1981a), a nationwide pilot project was embarked upon for the construction of sub-surface rainwater catchment tanks throughout Botswana. This pilot project consisted of the building of free demonstration tanks for interested farmers. More than 200 of these were built and the project then moved on to the next phase whereby farmers applied for a loan and subsidy to assist with the construction of the tanks. At the time of the field study more than 300 tanks had already been constructed and another 150 were either planned or under construction . The approximate location of those constructed by September 1983 is shown in Figure 7.3. Their concentration on the eastern side of the country is mainly due to the fact that this is where the majority of people reside. In addition, the sandy soils in the west are not

conducive to ground tank construction.

The pilot project was, however, not without its problems. In some parts of the country such as Kgatleng district, the pilot project was completely over-subscribed by farmers wanting to have free demonstration tanks. In other parts of the country, the project has been under-subscribed. This did not necessarily reflect a lack of interest, but in some cases suspicions that the Government might demand payments once the tanks were completed. It has thus been the more 'go ahead' and generally wealthier farmers who have received demonstration tanks in these regions, as they have been the first to apply. Although they have generally met the 'eligibility clause' of having less than 40 head of cattle, many have their own vehicles and one even ran a small bus company

Nevertheless, if the aim of the pilot project has been to demonstrate the technology and learn from mistakes it has succeeded fairly well. There has, however, been a tendency for the pilot project to develop much faster in certain parts of the country than in others. In the north and north-east half of the country, for example, fewer than 20 tanks have so far been constructed. This may, however, be partly due to the very sandy nature of the soils in some parts of this region which make the excavation of a hole very difficult.

Many useful lessons have been learned during the pilot project. In the Mahalapye area, for example, the price for not fencing the area around the tank with thorn bushes was paid when some cattle broke the cover to one of the tanks. In another instance a cow actually fell into an empty tank and as it could not be hauled out, had to be slaughtered in the tank.

Among other problems are pollution due to the decay of treated wooden poles supporting the tank cover which results in bad tasting water; and the cracking of tanks. Between 10-15% of the tanks so far constructed have suffered some form of cracking. This does not necessarily result in serious water losses depending on the size and position of the crack , which can generally be repaired. Among the possible reasons for cracking are.

1. The tank has been built much larger than the specifications and the mortar is spread very thinly and is not strong enough to support the weight of the water when the tank is full.

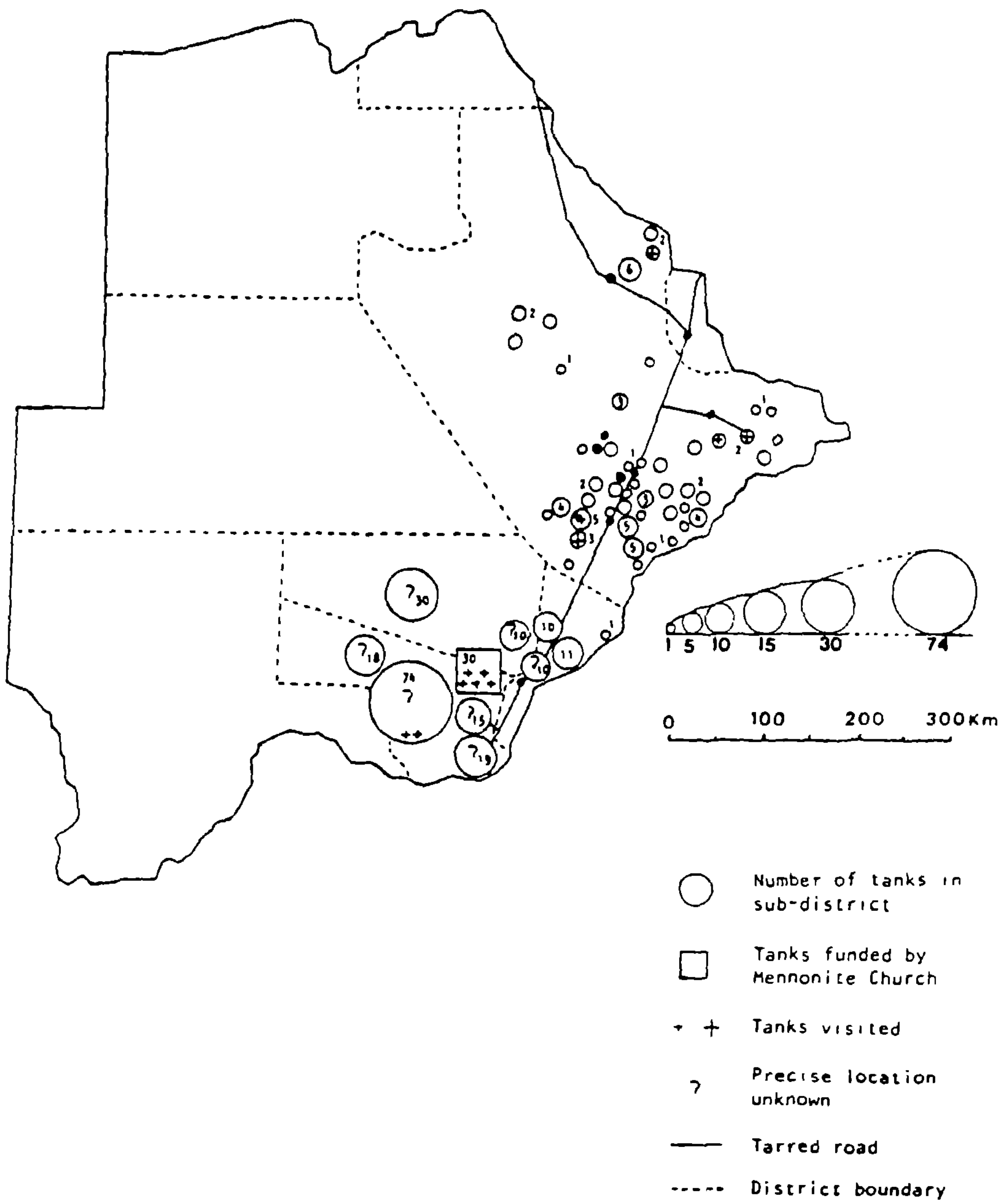

Figure 7.5 .Location of Known ALDEP Type Ground Catchment Tanks in Botswana in 1983

2. The wrong type and ratio of sand is mixed with the cement. This may be due to the builder not having had sufficient training and experience in tank construction.
3. The cement may not have been left to cure properly, or the tank and cement may have dried out completely allowing cracking to occur.

During drought periods the drying out and possible cracking of tanks presents a 'catch 22' situation since the very reason for having the tanks is to supply, not to consume water. The only solution is to fetch water from distant sources using oil drums and donkey carts.

A more general problem encountered during the project has been the shortage of trained builders, (Gaadingwe, personal communication 1983).[16]

There has also been considerable concern over the quality of the water in the catchment tanks, particularly when it was mainly used for domestic purposes including drinking, and not for watering oxen. This concern was partly due to a fear that cowdung used in plastering the threshing floor catchment apron might result in high nitrate levels and bacteriological contamination of the water. However, tests have shown that nitrate levels in tanks at Pelotshetlha were at an acceptable 1 p.p.m. (Maikano and Nyberg 1981a). Bacteriological tests, however, indicated the water to be of poorer quality than certain alternative sources previously used at sand rivers and wells. Consequently, farmers have been advised by agricultural field staff to boil water from the tanks before drinking it. Although most of the advice given in regard to the tanks has been adhered to by the farmers, there is very little evidence to suggest that few if any boil their water.

7.1.4 Results of Field Observations and Measurements

Table 7.1 gives the results of bacteriological analysis carried out on water from 8 ALDEP tanks in southern Botswana. Data on nitrate concentrations was collected for 4 of them. The results of the bacteriological analysis show that in all the tanks tested the water was not fit for human consumption according to the standards normally applied in rural Botswana.

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[16]S.Gaadingwe is the national ALDEP coordinator.

Table 7.1 ...Results of Bacteriological Analysis Conducted on water from ALDEP Ground Catchment Tanks

LOCATION OF TANK	TOTAL COLIFORMS	FAECAL COLIFORMS	FAECAL STREPTOCOCCI	NITRATE (NO_3+)mg/l
MOSETSE	342	15	29	-
TLOKWENG	2	6	124	-
SEBELE	CG	174	138	-
SEBELE	CG	150	194	-
MOSIME*	TNTC	600	-	13
JABE*	TNTC	1000	-	0
THATAYAONE*	TNTC	400	-	2
KEFETOGE*	6	300	-	2

*Source : Department of Water Affairs, P/Bag 0029, Gaborane

TNTC - Too Numerous To Count CG - Confluent Growth

	MAXIMUM PERMISSIBLE CONCENTRATION			
WHO RECOMMENDATION	<10	<1	<1	< 45
BOTSWANA GUIDELINES	<100	<10	<10	<100

This clearly provides grounds for concern and calls for a serious attempt to investigate ways to improve the water quality. It seems likely that the bacteriological contamination from animal sources is not due to dung in the catchment apron, but more from insects, lizards and other small animals entering the tank. The frequent extraction of water with a slightly dirty container and contamination of the catchment apron by small children are probably the main sources of human bacteriological pollution, (Brynolf, pers. com. 1983). Table 7.2 summarizes information collected from sixteen ALDEP tank sites visited all over Botswana. This sample does not include six tanks visited at I.F.P.P. (Integrated Farming Pilot Project) in Pelotshetlha in 1980, as these were larger experimental tanks

The most striking fact from the above sample is that the mean volume of the tanks in the sample was $16m^3$. This is in spite of the fact that the specifications provided were stated as being for $10m^3$ tanks. The main reason for the tanks being larger than this is that the measurements given by Whiteside(1982, p5) for the excavation were incorrect Many of the tanks constructed have been larger than the specifications given, mainly due to the over-enthusiastic efforts of some of the farmers. This has caused a number of major problems, especially as back filling of the holes is inadvisable if the tanks are to be structurally sound. The most significant effects of the hole being made too large are :

1. If the same amount of cement is used for a larger tank, it will be thinner, weaker and more likely to crack.
2. Builders get disgruntled as they have to do more work for the same pay.
3. The purchase of additional materials for larger tanks inflates their cost.

Since the average size of the 16 threshing floors sampled was $108m^2$, and as a runoff coefficient of about 0.5 can be expected for a well prepared floor,(Ainley 1984) in a typical locality in Botswana with mean annual rainfall of 450mm, almost $30m^3$ of rainwater could be expected to flow into the tank in an average year.

With this amount of water flowing into the tank it is highly likely that, even when constant extraction during the rainy season is taken into consideration, a $10-15m^3$ tank will

Table 7.2 ...Summary of Measurements from 16 ALDEP tanks in Botswana

	MEAN	GREATEST	SMALLEST	S.D.
TANK VOLUME (m^3)	16	29	8	7.4
AREA OF THRESHING FLOOR CATCHMENT APRON (m^2)	108	165	0	28
NUMBER OF PEOPLE USING THE TANK	7	15	2	4.1
DISTANCE TO NEAREST ALTERNATIVE SOURCE (km)	6.2	20	1	4.8
MEAN NUMBER OF CATTLE USING THE TANK	2	10	0	3.7

overflow regularly, especially in wetter years. A tank volume of 15-20m³, however, would only overflow only occasionally and would provide a significantly greater supply. This would enable a family to stay at the "lands" longer and might even provide some carry-over storage to enable a family to return to the lands at the end of the dry season, if they so wished. One advantage with a larger tank is that many farmers are, on average, digging holes of this size already. If the resources and materials required for larger tanks were allocated, it would be likely that some of the problems already encountered may be overcome. In addition, despite the cost of the tank having to be increased, the unit cost of the water would decrease. Builders could be paid more (perhaps P120-150 per tank), instead of the P80 they currently receive for tanks which invariably are larger than the $10m^3$ ones they are being paid to build.

Finally, as Classen (1980) pointed out in his report on small-scale rural water supplies the cost for a $20m^3$ tank is only 37% more than for a $10m^3$ one. In other words, the present cost of P450 for a $10m^3$ tank would in theory only have to be increased to P615 to build a $20m^3$ one. In fact, in his original report Classen (1980) recommended that tanks should be built between 15 and $20m^3$ in capacity, due to the economies of scale involved.

7.1.5 Results of Ministry of Agriculture Questionnaire

In addition to the data gathered during the field visits and interviews with District Agricultural Officers conducted during the present study, much useful information was gleaned from a follow up questionnaire survey conducted by the Ministry of Agriculture, ALDEP team (Ainley 1984). This postal questionnaire was sent to agricultural demonstrators (A/D's) throughout the country and responses were received from 104 out of the 212 extension areas. The average size of the extension areas is 1600 km^2 and about two thirds of the A/D's cover this area by foot, bicycle or donkey; just over a third have motor cycles. The extension areas contain on average almost 500 farming households, and the mean distance A/D's had to travel to reach the remotest farm was 43 km. It is obvious from these facts that the problems encountered in simply promoting the Arable Lands Development Programme ground catchment

tanks are immense. The Ministry of Agriculture is currently considering ways of assisting A/D's in purchasing motorcycles to increase their efficiency.

The questionnaire also included 24 specific questions relating to ALDEP catchment tanks. Some of the problems which were identified are cited in a report by Ainley (1984) these include the following.

1. Financial problems : Many farmers found the annual repayments required through the loan subsidy scheme to be excessive, particularly due to the limited financial resources available to them because of the drought. The loan, amounting to 65% of the total cost, was to be repaid over a 5 year period and was subject to a 6.5% interest rate, resulting in annual repayments of around P60 (US$45). Due to their remote location, most of the farmers found the high transportation costs which they are liable to pay to have builders and materials transported to the site, excessive.
2. Procedural and Social Problems : The loan/subsidy scheme was difficult to administer, resulting in long delays in delivery and problems collecting repayments. Many farmers did not know about or understand the ALDEP scheme and others were skeptical about government assistance. Some farmers were waiting for neighbours to take part in the scheme first.
3. Physical Problems : In many areas, shortages of builders, materials and transportation have hampered the speed at which the project could proceed. Another problem is that some of the threshing floor catchment aprons constructed by the farmers are too small, of poor quality or are not sloping towards the tank.

7.1.6 Possible Improvements to the Project

Ainley (1984) suggests that many of the financial and procedural problems should be eliminated due to the introduction of the new 85% grant/15% downpayment system which is now in effect. He also urges that the Ministry of Agriculture should either cover or at least make a major contribution towards the transportation costs now being met by the farmer. In

terms of increasing farmers awareness and understanding of the ALDEP scheme in general and the rainwater tanks in particular a nation-wide radio promotion is suggested. In addition to this, the construction of at least one demonstration tank should be encouraged in each extension areas where tanks are feasible but no tank presently exists. Field trips might also be arranged to show farmers successful tanks operating in other areas.

Solutions to some of the physical problems might include the reintroduction of a builder training programme and the encouragement of private builders and brigades to get involved in the construction of ground tanks. This would be one way to help overcome the problem of the shortage of builders The competition that would be created would probably force the price charged by builders down somewhat.

A large number of physical improvements to the project are also recommended by Ainley(1984). These include the following :

1. All tanks and threshing floor catchment aprons should be fenced with at least a thorn fence.
2. Tanks should be located so as to make maximum use of natural drainage.
3. The possibility for farmers to cement their threshing floor catchment aprons should be offered as an optional extra. Cement floors have the advantage over traditional ones of requiring little maintenance, having a higher runoff coefficient (0.9 compared with 0.5) and producing better quality water. The cost of a $100m^2$ cement apron would be around P160 (US$ 120).
4. Where farmers homes have corrugated iron roofs these should be utilized as a catchment surface due to the high quality of rainwater from this source.
5. A chain and bucket (permanently attached to the tank) and a simple sand filter should be provided when each tank is constructed to help to improve the quality of water from these tanks. The introduction of these should go hand in hand with a health education program in which the A/D's play an integral role.
6. A return to the original rectangular design should be given serious consideration, although

they use 25% more material per unit volume, (Classen 1980), they are easier to build, and there have been very few problems with them so far. They are also easier to cover, as extra strength IBR iron sheets can be used which span over 2m without support thereby making redundant the use of the treated wooden poles. The cover of the tanks should also be used to collect rainwater.

Improvements to the project as a whole may be achieved in other ways too. The introduction of a subsidized scotch cart scheme as part of the Arable Lands Development Programme (Ainley 1984) would allow farmers to collect water from distant boreholes and store it in their tanks, something which is already being done to a certain extent, see Plate 7.1. In some instances, in remote locations where a borehole supply is relatively close at hand, the benefits accrued from an ALDEP ground catchment tank may be as much a result of its use for storing transported groundwater, as of its use for collecting rainwater. If the tanks are to provide sufficient water for both humans and oxen, rainwater alone will never be sufficient. By encouraging the use of the tanks for storing high quality transported groundwater, the original rationale for implementing the tanks may be fullfilled. That is to say, draught animals may be well watered at the beginning of the rainy season and ploughing may begin early. The importance of fodder as well as water for the oxen should,however, also be considered.

7.2 THE FUTURE FOR GROUND CATCHMENT TANKS

During the past twenty years, a number of pilot projects and experimental ground catchment systems have been initiated in Botswana. These have been well documented, (ITDG 1969, 1971; Farrar and Pacey 1974; Classen 1980), and modifications and improvements have been made both to the technology itself and to the way it is implemented. A few problems still require attention, but the general success of the present ALDEP tank project, despite the drought, would seem to indicate that this technology will be adopted extensively in the near future. Because of the high cost of providing piped water supplies to remote, scattered lands and cattle post households, ground catchment tanks represent a viable convenient improved

Plate 7.1 ...Scotch Cart being used near Shoshong to supplement rainwater being stored in an ALDEP ground tank.

Plate 7.2 ...Mud/Dung Traditional Threshing Floor being used as a Catchment Apron for the same Tank near Shoshong.

water supply alternative which could easily be widely adopted within the foreseeable future.

Although farmers have been slow to take advantage of loans and subsidies offered for ground catchment tanks, this is not an unusual phenomena when new technologies are being introduced. This is particularly the case among the highly conservative rural poor, who generally adopt risk aversion strategies in respect to investments of their scarce resources. The recent drought has exacerbated this problem further. However, it is expected that with a return to normal rains and the adoption of the new 85% grant/15% downpayment system, farmers will find the tanks more attractive, and once they see other tanks operating successfully many will want to apply for their own. If rapid and effective implementation of the 240 additional tanks already budgeted for,(Ainley 1984), as well as other future ones is to be achieved, it is essential that bottlenecks resulting from a shortage of proficient builders willing to build tanks at a reasonable price is removed.

7.2.1 Replication of ALDEP Tanks

The ALDEP rainwater tank programme has already influenced both individuals and organizations resulting in replication of the technology. The most notable of these is a community group at Pitsing (50km west of Gaborone) who with the assistance of funding from the Mennonite Central Committee have constructed more than 25 ground tanks similar to the ALDEP design.

The Botswana Technology Centre has recently embarked on an ambitious experiment, in water self-sufficiency by constructing roof and ground catchment tanks for providing all the domestic water requirements of their new headquarters. The ground tanks being constructed are based on the ALDEP design but with capacities of 60m^3 to determine whether the design is suitable for tanks with such large volumes.

It seems likely that the construction of ground catchment tanks in Botswana will continue at a considerable rate within the immediate future and, if the technology proves successful, considerable replication will occur both within Botswana and elsewhere.

7.2.2 The Feasibility of Ground Catchment Tanks

The feasibility of various small scale rural water supply systems appropriate to Botswana's arable "lands" areas were examined by Classen(1980). The alternatives identified were hand dug wells, subsurface dams, protected springs and ground catchment tanks. Although a cost comparison revealed hand dug wells to be the cheapest alternative and ground catchment tanks to be the most expensive, it was noted that the prevailing geological, topographical and other physical conditions may override the question of cost. The lack of springs, sand rivers and the great depth to groundwater in many areas means that the direct collection of rainwater is often the only alternative. Wilson(1978) noted that sand rivers are only abundent in the northeast of Botswana and that only 357 hand dug wells have been recorded in the whole country. This is equivalent to one well per 1630 km^2. Although the lack of hand dug wells is partly due to the depth to groundwater, in many areas a land board ruling forbidding wells to be closer than 8km from each other, as a measure against over-grazing, has acted as a major constraint to well digging. Classen(1980) suggests that the land board ruling is inappropriate in arable lands areas where few cattle are grazed and that in these areas the Water Apportionment Board's ruling that wells should be not less than 230m apart makes more sense. The flat nature of the terrain means springs are also few and far between (Wilson 1979), and the saline nature of groundwater in many areas means that groundwater sources are not always suitable. The greatest advantage of ground tanks is that they always represent a possible alternative since all the other supplies are location specific. Where wells, springs and subsurface (sand river) dams cannot provide cheap convenient supplies, ground catchment tanks become a highly feasible alternative.

7.3 RUNOFF AGRICULTURE

Rainwater can be collected from ground surfaces by various methods. For many agricultural purposes, overland flow may simply be diverted and concentrated in a particular area through the creation of micro-catchments or contour catchments which employ terraces

which shed water onto a neighbouring strip of fertile soil. This is known as runoff farming and although a few experimental efforts with this technology have been attempted in Botswana they have never been developed., (A photograph by U.Nessler of 2 year old apricot trees grown in microcatchments in Botswana is, however, cited in NAS(1974).

In the Negev desert in Israel, runoff farming has been practiced for thousands of years and many crops including peaches, grapes, alfalfa, wheat and barley have been grown in areas with only 100mm of rainfall per annum, (Evenari, Shanan and Tadmor 1971). In Kenya a major programme of micro-catchment construction is currently underway in Turkana, (Cullis, personal communication 1984). The construction of microcatchments such as that shown in figure 7.4 offer great potential for agricultural development in eastern Botswana (ITDG 1969), and it is strongly recommended that further research and development be conducted in this field Although it is not the purpose of this thesis to assess the potential for the development of runoff agriculture in Botswana, it would seem that any major obstacles would tend to be cultural rather than technical. The very sandy nature of the soils in the regions and adjacent to the Kalahari may not, however, be suitable for runoff agriculture due to their high infiltration capacities. Nevertheless, there appears to be a major need for more research and development of this technology followed by its implementation in suitable areas.

7.4 ROCK CATCHMENT SYSTEMS

Another method of collecting rainwater from ground surfaces is from rock catchments, (figure 7.1). Although this is a widely used technique in many parts of Africa and particularly in Kenya (Sinclair 1983, Nissen-Peterson 1982) and in Zimbabwe (NAS 1974), relatively few suitable sites exist for this technology in Botswana. A few small rock catchments have been constructed in the past. These include one at Oodi, near Gaborone, where a local weaving and dyeing enterprise required pure rainwater for their production process.

The vast blanket of Kalahari sand in the west, the general absence of rocky outcrops and inselbergs in much of the rest of Botswana, and the highly jointed nature of such outcrops

where they do occur, all mitigate against any major development of this technology. Nevertheless, a few isolated sites do exist and these could be investigated with a view to possible development. One of the most promising areas of the country for the use of rock catchments is the region south of Gaborone.

7.4.1 SUMMARY

Three basic types of Ground Catchment Systems exist - micro-catchments (used for agricultural purposes), rock catchments and ground catchments. In Botswana ground catchment tanks are the most important of these, traditional systems known as haffirs have been used for generations. Since the 1960's, the research and development of more modern ground catchment tanks have resulted in a nationwide project which started in 1979 to construct sub-surface ferrocement tanks collecting rainwater from traditional threshing floors in remote arable lands areas. This project being administered by the Ministry of Agriculture had implemented more than 300 tanks by 1983 and the number is still growing despite a number of problems including a shortage of trained builders, difficulties of loan repayment partly due to the drought, and technical problems including the cracking of 10%-15% of the tanks.

The introduction of a new implementation strategy offering better conditions for the farmers, a grant/downpayment system (85%/15%) to replace the former loan/subsidy (65%/35%), better conditions for builders and an improved tank design are likely to result in renewed interest in the project. Concerns over the quality of the water in the tanks were confirmed by the results of of the bacteriological analysis conducted on eight samples . Although the quality of the water was found to be poor, it is still comparable or even somewhat better than many of the traditional sources currently being used. Measures, including a simple filter and an improved method for extraction are, however, being included in future designs. The lack of feasible alternatives for domestic water supply in remote rural land areas mean that ground catchment tanks are likely to play an important role in water supply provision in the areas within the foreseeable future. The main advantage of the ALDEP ground catchment

tanks is that they provide a convenient water source at the point of consumption in areas where alternative water sources are often several kilometres away. Since they are owned by individual households, this greatly assists in insuring effective operation and maintenance.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The aim of this research was to determine the current extent of usage and future potential role of rainwater catchment systems for providing a water supply in rural Botswana. The results indicate that, although rainwater catchment systems play only a minor role in current domestic water supply, in many localities they could provide a convenient supplementary supply in the future.

Water is an extremely scarce and important commodity in Botswana. Both the name of the national currency and the national greeting (PULA - meaning rain) reflect this fact. Many different types of water source are used and each have a distinct set of advantages and disadvantages associated with them.

Surface water sources are feasible only for large population centres since the very high evaporation rates and cost of treatment facilities preclude consideration of smaller scale open storage for settlements of only a few thousands or less. Francistown, Selebi Pikwe and Gaborone are the only settlements supplied by dams. [17]. The flat nature of the topography in Botswana means that springs are not abundant and few possibilities for gravity fed water schemes exist. Groundwater is currently the main source of improved supply in the country. It provides a suitable source for nucleated settlements in regions with abundant sweet groundwater. In remote locations where settlement is scattered its use becomes both increasingly expensive and problematic especially in areas where the quantity and quality of available groundwater is in question. The considerable depth of groundwater, 100m on average, makes the construction of low cost shallow wells with hand pumps impossible in most areas; since due to the high cost of drilling boreholes these are commonly equipped with diesel pumps and the water reticulated to standpipes.

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[17] In 1983 the level of water in Gaborone dam was so low that rationing had to be introduced in the capital

The majority of villages with populations exceeding 1000 now have groundwater supplies and standpipes (Brynolf 1981), but the frequent breakdown and the considerable distance of some residents from the standpipes mean that traditional alternative sources are frequently used . The poor quality of many of these traditional sources mean that health improvements are very unlikely to occur while they are being used, even if only on an occasional basis.

Traditionally a "multiple-source" approach to water supply provision has existed in Botswana (Farrar 1977), with various sources being used at different localities and in different seasons. A "fall back" strategy is generally employed in lands areas during dry periods and when one source dries up or becomes unavailable an alternative source is used (Fortmann and Roe 1981). A similar "fall back" strategy could be employed in the villages of Botswana for improved domestic rural supplies to insure a continuous supply of good quality water. In those areas where wells and springs exist, improvement of these sources would be an integal part of such a strategy, as could the development of sand river supplies (Wikner 1980) through the construction of subsurface dams. Roof catchment systems would also play a vital role in providing a "fall back" reserve supply for when the reticulated supply was not functioning, particularly in those regions where wells and sand rivers are not found.

8.1.1 Roof Catchment Systems

Effective design and construction are essential for rainwater catchment systems if they are to provide a feasible alternative or supplementary form of supply. In Botswana the efficient sizing of rainwater storage tanks is particularly important, since the rainfall regime in the country demands large storage capacities, an effective design can thus lead to considerable savings in the costs of the tanks.

The application of the Ottawa Computer Model to rainfall data from ten stations in Botswana revealed that the most effective storage capacities for rainwater catchment systems are equivalent to about 0.4 (40%) of the mean annual total useful runoff and that this will

provide a supply of approximately 0.7 (70%) of this runoff with a reliability of 95%.

Roof catchment systems can provide a useful high quality water supply alternative for the many rural dwellers possessing corrugated iron roofs. A roof area of almost $10m^2$ per capita ($70m^2$ for an average household) would be required to provide a total domestic supply (10 lpcd) even in the wettest areas such as around Gaborone and Kasane. Since the majority of households have roof areas of less than this , roof catchment is only generally feasible as a supplementary supply.

A detailed survey of four villages revealed that while almost 80% of the villagers perceived rainwater as clean and tasty only 46% collected it. This was generally done by placing buckets or basins in the open or under the eaves of corrugated iron roofs. Only 11% of households had catchment tanks and most of them were only temporary in nature consisting mainly of 200 litre oildrums. It was found that roof catchment potential is currently greatly under utilized. This form of supply could, however, be increased from its present level of less than 3% of daily village domestic consumption, to almost 30%, providing that the roofs of public buildings were included. An average household with a $47m^2$ roof would require a $7.7m^3$ roof tank and gutters costing around P360 (US$270). This could supply $13.5m^3$ annually with 95% reliability.

Although 33% of the villagers owned metal roofs only 3.5% had large permanent catchment tanks. Most people, however, expressed a desire to own a catchment tank but stated that lack of a corrugated iron roof, lack of money, or both, were the main reasons for not getting one. The costs of roof catchment supplies were calculated at between P1-3 per m^3 which although more expensive than the groundwater supplies being used in many locations are considerably cheaper than the transported bowser supplies being used in some villages such as Nata.

Table 8.1 outlines some of the advantages and disadvantages of roof catchment systems. Among the advantages the most significant are the great convenience and high quality water offered by this form of supply. The individual ownership of each supply is also beneficial

Table 8.1 ...Advantages and Disadvantages of Roof Catchment Systems

ADVANTAGES	DISADVANTAGES
1) CONVENIENCE - provides a water source at the point of usage	1) STORAGE IS COSTLY - requires high initial capital outlay
2) OPERATION - operation is simple	2) LIMITED TOTAL SUPPLY - this is dictated by the rainfall and catchment area.
3) MAINTENANCE - the systems need only limited maintenance	3) RISK OF FAILURE IN DROUGHT - this is the time the tank is most likely to run dry.
4) INDIVIDUAL OWNERSHIP - this is conducive to better operation and maintenance.	4) IRON ROOF ESSENTIAL - not suitable for people living in exclusively thatched homes.
5) SAVES TIME AND ENERGY - this might be put to productive labour and thus represent an economic benefit.	5) RATIONING - the organization and implementation of this may be difficult.
6) TASTY - sweet rainwater is generally considered tastier than groundwater which is often somewhat saline.	
7) QUALITY - water from roofs is of high quality and is conducive health improvements.	
8) UBIQUITOUS - a rainwater supply can be obtained anywhere.	
9) LOW RECURRENT COSTS - these are virtually negligible apart from maintenance costs.	

as it helps to insure that the supplies, in general, are better maintained than communally owned ones. The most significant limitation in Botswana at present is that this technology can, in most cases, only offer a supplementary water supply to households with corrugated iron roofs.

The belief by some workers (Fortmann and Roe 1981, Hall 1982) that rainwater runoff from grass roofs could form a viable supply for the majority of rural dwellers still living in exclusively thatched roofed households, seems unlikely to be applicable in practice. The village survey revealed that only 5.5% of households collected runoff from thatch roofs and only 0.5% used this for drinking or cooking. This agrees with the findings of Feachem et al.(1978) who noted that rainwater from thatched roofs in Lesotho was turbid and generally considered unsuitable for consumption.

8.1.2 Combined Roof and Ground Catchment Systems

The decision of whether to adopt a roof or ground catchment system will be largely dictated by circumstances. Roof catchment systems provide a higher yield per unit area of catchment and better quality water which can be safely consumed without treatment. They are, however, more expensive than ground catchment systems and require a corrugated iron roof as a catchment area. Ground tanks although providing lower quality water which requires treatment, are more suitable for poorer households which have thatched roofs and are far from alternative sources.

In many instances where a corrugated iron roof is already present it maybe appropriate to construct a combined roof and ground catchment system. This idea was first suggested by Farrar(1974) and an example is illustrated in figure 8.1. [18]. The roof catchment tank will provide the high quality water needed for drinking, cooking and washing, while lower quality water for building, washing clothes and watering small gardens and livestock will be provided by the ground catchment tank.

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[18]Systems of this type were observed in the village of Morwa, 22km north of Gaborone, these probably resulted from the influence of the research conducted in this area by Farrar and others in the early 1970's.

Plates 8.1 and 8.2 show a concrete block roof catchment tank and ferrocement ground catchment tank currently being used at the villages of Morwa and Sefophe, respectively. Although both these tanks provided only a supplementary supply it was one with which the owners were well satisfied.

Future Prospects

Rural Africa is changing rapidly and the villages of Botswana are no exception. The development process normally leads to the adoption of new innovations in larger settlements first, from where they slowly diffuse outwards to smaller and more remote communities. The term "development" does not merely refer to economic growth, but encompasses improvements in education, health, general welfare and income distribution. Nevertheless, it is the physical manifestations resulting from increased cash incomes which tend to be the most striking indicators of development. In Africa the replacement of thatched by corrugated iron roofs is perhaps the most visually striking indicator of economic development. Corrugated iron roofs although, aestetically less pleasing than the thatched roofs they are replacing , are more durable and better at keeping the rain out. In addition they form an ideal catchment surface from which high quality rainwater can be collected and used to supplement domestic water supplies.

The transition from using thatch to using corrugated iron as a roofing material is a steady ongoing process. A number of villages such as Borolong and many in the south have already reached a point where most households have at least one metal roofed building. If current trends continue it seems likely that by 2000 most households in most villages in Botswana will have one or more corrugated iron roofs, even though thatched buildings may still be more numerous than metal ones . In addition to this rural incomes are likely to continue to increase steadily during this period, especially if any "trickle-down" effect results from the large revenues Botswana is now receiving from her diamond industry. These trends are highly favourable towards roof catchment as not only will the number of catchment surfaces steady increase, but the storage tanks and gutters required will become increasingly affordable to more

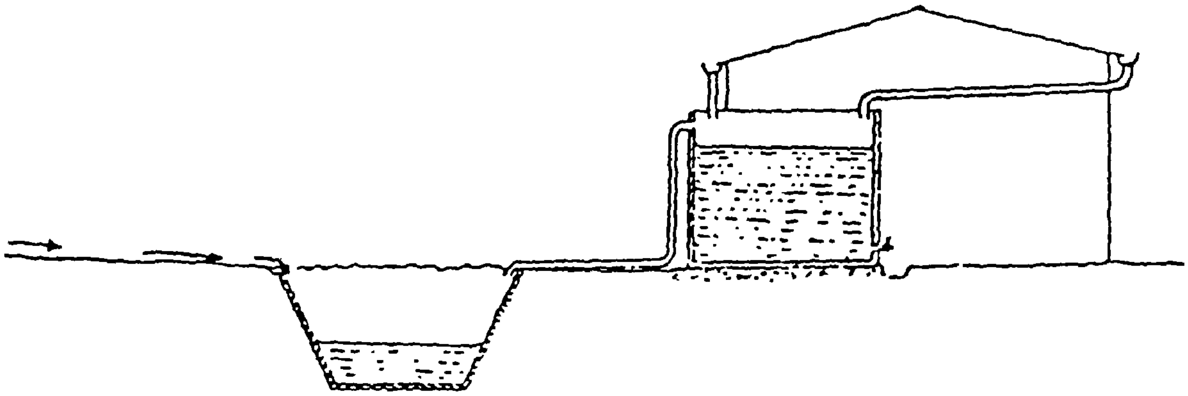

Figure 8.1 ...Combined Roof and Ground Catchment System (After Farrar 1974)

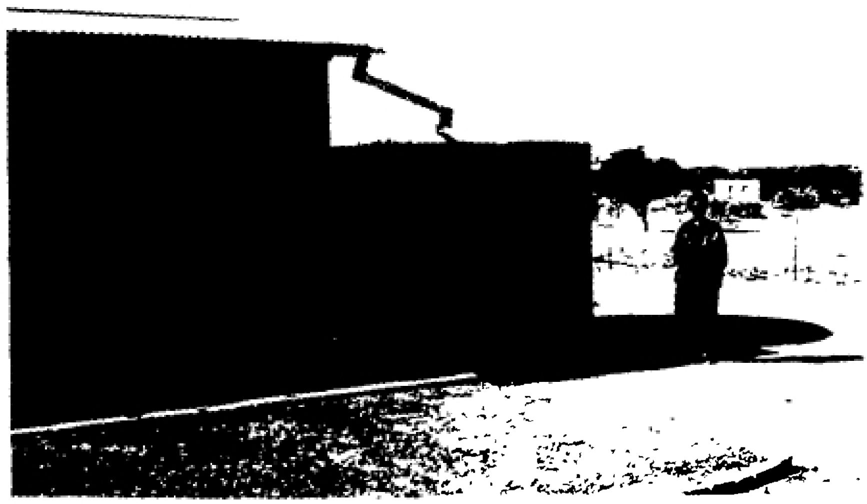

Plate 8.1 Roof Catchment Tank in Morwa

Plate 8.2 ALDEP Ground Catchment Tank at Remote Household 35km southeast of Selebi Pikwe

people (especially if subsidies are made available). At the present time galvanized corrugated iron tanks are the only readily available large storage tanks on the market. These provide good quality drinking water. The limited durability of these imported tanks, however, makes the production of locally built ferrocement tanks based on the designs currently being developed in Kenya, a more attractive alternative.

Botswana is a marginal area in terms of the utility of roof catchment systems. The low rainfall 300-600mm in most regions and the small areas of household corrugated iron roofs ($40m^2$-$50m^2$ on average where they do occur) result in rainwater supplies being limited. Nevertheless, the fact that almost half of the households surveyed already collect and use rainwater in some form indicates a willingness by the people to use this form of supply. Furthermore, the questionnaire revealed that the majority of people perceived rainwater as being clean and tasty. The severe under-utilization of rainwater supplies seems to be mainly due to the lack of iron roofs, the high cost of storage tanks relative to incomes and a general lack of awareness of the potential for this form of supply. If fully developed, roof catchment systems could play a significant role in overall domestic water supply by providing a clean, tasty, renewable and easily maintainable water source at the point of consumption.

8.1.3 Ground Catchments

The use of excavated ground catchment tanks are likely to play an important role in the provision of water in many parts of Botswana in the future. This will be especially true for cattle post, lands areas and other remote rural households lacking corrugated iron roofs and far from other alternative water sources. The extremely high cost of sinking boreholes or piping water to these scattered localities make ground catchment tanks based on the ALDEP design the most economically and technically appropriate water supply option. The poor bacteriological quality of water from these excavated ground tanks does give cause for concern. The use of a simple sand and charcoal filter and better methods of water extraction would assist in improving the situation.

To date some 500 ALDEP type tanks have been successfully constructed in Botswana mainly under the Arable Lands Development Programme. Although the project has not been without its problems, a number of improvements are now being made to the design of the tanks and their method of implementation. It is expected that with these improvements and a return to normal rains following the current drought, that the project will continue to expand and flourish.

At some localities the absence or poor quality of ground and surface water sources may make the large scale collection of rainwater from specially constructed rainwater harvesters an economically feasible water supply alternative. Nata provides an example of such a location. The construction of rainwater harvesters there to provide a clean fresh drinking water supply would form an interesting prototype of this technology in a semi-arid continental location which might have applications elsewhere in Africa.

Rainwater catchment systems provide another alternative improved renewable supply, which deserves to be given serious consideration when overall water development strategies are being drawn up. To date the Ministry of Water Development has not become involved in any form of rainwater catchment systems development - perhaps the time is ripe!

8.1.4 Further Research

. In this thesis the potential for using rainwater catchment systems in Botswana and the applications for using a computer model for their design have been demonstrated. Although the model used was run on a main frame computer this technique can be adapted for use on micro computers. This would make it more applicable for applications in countries like Botswana and research in this area is needed.

Another area where further research is urgently required is in the development of low cost appropriate methods of water purification and extraction in conjunction with the use of ground catchment tanks. Research and development of an appropriate low cost roof tank design is required to find a cheaper design appropriate for Botswana, field testing of some of the designs developed in Kenya would provide a useful starting point for such research. Finally, the development of effective methods of implementation need to be established which insure proper operation and maintenance (these should employ community participation at every stage) and detailed socioeconomic is required to this end.

8.2 RECOMMENDATIONS

8.2.1 Roof Tanks

1. The Ministry of Local Government and Lands and the Ministry of Education should give serious consideration to the implementation of large 20m^3 tanks at schools, clinics and other public buildings throughout Botswana.

   The implementing agencies might include the Botswana Technology Centre, regional building brigades and local communities. These tanks could be externally funded jointly by the government or a foreign donor. The project should start with those villages suffering from the most serious water problems, the criteria for selecting these are outlined in appendix 6.

2. Large roof catchment tanks ($20m^3$) should be considered for incorporation in the standard designs for all new schools, clinics and government buildings constructed in rural Botswana.
3. District councils, Government agencies, foreign donors and local communities should work together to initiate rural household roof tank projects. These would have to be heavily subsidized through external funds and could be coordinated by the Botswana Technology Centre. Construction might be conducted by the brigades and local communities. Each community would be involved in every phase from the initial planning to the final operation and maintenance. They would also need to contribute labour, materials and some money towards the project.
4. For the greatest efficiency in terms of maximizing the rainwater supply while minimizing the costs, a storage capacity equivalent to 40% of the amount of useful runoff is suggested for roof catchment systems in Botswana. These will yield on average a supply of between 70%-80% of the useful runoff with 95% reliability.

8.2.2 Ground Catchment Tanks

5. The government of Botswana and external agencies should continue to support and help expand the ALDEP rainwater tank project as this is one of the only realistic and affordable means of supplying water at the point of comsumption to remote cattle post and lands areas within the foreseeable future.
6. The Ministry of Agriculture in consultation with the Department of Water Affairs and the Ministry of Health should attempt to make every effort to improve the quality of water stored in the tanks. This could be done by investigating the use of various types of filters, since chlorination of supplies and the boiling of water seem unlikely to be adopted by the local people.
7. The Ministries of Agriculture and Health should pursue programs of both hygiene

education and operation and maintenance. This would help to ensure that the water does not get contaminated once it has entered the tank or after collection, and that a reliable supply can be organized through the adoption of a rationing schedule.

8. The Central District Council in conjunction with the Department of Water Affairs should investigate the possibility of constructing a rainwater harvester in the village of Nata to provide a cheap fresh drinking water supply. This would also act as a prototype for other possible schemes in other villages in Botswana and Africa where alternative sources are unavailable.

9. The Ministry of Agriculture should investigate the possibilities for runoff agriculture using micro catchments and excavated tanks for micro irrigation projects.

8.2.3 Promotion

10. Promotion of both the ALDEP ground catchment and roof catchment projects, should be conducted through radio stations, and mobile units showing demonstration films and distributing leaflets. Subsidies, tax relief for storage tank construction and free technical advice are all policies which should be adopted by the government to encourage the use of rainwater tanks throughout Botswana.

8.3 POSTSCRIPT

Following the completion of the fieldwork and the release of some of the preliminary findings of this study, a number of projects were initiated in Botswana. At Nata, Mogonye, Ramotswa and Dukwe refugee camp several $20m^3$ ferrocement roof catchment tanks have been constructed at schools and clinics, (Plate 8.3 and 8.4).

Although these projects received technical assistance from the Botswana Technology Centre which employed an engineer specifically for this purpose, they were funded by local district councils. Despite only limited involvement with rainwater catchment systems prior to the study, the Botswana Technology Centre has since become actively involved, and in conjunction with the Ministry of Local Government and Lands has been seeking funds from foreign donors (including Canada's CIDA and WUSC), for the implementation of a nationwide roof tank project at schools and clinics.

Furthermore, the Ministry of Agriculture's Ground Catchment tank project is still growing and the number of tanks now exceeds 500. Some of the modifications and improvements suggested in this thesis have been incorporated in the current design.

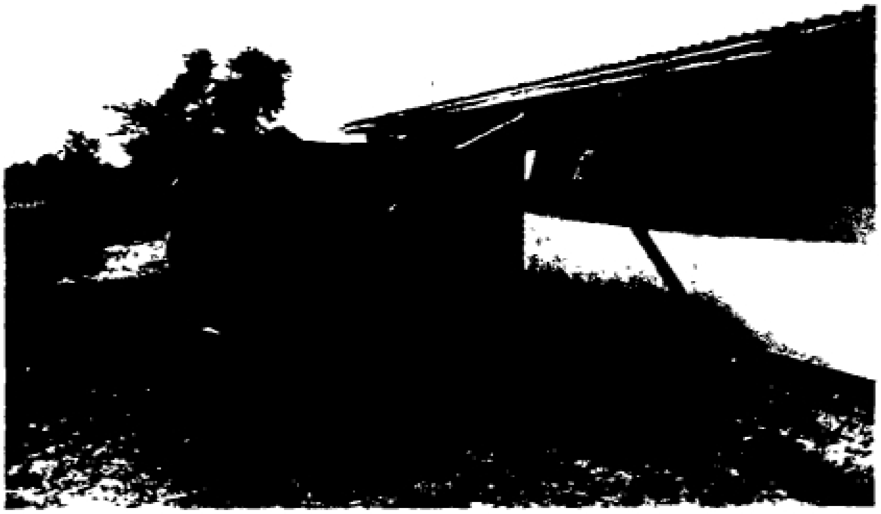

Plate 8.3 ...$20m^3$ Ferrocement Roof Tank Constructed at Nata Clinic in 1984

Plate 8.4 ...$20m^3$ Ferrocement Roof Tank Constructed at Nata Primary School in 1984 (Photos by H.Friederich).

BIBLIOGRAPHY

Aarsse, B. 1981. Report on the Preliminary Survey of Salinity of Boreholes in Botswana. The Botswana Technology Centre, Private Bag 0082, Gaborone. 10P.

Ainley, M.W. 1984. An Appraisal of the ALDEP Water Catchment Tank Program. Min. of Agriculture, P/Bag 003, Gaborone, 26p.

Alcock, P.G. 1983. A Water Supply Strategy for the Inadi Ward ,Vulindulela District, Kwazulu: A Research Framework. Subsistance Agriculture Study Group, Univ. of Natal. 13p.

Bhalotra, Y.P.R. (In press) Climates of Botswana. Dept. of Meteorology, Gaborone.

Brynolf, L.V. 1981. Water Pollution and Sanitation in Botswana In Sanitation in Developing Countries Proc. of Training Workshop Aug. 5-12, 1980, Zomba, Malawi. Ottawa/IDRC. Publication 167e, pp71-74

Brynolf, L.V. 1983a. Nitrates in Drinking Water. Circular for the Dept. of Water Affairs, Private Bag 0029, Gaborone. 1p.

Brynolf, L.V. 1983b. Drinking Water Criteria Circular for the Dept. of Water Affairs, Private Bag 0029, Gaborone. 1p.

Byrne, H. 1983. Clean Water in Kola.Waterlines Vol. 1. No.3. pp21-23.

Calvert, K.C. and R.J. Binning, 1977. Low Cost Water Tanks in Pacific Islands. Appropriate Technology Vol. 4, No. 3 , pp29-31.

Carothers, R. 1981. An Assessment Water-Pumping Technologies Using Locally Available Energy Resources, Botswana. Rural Water Supply in Developing Countries I.D.R.C. : Publication 167e pp44-52.

Carr, M. 1978. Appropriate Technology for African Women. United Nations Economic Commission for Africa.

Classen, G. 1980 . Small Scale Rural Water Supply Ministry of Agriculture, Private Bag 003, Gaborone. 80p.

Cooke, H.J. 1978 . The Problem of Drought in Botswana. Proc. of Symposium on Drought in Botswana. Ed: M.T. Hinchley. Botswana Society and Clark University Press, 305p.

Copperman, J. 1978 . The Impact of Village Water Supplies in Botswana . SIDA Report, Gaborone, 81p.

Crasta, F.M.; C.A. Fasso,; F.Patta and G.Putzu, 1982. Carthaginian-Roman Cisterns in Sardinia. Proc. Rain Water Systems Conf. Honolulu. pp37-45.

Cullis, A.D. 1984. A Study of Rainwater Collection and Storage Systems in Rural Africa with Special Reference to the Work of the Intermediate Technology Development Group Submitted as partial requirement for the M.Sc. Environmental Resources Course at the Department of Biology, Univ. of Salford, U.K.

Dedrick, A. 1976. Water Harvesting - Modern Application of an Ancient Method Civil Engineering - ASCE October 1976 pp86-88.

Diamant, B.Z. 1982. Roof Catchments: The Appropriate Safe Drinking Water Technology for Developing Countries. Proc. Rainwater Systems Conf. Honolulu. pp276-283.

Enge, M. 1982. You Can't Live Without Water Report - S.I.D.A., S-10525, Stockholm.

Enge, M. 1983. Water Hygiene Campaign Botswana. Draft Report - S.I.D.A., S-10525, Stockholm.

Evenari, M. ; L.Shanan ; N.Tadmor and Y.Aharoni, 1961. Ancient Agriculture in the Negev. Science 133 , pp 976-996.

Evenari, M.; L.Shanan and N.Tadmor, 1971. The Negev: The Challenge of a Desert Havard Univ. Press, Cambridge, Massachusetts.

Farrar, D.M. 1974. Aspects of Water Supply and Conservation in some parts of Africa. Unpublished PhD thesis, University of Manchester.

Farrar, D.M. 1977. Water Supply and Settlement Patterns in Swaziland and Botswana Ekistics Vol 43, 254. pp31-35.

Farrar, D.M. and A.J. Pacey, 1974. Catchment Tanks in Southern Botswana: A Review. Africa Fieldwork and Technology, Report 6, 13p. (Available from I.T.D.G. 9, King St. London.)

Feachem, R.G. 1973. The Pattern of Domestic Water Use in the New Guinea Highlands. S.Pacific Bull. Vol. 23. No. 3. pp10-14.

Feachem, R.G. et al., 1978. Water, Health and Development : An Interdisciplinary Evaluation Tri-Med Books, London, 218p.

Frasier, G.W. 1975. Introduction Proc. Water Harvesting Symp.(1974), Pheonix, Arizona, 325p .

Fortmann L. and E. Roe 1981. Water Use in Eastern Botswana : Policy Guide and Summary of the Water Points Survey. Min. of Agriculture, Gaborone. 96p.

Geddes, H.J. 1963. Water Harvesting, In: Water Resource Management - Melbourne Univ. Press, Australia.

Gibb, A. and Partners. 1979. Pre-Investment Study for Water Development in North-East Botswana Final Report. Vol. 1. Sir Alexander Gibb and Partners, Early House, London Road, Reading, England.

Gibbon, D.P. 1975. Dryland Crop Production in Botswana : A Review of Research, 1969-74. Min. of Agriculture, P/bag 003, Gaborone.

Gould J.E. 1983a. Report on Rainwater Catchment Systems in Kenya. Unpublished Report. I.T.D.G. 9, King St. London.

Gould J.E. 1983b. Preliminary Report on Rainwater Catchment Systems in Botswana Botswana Technology Centre, P/Bag 0082, Gaborone, 26p.

Gould J.E. 1983c. Report on Rainwater Catchment Systems in Matabeleland, Zimbabwe Unpublished Report. I.T.D.G. 9, King St. London. 7p.

Gould, J.E. 1984. Rainwater Catchment Systems in Botswana, Present, Past and Future. Waterlines Vol.2 No.4 pp14-18.

Grover, B. 1971. Harvesting Precipitation for Community Water Supplies., Unpublished report. World Bank, 110 p.

Guggenheim, H. 1974. Fighting the Drought The Wunderman Foundation, 575 Madison Ave, New York, N.Y.

Hall, N. 1982. Water Collection from Thatch. Waterlines Vol. 1, No. 1, pp23-26.

Henson, R. 1972. Tanks for Water from Roofs in Botswana and S.W.Rhodesia Friends Rural Training Centre, Hlekweni, 2p.

Hofkes, E.H. 1981. Rainwater Harvesting for Drinking Water Supply (Draft) International Reference Centre for Community Water Supply , The Hague , PO Box 5500, 2280 HM, Rijswijk, The Netherlands. 53p.

IRW. 1982. (Institute of Rural Water), Designing Roof Catchments Technical Note No. RWS 104.

ITDG 1969. The Introduction of Rainwater Catchment Tanks and Micro-Irrigation to Botswana Intermediate Technology Development Group, 9, King St. London. 74p.

ITDG 1971. Report on the State of the Botswana Catchment Tank Project after Three Years of Operation. Intermediate Technology Development Group, 9, King St. London. 14p.

ITDG. (in press) Rainwater Harvesting for Domestic Water Supplies. I.T. Publications. Intermediate Technology Development Group, 9, King St. London. 200p?.

Ionides, M. 1964. Village Water Tanks : Report on the "Yard Prototype" Programme Dioxidis Ionides Assoc. Ltd., Dorland House, Regent St., London.

IWACO. 1982. Construction Manual for 10m³ Rainwater Reservoir of Ferrocement International Water Supply Consultants, Rotterdam, Po Box 183, The Netherlands, 43p.

Jenkins, D. ; F. Pearson; E. Moore; S.J. Kim and R. Valentine, 1978. Feasibility of Rainwater Collection Systems in California Contribution No. 173, California Water Resources Center, Univ. of California, Davis. 55p.

Jian, L. 1979. Rain and Stormwater Harvesting in China. Report to UNEP Rain and Stormwater Harvesting Project. - Nairobi, 30p.

Johnson, A. 1982. Botswana : Landanalys (country analysis). S.I.D.A., Stockholm. 129p.

Keller, K. 1982. Rainwater Harvesting for Domestic Water Supplies in Developing Countries: A Literature Survey. Water and Sanitation for Health (WASH), USAID, Working Paper 20. 76p.

Kenyon, A.S. 1929. The Ironclad or Artificial Catchment. Journal of the Dept. of Ag., Victoria Vol 27, pp86-91.

Koplan J.P., R.D. Dean, W.H.Swanston and B. Tota 1978. Contaminated Roof-Collected Rainwater as a Possible Cause of an Outbreak of Salmonellosis. J. Hygiene Camb. Vol. 81, pp303-309.

Kovacs, G. 1979. Traditions of Rainwater Harvesting in Europe. Report to UNEP Rain and Stormwater Harvesting Project. Nairobi, 30p.

La Hire, P. de, 1742. The Philosophical History and Memoirs of the Royal Academy of Sciences at Paris., London.

Landsberg, H.E. 1966. World Maps of Climatology Ed : Heidelberger Akademie der Wissenschaften by Rodenwaldt and Jusatz. 3rd edition, Berlin, N.Y., Springer.

Latham, B. 1983. Rainwater Collection Systems: The Design of Single-Purpose Reservoirs. M.A. Sc. Thesis, Department of Civil Engineering, University of Ottawa. Canada. p. 232.

Latham, B. 1984. Rainwater Collection Activities in Indonesia and Thailand. Report to CIDA, Ottawa, 132p.

Latham, B. and E.J. Schiller, 1984. Rainwater Collection Systems : A Literature Review. Civil Engineering Department, Univ. of Ottawa. 32p.

Lee, G.F. and R.A. Jones, 1982. Quality of St. Thomas, U.S. Virgin Islands Household Cistern Water Supplies. Proc. Rainwater Cistern Conf. June 1982, Honolulu, pp233-243.

Maikano, G.J. and A. Nyberg, 1981a. Rainwater Catchment in Botswana. In Rural Water Supply in Developing Countries Proc. of Training Workshop Aug. 5-12, 1980, Zomba, Malawi. Ottawa/IDRC. Publication 167e, pp13-17.

Maikano, G.J. and A. Nyberg, 1981b. Views about Water Supply and Training at the Department of Water Affairs, Botswana. In Rural Water Supply in Developing Countries Proc. of Training Workshop Aug. 5-12, 1980, Zomba, Malawi. Ottawa/IDRC. Publication 167e, pp123-125.

McCallan, E.A. 1948. Life on Old St. David's, Bermuda. Hamilton : Bermuda Historical Monuments Trust.

Malik, U.A. 1982. Rainwater Cisterns Systems and Policy in Malaysia. Proc. Rainwater Cistern Conf. June 1982, Honolulu, Addenda 7p

McPherson H.J.; M. McGarry; J.E.Gould and B.Latham, 1984. Low Cost Appropriate Water and Sanitation Technologies for Kenya - Report to the Ministry of Water Development, Maji House, Nairobi. - Funded by GTZ, p225.

Michaelides G. and Young R.J. 1984. Diverting the foul flush from roof catchments used for potable water supply.African and Asian Water and Sewage December issue, pp18-21.

Moody, P. 1973. Swaziland Government and ITDG Report on the Tank Programme. Intermediate Technology Development Group, 9, King St, London.

Myers, L.E. 1964. Harvesting Precipitation. Int. Ass. Sci. Hydrology Pub. 65: pp343-351.

N.A.S. (National Academy of Sciences), 1974 More Water for Arid Lands Washington D.C. 153p.

N.D.P. 1980. National Development Plan 1979-1985. Min. of Finance and Development Planning. Gaborone. 426p.

Nissen-Petersen E. 1982. Rain Catchment and Water Supply in Rural Africa. Hodder and Stoughton. p.83.

Omwenga J.M. 1984. Rainwater Harvesting for Domestic Water Supply in Kisii, Kenya. Published M.Sc. Thesis, Tampere University, Finland. 132p.

Pacey, A. 1977. Water for the Thousand Millions London : Pergamon. 58p.

Parker, R.N. 1973. The Introduction of Catchment Systems for Rural Water Supplies - A Benefit/Cost Study in a S.E. Ghana Village.Dept of Ag. Econ. and Man., Univ. of Reading 45p

Perrens, S.J. 1975. Collection and Storage Strategies for Domestic Rainwater Supply. In Hydrologic Symposium Proceedings Armidale, NSW, Australia. pp168-172.

Perrens, S.J. 1982. Effect of Rationing on Reliability of Domestic Rainwater Systems. Proc. Raiwater Cistern Systems Conf., June 1982, Honolulu. pp108-117.

Pike, J.G. 1971. Rainfall and Evaporation in Botswana Technical Document No.1, FAO/UNDP/SF Project 359. F.A.O. , Rome.

Ree, W.O.; F.L. Wimberley, W.R. Guinn and C.W Lauritzen, 1971. Rainwater Harvesting System Design Paper ARS 41-184, Ag. Res. Service USDA. 12p.

Ree, W.O. 1976. Rooftop Runoff For Water Supply. USDA Rep. ARS-S-133. 10p

Rippl, W. 1883. The Capacity of Storage Reservoirs for Water Supply. Minutes of Proc. Inst. Civil Engs. London. Vol 71, pp270-278.

Robertson, L. 1981. The Development of Self-Help Gravity Piped Water Projects in Malawi :In Rural Water Supply in Developing Countries Proc. of Training Workshop Aug. 5-12, 1980, Zomba, Malawi. Ottawa/IDRC. Publication 167e, pp9-11.

Robles-Austriaco, L.; R.P. Pama and J Valls, 1981. Ferrocement for the Water Decade. J. of Ferrocement, Vol. 11, No. 3, pp229-245.

Rolloos, H. 1979. Tangki Air Hujan Bambusemen. (Bamboocement Rainwater Tank) - Institut Teknologi Bandung, Indonesia. 68p.

Romeo, C. 1982. A Water Quality Arguement for Rainwater Catchment Development in Belau. - Proc. Raiwater Cistern Systems Conf., June 1982, Honolulu. pp257-265.

Schiller, E.J. and B. Latham 1982. Computerized Methods in Optimizing Rainwater Catchment Systems. Proc. Raiwater Cistern Systems Conf., June 1982, Honolulu. pp92-101.

Schiller, E.J. 1982. Rooftop Rainwater Catchment Systems for Drinking Water Supply. In Water Supply and Sanitation in Developing Countries - Ann Arbour Science, pp85-100.

Sinclair, A. 1983. Domestic Water in N.Kitui : Practices, Problems and Potential. Unpublished Report. - Dept. of Geography, London School of Economics , 114p.

Sharpe, W.E. and E.S. Young, 1981. The Effects of Acid Precipitation on Water Quality in Roof Catchments Cistern Water Supplies. Proc. of Conf. on Effects of Acid Rain April 1-3, 1981. 24p.

Stenstrom, T. and B. de Jong, 1983. Botswana - Water Quality Surveillance Programme. Final Report (DRAFT), National Bacteriological Laboratory, S-105 21, Stockholm.

Thiadens, A. 1983 Catholic Diocese of Machakos Develelopment Office - Water Engineer Unpublished Internal Report. PO Box 640, Machakos, Kenya, 17p.

U.N., 1977. Country Report for Botswana. United Nations Water Conference. African Regional Meeting.

U.N.E.P. 1979. Rain and Stormwater Harvesting for Additional Water Supply in Rural Areas. Expert Group Meeting, Oct.30th-Nov. 2nd,1979. Nairobi. 30p.

U.N.E.P. 1983. Rain and Stormwater Harvesting in Rural Areas. Published for UNEP by Tycooly Int. Ltd., Dublin.

Waller, D.H. and D,V. Inman, 1982. Rainwater as an Alternative Source in Nova Scotia Proc. Raiwater Cistern Systems Conf., June 1982, Honolulu. pp. 202-209.

Vadhanavikkit, C. et al 1981. Roof Catchment (Thailand) Progress and Financial Report for the Period of July 1981 to December 1981, Faculty of Engineering, Khan Kaen University, Thailand.

Watt, S.B. 1978. Ferrocement Water Tanks and their Construction. IT Publications, 9, King St. London. 118p.

White, G.F., D.J. Bradley and A.U. White. 1972. Drawers of Water : Domestic Water Use in East Africa. Univ. of Chicago Press, 306p

Whiteside, M. 1982. How to Build a Water Catchment Tank. Mahalapye Development Trust (Botswana). Gaborone : Government Printers. 32p.

Wikner, T. 1980. Sand Rivers of Botswana A Reconaissance of the Major Sand Rivers. - Vol 1. Dept. of Water Affairs, Gaborone. S.I.D.A., S-105 25, Stockholm.

Wilson, B.H. 1978. A Mini Guide to the Water Resources of Botswana. Proc of the Symposium on Drought in Botswana. Ed : Hinchley, M.T. Publ. Clark Univ. Press. pp59-69

World Bank, 1980. World Bank Atlas. 1818H St., N.W./ Washington D.C. 24p.

APPENDIX 1

GLOSSARY 1

1. ALDEP - Arable Lands Development Programme. Ground catchment tanks built under this programme are referred to as Aldep tanks.
2. BAMB - Botswana Agricultural Marketing Board, marketing body for locally produced grain. BAMB owns a number of large warehouses in rural areas suitable for use as large scale roof catchment systems.
3. Bowser - Water tanker used for transporting domestic water supplies
4. Cattle Post Temporary dwelling where cattle are grazed in the rainy season (October to April).
5. Djabia - Kiswahili word which refers to traditional ground catchment systems constructed on the east coast of Africa using local coral, lime and sand.
6. Donga - refers to small ephemeral streams where water is often collected in the wet season.
7. Ferrocement - Low-cost cement technology based on plastering mortar on to chicken wire and reinforcing with fencing wire.
8. Ghala Basket - Low-cost rainwater catchment tank found predominently in Kenya, constructed by plastering mud and cement on a basket work frame.
9. Haffir - an excavated depression where water collects during wet periods.
10. IFPP - Integated Farming Pilot Project based at Pelotshetlha.
11. Lands Area - temporary dwelling place where arable agriculture is conducted during and immediately after the rainy season
12. Lolwapa - a Setswana word referring to the veranda area enclosed by mud walls in front of each hut, it also refers to the people residing in that compound.
13. Pan - a natural depression where water collects during wet periods.

APPENDIX 2

THE OTTAWA MODEL

The Ottawa Model like all other rainwater catchment tank sizing models, predicts future storage requirements on the basis of past rainfall data. The behaviour of the reservoir, based on past monthly rainfall data (preferably for at least 20 years), is modelled by the computer. Monthly inflows into the reservoir are matched with monthly outflows and the storage requirements needed to provide a constant level of supply (to satisfy some given demand) is determined. This is done through the identification of "critical periods" within the data, and the storage capacity needed to overcome the severest of these dry periods. The size of the storage requirement can also be determined for levels of reliability of supply of less than 100%. In arid and semi arid areas where rainfall is erratic, reducing the level of required reliability of supply from 100% to 95% can often lead to a major reduction in the storage requirement.

The calculation used in the Ottawa Model for determining the net addition or subtraction of rainwater to or from the tank lies midway between the "yield before spillage" method used by Grover(1971) based on the mass curve method (figure 1), and the "yield after spillage" method used by Jenkins et al.(1978), (figure 2) The effect of this is that the water demand is averaged over the month rather than being subtracted at the beginning ("yield before spillage") or end of the month ("yield after spillage"). A consequence of this is that the Ottawa Model reflects the results produced through the analysis of daily data more closely than the other methods, (Schiller and Latham , in press). This implies that it is probably the method which best mirrors reality.

A comparison of the Ottawa Model with the methods discussed in chapter 2, was conducted by Schiller and Latham(in press) using actual rainfall data for two stations and assuming a reliability of 98.3% (where applicable). The result of this comparison (figure 3) revealed that relative to the Ottawa Model Watt's and Keller's methods gave very low estimates

(After Latham 1983)

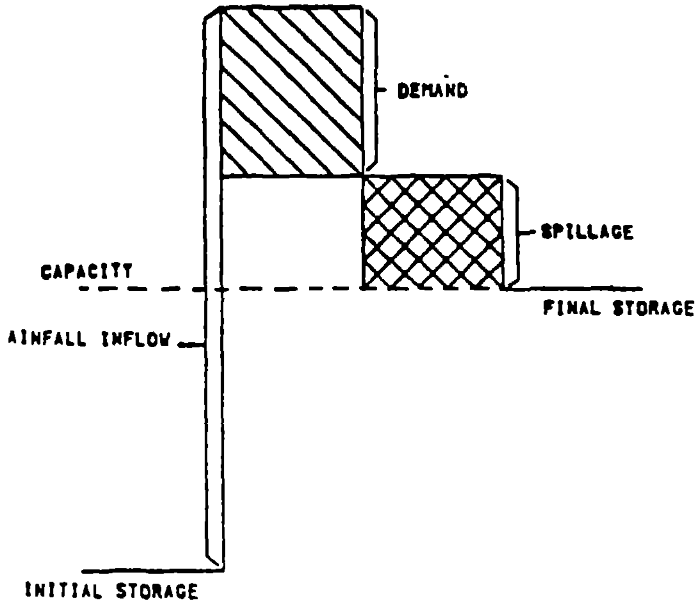

FIGURE 1 - Yield Before Spillage Calculation

(After Latham 1983)

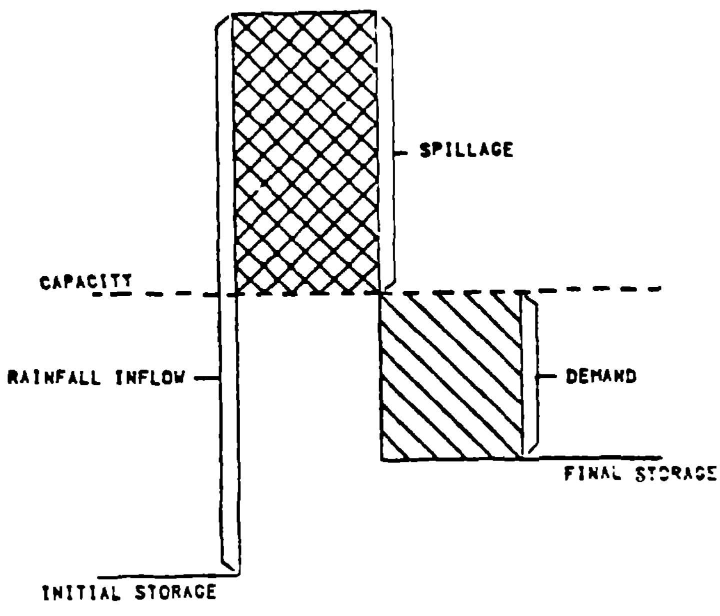

FIGURE 2 - Yield After Spillage Calculation

of required storage volumes, while Jenkins's method gave very high estimates. The mass curve method used by Grover also consistently gave high estimates of storage requirements but this was to be expected as it assumes 100% reliability, nevertheless, it still produced results closer to the Ottawa Model than Jenkins's method. Although, the probabilistic method used by Ree et al. gave a result close to the Ottawa Model, it was Perren's method which produced the closest similarity.

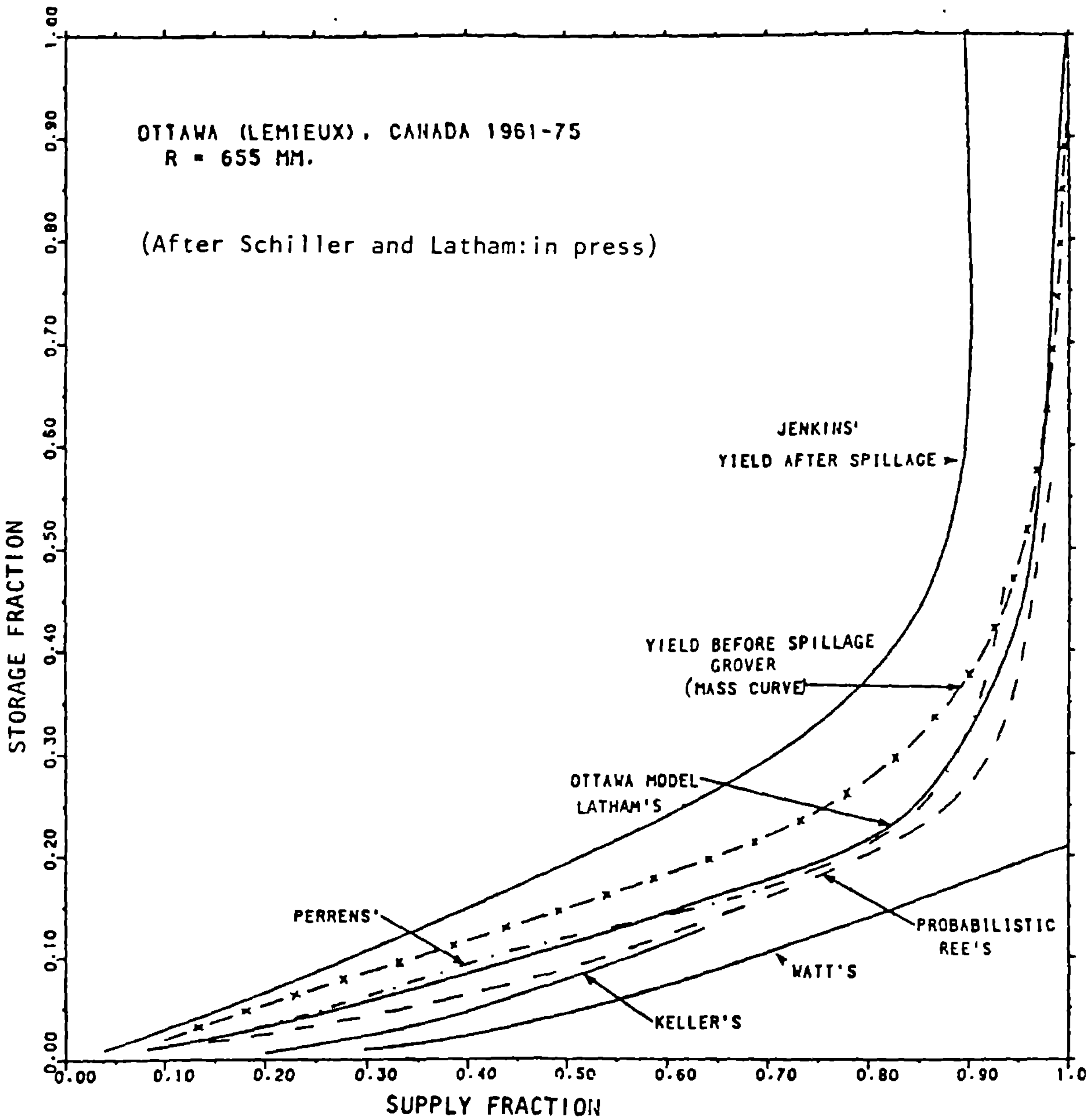

FIGURE 3. - Comparison of Rainwater Tank Sizing Models (using data from Ottawa (Lemieux), Canada 1961-1975)

APPENDIX 3

NUMBER ______

QUESTIONNAIRE

INTRODUCTORY GREETING : Hello , my name is John Gould , I am a graduate student from Canada , and am conducting research on water supply in Botswana as part of my studies.Please may I ask a few questions about your household and its water supply . I will try not to take up too much of your time. THANK YOU.

SECTION A

I) WATER SUPPLY.

1) Where do you get your water ? a) WET SEASON ______

b) DRY SEASON ______

2) How much do you fetch each day ? a) WET SEASON ______ l

b) DRY SEASON ______ l

3) What containers do you use for storing water ?

Capacity ______ l Condition ______

4) Do you consider the villages improved water supply to be :-

	YES	NO	DON'T KNOW
a) CLEAN AND HEALTHY	☐	☐	☐
b) WELL MAINTAINED	☐	☐	☐
c) CLOSE TO YOUR HOME	☐	☐	☐
d) TASTY	☐	☐	☐

5) Do you ever pay for water ? ___ ___ If so how much ? ___ t/l

6) a) Do you ever collect water from other sources ? ______

b) What are these ? ______

c) Why do you sometimes collect water from these sources ? ______

d) What do you use this water for ? ______

7) a) Does the improved water supply ever breakdown ? Yes ☐ No ☐

b) If so , how often ? ______

c) Why does it breakdown ? ______

8) What improvements could be made to the water supply ?

9) a) Do you ever use rainwater ? YES ☐ NO ☐

b) How do you collect it ? Buckets ☐ Oil drum ☐ Catchment Tank ☐ Other ☐

c) What do you use it for ? ______________________________

10) a) Do you consider rainwater to be a clean source ? YES ☐ NO ☐

b) Does it taste good ? ______________

11) What is the cost of a) Iron roofing sheet P_____

b) Storage containers 200l P_____

4500l P_____

FOR HOUSES WITHOUT IRON ROOFS

12) Have you ever considered getting a metal roof ?

Why did you decide not to get one ?

13) Do you ever collect water from your thatched roof ?

What do you use it for ?

II) ACTIVITIES

Now I would like to ask a few questions about how you use water.

	HOW OFTEN	WATER USED (litres)
1) Do you water a garden or fruit trees ?	_____	_____
2) Do you brew beer ?	_____	_____
3) How often do you smear the lolwapa ?	_____	_____
4) How often do you repair your huts ?	_____	_____
5) Where do the small livestock drink ?	_____	_____
6) Where do you wash your clothes ?	_____	_____

SECTION B FOR HOMES WITH METAL ROOFS.

		YES	NO
1) Have you ever considered buying	a) GUTTERS	☐	☐
	b) STORAGE CONTAINERS	☐	☐

2) How much do you think these would cost ? P ______

3) Could you afford this ?

4) Would you ever consider installing a rain water catchment tank ?

If not , why not ?

SECTION C FOR HOMES WITH METAL ROOFS, GUTTERS AND RAINWATER CATCHMENT TANKS

1) Are catchment tanks a) PERMANENT__ b) TEMPORARY__ c) VOLUME ______ l

2) When did you get a) GUTTERS________ b) STORAGE TANKS________

3) Who constructed them ?

4) What do you use rainwater for ?

5) What do you think is the greatest advantage of rainwater ?

6) Do you ever clean the storage tank ? YES ☐ NO ☐

If so , how often ?

7) In which months do you use rainwater ?

ANY OTHER RELEVANT INFORMATION ?

III) PERSONAL INFORMATION   Now I would like to ask a few general questions.

1) What is your position in the household ? ____

2) How many people are living in this compound at the moment ? ______
Children _____   Adults ____

3) What is the occupation of the head of the household ? ______________

4) For how long have you attended school ? ______________

5) Do any of your family live away from home ?

Where are they ? SCHOOL ☐ LANDS ☐ CATTLE POST ☐ FRANCISTOWN ☐
GABORONE ☐ SOUTH AFRICA ☐ OTHER ____________

6) How many cattle do you have ? __________

7) a) How many children have you had ?

b) How many are still alive ?

c) How many are living elsewhere ?

8) a) Are any of your family sick ?

b) What is wrong ?

c) Have any of your children ever suffered from diarrhoea or bilharzia ?

d) Have you been to the clinic ?

DO YOU HAVE ANY QUESTIONS ?

CATALOGUE OF WATER SOURCES

IMPROVED WATER SOURCES.

NUMBER :

TYPE : DATE OF INSTALLATION

% OPERATIONAL :

CONDITION :

QUALITY :

QUEUEING :

COST OF WATER :

MAINTENANCE :

UNIMPROVED WATER SOURCES.

TYPE :

CONDITION :

QUALITY :

FUNCTION : watering livestock _ washing _

drinking water _ washing clothes _

OTHER COMMENTS ON THE VILLAGE WATER SUPPLY :-

PUBLIC BUILDINGS

1) What is the building used for ? ______________

2) How many people use it ? ____________________

3) What water sources are used ? ______________

4) Does the building have a) Gutters ? ______________________________

b) Storage tanks ? ________________________

c) When were these built ? ______________

d) What condition are they in ? __________

5) Is rainwater collected ? ____________________

6) What is it used for ? ______________________

ANY ADDITIONAL INFORMATION ?

TECHNICAL FIELD SURVEY

HOUSEHOLD INFORMATION DATE :

1) Household No. _______

2) Area of the lolwapa ________ m²

3) Numbers of buildings a) THATCHED __
b) METAL ROOFED __
c) TOTAL __

4) Distance to nearest improved water source ____ m

5) Distance to nearest unimproved water source ___ m

6) Visible indicies of wealth a) CAR
b) DONKEY CART
c) BICYCLE OTHERS ?
d) RADIO
e) TRACTOR

7) Suitable rainwater catchment surfaces : AREA m²
a) NONE
b) THRESHING FLOOR
c) BARE ROCK
d) PART OF COMPOUND
e) OTHER

8) Type of latrine _________

9) General level of hygiene V.GOOD GOOD AVERAGE POOR V.POOR

OTHER INFORMATION ?

TECHNICAL FIELD SURVEY.

GENERAL INFORMATION

(I) VILLAGE

1) NAME :

2) LOCATION :

3) SIZE :

4) INFRASTRUCTURE :
   - a) Communications
   - b) Schools
   - c) Clinics
   - d) Administrative buildings
   - e) Roads
   - f) Electricity
   - g) Other

5) a) CLIMATE : b) SOILS :

6) a) HYDROLOGY : b) TOPOGRAPHY :

7) a) ETHNICITY : b) LANGUAGE :

8) TRADITIONAL ADMINISTRATIVE STRUCTURE :

   TRADITIONAL LEADERSHIP :

9) MODERN ADMINISTERATIVE STRUCTURE :

   MODERN LEADERSHIP :

10) ACCESS TO GOVERNMENT SERVICES :

11) ANY PREVIOUS COMMUNITY PROJECTS :

12) TRADITIONAL INSTITUTIONS :

a) Land Tenure

b) Inheritance Laws

c) Traditional Customs

d) Other

13) SOCIAL DIVISIONS

a) Political

b) Cultural

c) Ethnic

d) Other

14) a) Date on which first iron roof appeared in the village ______________

b) Number of metal roofs in the village in 1973 ______________

c) Number of metal roofs in the village in 1983 ______________

15) a) Number of threshing floors in the village ______

b) Mean Area ______ m^2

16) Other suitable rain catchment surfaces :

17) Other important information ?

HEALTH.

1) PREVALENT DISEASES :

2) HEALTH PROVISION :

3) INFANT MORTALITY :

4) WATER RELATED DISEASES :

5) VISIBLE HEALTH HAZARDS :

TECHNICAL INFORMATION

1) a) Number and type of water storage containers ____________

b) Approximate total storage volume __________________ l

c) Condition of the containers ____________________

2) Number and type of thatch roofed buildings in the compound ? a) LOOSE THATCH ___ b) TIGHT THATCH ___

3) FOR METAL ROOFED HOUSES ONLY

	ROOF 1	ROOF 2	ROOF 3	ROOF 4	ROOF 5
A) ROOF SHAPE					
B) ROOF TYPE					
C) ROOF AREA m^2					
D) LENGTH OF EAVES (m)					
F) LENGTH OF GUTTER (m)					
F) DOWNPIPE					

4) Is there any form of roof catchment tank? YES ☐ NO ☐

PERMANENT ☐ TEMPORARY ☐

VOLUME (m^3) ____

APPENDIX 4

A CASE STUDY OF THE VILLAGE OF NATA

It was not originally planned to include a case study in this thesis, however, Nata, one of the four villages visited as part of the questionnaire survey, proved such an interesting case that it was decided to focus special attention on the water situation in this village and the role which rainwater catchment might play in allieviating the serious water shortage there which results mainly from the highly saline nature of the groundwater in the area. It is important to realize that although Nata is not a typical village with regards to her water supply situation, the exceptional water shortage there is not a unique problem in Botswana. Other villages in the country (including Kang, Ramotswa, Orapa, Tsabong and Mopipi) suffer from saline groundwater supplies as do thousands of villages throughout Africa.

In areas with abundant clean water sources, rainwater catchment systems are unlikely to represent a feasible water supply method due to the high costs associated with them and the often somewhat limited supply they produce. However, in situations like Nata where all the various other water supply alternatives are either very expensive or not available at all, rainwater catchment systems may well have an increasingly important role to play in water supply provision in the near future.

DESCRIPTION OF THE VILLAGE

Nata is located 192km northwest of Francistown near the Makgadigadi Salt pans at lat. 20° 09'S and Long 26° 10'E. (see Figure 1.1). Although people have kept cattle in the area for centuries, the village itself is relatively new It was first established when a group of people came from Serowe and settled by the Nata River probably less than a hundred years ago. During the 1950's, Nata became the centre for the recruitment of mineworkers from northern Botswana, for work in the Witswaterrand and other mining areas in South Africa. Around 1950, Winala (Witswaterrand Native Labour) a mine labour recruitment company constructed

some barracks in Nata. These were the first large iron roofed buildings to be built in the village. A couple of smaller ones may have been built in the early 1940's on a trading store and private home. Since the 1950's the village has been growing rapidly from just a few hundred people to almost two thousand today. The number of corrugated iron roofed buildings, however, has been growing even faster than the population, and there are now almost one hundred in the village. Most of these are on government buildings or businesses, as the number of private households with corrugated roofs remains a small minority. Only 35 households out of a total of 280 had even a single iron roofed building in 1983.

Around the time of independence (1966) the Winala mining barracks was converted into a school and a number of new government and commercial buildings were constructed in the village. These included a tribal and government police station, a livestock advisory department office and a number of shops and trading stores. Since then, a host of additional buildings have been constructed including a public works department road construction camp, a number of government administrative offices, more shops, bars and bottle stores. Most recently a clinic and Botswana Agricultural Marketing Board warehouse have been built. Both the primary school and the police station have had a number of additional buildings added.

The visual character of Nata has changed dramatically over the last three decades, from one of a traditional African village uneffected by external influences, to a village now dominated by relatively large government and commercial buildings. Yet, despite this, more than 90% of the population still live in buildings of a traditional type. Traditional households vary considerably. Some may have ten or more large thatched huts with neat, tightly thatched roofs and large mud verandas('lolwapas'), all contained in a spacious fenced compound. At the other extreme a household containing ten people may be sharing a single hut, and in the case of one family who had recently moved to the village all nine members were still sleeping under the stars while constructing their first hut. On average a household would consist of 3 or 4 thatched huts in which the 6-7 family members would reside. Plates 6.1 and 6.2 show typical households in Nata.

Plate .1 ...A Typical Household in Nata

Plate .2 ...Humans and Livestock Sharing Contaminated Nata River Water

HEALTH, WEALTH, EMPLOYMENT AND EDUCATION

Health

The effects of exposure to the extremely poor quality water of the Nata River (the only main source) by almost the whole village seems to be reflected by the indicies and statistics relating to the health of the community. Although the death rate for the region is recorded as 11 per 1000 per year according to the 1981 census, for Nata itself it was 20 per 1000 per year. The incidence of reported cases of diarrhoea for the village is 4.3 cases per 1000 patients per week which is more than twice the average for the other health centres in the area (Egil Bovin, personal communication 1983)[19] According to Sister Motswenyane at Nata Clinic the most prevelant diseases in the village were gonorrhea, diarrhoea and tuberculosis, but coughing, skin and eye infections, alcoholism and bilharzia (schistosomiasis) are also problems. On average about 2 cases of bilharzia are reported per week compared with around 10 cases of diarrhoea per day. This ties in well with the results of the questionnaire survey in which 44% of the heads of households stated that members of the family had suffered from diarrhoea and 6% from bilharzia. Sister Motswenyane also noted that outbreaks of diarrhoea and gastroenteritis sometimes occur, when the water in the river becomes particularly contaminated. The lack of latrines in Nata (18%) and the use of the bush in general, and the river banks in particular for defecation make the spread of such waterborne diseases extremely likely, especially following periods of rain. The family welfare educator stated that most infants die because of "diarrhoea and vomitting", and although she advises mothers to boil drinking water, virtually noi one does, herself included, due to the long walk involved in fetching firewood.

Wealth

The traditional sign of wealth in Botswana is cattle and although they now outnumber people by 3 to 1 their ownership is very unequally distributed. In Nata the mean number of

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[19]Dr. Bovin is the Regional Medical Officer for the area.

cattle per household was 21, yet more than 50% of the households owned no cattle. It was the ownership of large herds some in excess of 300 head by a few wealthy individuals which accounted for the seemingly high average. Wealth through cattle ownership was not always reflected by other indicies of wealth such as the ownership of a car, radio or a metal roofed building. The general lack of these in Nata compared to the other study villages are indicative of a poor and traditional village. The poorest people in Nata are newly arrived residents forced to the village by the drought. Most are establishing homes on the edge of the village. For many of these households annual per capita incomes are unlikely to exceed P133 (US$100) per year and in some cases far less.

Employment

Very few people in Nata have permanent employment, most do some farming but due to the drought being experienced before and during the study there was nothing that could be done on the lands. Of the questionnaire respondents 32% stated farming as their main occupation although 44% of these owned no cattle. The drought made them temporily unemployed. Among the sample 16% had no job at all, while 8% said they did occasional piecework such as unloading sacks of grain at the Botswana Agricultural Marketing Board depot, cutting grass or fetching water and firewood for other people. 20% were employed either directly or indirectly by the government as teachers, police officers, cleaners, drivers etc... Other employment included owning or working in shops or bars, selling "khadi" (traditional beer) and "fatty cakes" scones, making bricks and wooden doors, basket weaving and thatching. Hunting for animal skins, the collection of crystalline salt from the river bed and a series of miscellaneous occupations represented other sources of income.

Education

Although 36% of the heads of households had never attended school, the average period of attendence was 4.4 years. At the present time the children of Nata are better formally

educated than their parents as most attend the local primary school which has 430 pupils enrolled. Only 10% of those interviewed had recieved any secondary education and most spoke no English. Although a family welfare educator worked full time to promote hygiene education and sanitary practices, most people either did not appear to be well informed on these issues or did not seem to be applying what they knew.

The Drought and Population Growth

The population of Nata is growing at an unprecedented rate. Since 1978 the village has more than doubled in size, growing on average at 14% per annum. The natural population increase for the village is only 2.1% according to the 1981 census and the balance is made up by a large influx of people into the village from surrounding areas. This massive in migration has been exacerbated by the recent drought and forced the growth rate of the village up to almost 20% per annum since 1981 when the census recorded 1303 residents in the village. At the time of the present study's survey (July 1983) the population was estimated at 1850. At that time the village was visibly growing with new compounds being cleared and huts erected almost daily A comparison with a 1978 areal photograph of the village showed a dramatic change.

The majority of those people moving into Nata are Basawa, these are the tribal group who originally inhabited this area and are sometimes referred to as Bushmen. Very few are still living an exclusively hunter-gatherer existance and there has been much intermarriage with the Tswana and Kalanga people, who now employ many Basawa to look after their cattle. The drought forced some of the Basawa in the region to move to Nata due to lack of employment elsewhere , as well as the existance of water at the river and some casual employment opportunities. The government has also attempted a series of job creation schemes as part of their drought relief program. Women are employed to pound sorghum at the primary school for P0.8 (US$ 0.6) per day.

THE PRESENT WATER SUPPLY PROBLEM

The main factor causing the curent water supply problem is the fact that the groundwater in the whole region is extremely saline. This is due in part to the location of Nata relative to the Makgadigadi Salt pans. Only one borehole is currently operating in the village and this is supplying water to the police station for flushing toilets and washing. This water was recently tested by the Department of Water Affairs who found it to have total dissolved solids (T.D.S.) in excess of 22,000mg/l. The police officers complain that it rusts the dishes and irritates the skin. The WHO maximum acceptable T.D.S. limit is 1500mg/l, although water starts tasting salty at around 1000mg/l.

The vast majority of people in the village depend on the river as their major source In the wet season water is collected directly, in the dry season even though there is normally some open water remaining in the river itself, people prefer to dig shallow pits in the river bed from which they draw slightly cleaner water. Nevertheless, the quality of the water from both sources is extremely poor and bacteriological analysis results indicated faecal and total coliform colonies in numbers too numerous to count. Plate 6.2 gives an indication of the contaminated nature of the river and shows how the source is shared by both man and animals. In an effort to improve the water situation in Nata the District Council has arranged for a bowser to collect fresh borehole water from Zoroga 43km away (Plate 6.3). However, the 5000 litre tractor and bowser are generally unable to make more than a single round trip per day. In addition to this breakdowns are not uncommon. Thus the supply of somewhat less than 5000 litres per day is normally delivered and poured into a 100m^3 subsurface concrete rainwater catchment tank which was built by Winala to collect water from the roof of the old mining barracks, now the primary school. A robust rotary pump supplies water from this tank to any villagers who have paid the P0.25 (US$ 0.20) per month fee. However, as can be seen from plate 6.3, queueing is a major problem and the bowser supply quickly runs out with more than 1000 people collecting what they can get from the 5000 litre supply. Almost everybody who uses water brought by the bowser, also uses river water, consequently all the health benefits which the expensive

transported water (P20/m^3 = US$ 15/m^3) are intended to bring are lost when people are forced to revert to the river water supply. When bacteriological analysis was conducted on the transported water being stored in the school catchment tank it was found to have a faecal coliform count of 29 on one occassion and 700 on another. Both these results indicate serious contamination, and while still better than the river water the supply requires immediate chlorination.

Other sources of water used by the residents include: 1) Open pools which form in some dugouts near the village in the rainy season, 2) Transported borehole water which a few private individuals and the police have collected for their own use from Dukwe more than 50km south of Nata, 3) Roof catchment systems.

EXISTING RAINWATER CATCHMENT SYSTEMS

Due to the lack of good quality fresh water in Nata, the collection of rainwater from corrugated iron roofs is restricted to government buildings and even on these the systems are often inefficient with only some of the roof area being served by gutters and storage tanks generally being undersized. The total existing corrugated iron roof area in Nata is 6767m^2 having a mean annual runoff of about 2700m^3. Yet, the functional rainwater catchment tank volume is only 230m^3, of which 212m^3 are on government buildings. Even this is not supplying the full 350m^3 per year which it has the potential to provide, due to leaky gutters. At the primary school the gutters supplying the 100m^3 ground tank are badly in need of repair, and the smaller roof tanks installed in the 1950's are also all leaking. The existing roof catchment systems are only serving around 40% of the existing iron roofed area in the village and even here it is often with inappropriately sized tanks, (plate 6.5). In some instances such as at the Whole Sale Centre gutters and downpipes already existed but a tank was absent, plate 6.6.

Plate 3 ...Bowser Used for Bringing Freshwater to Nata

Plate .4 . .Queueing for Limited Supply of Clean Freshwater at Nata Primary School

SCHEME FOR A POTENTIAL RAINWATER CATCHMENT SUPPLY

The current rate of domestic water consumption in Nata is 19litres/capita per day, this is equivalent to about 12,830,000 litres/year for the whole village. In order to supply this through the direct collection of rainwater a catchment area of 32,075 m^2 would be required. This is almost five times the present corrugated iron roof area of the entire village. Although the additional catchment area needed could be constructed it would be extremely expensive and would not be economically competative with other alternatives.

Among the alternatives which have been considered are the construction of a desalination plant in Nata This would necessitate the importation of high cost, high technology equipment from Belgium (or elsewhere).

The high recurrent costs, uncertain supply of spare parts and lack of locally available skills for repairing such equipment would suggest that this alternative is technically inappropriate to the situation. Another alternative is the construction of a pipeline from Dukwe, 50km to the south or some other high yielding borehole as close to Nata as possible. Due to the fact that the nearest known fresh groundwater is 35km from Nata, even if a good borehole was discovered here it would be an extremely expensive project piping the water and would probably require booster stations as there is little opportunity to use gravity supply due to the very flat terraine in the region. It is likely that such a project would cost several hundred thousand pula, more than twice that of a conventional reticulated supply for a village of this size.

Ultimately, however, piped water will probably come to Nata, particularly if the village continues to grow at the current phenomenal rate. At the present time it seems unlikely that such a development will take place within the next five years due to technical problems such as locating a suitable reliable high quality groundwater source and also due to administrative and bureaucratic delays. Even when the pipeline is constructed it is envisaged that breakdowns could be quite frequent. In the absence of any alternative source people will return to their traditional unimproved water source at such times and the benefits accrued from the improved supply will

be lost.

The possibility of constructing large roof catchment tanks on a number of sizable roofs on public buildings which are as yet unserviced, as well as two rainwater harvesters could provide Nata with a clean "drinking water only" supply within less than a year at only a moderate cost. If at some time in the future a pipeline is built the roof and rainwater harvester tanks would provide an excellent reserve supply which the villagers could use instead of reverting to the river for their drinking water.

It is thus suggested that large ferrocement roof tanks be constructed at the clinic, police station and government administrative buildings and that one of the rainwater harvesters be constructed at the Botswana Agricultural Marketing Board site. These are all government buildings so it would not be difficult for a government run project to use these sites and make the water available to the community.

The Botswana Agricultural Marketing Board site forms an ideal location for a rainwater catchment system. The 5000m^2 site is already fenced and already has more than 600m^2 of clean corrugated iron roof area which is only being partially used for rainwater collection. A large sloping expanse of unused ground within the fenced area if cemented over could provide an ideal catchment surface for a large subsurface tank constructed at one corner of the site. Figure 6.1 shows the site as it is at present and Figure 6.2 illustrates how it could be if the proposed rainwater havester was constructed. A similar but somewhat smaller harvester with no roof catchment component could be constructed opposite the primary school in the large unused area in the centre of the village. The 1600m^2 catchment area and 400m^3 covered excavated tank would have to be fenced off. A handpump with access from outside the fenced area at this tank and at the 600m^3 tank at the Botswana Agricultural Marketing Board would provide the general public with its two main improved water points. A third communal water point would be a tap at a 75m^3 roof tank to be constructed at the primary school, also with access from outside the school fence, this smallest tank might be kept in reserve for times of severe shortage.

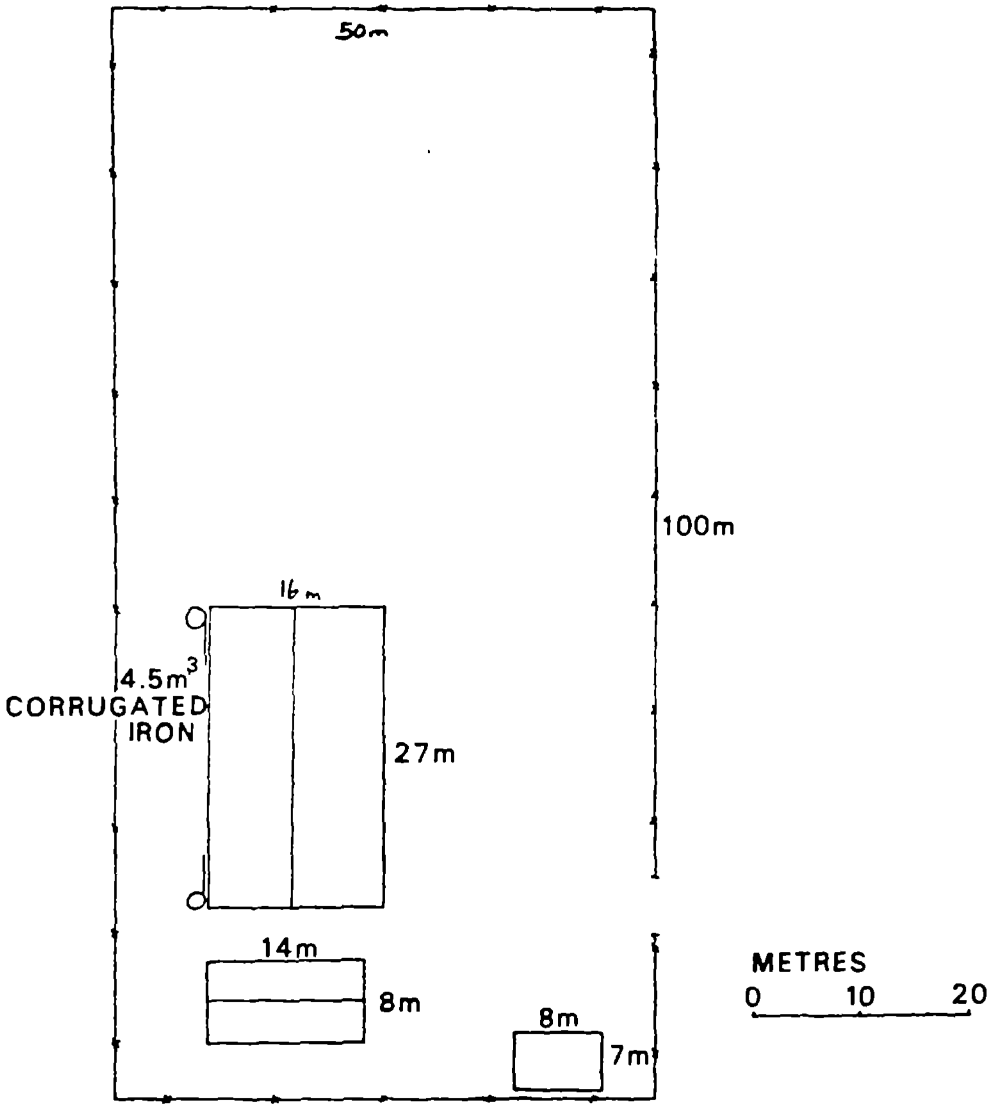

Figure 1 ......The Botswana Agricultural Marketing Board Site, Nata

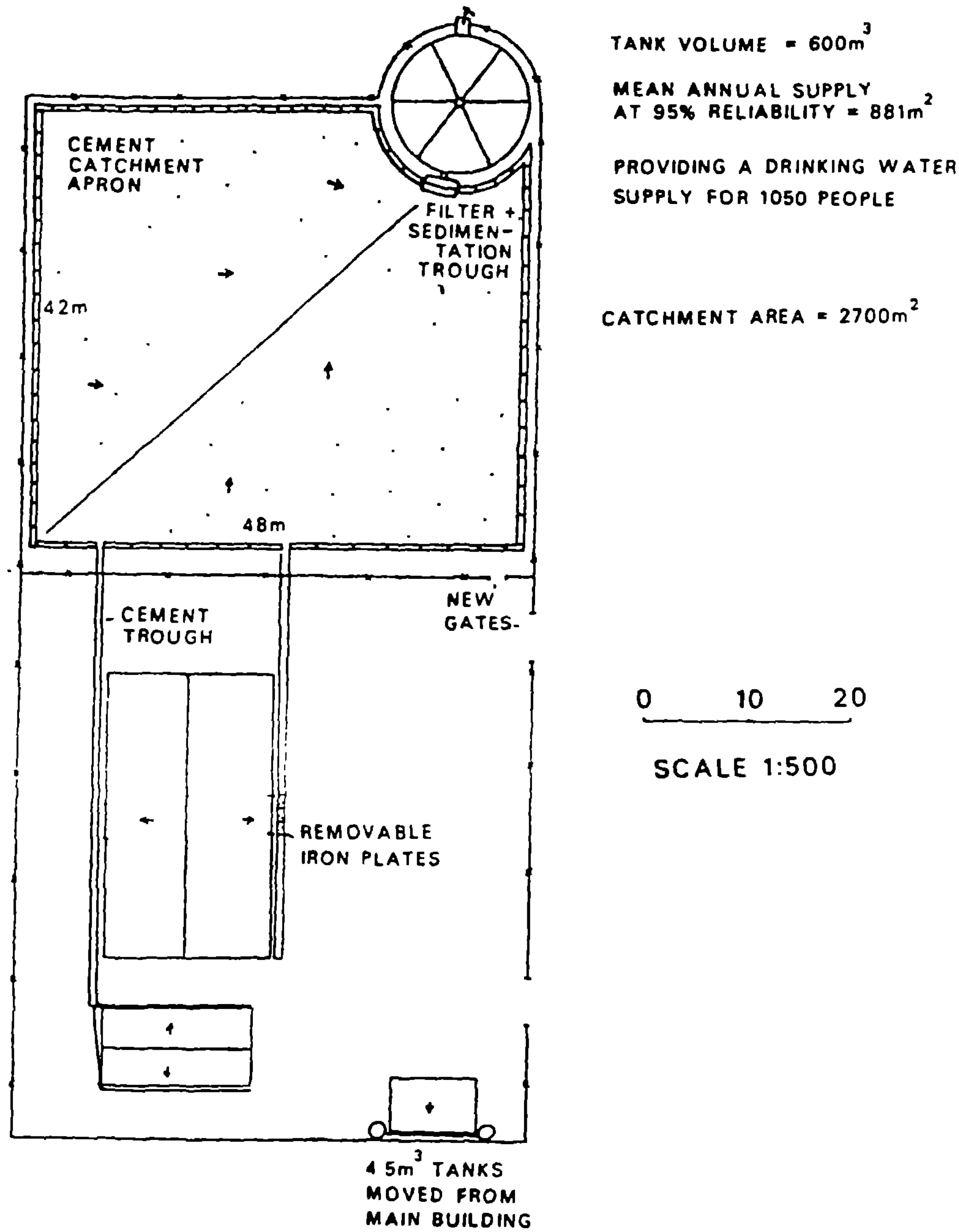

Figure 2 ......The Botswana Agricultural Marketing Board Site After the Construction of the Proposed Harvester

The yield of these three tanks has been calculated using the approach discussed in chapter 4, as being 1575m³ per year with a reliability of 95%. What this effectively means is that at least 1575m³ will be supplied for 95% of the time assumming a constant rate of withdrawal, or that for 5% of the time the tank will empty. This would occur during times of severe drought and could be avoided altogether if tighter rationing of the supplies was introduced during periods of water shortage.

If a ration of 2.5 litres of drinking water per capita per day was provided the three tanks could provide drinking water for 1725 people. Although this is not equivalent to the entire population of the village, about 50 people already have access to their own private rainwater supplies. If additional roof tanks were built at the police station, land board, public works department depot and other government buildings for the use of those who work there and their families and if private individuals owning homes, shops or businesses with corrugated iron roofs could be encouraged possibly through some loan subsidy scheme to erect their own catchment tanks, then the communal supply would easily suffice for the remainer of the village and would even allow for some increase in the numbers using the supply.

The large existing 100m³ tank at the primary school needs its gutters repaired and could then be reserved for exclusive use by the school. Roof tanks constructed at the clinic should also be reserved for the exclusive use of the medical staff and patients.

Construction, Operation and Maintenance

The possibility of constructing the rainwater harvester proposed here was investigated by the Botswana Technology Centre in 1983. Professional drawings and costings were carried out by the Bamalete Builders Brigade of Ramotswa (Hartkoorn, personal communication 1983) and are available from them or the Botswana Technology Centre[20]. The price of the materials for the main 600m³ tank and apron at the Botswana Agricultural Marketing Board site would be around P 25,000 (US$19,500) and P 20,000 (US$ 15,000) for the 400 m³ tank and catchment

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[20]Adri Hartkoorn, Architect, Bamalete Builders Brigade, PO. Box 99, Ramotswa.

apron. In addition to this approximately P4000 (US$ 3000) would be required for the communal roof tank to be constructed at the primary school. However, on top of this P50,000 (US$ 7,500) required for materials, an additional 101% would need to be added for labour (40%), transport (30%), profit and contingencies (15%) if the construction were to be contracted out. These components being accumulatively added making the total cost P100,500 (US$ 75,375).

This price could be considerably reduced if the government itself took on the project and covered some of these additional costs indirectly. This could be done by using central transport organization (CTO) or department of water affairs vehicles and drivers for reducing transportation costs and using government personnel and drought relief labour for reducing labour costs. Funds already exist for paying for labour for self-help projects of this kind through the drought relief program and labour based relief project . A further incentive to attract cheap or voluntary labour for the extensive excavation work which needs to be done, would be to offer free water to every household who contributes labour towards the project. A small fee would be levied on households who use the supply but did not contribute to the project , so those wealthier households unwilling to contribute labour for the construction of the scheme would at least be providing money to assist in paying for the running of the scheme. This should be paid annually in advance.

This approach to the project apart from reducing the direct total cost considerably also has a number of other beneficial aspects associated with it. The direct involvement of the community in the project, especially if they are consulted and included in the planning and construction right from the start, will both familiarize the people with the technology, give them the feeling it belongs to them and thus make the chances of it being operated and maintained much higher This community participation approach should have other aspects to it. Locally made bricks currently produced in Nata should be used for the project even if they are slightly more expensive than commercially produced ones from Francistown. The maximization of the use of local labour and materials will result in a significant proportion of

the cost of the project being poured back into the community.

One of the major obstacles which needs to be overcome for the successful operation of the project, is how to ration the supply effectively. It would be necessary to employ two tank attentents who would be responsible for the distribution of water and the regular cleaning, maintenance and general upkeep of the systems. The attendents would have keys to the pumps in the tanks and would issue water daily for about 1-2 hours before dusk. Sheets with all of the households eligible to use the supply would be used to check that people do not take more than one bucket per household per day. As the mean household size is 6.5 and 2.5 litres per capita is the drinking water ration available, the only workable means to operate the system is to allow each household to have one 15 litre bucket of drinking water per day. The tank attendent should remind people to cover the bucket at home and to use a clean recepticle when drinking the water. The family welfare educator should check that this is being done. The employment of tank attendents would also create two new jobs in the community, these would be part time government appointments and although not highly paid a bonus should be given monthly, if the rationing and upkeep of the supply is done properly. This would be the only major recurrent cost of the project, probably around P1000 per year with a further P1000 for maintenance.

The tanks should be visited by a local water technician monthly and checked, at these times the supplies should chlorinated using a standard hypochlorite compound. A water sample should be taken and analysed at least once or twice a year.

The total capital cost of all the roof tanks and rainwater harvesters needed for the water supply for Nata would amount to around than P100,000 (US$ 75,000) excluding the use of a few government vehicles, a government engineer, masons and foremen. Recurrent costs are unlikely to exceed P2000 for at least the first 5-10 years after the completion of the project. The daily supply would be approximately 5000 litres which is equivalent to that currently being brought by bowser. However, the recurrent cost alone of the transported water supply is P35,000 per year. When this is compared with the cost of the proposed rainwater supply it can be seen that this could pay for itself within three years. Moreover, the reliability of this supply

would probably be greater as the bowser certainly operates less than 95% of the time and the quality of rainwater if chlorinated regularly would be much better than that currently obtained due to contamination of the water in the storage tank at the school, plate 6.4.

If piped water does arrive in the village within a few years it is likely the rainwater catchment scheme will have already paid for itself and even if it hadn't rainwater catchment tanks could double as storage tanks required for the reticulated supply thus saving the expense of constructing these in future and also ensuring that the tank is always topped up in case the stored water is required during a period when the piped supply is not functioning. One problem that is envisaged as a result of the suggested scheme is that more people may be attracted to Nata. Nevertheless, this problem should be off set at some point in the future by the arrival of piped water in the village.

The rainwater harvesters described in this chapter are similar to ones designed by Grover(1971) and recorded by McPherson et al.(1984) on the coast of Kenya. However, no case of such a technology being used in a semi-arid environment is known of in Africa or elsewhere. If implemented the project in Nata would represent a prototype for this technology in semi-arid environments which if successful might have wide application in other areas where non-existant or contaminated surface and groundwater supplies make the direct collection, storage and use of rainwater a feasible option as a limited water supply.

THE BOTSWANA
TECHNOLOGY CENTRE

PRIVATE BAG 0082
GABORONE BOTSWANA
TELEPHONE 52488
TELEX 2319 BRE TP BD
CABLES ADDRESS DEVELOP

29 August 1983

Rainwater Catchment Survey - PRIMARY SCHOOLS

Index of Replies

KGALAGADI DISTRICT

1.	Khuis	P.O. Middlepits
2.	Kisa	P/Bag 5 Tsabong
3.	Kolonkwaneng	P.O. Middlepits
4.	Lehututu	P.O. Box 36 Hukuntsi
5.	Lokgwabe	P/Bag 1 Hukuntsi
6.	Mosiiwa	P.O. Box 5 Hukuntsi
7.	O inaweneno	P/Bag 5 Tsabong
8.	Tsabong	P.O. Box 19 Tsabong
9.	Tshane	P.O. Box 19 Tshane

SOUTH EAST DISTRICT

10.	Botsalano, Tlokweng	P.O. Box X04 Gaborone
11.	Magopane, Ramotswa	P.O. Box 100 Ramotswa
12.	Otse	P.O. Box 11 Otse

GABORONE

13.	Camp, Gaborone	P.O. Box 10011

KWENENG DISTRICT

14.	Canon Gordon, Molepolole.	P.O. Box 38 Molepolole

KGATLENG DISTRICT

15.	Seingwaeng, Mochudi.	P.O. Box 257 Mochudi

NORTH EAST

38.	Gainbule, Tshesebe	P.O. Masanga Francistown
39.	Gulubane	P.O. Box 218, Francistown
40.	Jackalasi // 1	P.O. Bo Rainokgwabana Francistown
41.	Jackalasi // 2	Bisoli Siding via Francistown
42.	Kalakainati	Shashe Drift via Francistown
43.	Kgari	P.O. Box 18, Rainokgwebana
44.	Letsholathebe	P.O. Masunga, Francistown
45.	Makaleng	P/Bag Makaleng, Francistown
46.	Masokwane	P.O. Box 38 Tshesebe
47.	Masunga	P.O. Masunga, Francistown
48.	Moroka	P.O. Rainokgwabane, Francistown
49.	Sechele	P/Bag Makaleng Francistown
50.	Sekakangwe	P.O. Tshesebe, Francistown
51.	Siviya	P/Bag 006 Francistown
52.	Tati Siding	P/Bag 1 Tatitown
53.	Theinashanga	P.O. Box 2 Tshesebe
54.	Tsainaya	P/Bag F8 Francistown
55.	Zwenshainbe	P.O. Tshesebe Francistown

NORTH WEST

56.	Bodibeng	P/Bag 3 Sehithwa
57.	Goinare	P/Bag 9 Goinare
58.	Habu	P.O. Box 80 Maun
59.	Ikoga	P.O. Box 80 Maun
60.	Kayiinba	P/Bag 12 Kasane
61.	Kazungula	P.O. Box 20 Kasane
62.	Moreini III Maun	P.O. Box 31 Maun
63.	Nxamasere	c/o Box 80 Maun
64.	Seronga	P.O. Box 2 Seronga

CENTRAL DISTRICT

16.	Chakaloba, Topisi.	P/Bag 9 Palapye
17.	Kukubjwe	P.O Lerala
18.	Lerala	P.O. Box 5 Lerala
19.	Minashoro	P/Bag 8 Serowe
20.	Newtown, Serowe	P.O. Box 63 Serowe
21.	Ratholo	P.O. Box 19 Moeng
22.	Sebeso, Palapye	P.O. Box 14 Palapye
23.	Serule	P.O. Box 9 Serule
24.	Swaneng, Serowe	P.O. Box 101 Serowe
25.	Tshiinoyapula	Postal Agency via Serowe

Bobirwa Sub-District

26.	Mathathane	P/Bag 3 Bobonong
27.	Maunatlala	Postal Agency via Palapye

Boteti Sub-District

28.	Kedia	C/o P/Bag 5 Letlhakane
29.	Mokubilo	P/Bag 23 Mokubilo

Mahalapye Sub - District

30.	Frederick Mahero, Mahalapye.		P.O. Box 269 Mahalapye
31.	Leetile	Mahalapye	P.O. Box 92 Mahalapye
32.	St Janes	Mahalapye	P.O. Box 14 Mahalapye
33.	St Patricks	Mahalapye	P.O. Box 72 Mahalapye
34.	Tshikyega	Mahalapye	P.O. Box 799 Mahalapye
35.	Two Rivers,	Sherwood Ranch	P/Bag 33 Sherwood Ranch
36.	Xhosa School,	Mahalapye	P.O. Box 920

Tutume Sub - District

37.	Nata	P/Bag Francistown

APPENDIX 6

SUB-SURFACE RAINWATER CATCHMENT TANK SURVEY

DISTRICT: LOCATION OF TANK: Village- Lands area- Cattle post-

Agency responsible: ALDEP ☐ Private ☐ Other ☐

Type of tank: Ferro-cement ☐ Brick-cement ☐ Other ☐

Date of construction ______

Condition of tank:

Approximate capacity of tank ____ m^3 Volume of water in the tank ___ m^3

Type of cover 1) corrugated iron 2) cement 3) none 4) other

CATCHMENT APRON:

Type....1) Natural 2) Theshing floor 3) Cement 4) Other

Area of apron ___m^2 Condition of apron- (Dung used ?) (Is it fenced?)

USES OF STORED RAINWATER: Drinking, Domestic, Watering cattle, Irrigation, Others

Number of people ___ / cattle ____ relying on the source.

Approximate rate of withdrawal _____ litres/day

Estimated distance to nearest alternative source _________ km
Type of source

APPROXIMATE COST OF THE TANK - P .... Details ?

Arrangement for the purchase of tank: Free demonstration
Grant
Loan
Other

Occupation of tank owner ___________ Indicies of wealth:

Was stored rainwater used to water oxen before ploughing ?

Was this supplemented with any crop residue or other feed?

If so , was crop yield any higher ?

ANY GENERAL COMMENTS :-

Sketch of tank.... P.T.O.

BAMALETE/ TLOKWENG	10	10	-	Domestic consumption Watering calves & sheep	1) Due to poor construction insects etc ... get under cover.
I.F.P.P.	74	72 IFPP Pilot	2	Domestic consumption	1) A few cases of cracking experienced.
NGWAKETSE NORTH	18	15	3	Domestic consumption	1) Some tank leaking as farmers dug holes extremely deep 2) Agriculture Dept. has to transport water to lands for tank construction.
NGWAKETSE SOUTH	15	15	-	Domestic consumption	1) Cracking & leaking has occurred with 3 tanks 2) No water for tank construction at the lands 3) Builders demanding exhorbitant price.
BAROLONG	19	14	5	Domestic	1) Frogs/Lizards/insects have fallen into tanks 2) Several tanks have slow leaks 3) Only one tank fenced
TOTAL	312	217	95		

APPENDIX 8

In deciding which communities should be given the highest priority in terms of assistance with construction of these large rainwater tanks a set of criteria should be adopted. These would relate to the reliability, quality and distance to existing sources. Thus a village with poor quality, unreliable or very distant water sources, would be given highest priority.
The criteria would include:

1) Distance to the nearest alternative improved source

  a) - less than 400m

  b) - 400m - 1000m

  c) - more than 1000m

2) Nature of available improved supply

  a) - fresh

  b) - saline but drinkable

  c) - saline and undrinkable

3) Reliability of improved supply

  a) - reliable

  b) - only moderately reliable (several breakdowns per year)

  c) - unreliable