

VICTORIA UNIVERSITY OF MANCHESTER

FACULTY OF TECHNOLOGY

ASPECTS OF WATER SUPPLY AND CONSERVATION
IN SOME SEMI-ARID PARTS OF AFRICA

A Thesis presented for the Degree
of
Doctor of Philosophy
by

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P R E F A C E

The seeds of this thesis were sown in 1969 when I was engaged on quite separate research work in the Department of History of Science and Technology at U.M.I.S.T., and originated in discussions involving Dr. Arnold Pacey (my supervisor at the time), members of the Intermediate Technology Development^{Group} Ltd. (I.T.D.G.) of London, and myself. The intention at that time was to consider extending the scope of history of technology so that it embraced present day technological developments in countries which have now come to be known as the Third World. One area of study suggested by I.T.D.G. was water supplies, and in particular, the development of a reliable, cheap hand-pump for use with the I.T.D.G. catchment tank programme in Swaziland.

A proposal for a research programme which included this basis, and an extended study of water supply and conservation in southern Africa, involving fieldwork, was presented to the Joseph Rowntree Social Service Trust which agreed to support the project. I am especially grateful to the Trustees for providing the funds, and to Arnold Pacey for helping with the arrangements for the grant. My thanks are also due to the Trustees of the Dorothy and Edward Cadbury Trust for providing a bridging grant before the formal start of research in April 1971.

The work has been carried out in the Department of Civil Engineering at U.M.I.S.T. I would like to thank Professor A.N. Schofield for making available the facilities of the Department, and for the personal interest he has shown in the work.

At the start of the project, considerable attention was devoted to the design of an appropriate hand pump. The conclusion reached was that the most suitable for low lifts was a diaphragm pump. But partly for reasons explained in Chapter 1, it was felt to be unrealistic to continue with this work in isolation when so little was known in general about the water supplies and communities for which such a pump would be of use. Thus, one criticism of the "intermediate technology" approach, as originally formulated, is that it saw the problems of development in terms of individual pieces of "hardware" without properly considering how they could be integrated into an overall system. A more suitable term which includes this condition is "appropriate technology".

Consequently, the direction of the project changed to consider the complete sub-system of water supplies within rural communities of semi-arid parts of southern Africa. This approach required a much

broader outlook. As well as considering such items as the quantities of water people use, the distances water is carried, and what qualities are preferred, it required investigations into the social and local political systems of these communities - what sort of improvements in water supply can be anticipated in terms of capital and skills available, and what are the likely consequences. It also required identifying the deficiencies of current water supply technology, and considering what technology is appropriate for semi-arid rural communities.

Such a task is enormous and it could not all be dealt with in depth in one thesis, but a broad approach is necessary and more suited to the needs of developing countries, rather than the very specific approach more familiar to those in engineering departments.

When the work started, very little published information existed on the topics mentioned above. But, as pointed out in Chapter 1, following the declared intention of such countries as Tanzania and Kenya to devote more resources to rural development and water supplies in particular, there has been an awakening of interest in these questions. There are now a few important works which have helped to present in a coherent form much of the miscellaneous information on water supplies and rural development (e.g. Carruthers 1973c). These sources of information will be referred to frequently in the thesis, and a recent paper presented to the Lausanne Seminar (White & Seviour 1973) is a bibliography of much of the current information on rural water supplies in developing countries. However, these sources provide little about the form of water supply technology in these societies, and this thesis attempts to make good this shortcoming.

Apart from these sources, background information for this thesis has been gleaned from a variety of engineering and other professional journals (which tend to emphasise the large-scale, urban developments), and from miscellaneous government and official reports. But, as will become apparent, other major sources of information have been conversations with government officials, field-workers of various aid agencies etc., and people living in the rural communities studied.

In order that the work would not be too diffuse, a particular study was made of a community in the semi-arid Lowveld of Swaziland. This country was chosen for the fieldwork because of I.T.D.G. contacts there. In fact, it was a most apposite choice, for Swaziland exhibits many of the characteristics of developing countries, but it is small enough to be taken as a whole. It also proved to be most enjoyable place

for the fieldwork. Two visits were made; one from March to June 1972 which was followed by a visit to Botswana, and a second visit in August 1973. Before this, a series of short visits during July to Kenya, Tanzania and Malawi were made, the object of which was to obtain comparative information and further background material.

During the first Swaziland visit, the pumping problem was still under serious consideration. Two diaphragm hand pumps of British manufacture were taken there for trials with the I.T.D.G./Swaziland Government catchment programme. Both proved successful and superior to the semi-rotary pumps in current use.

The most important part of the first visit was the period of living in the rural community of Mpolonjeni from the 5th - 13th June 1972. Arnold Pacey collaborated with this fieldwork, and we are grateful to Mr. Aaron Zwane, Permanent Secretary of the Ministry of Local Administration, and to members of the Community Development Department for arranging the stay at Mpolonjeni.

For the second visit to Swaziland, my wife was able to accompany me and assist with a more thorough examination of the water sources in and around Mpolonjeni.

During both periods in Africa, I met many helpful people and made many friends, and I regard myself fortunate that this work has given me the opportunity of travelling to Africa and broadening my education. I would like to thank for their help and friendship during the fieldwork at Mpolonjeni, Mr. Absalom Langwenya, headmaster of Siphoso Community School, Mpolonjeni, and Mr. Vincent Dlamini, Assistant Community Development Officer for the Lubombo District, and all the other members of the Mpolonjeni community who helped to make the stays there so enjoyable.

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The contributions of these people and others are acknowledged by references to "private communications" in the text.

In this country, I would like to acknowledge the assistance of members of I.T.D.G., notably Messrs. George McRobie, Peter Stern and Simon Watt. Thanks are also due to all members of the Department of Civil Engineering at U.M.I.S.T., particularly to Mr J.B. White for undertaking the onerous task of supervising this work. His comments and suggestions have always been pertinent.

I owe a deep gratitude to Arnold Pacey who has maintained his strong interest in the work throughout, and has helped considerably in its direction. He and I have co-authored a series of short, pamphlet-length articles which are intended to make the principal findings of this work, and other aspects of the fieldwork in Africa, available to government officials and voluntary agencies. One of the main purposes of the project was to produce a thesis which would be of use in the immediate solution of specific practical problems as expressed by the people in the rural communities. Although the pump problem has remained unresolved, it is hoped that these pamphlets will be of practical use; one of them is included as an appendix.

Finally, I express my gratitude to my wife who has had to "live" with this thesis. She not only helped with the fieldwork in Swaziland, but also helped with corrections and suggestions, and putting the thesis together.

D.M.F.
Manchester
April 1974.

CHAPTER 1

INTRODUCTION

1.1 Development Strategies

In the newly independent countries of the 1950's and 1960's, much was achieved by the first efforts to promote rapid economic development, but by 1970, widespread disappointment and many misgivings had already been expressed (Dumont 1966, Hunter 1967). It was felt that "development" had been identified too closely with industrialisation and capital accumulation, and that the rural poor had scarcely benefited from the economic growth which had occurred. The "green revolution" had made some impact on the wheat and rice growing areas, but away from these, agriculture had changed only slowly, and rural populations were being left behind by the privileged minority employed in industry and administration. The poor members of rural communities were attracted to the cities in search of these few well-paid jobs. The resulting growth of urban populations far outstripped the creation of new jobs, so that the cities are now faced with almost overwhelming problems of unemployment, and inadequate housing and services. In addition to these undesirable social effects of economic growth, this strategy for development has recently been further discredited by the disastrous prophecies made for an unlimited economic growth policy for industrialised societies (see, for example, Meadows 1971).

Since the late 1960's, there has been an increasing effort to reverse some of these trends. Emphasis has moved away from growth as a generalised target for a whole economy, and there is now a more discriminating approach as to where, in the economy, growth should be most strongly encouraged. Rural development is being energetically

promoted to try to counter the drift of population to the towns, and agriculture is actively encouraged as part of this new rural emphasis, because the complacency about food shortages which followed the "green revolution" has now largely been dispelled.

Among economists, reactions to the problems created by growth policies have led to the formulation of such concepts as "intermediate technology" and "integrated rural development". The first of these concepts arose among those who questioned the validity of capital-intensive forms of development in countries where capital was scarce and labour plentiful. There has been a long debate on this issue, with contributions from Ranis (1957) and Sen (1960) among many others, but while theoretical arguments have been inconclusive, events have strengthened the case against capital-intensive development which fails to create sufficient employment. Western technology generally demands a high level of capital investment, and so a contrasting "intermediate technology" was proposed by Schumacher (see Schumacher & McRobie 1969), where the word "intermediate" refers to the level of capital investment or capital intensity in a given project. Thus, if capital intensity is "intermediate" or "low" instead of "high", limited capital resources can be spread more equally, and widespread rural development can be given priority.

The term "intermediate technology" is now widely used in discussions on technical aid (see, for example, Hart 1973). The Intermediate Technology Development Group (ITDG), which was founded in 1965 to promote the concept of intermediate technology, saw the major problem for technical aid as one of equipment and machinery. Western technology was ill-fitted, it seemed, to produce equipment which is suitable for local manufacture, capable of local maintenance, and above all, commensurate with local earning capacity, so that employment opportunities would be created.

This emphasis by ITDG on "hardware" has tended to over-simplify the problem, and a more complete view is provided by current thinking about "integrated rural development" (Marsden 1969), the adjective "integrated" with a wide range of inputs designed to complement one another. Rather than seeking some individual innovation that will create a breakthrough, the objective is to treat the rural community as a whole, and push forward gradually.

An "integrated" approach implies that the development of infrastructure, or in economists' language "social overhead investment", is just as important as the individual projects. Experience of modern developing countries has shown that their infra-structures, i.e. transport, water supplies, education, social organisation, etc. are generally too weak to support sustained economic development on the western pattern. Clearly, the success of any given development project is dependent on the presence of a certain level of infra-structure, but the important question of whether further social overhead investment should precede or follow further economic development has never been satisfactorily resolved. Lewis (1955) and Rostow (1960) both favour high social overhead investment at an early stage in a country's development. Others, notably Hirschman (1966), have argued that "development by shortage" avoids over-investment in any particular sector. Examples from history can as usual provide much evidence to support both viewpoints, but as William (1972, p.3) has pointed out, the economic and social conditions under which Europe and America developed bear little relation to those found in present-day developing nations. A reasonable proposition is that development has occurred, and probably will occur again, if either course is pursued separately, but that more balanced development should result when both are followed in part and simultaneously.

Such a course would be taken in integrated rural development when each aspect of the rural community would be considered in its context with the rural way of life and economy. Although this approach to rural development may be new to the economists, it implies a way of looking at problems which is already familiar to design technologists and other engineers as the "systems" approach. The aim is to look at the problem as a whole and also in detail, and to formulate solutions in terms of a many-sided total system as well as in terms of products and components. The weakness of the intermediate technology argument has been that it has concentrated too much on products and components, and too little on the total system in which they are used.

Water supply is one important part of the social and economic infra-structure of a community, and may be regarded as a system by itself, or as a sub-system within the total system of a community. This thesis attempts to achieve an "integrated" view of the water supply problem in some African countries, and engineering design is discussed here on the level of systems as well as on the level of components. When water supply is considered as part of the larger system of a rural community, we see that an improved water supply is just one of several inputs which must accompany one another in an integrated scheme of development. For the benefits of an improved supply to be realised, inputs that are needed besides the pipes and source works are education in hygiene, child care and family planning services, soil conservation measures, and other agricultural measures. The relationships of these apparently disparate elements to the water supply problem will be made clearer in later chapters.

1.2 Development Objectives

In all the arguments about the economic and technological processes of development, it is taken for granted that the objectives of development

are clear and well known. Certainly, as far as economists are concerned "development" has been firmly equated with the growth in the Gross National Product per head of the population (Elliot 1973). But more recently, broader concepts of development have emerged which also specify social objectives. Thus the Second World Food Congress in 1970 defined development as "social justice, self-reliance and economic growth". The United Nations Development Strategy for the Second Development Decade states that "the ultimate objective of development must be to bring about sustained improvement in the well-being of the individual and bestow benefits on all." (Hodson 1972).

Most people would agree that development is now concerned with the "abolition of poverty", and with promoting the "well-being" of people in society. Food and water, clothing and shelter are necessary for these ends in all societies, but beyond these, ideas about reducing poverty or promoting well-being are likely to be conditioned by cultural, political and moral values. The danger to a European in a developing country is that he applies his own standards, and imposes his own solutions to other peoples' problems.

As Elliot (1973) has said, data are lacking "on the subjective assessment of poverty by the poor themselves ... it may well be that our common assumption that food, housing, health and education are the critical areas is mistaken ... it would be valuable to know the areas in which the poor feel most threatened." One way to avoid the difficulties created by this ignorance is to leave the people being helped to make their own choices about the improvements they adopt. This is the basis of the user-choice approach to water supplies which will be discussed later.

But even with this danger of confusing the issue with values derived from European culture, it is still worth trying to clarify the

objectives of development further. Kuiper (1971) has discussed this in connection with water supply by listing ten factors which contribute to a person's well-being:

1. Food, cloths and shelter
2. Individual and collective security
3. Luxury and convenience
4. Good health
5. Good education
6. Harmonious family relations
7. Pleasant working conditions
8. A clean and stimulating environment
9. A certain level of culture
10. A certain level of morality

One might wish to add other factors to this list which stress the importance of liberty, equality and justice, but all such lists tend to be a product of the author's own background, and are useful only in emphasising the partial relevance of economic growth to the well-being of most people. Francome and Wharton (1973) have recently suggested an international social index for comparing the disparate items of education. Of course, growth can help to provide material necessities, health services and education, though experience so far in the developing countries is that these benefits have not been equitably distributed. However, the social aspects of well-being are scarcely encouraged by economic growth alone, and in terms of cultural and communal completeness, many African communities which have been by-passed by economic growth are probably superior in this respect to most of Western industrialised society.

The first three of Kuiper's ten conditions are those which are expected to follow directly from economic growth, whilst the remainder

are associated with social development. Even if it is assumed that each of these conditions does not carry equal significance in the promotion of well-being, striking a proper balance in the distribution of time, energy and resources amongst them all will produce a greater improvement in well-being than devoting all resources to the first three conditions.

This discussion on well-being is still not conclusive about the form development objectives should take, but it does underline the earlier conclusions that there are serious social objections to an undiluted economic growth policy, and these are sufficient reasons in themselves for the author to advocate a policy of small-scale rural development which is essentially labour-intensive and employment creating.

1.3 The World Rural Water Situation

The majority of people in the less developed countries live in the rural areas and depend on agriculture, or on trades directly associated with it for a living. There is concern about the water supplies available to this large proportion of mankind for two main reasons. Firstly, poor water supplies are considered a significant restraint on the "economic development" of rural communities, but a more important reason is that inadequate supplies are the cause of much hardship, and in some instances, acute suffering as, for example, the droughts of Botswana in the late 1960's, and those of India and West Africa in 1972-73. Although the droughts in these places were most severe in the years mentioned, their effects are more long-lasting.

A water supply may be deficient in three ways:

1. Insufficient quantities of water are available during long dry seasons, and may be non-existent during droughts.
2. The quality of water threatens health and hinders domestic activities such as washing.

3. The water source is so far removed that a great deal of time and energy is expended obtaining water.

There are few areas where none of these limitations apply, and in some places all three apply at the same time. This thesis is concerned with the water supply problems in some semi-arid areas of Africa (Chapter 2), but for the remaining sections of this chapter the overall magnitude of the world water problem will be discussed together with some of the issues involved.

The World Health Organisation (WHO) is the United Nations agency which is directly concerned with community water supply. The Twelfth World Health Assembly in 1959 initiated the WHO Community Water Supply Programme "to provide ample, continuous and convenient supplies of safe water to all people" (WHO 1972). In 1971, WHO made an assessment of the water supply situation in rural areas. The results of a questionnaire survey answered by 90 developing countries (including 34 in Africa) are summarised in Table 1.1. The expected population growths in these same 90 countries for the period 1970 to 1980 are shown in Table 1.2.

Table 1.1. World Rural Water Supply Situation 1970
and Planned Improvements 1970-1980

	(population in millions)				Increase 1970-1980
	1970	%	1980	%	
Adequately served	140	12	357	25	217
Not adequately served	1026	88	1081	75	55
Total rural population	1166	100	1438	100	272
(90 countries)					

Table 1.2 Population Growth in 90 Developing Countries

	(in millions)					
	1970	%	1980	%	Increase	%
Rural	1166	72	1438	67	270	23
Urban	461	28	712	33	251	54
Total	1627	100	2150	100	523	32

Sources (WHO 1972. Community Water Supply Programme Progress Report by the Director-General).

Table 1.1 shows that only 12 per cent (140 million people) of the present rural population is "adequately served" with water. WHO has set a target for the United Nations Second Development Decade, 1970 to 1980, that requires each year a further 20 million people should come within this category. At the end of the ten year period, the rural population adequately served would be 357 million, or about 25 per cent of those living in the rural areas. The construction costs of this programme are estimated at \$ 1600 million (US) (WHO 1972). In spite of this laudable target and the expenditure involved, the programme would barely keep pace with the anticipated population expansion (Table 1.2). Although the proportion of rural dwellers is expected to fall in this period, total numbers will not decrease, and those not adequately served will rise from 1026 million to 1081 million.

Burton (1973) has argued that these figures tend to misrepresent the situation because the definitions of "adequate supplies" used by WHO are open to a wide variety of interpretations. An adequate supply is said to be one where people have "reasonable access to safe water". This phrase is clarified a little by saying reasonable access exists

when the housewife does not have to spend a disproportionate part of the day in fetching the family's needs for water", and safe water is that which "includes treated surface waters, or untreated but uncontaminated water such as from: boreholes, protected springs and sanitary wells. Others of doubtful quality will be classified as unsafe." But expressions such as "disproportionate time of the day" and "family's needs" have different meanings to different people, and depend on whether the person passing judgement is a user of the water or merely an observer. Their assessments will be influenced by what is considered "normal" for similar circumstances, and may change according to the seasons of the year. The term "safe water" is more explicitly defined, but here the implication is that only two types of water supply exist: "safe" and "unsafe".

The actual situation is quite different. There are degrees of risk associated with even the most sophisticated "safe" water supply, and similarly, those supplies which fall into the "inadequate" category cover a wide range of qualities, quantities and distances to sources. WHO was aware of this difficulty in defining "adequate supplies", and an imprecise definition was probably needed in order to achieve a satisfactory response to their questionnaire survey. However, as Burton says, a finer classification of "reasonable access to safe water" into different degrees of access and different degrees of safety, would help to give a more accurate picture of the situation. Such a classification would be less subjective and would avoid a demarcation line between "safe" and "unsafe" supplies.

In spite of these criticisms, the WHO survey provides evidence of an increased interest in rural water supply, as also do academic studies such as the present thesis. During the course of this research project, one notable book has been published (White et al. 1972) which

deals with water supply in East Africa, and there have been extensive studies relating to rural water supplies in Tanzania (BRALUP 1969-1973). More recently, rural water supplies have been accepted as a problem worthy of academic study by groups outside the developing countries, such as the International Development Research Center, Ottawa (IDRC, Lausanne Seminar 1973), and Oklahoma University, U.S.A. This last study involves a sum of \$270,000 (US) spread over three years (Stern 1973).

One of the original functions of this thesis was to demonstrate the existence of the rural water supply problem. This recent activity in the field suggests that this task has already been partially accomplished. Once the problem has been recognised and understood, the next stage is to decide what standards and design criteria to adopt. It can be argued that the main driving force for the solution of this world problem should be the removal of the great inequalities which exist between rich and poor, rather than trying to establish some arbitrary minimum acceptable standards. Perhaps this solution can only be brought about by political changes, but even then, some analysis of the present situation, the adoption of standards and setting targets would be important stages in any programme of improvements. As Warner (1973) has pointed out,

" Design criteria for water supply often are a reflection of the pervading political and economic realities. The more activity that is introduced in the area of water supply development, the more pressures there are for the establishment and/or the strengthening of formal design criteria. Where criteria are poorly formulated or even non-existent, the degree of development activity is likely to be small. "

Clearly, establishment of criteria in themselves does not lead to water supply development, but can help in stimulating activity and can assist planning.

The WHO "standards" mentioned above misrepresent the world situation, and the WHO drinking water standards have also been criticised

as being hopelessly unrealistic for the needs of the developing countries (White et al 1972), and thus we might consider what can be achieved by using "reduced standards". The programme which WHO recommends, will cost \$1600 million (US) over ten years and should provide improvements for 200 million people, i.e. \$8 per head. This unit cost is less than the figure for Tanzania's water supply programme. Warner (1970) quotes a figure of 142 Tanzanian shillings per head for 1968 to 1969, with a maximum of 200 shillings for more difficult or sparsely populated areas; these are equivalent to approximately \$18 and \$25 per head. Few people would argue that Tanzania is being extravagant in this respect, with its declared policy of self-sufficiency and austerity. It should be remembered that the WHO figure is likely to be biased by the more densely populated countries of Asia and Latin America. In Africa, where rural populations are much more scattered, unit costs will be higher. Possibly the cheapest water schemes in Africa are the gravity fed supplies in Malawi. The cost per head of population for a densely populated rural area was £1 (1969 figure, Robertson 1970), or approximately \$2.40. The quality of water from these schemes would be unlikely to meet WHO standards and voluntary, unpaid labour was used. Thus even this suggests that \$8 per head is a low estimate for African conditions.

Assuming a re-assessment of standards, it would seem that the proposed level of activity for the ten year period 1970 to 1980 would still be insufficient to make a real impact on the world rural water supply problem. In the light of this, Burton (1973) has argued that the only realistic aim is not accessibility to safe water by a few people, but "greater access to safer water" for everybody. One should think of improving water supplies in a series of stages, so that everybody throughout the developing rural lands can take at least the first

steps in improving their supply - even though this means that very few will have an ideal supply in 1980. Burton calls this a policy of "incremental" improvement.

1.4 Community Participation

Often, water supply developments have neglected any real consideration of the people who are expected to benefit. Just as "developing nations" is used as a collective term to describe all the countries which do not fit the pattern of Western society, the people of rural communities are considered in the same way to be one homogeneous section of society. It is assumed that they have common aspirations and prejudices, and above all, it is assumed that they are inherently conservative and that their attitudes are incompatible with any sort of technical progress. This assumption leads engineers and planners to consider them as one other design constraint without giving due thought to the real effect of an improved water supply on any one person's life. However, as the case study in this thesis shows (Chapter 3), the people of rural communities exhibit the full range of character which is to be found in any section of society, and as for being unable to adapt to change, the way of life of people in this area of the Swaziland Lowveld has radically changed since the start of the present century. The processes of change have accelerated; within the last fifteen years these people have absorbed greater relative changes than most people in industrialised societies in the same period.

The important word here is "relative", for the impact of an engineering project in a rural community is likely to have a greater socio-economic significance than in industrialised societies. The effect of cultural and economic change has been to increase the separation between man and the rest of nature, and therefore, to decrease the extent

to which small changes in his environment affect him (Feachem 1970). In order to try to predict the impact of a water supply project it is essential that the attitudes of the anticipated beneficiaries, and all the other aspects of their way of life affecting, and affected by, the development should be assessed. But even this comprehensive study may be insufficient for the scheme to be "accepted" by the rural community, in spite of the fact that every possible failing has apparently been covered. The obvious omission is that the people themselves are not involved in the decisions.

An example of this type of "failure" is provided by the dams in the rural areas of Swaziland. These are the result of an extensive government programme for relieving water shortages for cattle. They were constructed in places where the need for water was greatest, but with little consultation in the rural communities. Local people thus see the government as an external force which cannot be influenced by them. Once the dams have been constructed, the government considers maintenance as the responsibility of the communities. On the other hand, the communities, although making use of the new water sources, consider them to be the property of government, and hence the government's responsibility. The condition of the dams has deteriorated to such an extent that a completely new maintenance programme needs to be instituted to avoid their total destruction.

How can the involvement of the people be achieved so that not only are works maintained, but new schemes are initiated from within the communities? The usual answer is by community development and self-help policies. This only partially solves the problem; the communities are involved in construction and payment, but they still have to accept unconditionally the opinion of outside "experts" and government officials on what is the best solution to their water supply

problem. A better answer is that the communities should be involved at all stages of the project. The role of the expert would now be that of advisor who presents a range of schemes with suggestions about construction techniques and estimates of costs. The decision on what standards of water quality are desirable would then rest with the communities, and they would have their own ideas on what is "reasonable access" and what constitutes "safe" water. Burton (1973) called this community participation "user - choice systems" and used it to amplify his concept of "incremental improvement".

He summarises his approach by listing the following objectives:

1. To develop the means and techniques whereby rural people can express a choice in the degree and type of water supply improvement that they wish to adopt.
2. To make it possible for communities to take some initial steps in the direction of better water supply without being committed initially to a programme of heavy investment or expense.
3. To allow village communities to develop the capacity to operate water supply systems and to appreciate their benefits.
4. To identify more clearly those areas in which technological research and development is needed to make the available choices more appropriate to the needs, and to indicate gaps where new technology or new scientific understanding are needed.

The sort of solutions produced by this incremental approach may not be the best in a technical sense, and almost certainly will not meet the sort of standards set by WHO, or conventionally trained engineers and government officials. But since most rural communities are aware

of deficiencies in their present supplies, and have strong opinions on what sort of improvements they would like to see and consider practicable, it seems more sensible to use this present store of knowledge and concern by making small but significant improvements to present supplies.

1.5 Choice of Technology

The last of Burton's objectives in the incremental approach raises the question of technology. It is often stated that a completely adequate technology of water supply already exists; all that is required for a solution to supply problems is money and organisation. This is probably true in the sense that the knowledge and the individual items of equipment already exist; but technology also involves a way of thinking and a discipline for solving problems which is an integral part of the culture which created it (Pacey 1974). It seems reasonable to say that the existing discipline in water engineering presupposes cost levels and organisation which are inappropriate to the needs of developing rural areas, so that the existing knowledge, skills and equipment are not readily brought together in a form that will solve the problem. Whilst it is true that individual techniques exist, this does not bring one near to finding an answer.

Once the water supply problem of a particular area has been understood, there are three ways in which it can be overcome. Either high costs and other restraints are reluctantly accepted and conventional techniques are used; or the apparent magnitude of the problem is reduced by accepting a reduction in standards, so that the cost restraints are not exceeded using the same conventional techniques; or new techniques are sought which will allow the problem to be solved within the same limitations.

In very general terms, policies in Kenya and Tanzania are examples

of the first two types of approach. Both these countries have accepted the need for a rural water supply programme. In Kenya, £6.9 million is being invested in water supply over the period 1970 to 1974. This represents 3.6 percent of total public investment and 17.4 percent of the agriculture allocation (Carruthers 1970). The comparable figures for Tanzania for the period 1969 to 1974 are a total expenditure on rural services of about £4.8 million, representing 3.04 percent of development expenditure (Tanzania, Second Five-Year Plan 1969).

Although Tanzania's aims are similar to Kenya's (both intend to supply the whole rural population by the end of the century), less rigid standards of water quality and distribution have been accepted (Warner 1973) so that the overall costs are reduced.

No obvious example of a country which has adopted the third approach presents itself, though processes like desalination, and techniques such as rainwater run-off catchment and storage of water in sand reservoirs (Chapter 9) would be the sort of ideas which could affect the situation. Novel construction methods, labour-intensive methods, and unconventional materials could also provide some answers to particular problems.

Essentially, the first of these approaches outlined here is the conventional one which uses proven methods applied to accepted design criteria. A combination of the second and third methods might be regarded as Burton's (1973) incremental improvement. Where the costs of a conventional solution are too high, a series of stages of improvements should be worked out, the first of which can be implemented quickly and cheaply. With this approach, the ultimate high standard is not forgotten, but amelioration of a situation does not depend on a high cost/high quality solution. The second and third combination

also describes quite well the concept of "appropriate technology". This involves a re-assessment of the objectives of the water supply programme and the appropriate techniques are matched accordingly by taking into account the national resources of materials and labour, and the limitations of such items as foreign exchange and spare parts. In some circumstances, this could lead to the use of outmoded equipment and very labour-intensive methods of construction which would be inconceivable in Western societies, but which are appropriate to the conditions in developing rural areas.

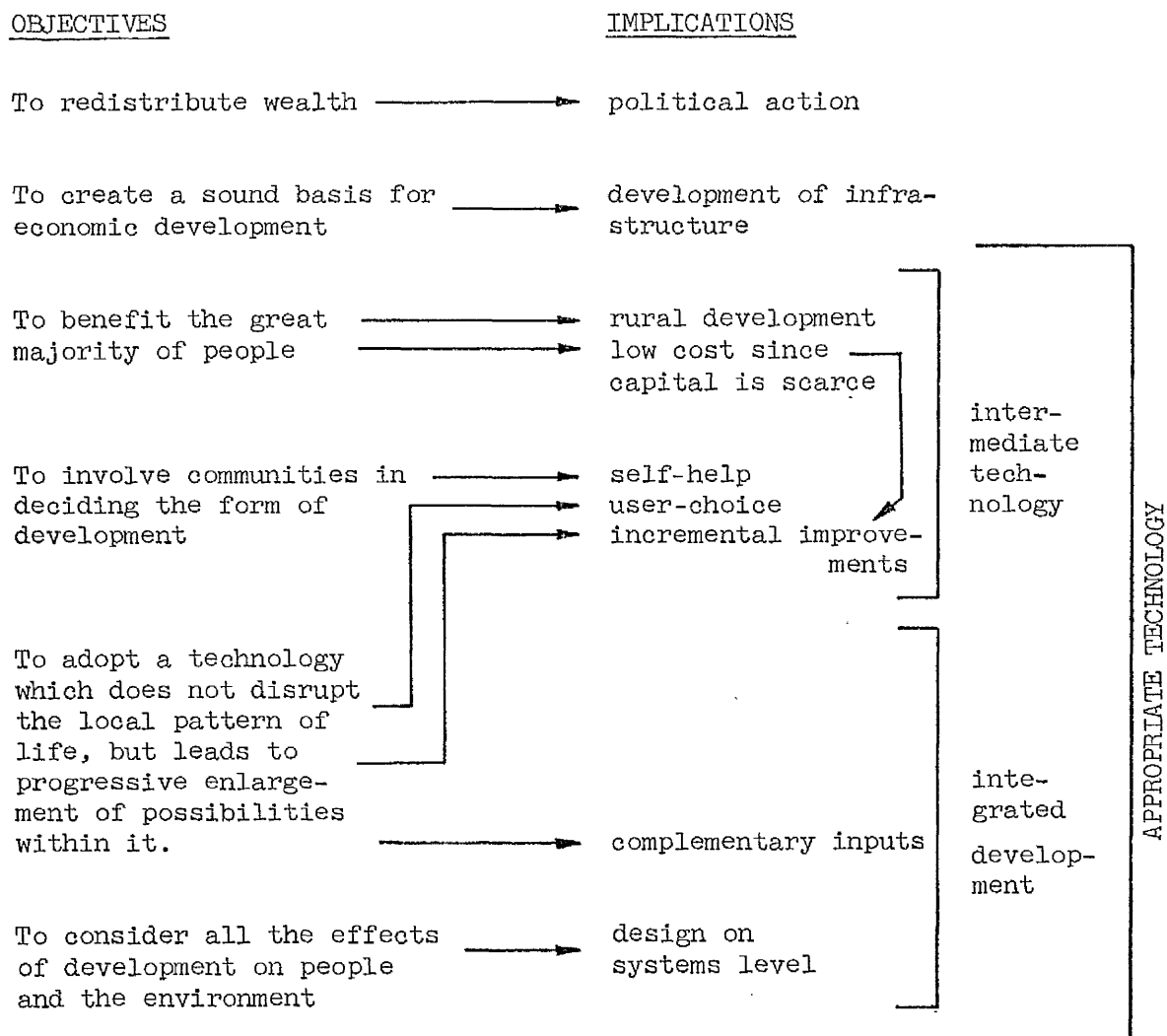
1.6 Appropriate Technology

Having introduced the concept of appropriate technology, it should be said that it is much easier to decide what seems to be "inappropriate" than to say what is "appropriate". The economic growth policies of the 1950's and 1960's were characterised by the use of the most modern capital-intensive, labour-saving equipment which was unfamiliar in operation and difficult to maintain. This clearly coupled the wrong sort of equipment and techniques with socially inappropriate policies. However, other examples are known, though more difficult to find, where less sophisticated equipment and labour-intensive techniques which might have been considered appropriate, have also failed. Under these circumstances the responsibility for failure is usually placed squarely on the designer, whose technical judgement is called into question. Had he chosen the more conventional approach of proven methods applied to engineering standards, then failure could easily be attributed to local conditions, or the inability of the local population to adapt to a modern world. Burton (1973) sees the challenge of appropriate technology as one of adapting and developing technology to meet the needs and capabilities of the local populations, rather than expecting these people to acquire unfamiliar

skills, or disrupt the pattern of their lives to meet the needs of an alien technology.

So far, water supply developments have been discussed in economic terms such as capital and labour intensity; in terms of systems and levels of design; in terms of user participation; and in terms of techniques and technologies. The main points of this discussion involving development objectives and some of the implications are summarised in Figure 1.1. A common factor in each of the "implications", is the necessity to match development to the needs of the recipients and the prevailing conditions. Thus each element of water supply development should be "appropriate". The diagram in Figure 1.1 suggests how an "appropriate technology" can emerge, and it is this term which adequately describes the approach adopted to the water supply problems discussed in this thesis.

Figure 1.1 - Development and Appropriate Technology



CHAPTER 2

THE WATER SUPPLY PROBLEM IN SEMI-ARID AREAS

2.1 Introduction

By re-assessing our objectives, as suggested in Chapter 1, we have a different perspective on the relevance of much existing technology for dealing with rural water supply problems. If we then consider the technical problems associated with semi-arid areas, we are presented with further reasons for seeking novel technological solutions.

The main purpose of this chapter will be to define the semi-arid areas dealt with in this thesis, describe their physical characteristics, and explain how the problem of water supplies can be affected by the culture of the inhabitants and their settlement patterns. This will be followed in Chapter 3 by a more detailed description of a community in the semi-arid Lowveld of Swaziland, which provides a case study for this work. From these sections, an understanding of the water supply problems of rural communities in these areas will emerge.

2.2 Semi-Arid Climates

The principal feature of an arid or semi-arid region is a scarcity of water for plant growth; that which is available from rain, dew, and moisture carried to the region as groundwater is insufficient to balance the "losses" from deep percolation in the ground, from run-off, and from the potential losses from moisture transfer between the ground and vegetation and the atmosphere. Thus aridity could be defined in terms of this apparent water deficiency.

Of these components of the water balance, only rainfall data are widely available for semi-arid areas. River flows, where they exist,

are being increasingly recorded but there is the difficulty of deciding the various contributions of groundwater flow, surface run-off, and sub-surface run-off. The evaporation components are difficult to measure and readings are unreliable. Early attempts to define aridity avoided this elaborate water balance by proposing empirical relationships between rainfall and temperature. These definitions depend on being able to express the evaporation terms as functions of temperature alone, and this is not an unreasonable approximation. Two of these definitions are given (Wallén 1966, Walton 1969):

	<u>Arid Zones</u>	<u>Semi-Arid Zones</u>
Köppen's classification for summer rainfall areas	$R \leq 10 (T + 14)$	$R \leq 20 (T + 14)$
De Martonne's "aridity index" $I = \frac{n.p}{t+10}$	$I < 20$	$I < 30$

In these relationships R = annual rainfall in mm.

T = annual mean temperature, °C.

n = number of rainy days

p = mean precipitation per day in mm

t = mean temperature in the selected period, °C.

However a more precise definition of aridity is given by Thornthwaite's "moisture index". Thornthwaite first put this forward in 1948 but later modified it (Sellers 1965). The index is based on the concept of potential evapotranspiration (E_t), defined as "the rate of evaporation from an extended surface of short green crop, actively growing, completely shading the ground, and not short of water". In a dry area such plant growth could only exist with year round irrigation. The Thornthwaite moisture index attempts to measure the extent to which a climate exceeds or falls short of providing the moisture needed for

this kind of plant growth over a year, or any other defined period.

The modified form of the index (Sellers 1965) is:

$$I_m = \left(\frac{R - E_t}{E_t} \right) 100 \quad \text{where } R \text{ is the mean annual rainfall}$$

and $E_t = 0.8 \times \text{open water evaporation (E}_o\text{)}.$

Among the places discussed in this thesis are those shown in Table 2.1. The moisture index has been calculated for the four places, Köppen's classification is shown for comparison. In each case, the moisture index is negative and falls within the range of -20 to -100, which is Thornthwaite's definition of a semi-arid climate. Those areas with a moisture index below -100 are said to be arid. These and other climatic regions are shown on the maps of southern Africa in figures 2.1 and 2.2 which therefore, define the areas dealt with in this report. There are also large areas of semi-arid land north of the equator in the Sahelian region of West Africa, in the Sudan and in Kenya. In eastern Africa, parts of Tanzania and Moçambique are semi-arid, whilst in central Africa, southern Zambia, the Zambezi Valley, and southern and western regions of Rhodesia are semi-arid. Further south, almost the whole of Botswana and Namibia (i.e. the Kalahari Desert) is classed as semi-arid. In South Africa, the Cape Province and Western Transvaal have predominantly semi-arid climates. South eastern Africa is better watered, but there is a small semi-arid region which includes the Lowveld of Swaziland and some parts of Natal and eastern Transvaal.

In principle, this thesis is concerned with rural water supplies in the semi-arid areas of Africa outlined above. Some extensive studies of water supplies in East Africa have already been made (White *et al.* 1972, and BRAIUP 1969-1973), and the main emphasis for this work is further south, particularly Botswana and the Lowveld of Swaziland, where the author has been able to carry out fieldwork studies. The author's visits to Kenya, Tanzania and Malawi provided comparative

Table 2.1 Classification of climate of places in Africa using Köppen's method and the Thornthwaite Moisture Index.

Place (see Figure 2.2)	Mean ann. rainfall mm	Mean ann. Temp. °C	Pot. Evapo- trans. mm	Köppen's classification	Thornthwaite's moisture, I	Sources
Kisongo, Tanzania	750	n.a.	1360	n.a.	- 45	* Murray-Rust, 1971
Hlekweni, Rhodesia	500 - 600	17.5 - 20	1350	550 < 650 semi-arid	~ - 60	Collins, 1965
Serowe, Botswana	460	20.5	1550	460 < 690 semi-arid	- 69	* Bawden & Stobbs, 1963
Mpolonjeni, Swaziland	635	22	1100	635 < 720 semi-arid	- 42	Chapter 3

* These figures are based on the assumption that the evaporation data given by these sources is from open water, i.e. Et = 0.8 Eo.



Scale 1 : 25,000,000 (approx.)

Figure 2.1 SOIL MOISTURE REGIONS IN SOUTHERN AFRICA (Ady 1965).

Isopleths refer to the Thornthwaite moisture index; the line for zero index is shown by a dashed line. Dotted lines are state boundaries.

<u>Moisture index</u>		
less than 100	-	Arid
-100 to -20	-	Semi-arid
-20 to 0	-	Dry sub-humid
0 to 20	-	Moist sub-humid
20 to 100	-	Humid
more than 100	-	Very humid

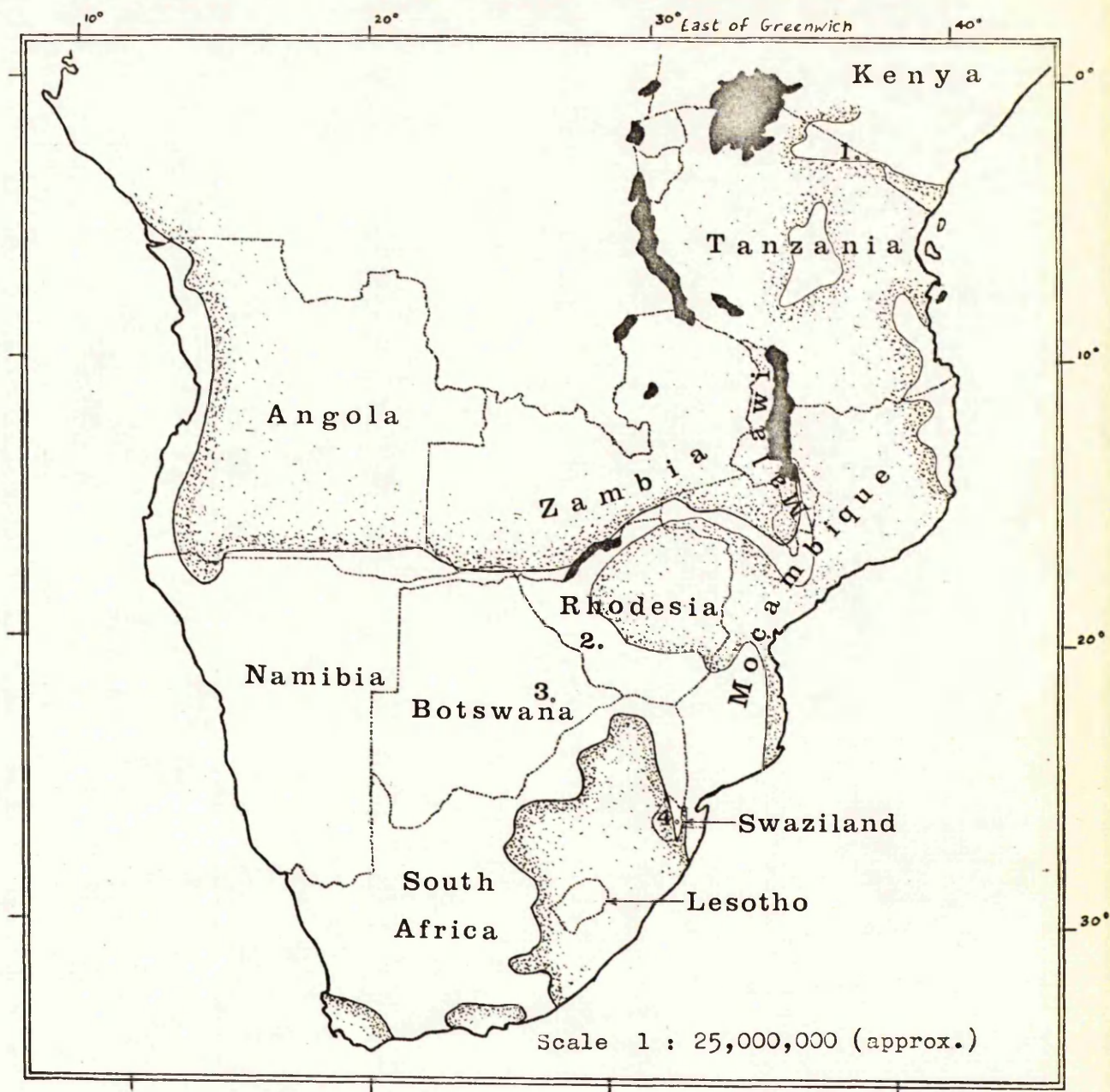


Figure 2.2 ARID AND SEMI-ARID REGIONS IN SOUTHERN AFRICA

The iso-line, moisture index -20, defines the zones:

The principal places discussed in the thesis are shown. All are within the semi-arid zones (see also table 2.1), though the map does not show precise boundaries.

1. Kisongo, near Arusha, Tanzania
2. Hlekweni, near Bulawayo, Rhodesia
3. Serowe, Botswana
4. Mpolonjeni, Swaziland

information and give completeness to the discussion of semi-arid areas which is presented here. Unusual socio-political considerations in South Africa and language problems for Mozambique precluded any detailed study in these countries.

2.3 Availability of Water

The characteristics of semi-arid areas which are most relevant to the problems of water supply are:

1. Low rainfall with low reliability,
2. a long dry season of at least six months, during which little rain falls and river flows cease,
3. high potential evaporation,
4. high sediment loads in rivers.

From these points, it is clear that water supply systems which depend on open storage of surface water will require exceptionally large reservoir capacity (by European standards) to allow for the long dry season, the high evaporation losses, and the reduction in capacity as a result of silting.

In discussing these problems, it is worth considering how the Thornthwaite moisture index can be related to them, thus providing a general indicator to factors which are relevant to water supply. A negative moisture index means that rainfall is insufficient to maintain a flourishing plant cover throughout the year. This follows from the definitions of potential evapotranspiration and of the moisture index given above, and means that plants either die or remain effectively dormant for long periods. Plants which grow in arid and semi-arid conditions have life cycles adapted to these long periods of inactivity, so that another way of classifying arid areas is by identifying the type and measuring the extent of vegetation (Kassas 1966, Walton 1969).

Eveneri et al (1971) have described in detail how plants (and animal life) have adapted to desert conditions. One important factor which enables vegetation to survive long dry spells is dew. Semi-arid areas are often subject to a heavy dew (as experienced by the author in Swaziland), and it is a factor which could influence the long term agricultural prospects of such areas (Deacon, Priestly & Swinbank 1958).

For much of the year, plant life in areas with a negative moisture index only partially covers the ground, leaving the soil vulnerable to erosion. Thus surface run-off may carry very high quantities of sediment. Not only is the ground ill-protected, but rainfall has greater "erosivity" than in temperate climates, with high intensity storms and larger rain drops (Hudson 1971). Human influences, such as allowing herds of cattle to denude the vegetation, have often accelerated the high natural erosion rates in many semi-arid areas, producing extremely high sediment loads in rivers (UNESCO 1972).

If plants have difficulty in obtaining sufficient water, a large moisture deficit is likely to build up during the dry season, and much of the first rains will be absorbed by the soil. In fact, run-off only occurs during intensive storms when rain is falling faster than the soil can absorb it. On these occasions, flash floods can develop very quickly, causing further erosion problems. The relationship between rainfall, run-off and climatic zone is very complex, but some generalisations can be made. Areas with moisture indices in the arid and semi-arid range will lose relatively small percentages of their rainfall as run-off. This figure is often as low as 5 per cent for semi-arid areas of southern Africa, and for years of lower than average rainfall it may even be only 1 to 2 per cent (Midgley and Pitman 1969).

From its definition, evapotranspiration is closely related to evaporation from open surfaces. Penman (quoted by Murdoch & Andriesse

1964) gives a relationship for the Swaziland Lowveld:

$$Et = 0.8 Eo \quad \text{where } Eo \text{ is the evaporation from open water.}$$

Thus, reservoirs in areas with a negative moisture index will be subject to high evaporation losses in relation to the volume stored.

2.4 Environmental Influences and Water Quality

The natural vegetation, as already remarked, is strongly conditioned by the long dry season. Semi-arid land in southern Africa, with its characteristic vegetation of grassland with many small trees and bushes, is generally known as "the bush". Most of the trees and shrubs are of the acacia family. This type of dry savanna grassland is, according to modern agricultural opinion (e.g. Murdoch 1968), best suited for cattle-ranching and stock raising. This is in fact, how the land has been traditionally used by the majority of the peoples living there. The difficulty is that cattle ranching can support only a relatively limited human population on wide expanses of land. In much of Africa, population densities already exceed the level which can be safely supported by traditional cattle-raising and cultivation methods. Thus, methods which were once admirably adapted to the environment are now carried on so intensively that vegetation and soil is being damaged, often irreparably. In semi-arid areas in particular, there is a great danger of over-grazing which results in either bare ground, and therefore increasing the naturally high levels of soil erosion, or encroachment by thorny scrub which then reduces the available grazing land and is difficult to eradicate.

Cattle and other stock are important parts of the environment and must be considered not only as consumers, but also potential polluters of water sources. In many cases, cattle and people share the same open source and wade in for a considerable distance. This is particularly common in Swaziland.

The influence of geology on water supplies in semi-arid areas of southern Africa is equally complex. Dixey's (1931) account of geology and water supply covers most of the countries considered in this thesis. Large areas of the semi-arid regions of Tanzania, Rhodesia and Botswana are associated with schists, gneisses and granites, whilst volcanic lavas (including basalts) and ashes are associated with the Rift Valley faulting system and its branches. Basalts are common in Malawi and in the Lowveld of Swaziland, and in this latter area dolerite dykes can greatly affect the occurrence of groundwater (Figure 2.3). Basalts often give rise to heavy dark-coloured soils sometimes known as "black tropical clay" or "black cotton soil".

The dominant clay mineral in these soils is montmorillonite, which can absorb several times its own weight of water. During the wet season, the clays swell and create an almost impermeable layer. From these soils, then, there is a high percentage run-off. During the dry season, the clays gradually dry out and shrink. Cracks develop which widen and deepen as the drought continues. The first rains after the drought are quickly swallowed up by the shrunken, cracked soil, and until the clays swell again, run-off is reduced (Figure 2.4). The flow of water down the cracks washes down top soil and salts into the subsoil which eventually lead to concretions in the soil. These concretions are important in the development of sheet erosion as Murray-Rust (1971) has shown.

The quality of groundwater, and to a lesser extent surface water, is greatly influenced by the geology and soils which it encounters. The degree of interaction between water, soils and geology depends very largely on weathering processes. In all hot climates weathering proceeds at much faster rates, and if the temperature of the rain penetrating rocks and soils is say 25°C instead of the 10°C

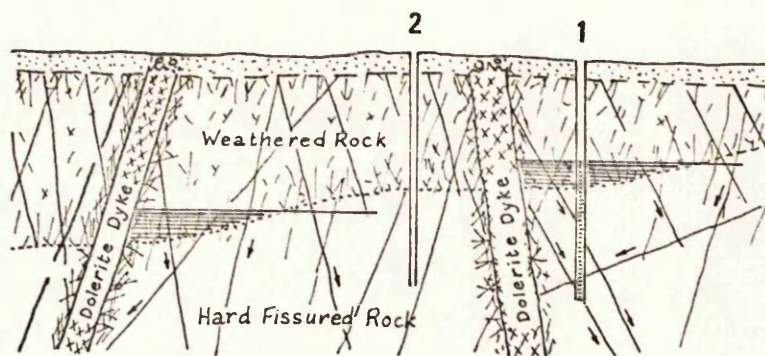


Figure 2.3 DOLERITE DYKES AND GROUNDWATER, after Dixey (1931).

Groundwater is held up locally behind the dykes; bore-hole 1 on the upper side strikes water both in weathered rock at shallow depth and in fissures at greater depth, whereas bore-hole 2 on the lower side remains dry.

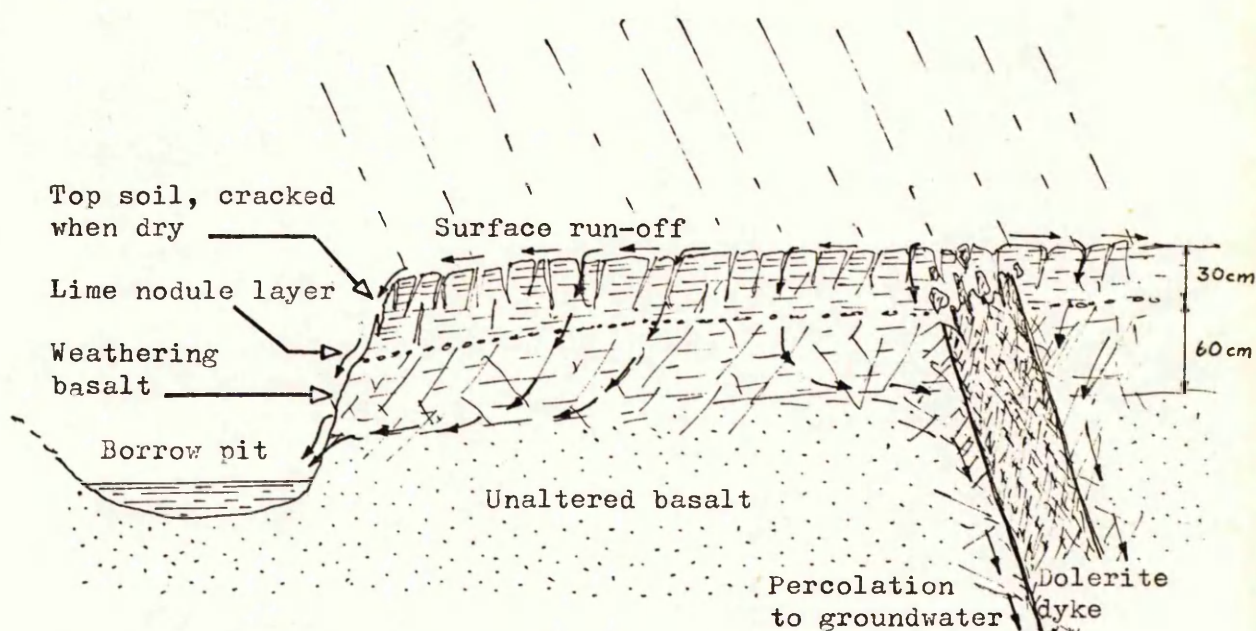


Figure 2.4 SCHEMATIC REPRESENTATION OF SUB-SURFACE FLOW IN A CLAY SOIL AT MPOLONJENI (Pacey 1973).

The arrows represent routes along which water might be expected to flow during the first heavy rain after a drought, i.e. before cracks in the soil can close up.

which is expected in temperate climates, then the weathering processes are modified in the following way (Buringh 1970):

1. Ionization is four times as great,
2. silica is eight times more soluble,
3. solution proceeds much faster,
4. more water penetrates to a greater depth because of its reduced viscosity and surface tension.

Faults and fissures in granite and basalt rocks coupled with relatively deep weathering near the surface have sometimes created reasonably good aquifers in relatively unpromising material (Howell 1971). Kates (1973) notes that groundwater may be expected in semi-arid areas of Kenya and Tanzania "in weathered granite". The most extensive area of groundwater exploitation in Swaziland - at Malkerns in the temperate Middleveld, has occurred where weathered granite underlies a red soil. Dixey (1931) gives numerous examples of small reliable supplies coming from sources such as this. However, because of the restricted movement of ground water in these rocks, and the release of soluble salts by weathering, groundwater is often brackish to taste. This is especially true in basalt areas, where calcium, magnesium and sodium ions are easily released (Chapter 5).

Surface water can be affected by soils and geology in a similar way, and plant-life also has an influence. Some plants, particularly the tenacious varieties found in semi-arid and arid areas, are able to draw water from considerable depths in the soil, sometimes up to 2 metres (Eveneri et al. 1971). The mineral content of the water used by these plants remains in the upper soil levels, and since rainfall is low, dissolved salts brought to the surface may not be leached away. Thus top soil may become sufficiently saline to affect surface water.

Almost the only rivers in southern Africa with a perennial flow

are those which rise in the well-watered south-east of the continent which includes the Highveld region of Swaziland, the snow-capped mountains of Lesotho, and parts of the Orange Free State and Natal (Figure 2.5). Most rivers dependent on semi-arid catchments, dry up for several months of the year. In regions where sandy soils predominate, and where the sediment load of the rivers consists of sand or large grained particles, water is often retained to flow in the river bed, even though the surface flow stops at the end of the rainy season. These "sand rivers" are quite common on the fringes of the Kalahari Desert in Botswana, Rhodesia and Namibia, and constitute an important source of domestic and stock water (Morton 1958). If this sub-surface flow is interrupted, either by a naturally occurring dolerite dyke, or by a concrete dam, then a considerable reservoir of water can be maintained in the "sand dam" long after the free standing water has been lost by evaporation. Small scale sand dams like this are a common method of water supply in northern Kenya, and large scale versions have been developed in Namibia (Wipplinger 1958, see also Chapter 9).

Sub-surface flow in sand is a case where there is no clear distinction between surface and ground water, and where the quality derives something from both. In fact, in only a few instances can water be said to be unambiguously "surface water". One such instance occurs with the very sudden intense storms characteristic of Botswana's climate. Sheets of water 2 to 3 cm deep flow across the ground surface to natural drainage channels with only transitory contact with the soils and rocks (Gibberd 1972). But more generally, a significant component of "surface water" reaches rivers and streams after movement through superficial soil and rock layers without reaching a well-established water table. This movement is sometimes known as "interflow",



Figure 2.5 THE PERENNIAL RIVERS OF SOUTH-EASTERN AFRICA

International boundaries are shown by the broken lines. Dotted lines indicate state boundaries. The shaded areas are those regions where rivers have perennial flow. From these regions, larger, isolated perennial rivers discharge into the sea.

but the mechanics of this phenomenon are not well understood unless "perched groundwater flow" is envisaged. A special case from the Swaziland Lowveld illustrates this (Figure 2.4). Shallow clay soils are found overlying permeable, gravelly layers of weathered rock. At times, after the first rains, there may be considerable lateral movement of water in this weathered rock, some of which emerges to join bodies of surface water. In many ways this water behaves as groundwater, but because its flow is ephemeral and there are no permanent water tables or springs, it is not normally recognised as groundwater.

Where these geological conditions occur, there is the possibility of a water storage system based on the construction of a vertical barrier down to impermeable rock, so that water is trapped in the gravelly, weathered layer. Such water storage would be protected from evaporation loss, though dissolved minerals may be a problem. In effect, this system works in the same way as sand dams. Precedents for sub-soil barrages of this kind are provided by recent water storage projects in Yemen (Howard Humphries 1971), and by coastal "aquavoids" invented by a Bahamian engineer (British Patent No. 1013025) and constructed at Long Island, New York and in the Bahamas (O.D.A. 1971). Considerable research would, of course, be needed to establish whether sub-soil barrages in the Swaziland Lowveld could store worthwhile quantities of water.

These comments on water flow in the superficial ground layers are a necessary introduction to a discussion of dissolved minerals which occur in both surface and ground water. Streams and rivers become richer in minerals as the length of time since the last major storm increases, because a greater proportion of their flow is provided by groundwater and "interflow" contributions. In addition, high

evaporation losses tend to concentrate the dissolved solids. Thus a typical problem of small reservoirs in semi-arid areas is that the water stored contains a large proportion of dissolved solids. Berry and Kates (1970) report that a reservoir in Tanzania, 8,630,000 m³ capacity and built in 1951 for irrigation, had to be flushed out in 1970 because the water had become too brackish.

Other examples from Tanzania (Berry and Kates 1970, Murray-Rust 1971) illustrate how the high sediment loads of rivers in semi-arid areas can reduce the effective life of reservoirs; in some parts of Tanzania the life of reservoirs is estimated at only 15 to 20 years. According to data given by Midgley and Pitman (1969), sediment loads in many southern African rivers are also very high, and thus similar problems can be expected in Swaziland.

From these considerations the special problems of water supply in semi-arid areas are clear. Quantities of water are limited, storage requirements are larger in relation to the supply requirements, and water conservation in the form of evaporation reduction is of great importance. Water quality is adversely affected by dissolved minerals, bacterial pollution, and sediment. This latter consideration may add greatly to the cost of storage.

2.5 Rural Communities in Semi-Arid Areas of Africa

The peoples of eastern, central, and southern Africa present a great variety of national, racial and cultural groupings. Most of the Asians and Europeans live in urban communities and are thus outside the scope of this thesis. Here we are mainly concerned with peoples of Negro descent living in rural communities. Such communities account for more than four-fifths of the total population. However there are two groups of non-Negro rural dwellers, whose techniques and practices

may have something to offer to this study. First there are many isolated European farmers who have had to develop farm water supplies which are of a similar scale to village supplies (see for example Rhodesia, Department of Conservation & Extension 1962). And also there are the small numbers of Bushmen who live in the Kalahari Desert, and once lived over greater areas of southern Africa. Because of their intimate practical knowledge of their environment, they are able to find shallow groundwater sources, and raise small quantities for drinking through a head of up to two metres by using their lungs and mouths and sucking through a tube (van der Post 1958).

Even when attention is confined to people of Negro descent, there are major cultural differences between nations and tribes which affect water habits. Kirkby (1973) has distinguished two cultural factors (numbers 1 and 2 below) which are relevant, and the author's fieldwork has helped to emphasise two more (numbers 3 and 4).

1. Traditional, culture-conditioned ideas and beliefs about how diseases are caused, and what precautions should be taken against them. This is relevant to choices affecting water quality.
2. Traditions of leadership or democracy within communities which affect the way in which technical innovations are introduced.
3. The layout of settlements on the ground, in either dispersed or nucleated form. This has considerable relevance for water distribution.
4. Experience of physical laws and mechanical equipment.

The first of these factors is generally well appreciated, and many works already exist which describe the customs of African tribes. Gelfand (1964) has dealt in some detail with the medical beliefs of

the peoples of Rhodesia. Schapera (1940a, 1940b, 1970) has written extensively on the Batswana, whilst for the Swazi people, Kuper (1947) and Marwick (1966) have published anthropological studies. Jones (1963) describes the traditional beliefs associated with health, nutrition and matrimony in Swaziland.

The second factor is one which affects all societies, and it is not possible to summarise briefly all the differences which occur in African societies. But as an illustration of what can happen, it is worth recording Ricardo's experiences of volunteer labour in Tanzania for community development work (Ricardo 1973). Following President Nyerere's "Arusha Declaration"* and Tanzania's avowed policy of self-reliance, self-help projects there proceed very rapidly, and the supply of labour is not usually the limiting factor which affects progress. If any community or individual community member is considered dilatory in this respect, then the matter is taken up politically with the local TANU (Tanzania African National Union) party representative. This situation is in sharp contrast to the one in Swaziland, where the difficulty of finding volunteerlabour is a major inhibiting factor in community development work (Moody 1973). However, the Swaziland system of democracy can be effective where there is strong leadership from the community chief, and later (Chapter 6) two adjoining communities are compared to demonstrate the differences.

The third "cultural" factor perhaps provides the most graphic illustration of the variations which occur among the peoples discussed in this report. In Swaziland, individual families have preferred to live close to the fields where their crops are grown. This has often led people to build their homes on land where the soils seemed good

* "All citizens together possess all the natural resources of the country in trust for their descendents "
(Africa Report XII, March 1967, pp.11-13)

for cultivation, separated from their neighbours by at least the extent of their own fields, and sometimes by the large distance between one patch of good soil and the next. Any land which is not used for cultivation is common grazing land. In the fairly recent past, shifting cultivation was common practice, and sometimes complete communities would move to new land (Kuper 1946). This pattern of settlement has been greatly modified in recent years by population pressures, and by government land-use plans which set aside large areas of land for grazing, and which attempt to re-settle people in planned village sites (Swaziland, Ministry of Agriculture 1969, of. Ujaama villages in Tanzania).

In spite of these developments, there are only a small number of distinct villages in the familiar English sense, and the highly dispersed settlement is still characteristic of most of Swaziland. This means that people often live a long distance from any source of water.

The customs of the Tswana people represent the opposite extreme (Figure 2.6). They live in large nucleated settlements with populations of 500 to 1,000, but sometimes with populations as great as 20,000. Serowe is the outstanding example of a community of this size, but other places in Botswana, such as Mochudi, Mahalapye and Kanye are traditional settlements with populations well over 10,000.

Though these communities are of urban densities, and in fact they support a number of traders and craftsmen, they are more a part of the rural economy, since most of their inhabitants are farmers. The settlements are made up of many sub-communities each with its own "headman" and group of fields some distance away, perhaps up to 50 km. Thus at ploughing, harvest and other seasons when work in the fields is necessary, some farmers go out and camp there, often maintaining a second "home". Occasionally, a third "home" is maintained in yet another region where the cattle are grazed.

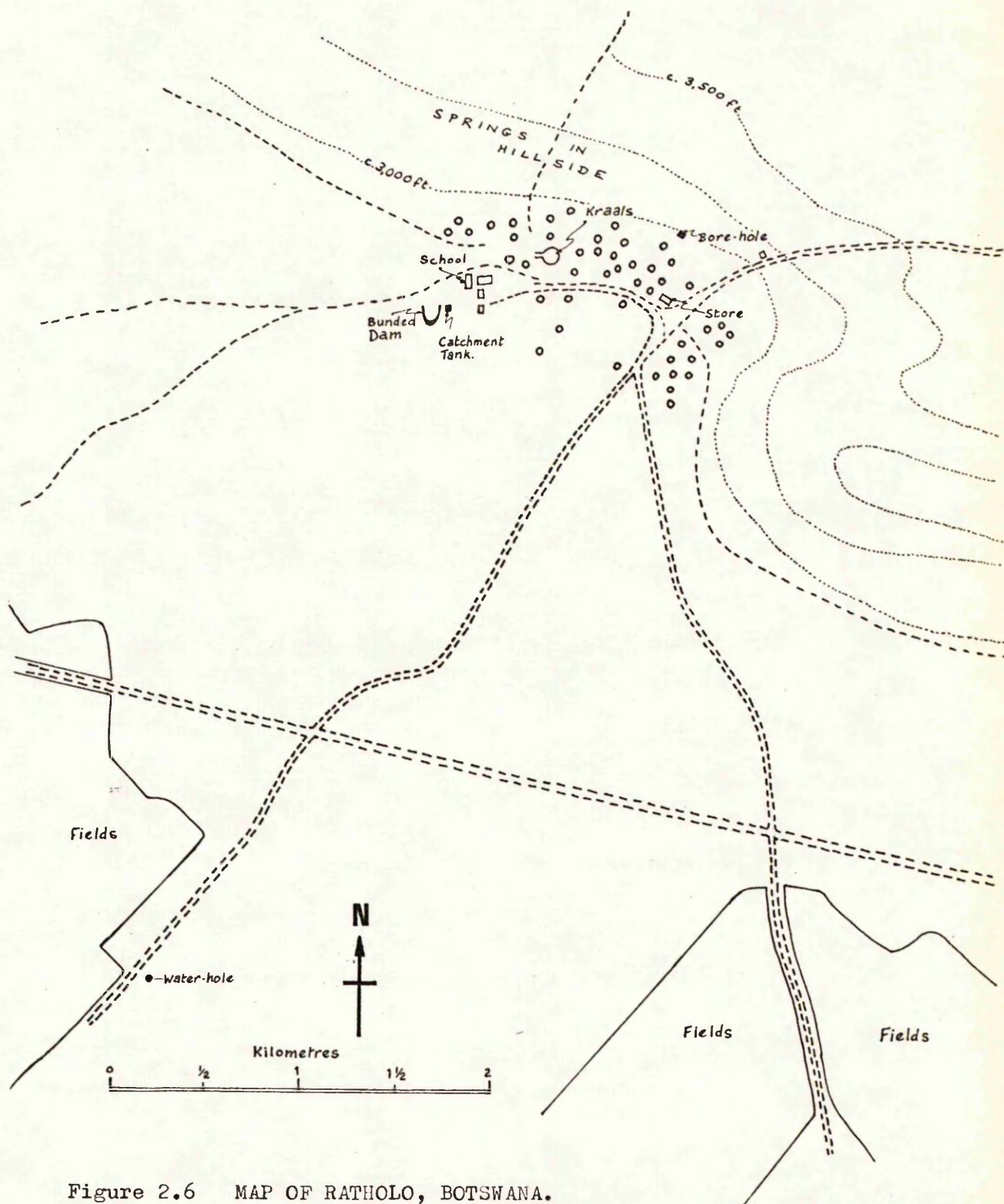


Figure 2.6 MAP OF RATHOLO, BOTSWANA.

This map shows the settlement pattern and disposition of water sources. It should be compared with that of Mpolonjeni, Swaziland (Figure 3.13) drawn to the same scale and a similar standard of detail.

The siting of these huge settlements was strongly influenced by the availability of water. Serowe was founded in 1902 by Khama III as the capital of the Bamangwato tribe, after two other places, Shoshong and Old Palapye, had been found to be unsuitable because of inadequate water supplies. The original supply at Serowe was provided by a spring, but wells were soon dug following the example of Europeans (Schapera 1970). Today, boreholes provide the water. Mochudi (founded in 1871 by Chief Kgamangyane) and Mahalapye originally depended on sand rivers rather than springs for their water (Schapera 1940).

The last of the cultural differences which have been identified, namely different experiences of physical laws and mechanical equipment, is one of the main reasons why a new approach to technical aid is considered necessary (Chapter 1). As an example of the sort of problem which has been encountered, we can look to the work of the Community Development Department in Malawi. Here, water supplies have been provided in mountainous south-eastern districts by piping water from mountain streams to the densely populated plains below. There was initial reluctance to start the work because not many villagers believed water would flow five miles in a pipe without a pump (Robertson 1970).

Social structure and culture are intimately related to environment in any rural community, and in this chapter we have briefly reviewed the elements of this relationship as they are commonly found in semi-arid regions of eastern and southern Africa. These regions occupy an enormous area, however, and despite the many characteristics they have in common, generalisations about them can be misleading. Thus several references have been made to specific places in order to prevent generalities from becoming too diffuse. In the next chapter, one of these places will be used to provide an individual case study, but again it is hoped to maintain a balance between the general and the specific,

by using the particular problems of this single community to illuminate the general conclusions about rural water supply practice which will be discussed in the rest of the thesis.

CHAPTER 3

THE WATER SUPPLY PROBLEM AT MPOLONJENTI, SWAZILAND - A CASE STUDY

3.1 Introduction

A community in the semi-arid Lowveld region of Swaziland has been examined in detail to provide a case study in rural water supply. The value of such a study is that a single community is small enough to be considered as a whole, whereas an authoritative assessment of all the rural communities in semi-arid southern Africa would be a task of too great a magnitude to be attempted here. It is hoped that by studying one area in depth, some general conclusions can be reached, not only for the Lowveld of Swaziland, but for other areas of Africa. However, if too much weight were placed on a single case study, the work would be inordinately biased by a single situation. It is thus fortunate that a brief field exploration of the Serowe-Palapye area in Botswana was possible, so that comparisons may be made of the water supply situation in a different cultural and physical context.

In this chapter then, the study area Mpolonjeni will be described, in particular those features which emphasize the semi-arid nature of the area, and the water problems of the community. This description is based on field work undertaken in June 1972 and August 1973. More detailed results from the field work are used in later chapters to illustrate general points about the water supply situation in semi-arid areas.

3.2 The Swaziland Background

Swaziland is a small land-locked kingdom in south-east Africa, bordered by Mozambique and the Republic of South Africa (Figure 3.1).

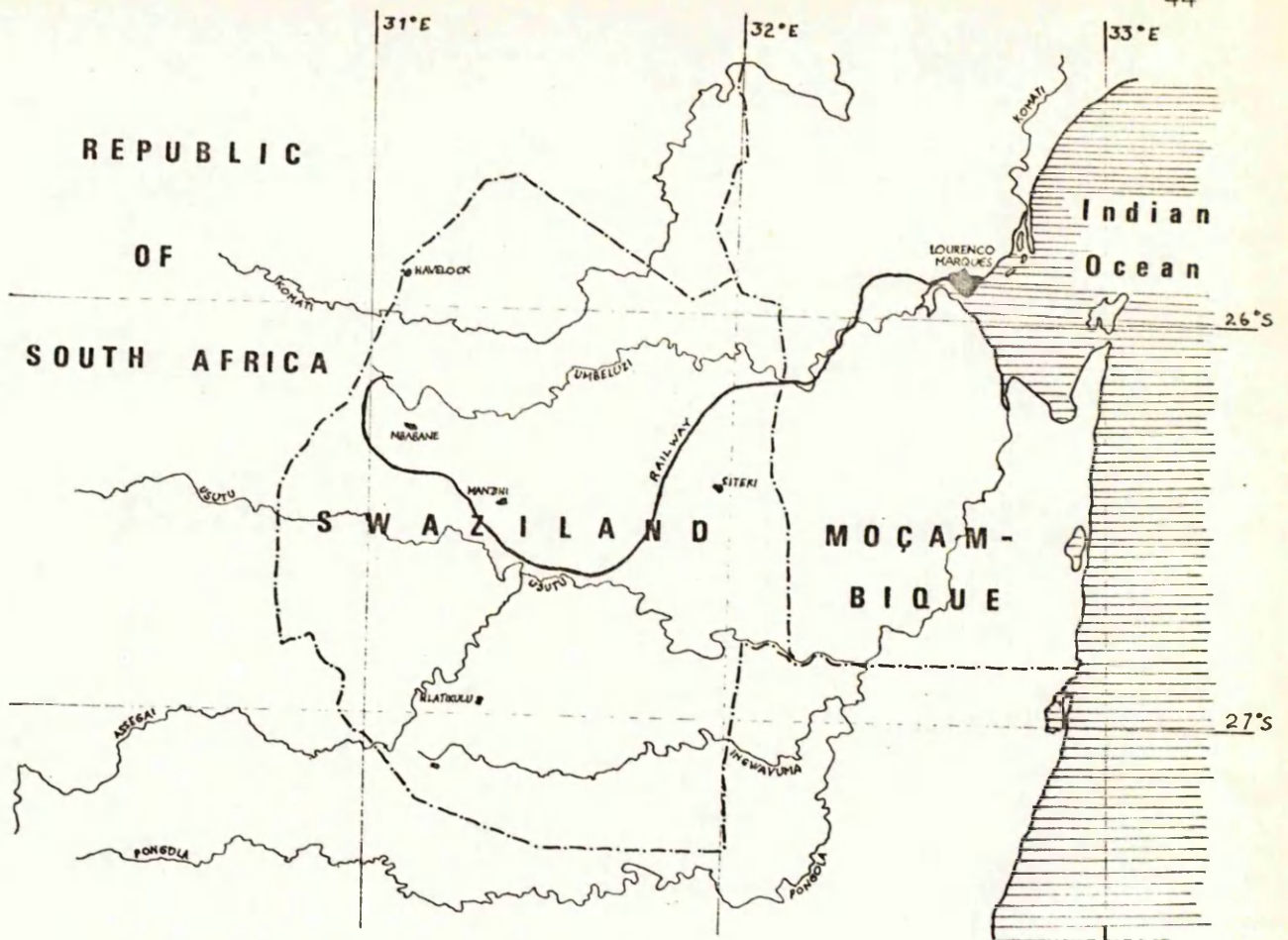


Figure 3.1 SWAZILAND - LOCATION MAP

The map shows Swaziland in relation to the coast and river system of south-east Africa.

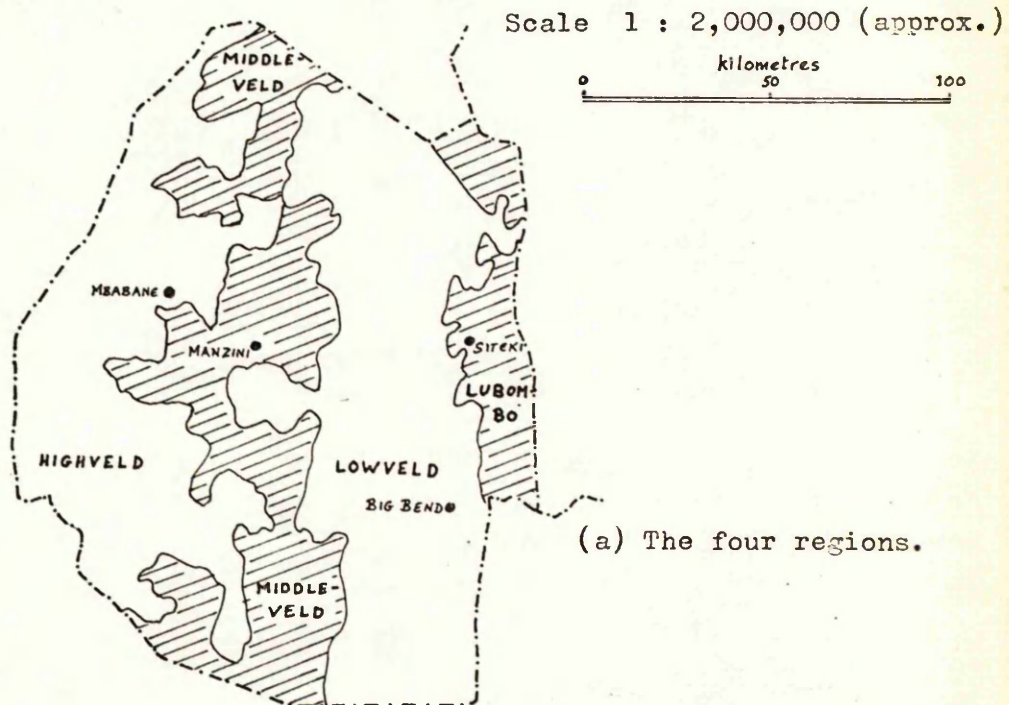
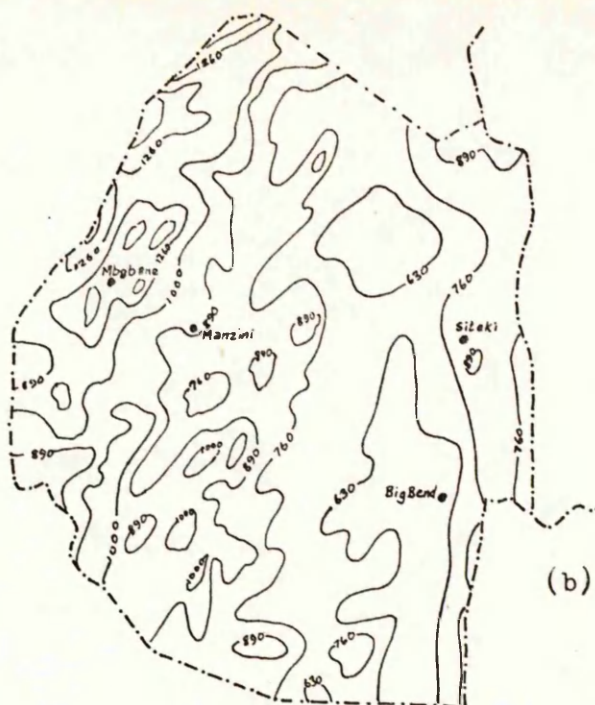
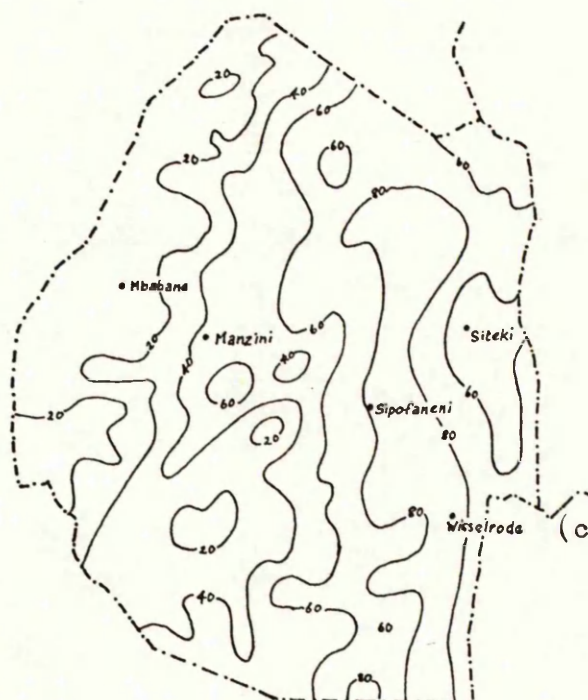


Figure 3.2 SWAZILAND - REGIONS, RAINFALL AND DROUGHT HAZARD



(b) Isohyets show the rainfall associated with the four regions.
(after Murdoch & Murdoch 1957)



(c) Drought hazard - the iso-lines show the percentage of summers (October to March) receiving less than 630mm rainfall.
(after Murdoch 1968)

20% drought risk coincides approximately with 1000mm mean annual rainfall; 40% with 890mm; 60% with 760mm; and 80% with 630mm.

Figure 3.2 cont. SWAZILAND - REGIONS, RAINFALL AND DROUGHT HAZARD

The land area of some 17,400 km² is a little less than that of Wales.

Within its borders there is great variety of physical features and climate, but four well-defined regions running from north to south are readily identifiable (Figure 3.2). The mean annual rainfall and drought risk which are closely associated with the four regions are also shown. In the west, the Veld plateau is terminated by a mountainous zone - a continuation of the Drakensberg range - and the land becomes progressively lower and of more gentle relief nearer the Indian Ocean, until the sharp uniform escarpment of the Lubombo range is encountered running in a north-south direction. The eastern border of Swaziland is the ridge of the Lubombo range. The four regions, based on elevation and relief, are as follows:

Highveld. Much of the land is more than 1200 m above sea level with some peaks over 1800 m. The climate is humid to near temperate. The capital, Mbabane (population around 20,000) is situated in this region.

Middleveld. The altitude of the land ranges from 340 m to 910 m. The warmer, drier climate and generally fertile soils have resulted in this region being the most densely populated, and serious land shortages and soil erosion problems are now making themselves felt. Many of Swaziland's industrial and commercial developments, including Manzini, the other major town, are in the Middleveld.

Lowveld. The altitude ranges from 150 m to 300 m, and the climate is semi-arid. This is the least densely populated region.

Lubombo. The region covers only 1300 km², and is similar in most respects to the Middleveld, though there have been virtually no European developments.

The Swazi first settled permanently in the south-west of present-day Swaziland during the late 1700's. By 1830, King Sobhuza I, with regiments modelled on the Zulu pattern, had extended his control

northwards and westwards to cover an area more than twice that of present-day Swaziland. European missionaries and settlers arrived in the 1850's and iron ploughs were in use by 1860 (Murdoch 1968). King Mbandzeni, who reigned from 1874-1889, granted freely land and mineral concessions to Europeans, actions which had long-term repercussions. Swaziland became politically involved in the Boer War and "protectorate" status under the British followed in 1902. The British rule established an administration and a policing force, but the traditional form of government based on chiefdoms remained largely unaffected. The land and mineral concessions of the 19th century have long been a source of dispute in Swaziland politics, and they provided the background for the subsequent wrangles over the form that the new constitution for independence should take (Halpern 1965). At present, only 55 per cent of the land is held by the Swazi Nation or the Government, the rest is in private hands - mainly Europeans.

Swaziland gained Independence in 1968. The King (Ngwenyama), as Head of State, presides over a dual form of government. An elected and nominated bicameral Parliament provides a western-style government, and the Swazi National Council, made up of the traditional chiefs and therefore representing in theory all adult male Swazis, advises on all matters of Swazi law and custom. The two styles of government have co-existed uneasily, until Spring 1973, when King Sobhuza II suspended the Constitution and took complete control of the country's affairs.

The present population is estimated at 480,000 (1972 estimate, Second National Development Plan, Swaziland Government 1973). Of these, 465,000 are Africans, 94 per cent of whom are Swazi. Thus the great majority of the population has a common language and culture. In 1966, the crude birth rate was estimated at 47-48 per thousand, which is near the biological limit for any fairly large population. The present

growth rate is thought to be around 3.1 per cent per annum, which, if continued, would mean a doubling of the population by the year 2000.

It is interesting to note that of the several reports and development plans produced in the post-war years, only one made reference to the latent population and employment problem (Swaziland, Department of Animal Industry, Agriculture and Forestry 1944):

" yet the day must surely come when every avenue of employment will have to be explored in order to absorb those members of the community not suited to farming, or for whom a place on the land cannot be found. "

The other miscellaneous reports (available in the Library of the Archives and Records Office, Deputy Prime Minister's Office, Mbabane) refer to the need to control cattle population, but that the human population pressures were slight. A population problem was predicted in the Swaziland Census of 1946 when water supplies were suggested as a limiting factor to growth. Even in the current National Development Plan (Swaziland Government 1973) the implications of rapid uncontrolled population growth do not seem to have been fully appreciated.

Swaziland exhibits many aspects of the dual economy typical of developing countries. Because of its geographical and historical connections with the Europeans of South Africa, it is inextricably linked with the economy of the Republic, and it is part of the Rand Currency Area and Customs Union. In the past, the mines and industries of the Witwatersrand attracted migratory labour from Swaziland. This practice is now less common as industries have been developed within Swaziland. The Havelock asbestos mine was opened in the late 1930's, but the most prolific period of Western developments was in the late 1950's and 1960's. During this period afforestation was begun, and a pulp mill opened; extensive irrigated sugar industries were developed in the Lowveld, and

irrigated citrus crops (oranges, grapefruits) and pineapple plantations were established; several light industries were started, and a large iron ore mine was opened up. The railway was opened in 1964, primarily to carry iron ore to the port of Lourenço Marques, but it has had the additional effect of providing a major outlet for Swaziland's other exports.

Most of these developments are controlled by outside interests, and apart from providing some wage employment to a select few, they have had only a marginal influence on most of the rural dwellers who make up 85 per cent of the population. The traditional sector of agriculture contributes less than 2 per cent of total exports. There is evidence that, with the introduction of cash crops such as cotton, the traditional sector began to make a significant contribution during the years before independence, but this advance now seems to have been lost (Maina & Streiker 1971).

In spite of the widening gulf between the traditional and Western economies, it would be wrong to assume that rural people are completely out of touch with European life-styles. Many people have spent periods of employment in the urban centres of South Africa, and migratory labour practices continue within Swaziland itself. The small size of the country and the good road network and bus services enable most people to make at least occasional visits to urban centres.

3.3 Mpolonjeni - the Study Area

1. Location

Mpolonjeni is a subsistence farming community situated about 25 km north of Big Bend. There is no nucleated village: the family homesteads are scattered over an area of some 30 km², lying both sides of the Big Bend to Siteki road. The reference figures 26° 32' south and 32° 75' east locate the area (Figure 3.3).

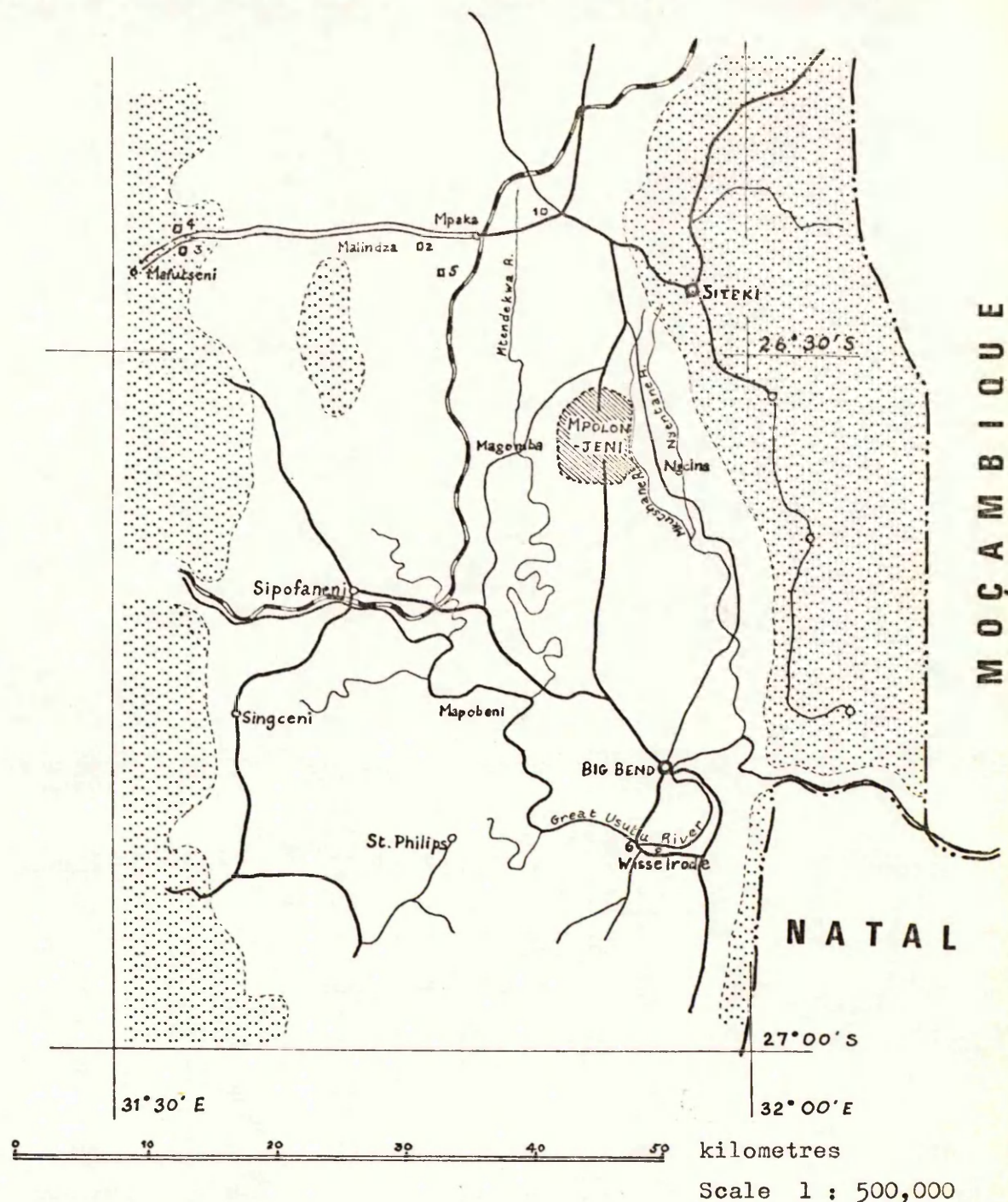


Figure 3.3 MPOLONJENI - LOCATION MAP

The map shows the study area in relation to the rivers, roads and towns of eastern Swaziland. The stippled areas show the limits of the Middleveld (in the west), and the Lubombo region (in the east).

The type and location of the water sources tested (chapter 5) outside the Mpolonjeni area are also indicated, by the symbol \square , and are listed below.

catchment tanks	1. Maphatinduku
	2. Secusha School
roof tank	3. Mafutseni Nazarene School
dam	4. Mafutseni Dam
bore-hole	5. Malindza
river	6. River Usutu

In 1966 Mpolonjeni, and much of the surrounding area, was designated a Rural Development Area (RDA) by the government. A programme for an RDA involves establishing a village site (shops, clinic, school, water supply etc), and consolidation of fragmented arable land and enclosure of communal land. Much of the latter reorganisation of land and the necessary re-settlement of people has already been accomplished. At the village site, Nkundla - a traditional meeting hall (c.f. village hall) is now under construction. A primary school was opened at the site of the Christian Church in 1968, and has been extended to provide for 7 classes. It is likely that the school and the store which have also opened since 1966 have no connection with Mpolonjeni's RDA status.

2. Topography

Mpolonjeni is situated in the eastern Lowveld sub-region as identified by Murdoch (1968). This is the lowest and most uniform terrain in Swaziland, but the land is undulating rather than plain. Mpolonjeni itself lies between 250 m to 320 m above sea level; the median slope of the land is 3° (1 in 19). The main road runs for the most part along the ridge dividing the catchment areas of the two rivers Mkutshane and Mtendekwa (Figure 3.4). Less than 10 km to the east of the road, the Lubombo range rises sharply to heights of 720 m above sea level.

3. Geology

The geological structure of Swaziland is shown in Figure 3.5. Figures 3.6 and 3.7 show the geological map at Mpolonjeni and a typical east-west section. Moving eastwards towards the Indian Ocean, successively younger rocks are encountered. A north-south trend is evident in the eastern Lowveld, so that the geology of the eastern part of Mpolonjeni consists of basalts of the Stormberg Series which overlie the Ecca

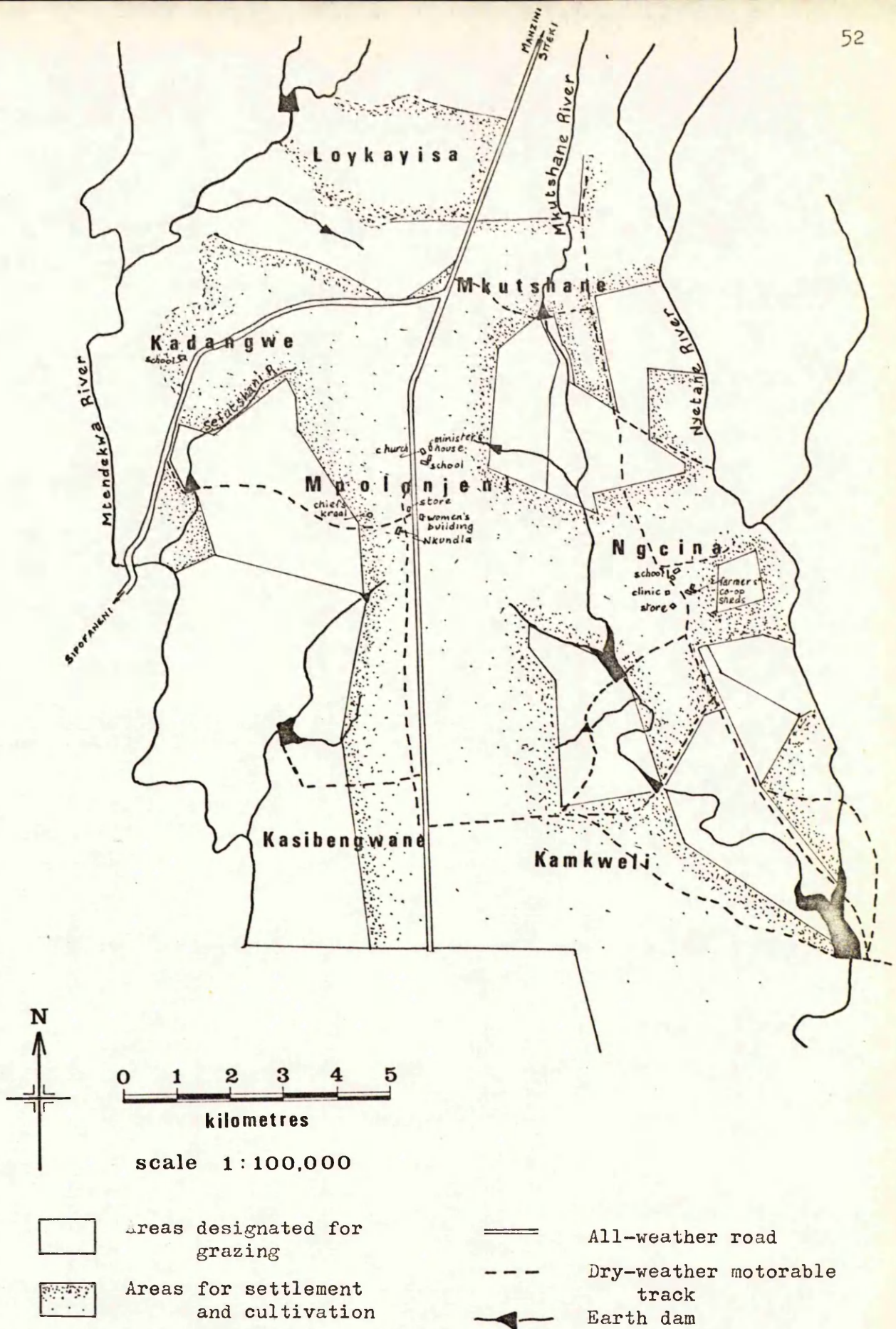
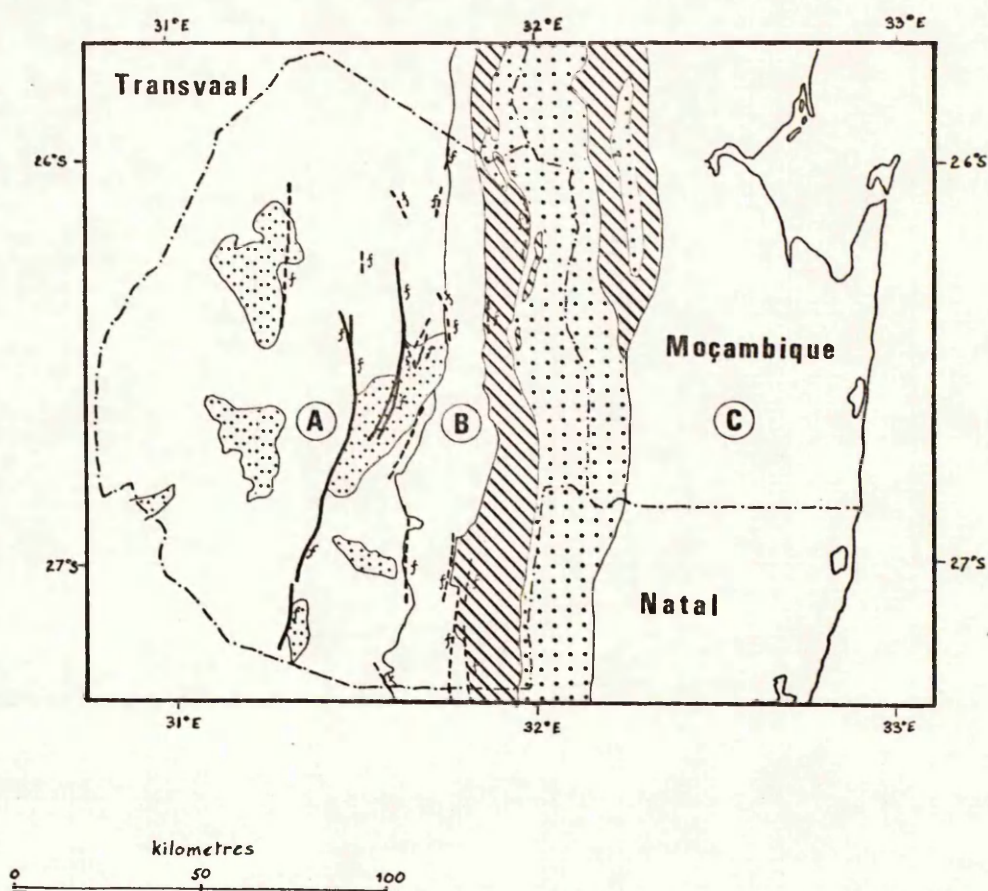


Figure 3.4 LAND USE AND LANDMARKS AT MPOLONJENI

The actual positions of the fencing defining the grazing areas are slightly different (e.g. see Figure 3.13). This map was drawn using information provided by the Ministry of Agriculture



- | | |
|---|---|
| <p>③ Holocene to Cretaceous beds - sands, limestones etc.</p> <p>⊙ Lubombo andesite, rhyolite and granophyre</p> <p>▨ Basalts</p> <p>② Karoo sediments in the Lowveld, mainly sandstones and shales</p> | <p>⊙ Granite plutons</p> <p>① Precambrian undermass, mainly metamorphosed rocks</p> <p>▨ Mylonite in shear zones</p> <p>▨ Other major faults along most of which Postkaroo movement can be proved or is suspected</p> |
|---|---|

Figure 3.5 SWAZILAND - THE GEOLOGICAL BACKGROUND
(after Murdoch & Andriesse 1964)

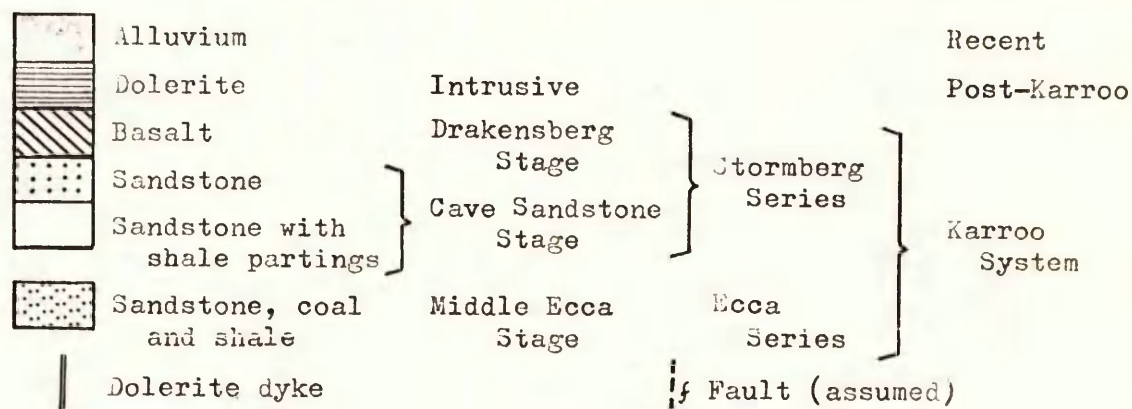
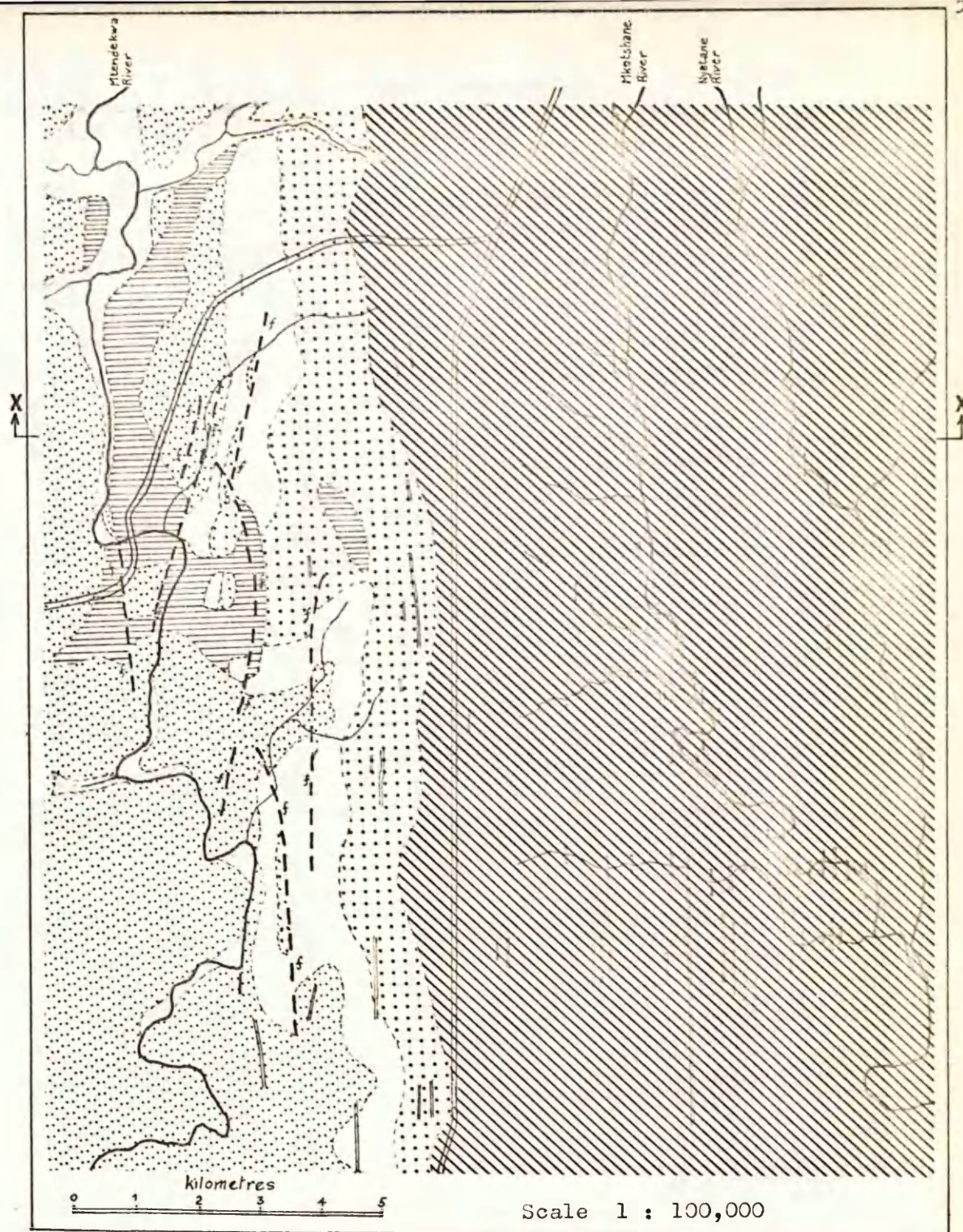


Figure 3.6 MPOLONJENI - GEOLOGY

The geological section at X-X is shown in figure 3.7

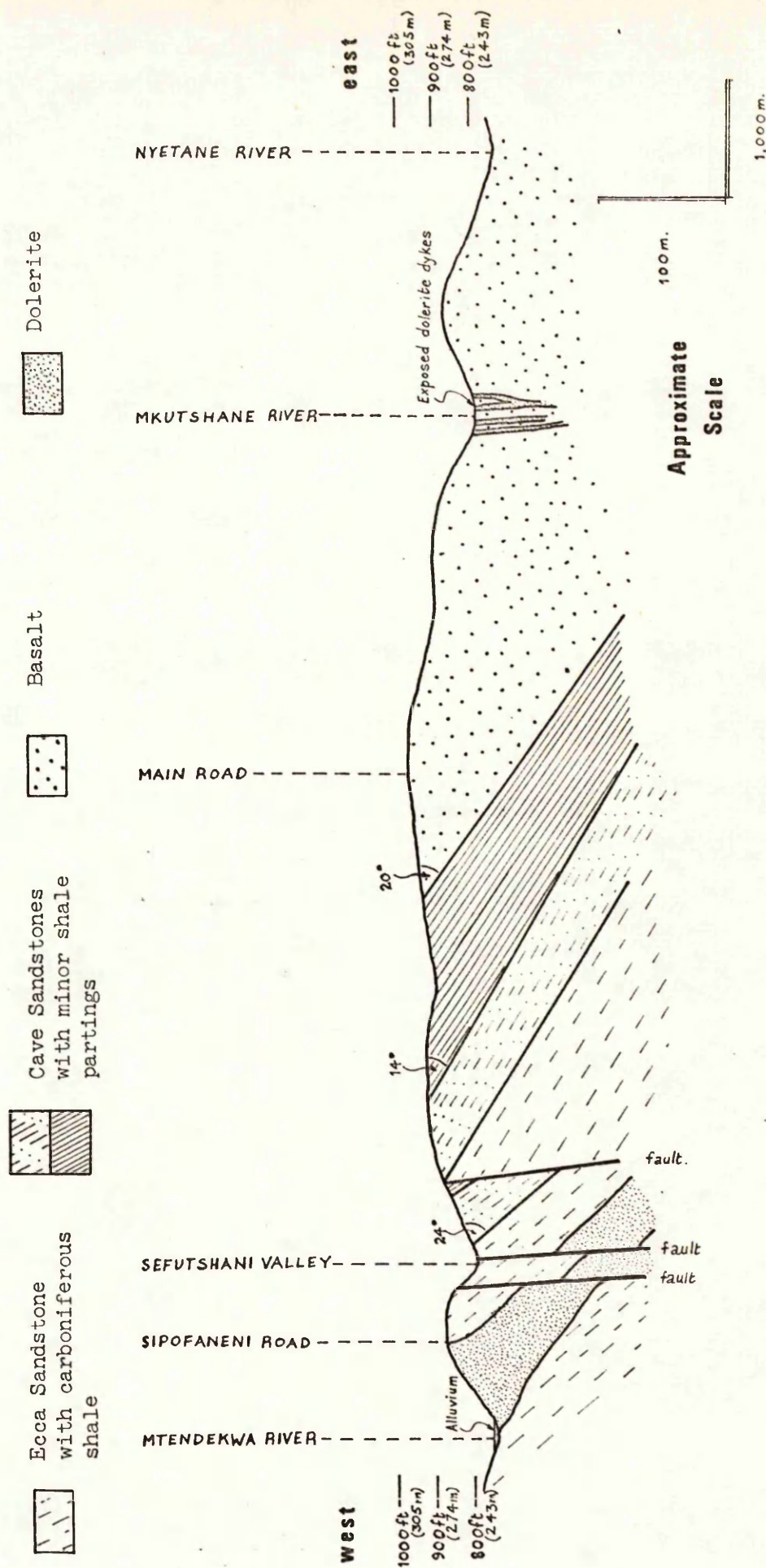


FIG. 3.7

MPOLONJENI, GEOLOGICAL CROSS-SECTION

- approximately at X - X in Figure 3.6
 The Stormberg Series corresponds to Lower Triassic and Upper Triassic times in terms of European geochronology. The Ecca Series corresponds to Permian times.

sandstones and shales of the Karoo system found in the western part. The basalts are interlaced with innumerable dolerite dykes which are readily visible in the stream beds. In the west, dolerite sheets and sills are common. (Murdoch and Andriesse 1964, Murdoch 1968).

4. Soils

The soils of Swaziland have been the subject of a comprehensive study by Murdoch (1968). Pacey (1973) has made a particular study of the soils and land use in Mpolonjeni, and analysed samples of soil from the area. Other information on the parent material of soil in the Lowveld is given by Murdoch and Andriesse (1964).

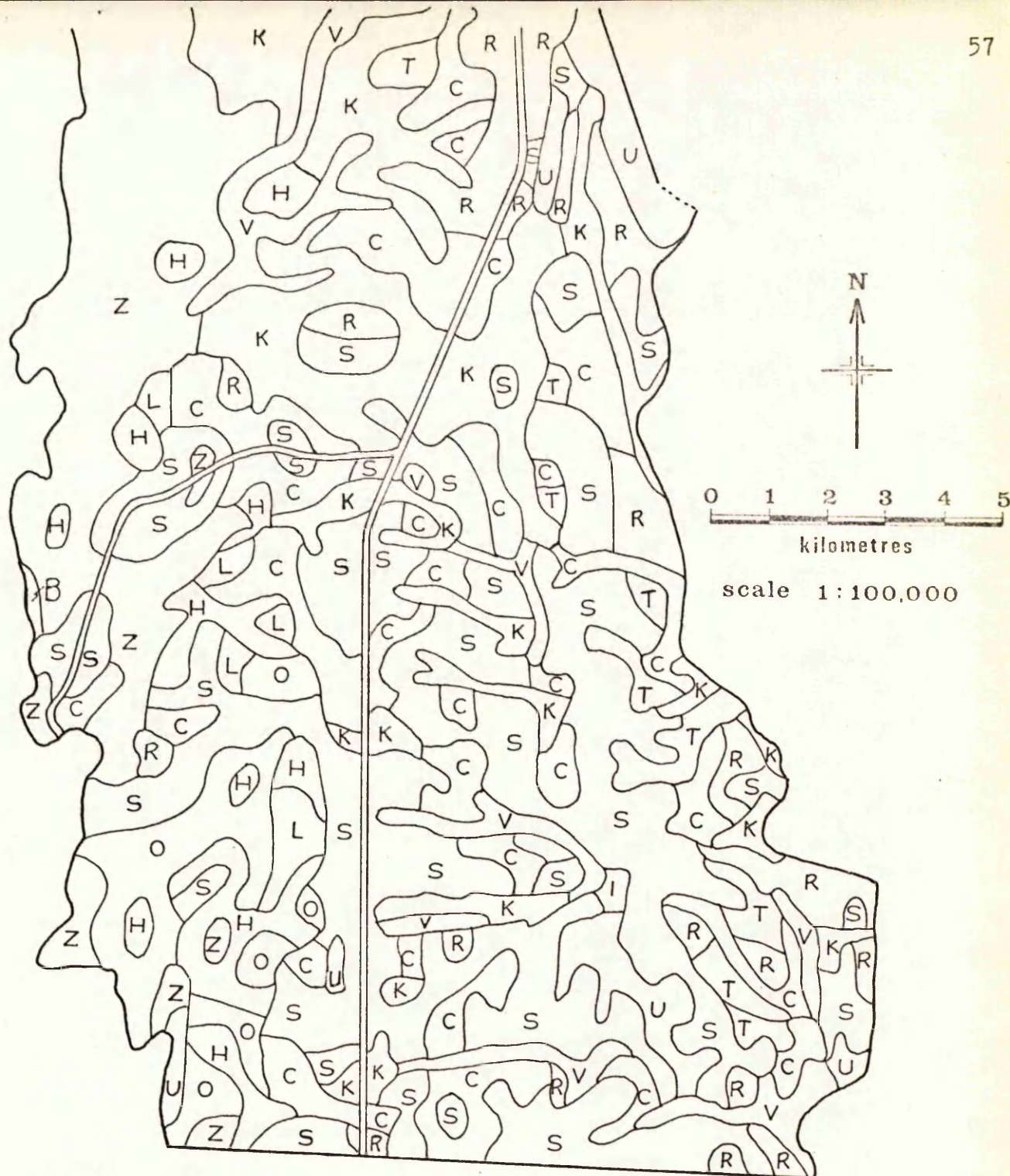
The soils of Mpolonjeni are strongly influenced by geology, but a common feature of them all is their shallowness. Those overlying the basalt rocks in the east are basic, and are generally dark-coloured heavy soils, similar to the well-known "black cotton soils" (Chapter 2).

The sedimentary rocks in the west produce acid and intermediate soils, which are often brown, sandy loams with clay sub-soil. The other main soil type in the area is one which is derived from acid and basic rocks, its parent rock being an admixture of dolerite and sandstone.

Murdoch (1967) produced a soil reconnaissance map for the east-central Lowveld which included Mpolonjeni (Figure 3.8).

5. Vegetation

The Lowveld is often known as the "bushveld". Most of the non-cultivated land in Mpolonjeni could be classed as "parkland-woodland", i.e. medium density bush with the trees spaced approximately 10 to 15 m apart. The height of the trees is rarely more than 4 m, and the average diameter of the larger trunks would fall into the 23 to 30 cm range, i.e. girths of 78 to 94 cm. The main genus is the Acacia, of which the Acacia nigrescens (knobthorn) is the most common, particularly in the shallow soils derived from the basic rocks. Along the ephemeral streams,



Good or fair soils

- L red loam
- R red clay
- C brown clay, very dark
- K black clay
- T grey clay

Unfit ground

- U rocky ground

Poor or very poor soils

- B yellow sand, deep
- H grey sand on mottled clay
- S dark brown loam, shallow (sometimes quite good soil)
- Z grey loam on clay
- O dark grey or brown sand, shallow
- V black clay, deep

These soil ratings refer to rain-grown maize, rain-grown sorghum/cotton rotation, and rain-grown pasture (Pacey).

Figure 3.8 SOIL RECONNAISSANCE MAP FOR MPOLONJENI
(after Murdoch 1967)

Acacia xanthophlea (fever tree) is prominent. Most of the grasses are "sweet", palatable and nutritious all year, hence the recommendation that the land is best suited for stock raising. The main types of grass are Panicum maximum (buffalograss), Themeda triandra (redgrass), and Digitaria (finger grass). Murdoch and Andriesse (1964) have described the veld types found in the area of the Lowveld south of Big Bend. Mpolonjeni best fits their category of "undulating terrain with rather shallow and heavy soils."

3.4 Hydrological and Climatic Data - Water Sources and their Hydrology

Mpolonjeni, as part of the Eastern Lowveld, is unequivocally semi-arid (Murdoch and Andriesse 1964). In making this point in Table 2.1 (section 2.2), some basic meteorological data have already been quoted: the mean temperature at Mpolonjeni is 22°C., and mean annual rainfall is 635 mm. This rainfall is somewhat lower than in many surrounding areas because Mpolonjeni is near the middle of the "rain shadow" produced by the Lubombo Range. Open water evaporation (E_o) is estimated as 1370 mm annually, and potential evapotranspiration (E_c) as 1100 mm.

These figures have been obtained from maps showing isohyets and iso-evaporation lines (Murdoch & Murdoch 1958, Republic of South Africa Development Atlas 1966), and from estimates based on the records of local weather stations. Murdoch (1968) gives mean annual, and mean monthly rainfall figures for four of the Lowveld weather stations, including Sipofaneni, 23 km to the west, and Wisselrode, 36 km to the south of Mpolonjeni. The author was able to obtain more recent data for the Wisselrode station, which has the longest continuous record of rainfall and evaporation in the Lowveld, and Mr. T.R. Brook of the Swaziland Ministry of Works supplied more recent data for the other stations.

Murdoch (1968) gives an empirical formula which describes how mean annual rainfall varies with elevation. Mean annual rainfall (in inches) is approximately equal to

$$16 + \frac{1}{100} \times \text{altitude (in feet)}.$$

Using this relationship, and comparing records of local weather stations, it was possible to estimate a mean annual rainfall, and mean monthly rainfall figures for Mpolonjeni (Table 3.1). Open water evaporation is more difficult to estimate since a knowledge of how the pan coefficient varies for different regions and different seasons of the year is needed. Pacey (1973) has studied the evaporation records for Lowveld weather stations and made an assessment of pan coefficient variation with the seasons for Mpolonjeni conditions. His estimates of monthly open water evaporation at Mpolonjeni are also shown in Table 3.1a.

Records of weather stations in the Lowveld show that, on average, 76 per cent of the annual rainfall comes in the period October to March, whilst April to September constitutes the dry season. Sometimes no rain at all falls in July or August, though more typically there is an occasional storm with up to 20 mm of rain. Because the rainy season begins around the beginning of October, it is more convenient to quote the actual annual rainfall for the year beginning in October. On this basis, estimates of actual rainfall at Mpolonjeni in recent years are given in Table 3.1b together with monthly estimates. As with the estimates of mean monthly rainfall described above, it was assumed that the rainfall patterns at Mpolonjeni would be consistent with the patterns of local weather stations. This is a reasonable assumption for average figures, but because of the localised nature of the rain, the monthly estimates given for specific years could be in error.

Table 3.1 Estimates of Rainfall and Evaporation at MpolonjeniTable 3.1aMean Monthly Rainfall in mm

	<u>1922-1972</u> <u>Wisselrode</u>	<u>1937-1972</u> <u>Sipofaneni</u>	<u>Estimated</u> <u>Mpolonjeni</u>
October	46.7	57.8	56
November	75.0	78.1	81
December	85.0	90.2	95
January	87.2	94.5	96
February	65.5	99.0	88
March	62.5	85.5	79
April	36.7	56.1	48
May	22.7	26.0	24
June	12.3	16.6	13
July	10.1	14.1	11
August	10.3	18.8	14
September	25.0	31.3	30
TOTAL	539.0	668	635

Mean monthly evaporation in mm

	<u>Wisselrode</u> <u>Class 'A'</u>	<u>Pan</u> <u>Coefficient</u>	<u>Open</u> <u>Water</u>	<u>Estimated for</u> <u>Mpolonjeni</u>
October	202	0.7	141	120
November	212	0.8	169	144
December	244	0.8	195	166
January	248	0.8	198	168
February	208	0.8	166	140
March	187	0.8	150	128
April	146	0.8	117	100
May	106	0.8	85	73
June	89	0.8	71	60
July	108	0.7	76	65
August	157	0.7	110	94
September	188	0.7	132	112
TOTAL	2095		1610	1370

Table 3.1 (cont.)Table 3.1bEstimated monthly rainfall at Mpolonjeni for the years 1969-73 (mm)

	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>
October	140	89	81	19	
November	102	36	114	73	
December	59	89	123	48	
January		13	158	166	47
February		75	34	166	190
March		30	83	150	11
April		24	87	3	31
May		33	36	90	60
June		2	5	14	5
July		2	0	15	0
August		24	0	3	23
September		18	11	5	25
TOTALS	540	625	924	532	

Totals:	1969-70	540mm
	1970-71	625mm
	1971-72	924mm
	1972-73	532mm

These figures reflect the great variations which must be expected. Monthly figures show an even more erratic pattern; 1972-73 was disastrously dry during the growing season of November, December and January, so that maize crops suffered very badly. But a series of heavy storms in February produced almost 200 mm in one month, bringing the total for the year within sight of the mean figure.

Sources of water for domestic supplies and watering livestock include streams and rivers; impounding reservoirs (dams) in river or stream channels; small bunded dams on sloping ground; and tanks for collecting water from corrugated iron roofs. In addition, natural depressions which retain rainwater for more than a few days are used for washing clothes and watering cattle. Some of the borrow pits near the main road receive significant quantities of run-off water, and are large enough to be considered permanent water sources. Several of the neighbouring communities have bore-holes, but there is none at Mpolonjeni itself. The locations of the larger sources are shown in Figure 3.9.

Surface Sources

Rivers and streams, and the earth impounding dams, are by far the most important sources of supply at Mpolonjeni. All the rivers have an ephemeral flow which may be quite considerable during and after storms, but which ceases altogether during the long dry season. In the long intervals between storms, river flow declines very quickly, but in the larger rivers there is a base flow element which persists for three or four weeks, and which is due to the seepage processes of water moving through soil and weathered rock layers (Chapter 2). During the exceptionally wet year of 1971-72, flow persisted for a total of nine months in the Nyetane River; more usually river flow may be expected only from late November to early April, with very occasional floods at other times.

--- ~~1~~ Piped supplies; water is pumped from the reservoirs to storage tanks; then gravity flow to villages". The Mpolonjeni scheme is incomplete.

..... Transient streams

Water-holes; when marked with B.P. - formerly borrow pits for road construction

Magomba Cattle dip tank

• Bunded dams

* Bore-holes; yield as shown	1 - dry	2 - 0 to 450
in litres/hr:	3 - 451 to 1350	4 - 1351 to 2700
	5 - 2701 to 4500	6 - 4500

Figure 3.9 WATER SOURCES IN AND AROUND MPOLONJENI

Water quality tests were performed on those sources marked with a T. The names of the dams are the local ones, and are those used in the text. The official names, where different are shown in brackets.

All the rivers from the Mpolonjeni area discharge into the perennial Usutu River, which rises in a well-watered region of the Swaziland and Transvaal Highveld. Gauging stations on the Usutu suggest that Lowveld rivers discharge 4 per cent of the rainfall over their catchment areas (Murdoch 1968), and this agrees with more detailed data which Midgley and Pitman (1969) obtained from a computer analysis of all recorded river flows in southern Africa. Mpolonjeni straddles the ridge which divides the catchment areas of the Mtendekwa and Nyetane Rivers. Midgley and Pitman give figures for mean annual run-off in these catchment areas which can be expressed as follows:

	Area	Mean Annual run-off	%age run-off	Mean Annual Rainfall
	km ²	m ³ x 10 ⁴	%	mm.
Lower Mtendekwa catchment	261	717	4.2	651
Nyetane catchment	386	1378	5.3	687

The Nyetane catchment receives rainfall from the well-watered Lubombo Range, and because the rainfall estimate for Mpolonjeni is less than the mean for either of these two catchments, the percentage run-off has been estimated at 4.1, that is, for an annual rainfall of 635 mm, mean annual run-off should be 26 mm.

More detailed run-off data seemed necessary if the surface water resources at Mpolonjeni were to be properly assessed, and the only way open to the author of obtaining these additional data was to observe water levels and spillway conditions at dams in the area. Thus the spillway at Sefutshani Dam (Figure 3.9) was badly eroded, giving evidence of a very considerable overflow. It could be concluded that the capacity of this dam was small in relation to the run-off produced by its catchment. Similarly, an inspection of the spillway at Maggenya's Dam indicated that there had never been any overflow, and thus the capacity of this

dam was large in terms of the run-off from the catchment. The capacities of five dams were estimated by taking a few basic measurements in the field and checking them against aerial photographs. The results are shown in Table 3.2 (see also Chapter 8). All the dams were filled almost to capacity when the fieldwork was done in June 1972, and Mkutshane and Mbonga Dams were actually overflowing. Rough estimates based on a study of these conditions suggested that in the exceptionally wet year of 1971-72, mean run-off was approximately 60 mm, compared with the 26 mm average.

In August 1973, an effort was made to check the change in water level in four dams which occurred during a two-week interval. Since August is usually a dry month, it was anticipated that water levels would fall, and estimating the losses from evaporation, it should have been possible to estimate seepage losses. In fact, an unusually heavy storm occurred, and water levels actually rose in two dams. The original intention of measuring seepage losses had to be abandoned, but the records of changes in water levels combined with theoretical estimates of seepage losses (Farrar & Pacey 1974, and Chapter 8) enabled estimates of run-off to be made instead (Table 3.3). The measurements of water levels were not very accurate because cattle trampled on some of the markers used to fix the initial water level.

For a period of 13 days in August, evaporation at Mpolonjeni is about 39 mm. Seepage losses at Maggenya's Dam were estimated, as indicated above, at 3.3 mm/day and for this period would amount to 43 mm. Allowing a small amount for water drunk by cattle and used by people - around 5 mm - and subtracting the estimated rainfall of say 22 mm for the period gives a figure of 65 mm for the net loss. The figures for net losses for the other dams were calculated in the same way.

Table 3.2

Dimensions of Five Dams at Mpolonjeni

(based on fieldwork, June 1972 and August 1973, checked by examination of aerial photography).

Dam	Length of Dam Wall (m)	Maximum water depth June 72 (m)	Capacity (m ³)	Remarks
Sefutshani	305	6.8	185,000	Badly eroded spillway
Mkutshane	260	6.5	140,000	Overflowing June 72, supplies dip tank and proposed source for Mpolonjeni supply.
Maggenya's	207	3.65	45,000	No evidence of overflow, large seepage losses.
Mbonga	220	4.7	206,000	Overflowing June 72, source for Ngcina supply, eroded spillway, draw-off pipe.
Hlangothi Old	200	3.7	22,800	Silted, serious damage to downstream embankment at one point, disused drinking trough.

Table 3.3

Observed Changes in Storage at Four Dams, August 1973, and estimates of Run-Off

Dam, and dates of Record	Change in water level (mm) (h)	Net losses (L) (mm)	Water Surface Area (m ²)	Catchment Area (ha)	Run-off (mm)
Mkutshane 6 - 19 Aug	+ 100	60	45,000	800	0.9
Maggenya's 6 - 19 Aug	- 50	65	16,500	170	0.15
Mbonga 6 - 19 Aug	- 20	60	105,000	2800	0.15
Hlangothi Old 3 - 17 Aug	+ 250	25	12,500	90	3.8

The figures for run-off in the last column are calculated as follows:

$$\text{Run-off} = \frac{(h + L) \times (\text{water surface area})}{10,000 \times (\text{catchment area in ha})}$$

Net loss is the total loss by evaporation and seepage less the depth of rain which falls directly on the water surface of each reservoir.

The major storm was very localised, and probably produced 15-20 mm of the rain during the period under study. On this basis, the dams which received run-off amounting to an average of 0.15 mm over their catchment were probably receiving around 1 per cent of the rainfall. It is possible that seepage losses have been under-estimated, but run-off from dry-season storms would tend to be less than the overall, long-term average for the area, because the ground will be completely dried out. At Mpolonjeni, low run-off at the end of the dry season could well be explained by the nature of the C-set and K-set soils (Figure 3.8). On drying out these soils shrink and cracks develop. In the first rains, the cracks take much of the run-off, but after a few storms the soil swells, the cracks close up, and the soil becomes less permeable. This may partially account for the low run-off in the Mbonga and Maggenya's catchments, but of course, another explanation is that these areas received a much lower rainfall during the storm.

The estimates of net losses, rainfall, and change in levels are obviously somewhat approximate, but the rise in the water level at Hlangothi Old Dam was so large that errors in estimating losses make little difference to the result. The catchment area of this dam may have caught the full brunt of the storm, and water may also have drained from the main road at the head of the catchment, but the main cause is the heavy overgrazing which has occurred on land immediately surrounding the dam. This overgrazing has left the ground almost denuded of grass, though it still supports thorn bushes. Bare soil such as this often develops an impermeable layer or "cap" as a result of raindrop impact. With these conditions on a fairly steep slope, it is possible for almost 100 per cent of rainfall to be run-off, and this is undoubtedly happening in limited areas of the Hlangothi catchment.

It is significant that a little to the west of Hlangothi dam,

serious gully erosion is occurring (plate 8), largely due to the accelerated run-off caused by the overgrazing. In contrast, the catchment areas of Mbonga and Maggenya's Dams contain a large amount of cultivated land. Contour ploughing is practised which controls soil erosion by discouraging channelling of run-off water.

A technical discussion of these dams will be provided in Chapter 8, where the high level of seepage losses will be examined and plans of typical sites will be given. Here they are relevant as illustrating the hydrology of the area, and as amplifying the points made in Chapter 2 about run-off and erosion in semi-arid areas.

Groundwater Sources

Since bore-holes are considered by many to be the best overall solution to the water supply problem in semi-arid areas, it is worth considering in more detail the prospects for underground supplies in the Lowveld.

In Chapter 2, some general points were made about the hydrological properties of the rocks underlying the Lowveld. Even the shales and sandstones of the Karoo System in the west have primary hydrological properties which make them poor aquifer material. Only when they and the basalts in the east, have been affected by events subsequent to their formation, such as jointing, fracturing, and weathering, do they give any prospects for underground supplies.

Such conditions for fissuring were provided by the baking and cooling which occurred with the intrusion of the many dolerite dykes, and thus the possibilities exist for numerous small confined aquifers in the contact areas of the dykes. However, the water yielding zones are relatively narrow - ranging from a few centimetres to a number of metres - and must therefore be located accurately. All high yield bore-holes in the Lowveld have been sited on vertical dykes within 0.6 m of

dyke contact (Urie 1969), and yields fall off sharply if they are sited outside this area. Because the striking of groundwater is so unpredictable, Urie recommends that the drilling of more than one site hole be accepted as part of the estimate.

Groundwater supplies for the Swazi Lowveld population (as opposed to European farmers) were only seriously considered after 1965 - as an emergency measure to counteract the effects of the drought during the early 1960's. The Magomba bore-hole to the north-west of Mpolonjeni (Figure 3.9) was drilled in 1966 for this reason. The Ngcina bore-hole, to the east of Mpolonjeni, was drilled in 1967-68, and was intended as a stock watering point for the Rural Development Area. The Annual Reports of the Geological Survey and Mines Department (1965-70) describe a number of surveys (largely unsuccessful) to locate and assess Lowveld groundwater supplies. In some cases, bore-holes which had yielded 450 to 1350 litres per hour in 1967, were dry in 1970 (Annual Report 1970).

The records for Lowveld bore-holes for the period 1946 to 1970 are shown below in Table 3.4.

Table 3.4

Record of Lowveld Bore-Holes for the Period 1946-70

(From the records of the Department of Geological Survey,
Swaziland).

Total	Yields (litres/hour)						Brackish ⁺
	Dry	0-450	451-1350	1351-2700	2701-4500	4500	
162*	41	17	27	20	14	38	15

Notes: + Most of the bore-holes were for stock watering purposes, and thus the taste of the water was seldom recorded.

* The yields of 5 bore-holes were not recorded.

The success rate is low, and yields are relatively low. It is clear that groundwater supplies are not a satisfactory answer to Lowveld water supply problems, though if a sweet-tasting, reliable supply could be located near a densely populated area, it could provide a solution for that particular community.

Perched Water Tables

Although the regional groundwater table is deep-seated, perched water tables are another matter, and occur in many places at depths from a few centimetres up to 2 metres or more (Murdoch 1962). Two perched water tables were seen in the Mpolonjeni district, both probably the result of underlying clay soils. One, about 300 m north of the school was used for the school water source. 44-gallon (200 litre) oil drums, filled by ladling water into them, were then rolled back to the school compound. Water had long been observed at this point, and at some time the source had been deepened to improve the availability of supply. But even at the end of the rainy season, the depth of water would not be more than 0.5 m nor the area more than 50 m². The source was usually dry at the end of April.

The other perched water table was at Magomba (to the north-west of Mpolonjeni). This source was little used since there were others nearby. However there were signs that here water was retained for a longer period. After the drier than average season, 1972-73, water from this source was still being used in August 1973.

3.5 Population, Land Tenure, Local Government and Land Use

The development of the community at Mpolonjeni has to be pieced together from a variety of interrelated sources and is presented mainly as a series of maps (Figures 3.10 to 3.13) and tables. Apart from the major published works of Jones (1968) and Holleman (1964),

personal observations, air photographs, and Pacey (1973) provide most of the information.

Before the 1950's the Lowveld had few permanent settlements. Since then, the major hazards of malaria and trypanosomiasis, a cattle disease, have been largely eradicated. Numerous small dams have been built, which have overcome the most immediate water shortages, though the semi-arid climate still makes the growing of maize and even sorghum a risky undertaking. In 1966 the Lowveld, comprising 36.9 per cent of the land area of Swaziland, supported 23.8 per cent of the rural population at a mean density of 17.2 persons per square kilometre. The indications are that the region will be increasingly settled as a result of population pressures in the Middleveld. This density of population is relatively high compared to other semi-arid environments in Africa. For example, the population densities of the semi-arid regions of northern Kenya are around one person per square kilometre. (e.g. Ref. Atlas of Kenya 1967, The Survey of Kenya, Nairobi.)

Mpolonjeni was one of the earliest settlements in the Lowveld, although the community in its present form can be said to have developed only since 1950 - the 1947 air photographs reveal a sparse population with very little to anticipate the present settlement pattern. If the school, store, Nkundla and Hlangothi Old Dam are taken as representing the main focal points of the community today, then the chief's kraal which probably acted as the original focus of the settlement seems to have been situated one or two kilometres to the north. This original settlement dates from 1880, when King Mbandzeni established a royal cattle post there, and appointed Chief Duba as responsible for the King's cattle.

1. Population

The map in Figure 3.10 shows the distribution of population in

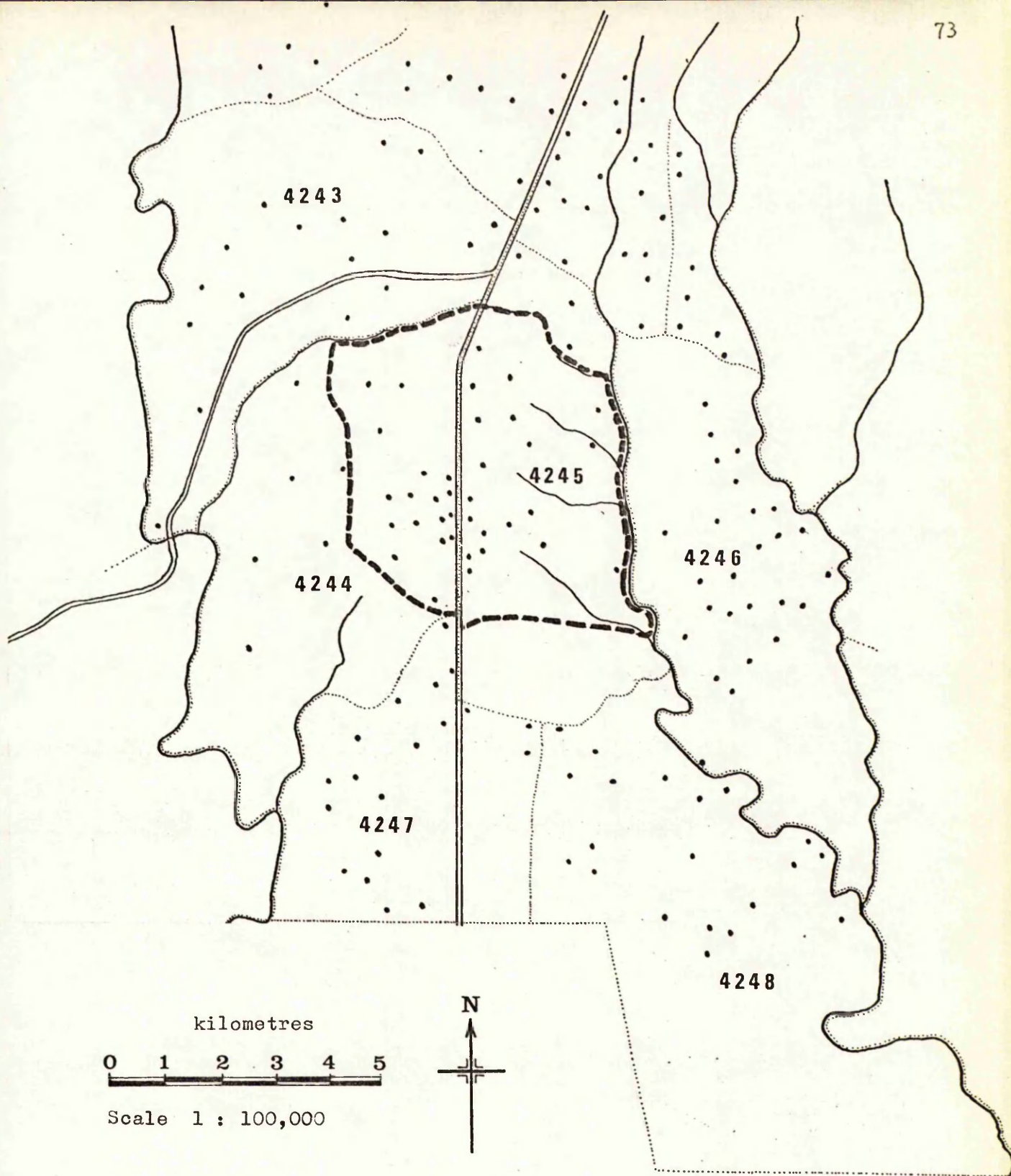


Figure 3.10 DISTRIBUTION OF POPULATION IN AND AROUND MPOLONJENI

This map is based on one published after the 1966 census, and reproduced on a smaller scale by Leistner & Smit (1969).

Each dot represents 20 people. The numbered areas bounded by dotted lines are the enumeration areas used in the 1966 census (tables 3.5 and 3.6)

The heavy dashed line shows the extent of Mpolonjeni where about 770 people lived in 1966.

1966, with marked concentrations around the focal points mentioned. From this, the population is estimated at around 770. The census data on which this is based is shown in another form in Table 3.5; Mpolonjeni is included in districts 4244 and 4245 and accounts for most of the population in these districts. The number of temporary absentees (people who have been absent for less than three years and who are expected to return) is 26. This is equivalent to 2.8 per cent of the population, which is an average figure for other parts of the Lowveld. It is assumed that the temporary absentees were in the Republic of South Africa seeking employment. Figures for other parts of Swaziland, particularly the south west, show that sometimes over 25 per cent of the population are temporarily absent (Jones 1968). Since the majority of these absentees are men of working age, the populations in the rural areas have disproportionate numbers of females, children and elderly people. Table 3.6 shows the age distribution for the Mpolonjeni districts. There are relatively few people in the middle groupings and approximately twice as many women as men in the 20-34 age category. The absence of young men and the preponderance of children and elderly people was quite obvious during the author's visits, and it is probable that many of the men had temporary employment in Manzini or Mbabane. In this respect the Swazis are similar to other southern African peoples who find work in the urban areas, but still retain the interests of their dependents, land and property in the home districts.

Another conclusion which is apparent from the census data, is that children comprise half the population. This is partially a reflection of the absentees in the middle age group, but the population distribution in Mpolonjeni is consistent with the general pattern for developing countries with high birth rates and death rates; approximately 45 per cent are children under 15 and 6 per cent are adults over 60 years

Table 3.5

Census Data for Mpolonjeni (1966 Swaziland Population Census, Jones 1968)

Table 3.5a

Census Area (Figure 3.10)	Area	Population	Densities, ² people/km	Temporary Absentees	
				Male	Female
4243	21.3	379	17.8	1	1
4244	31.3	556	17.7	14	3
4245	22.0	362	16.4	9	-
4246	27.2	538	19.4	1	-
4247	21.5	383	17.8	12	-
4248	42.3	382	9.1	18	-

Table 3.5b

Census Area	Age Group	0 - 4	5 - 9	10 - 14	15 - 19	20 - 34	35 - 49	50 - 64	65 - 99	Total
4244	Male	49	48	45	17	16	32	23	13	243
	Female	67	55	30	9	38	77	18	19	313
4245	Male	20	40	33	16	21	29	12	9	180
	Female	40	19	12	14	42	24	16	15	182

Table 3.6

Details of Chiefs' Followers in and around Mpolonjeni (Jones 1968)

(See Figures 3.4 and 3.13 for place names)

Name of Chief	Type	Area of Jurisdiction	Followers	
			1956	1966
Mnt. Maholabandzaba Dlamini	B	KaMkweli	1473	1515
Mcoshwa Shongwe	C	Magomba (Kadangwe)	398	634
Macebo Duba (deceased)	T	Mpolonjeni	946	1284
Mnt. Mkhosini Dlamini	B	Ngcina	341	478
Sibongwane Ndzimande	C	Nhlangotsini (Kasibengwane)	545	693

- Key to Chief type: B - Bantfwabenkosi - Princes of the royal Dlamini house who have been given territorial jurisdiction.
- C - Clan - Originally leaders of clans living in Swaziland when the Dlamini clan arrived, or who were allowed to settle in the country at a later date.
- T - Tindvuna - Lieutenants of the Ngwenyama, who have control over royal homesteads or royal cattle posts.

Of the 770 people in the Mpolonjeni study area in 1966, perhaps 570 come under the late Chief Duba's jurisdiction and 200 under Sibongwane Ndzimande.

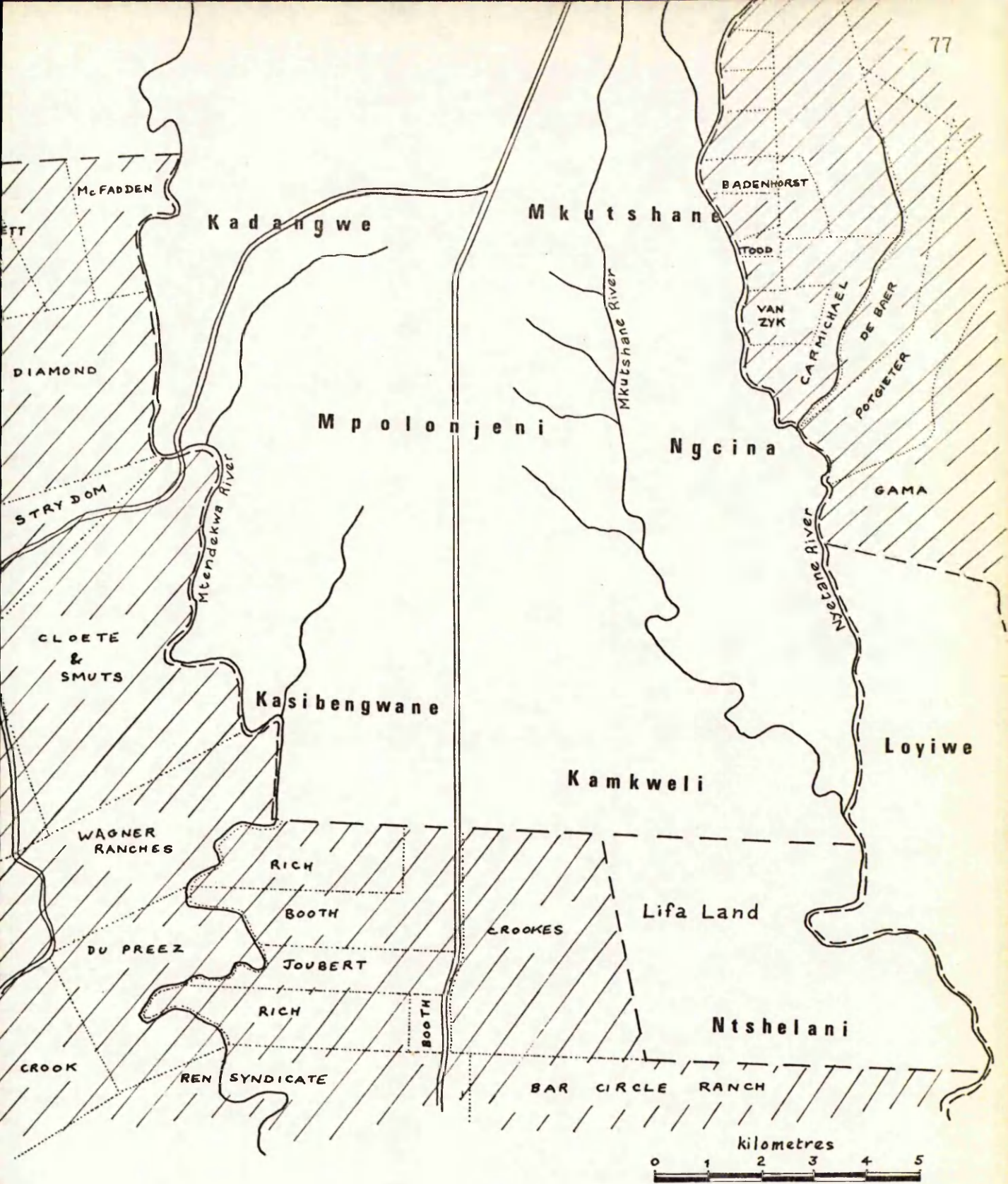
of age. The figures for rural Africans in South Africa are 44 per cent and 6 per cent respectively. The non-African population in South Africa has figures of 32 per cent and 10 per cent, in agreement with trends in Western countries (Holleman 1964, p.107).

The growth rate of the population in 1968, following the 1966 census, was estimated at 2.7 per cent. More recent evidence has suggested that 3.1 per cent is the current growth rate (Swaziland Government 1973). Assuming 2.9 per cent as an estimate for the period 1966 to 1971, then the population of Mpolonjeni would be around 890 in 1971.

2. Land Tenure

In Swaziland there are two main categories of land in the rural areas. The essential distinction is between individual tenure holdings, which are owned almost exclusively by Europeans and result from "concessions" granted by King Mbandzeni in the last century, and what is collectively known as "Swazi Nation Land", which places ownership with the Ngwenyama in trust for the Nation. This second category originally accounted for only 38 per cent of the country, but since 1946 the policy has been to purchase individual tenure land as it became available, with money raised by the Lifa Fund (a cattle levy: Lifa means heritage). The map of Figure 3.11 shows the land tenure boundaries around Mpolonjeni.

Individual ownership of land is not recognized on Swazi Nation Land. Instead, it is divided into chiefdoms, and each chief allocates arable plots and a homestead site to each family in his domain. The remaining land is grazed communally. The area under a chief's jurisdiction is not usually marked by formal boundaries, but the author's enquiries and the census data set out in Table 3.5, have enabled some



Scale 1 : 100,000



Swazi Communal & National Land



Individual Tenure Land with names of land-owners as shown on official map of 1963.



boundaries on Swazi National Land



boundaries on Individual Tenure Land

Kamkweli

names of communities on Swazi National Land, as shown on the same map (Department of Agriculture, Mbabane 1963).

Figure 3.11 LAND TENURE IN AND AROUND MPOLONJENI

tentative boundaries to be drawn for the study area (Figure 3.13). The single community of Mpolonjeni rather unusually falls within two chiefs' areas. Most of Mpolonjeni came within the late Chief Macebo Duba's domain, and this is now administrated by his Nduna* (lieutenant) Mr. Gadele Gwebu. The southern part of the study area comes under Chief Sibongwana Ndzimande of Nhlangotsini. Mpolonjeni plays an important part in the way of life of this part of the Lowveld, because within the district, there is the Nkundla - the meeting place for discussion of regional affairs concerning the six neighbouring chiefdoms.

3. Local Government

The chiefs administer land rights according to Swazi Customary Law, and they form part of a system of government which has survived from long before the colonial era with remarkably little alteration. Kuper (1947) has described the heirarchy of chiefs in Swaziland whose apex is the Ngwenyama - the "paramount" chief or King. The British administration recognised the authority of the King and chiefs within the country, and modified the system only by setting up courts to hear cases arising from the enforcement of Swazi Customary Law, and by strengthening the National Council which advises the King.

All these traditional arrangements remain, but grafted on is a "Whitehall"-type of administration complete with Ministers, Permanent Secretaries and a Civil Service. At local level, there are District Offices, the extension and veterinary staff of the Ministry of Agriculture and a small number of community development and home economics officers. Much of the initiative for development in the rural areas arises within these Civil Service organisations, but because of the dual system of government, civil servants cannot act in a particular area without the acquiescence of the local chiefs and ndunas. There is sense in this, because the chiefs are an integral

* plural actually tinduna

part of the local community, and reflect its views as well as sometimes attempting to influence them.

How this dual system of government works in practice can be better understood by looking at the brief history of the Mpolonjeni water supply project. Shortly after Mpolonjeni became part of the central Lowveld R.D.A., a piped water supply was proposed for the Nkundla and the school. The project was instigated and planned within the Ministry of Agriculture, whose officers then arranged meetings with the community to explain the proposal. Meetings of this type are attended by the male members of the community, the ndunas and the chief. Mpolonjeni is unfortunate in being without a chief at the moment, and having an nduna who is not well enough to attend all the meetings. The first discussions concern the principle of the project. Once this has been accepted, further meetings are arranged with members of the District Office to consider how the project should be implemented. The author was allowed to attend one of these meetings at Mpolonjeni during June 1972, when the main point at issue was whether the community members should contribute their own labour to the project, or whether it was better to obtain a monetary contribution from all the families and then use paid labour.

In theory, these political discussions are continued until a unanimous decision has been reached, but the chief, who is more than just a representative of the people, generally has the final word in the matter. Delays seem unavoidable. It is often necessary to hold one meeting to arrange another where more people can attend. The Mpolonjeni water supply has only recently been started, and very little of the work which requires community labour or contributions has been done. The supervising officer from the Ministry of Agriculture, Mr. John Tsabedze, is very pessimistic about future progress. At present, Mpolonjeni is suffering from lack of leadership, but the

problem is further complicated by the fact that the water project is meant to serve the Nkundla and is therefore a regional affair, requiring further discussions in the neighbouring chiefdoms.

On a national level, this form of prolonged discussion occurs in the Swazi National Council, and here a delay in some important development decisions has resulted. For example, in late 1970, a United Nations plan (FAO/UNDP 1970) for the development and utilisation of water resources in Swaziland was presented to the Government. The first stage of this scheme is still awaiting approval from the National Council.

Because of these procrastinations, the traditional government is often regarded as a brake on "progress" or "technical development" in Swaziland, but the delays are more often associated with political manoeuvres. On the strictly community level, the Swazi traditional government can be very effective - the neighbouring community of Ngcina providing one very good example (Chapter 6).

4. Land Use - Water Sources and Settlement Patterns

The evidence presented in the previous section has indicated how rapidly the population of Mpolonjeni increased in the 1940's, and this can be attributed in part to improvements in water supplies, though as with most "cause and effect" questions of this nature, it is not possible to say conclusively that the increased population is solely a direct result of improved water supplies. Possibly the most important constraint on settlement in the Lowveld in this period after the risks of malaria had been reduced, was the availability of permanent water sources for cattle. The human population would probably have been prepared to undergo the hardships of uncertain supplies for one or two months of the year (in any case the well-watered Lubombo Hills are never very far away) provided that they could rely on water for

their cattle. The prospects of being able to raise large herds of cattle, representing the most important aspects of material wealth and prestige in the Swazi culture, would have been sufficient incentive for settlement.

In 1947 aerial photographs of the Lowveld reveal a number of permanent water sources. The nearest one for the royal cattle post at Mpolonjeni was the large pool formed by the natural damming of the Mtendekwa River by a dolerite sill. Even if the surface water failed to last the winter, sub-surface water could usually be found by digging into the sand river bed (Figure 3.12)* In the mid 1940's several small capacity dams were built and these greatly improved the water supply situation. It seems that these new supplies had an immediate effect on opening up the Lowveld for cattle grazing, because the total cattle population for the whole country rose to 360,026 in 1947, a figure which was not exceeded until 1958 (388,688). The decline after 1947 is attributed to disease rather than the official current policy of destocking (Daniel 1964). Since 1958 the cattle population has again risen very rapidly: the 1972 total being 572,000 (Swaziland Government 1973).

Hlangothi Old Dam was built during the mid 1940's and became the main source of water for Mpolonjeni. Figure 3.12 shows the water sources and settlement pattern in 1947, and some possible cattle and water carrying routes are indicated. The 1947 photographs reveal little permanent settlement in the vicinity of the recently constructed Hlangothi Old Dam, yet there are the two well established chiefdoms of Mpolonjeni and Kasibengwane (Nhlangotsini) to the north and south. This situation contrasts sharply with the 1961 and 1971 photographs

* This was the situation in August 1973 after the dry 1972-1973 season.

Keys to Figures 3.12 (opposite) and 3.13 (page 83)

Figure 3.12

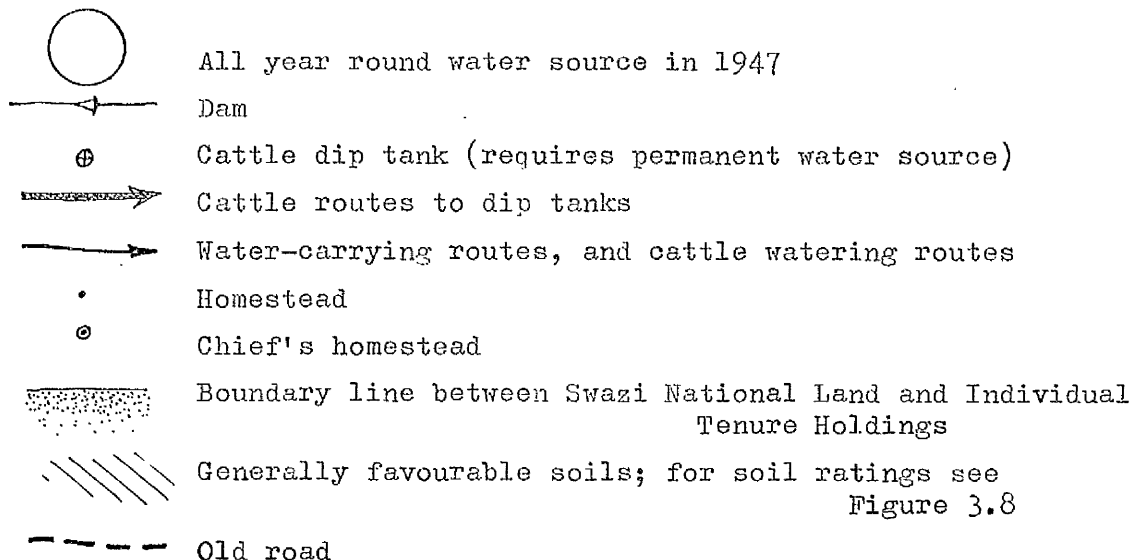
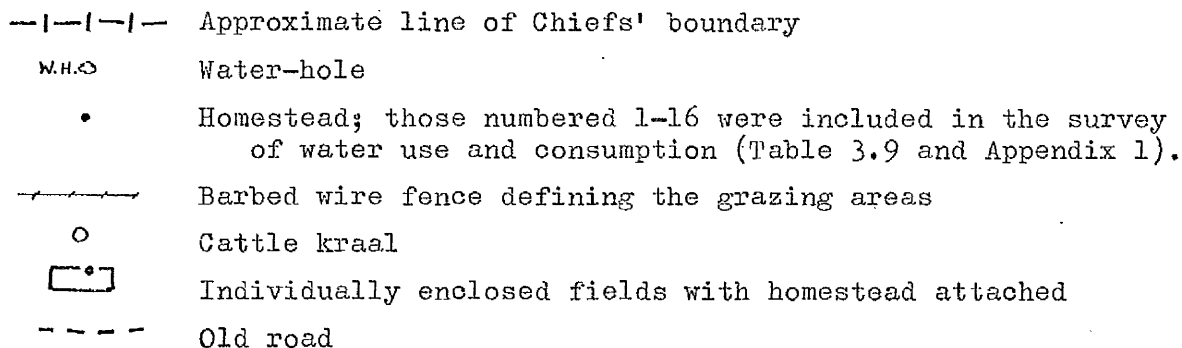


Figure 3.13



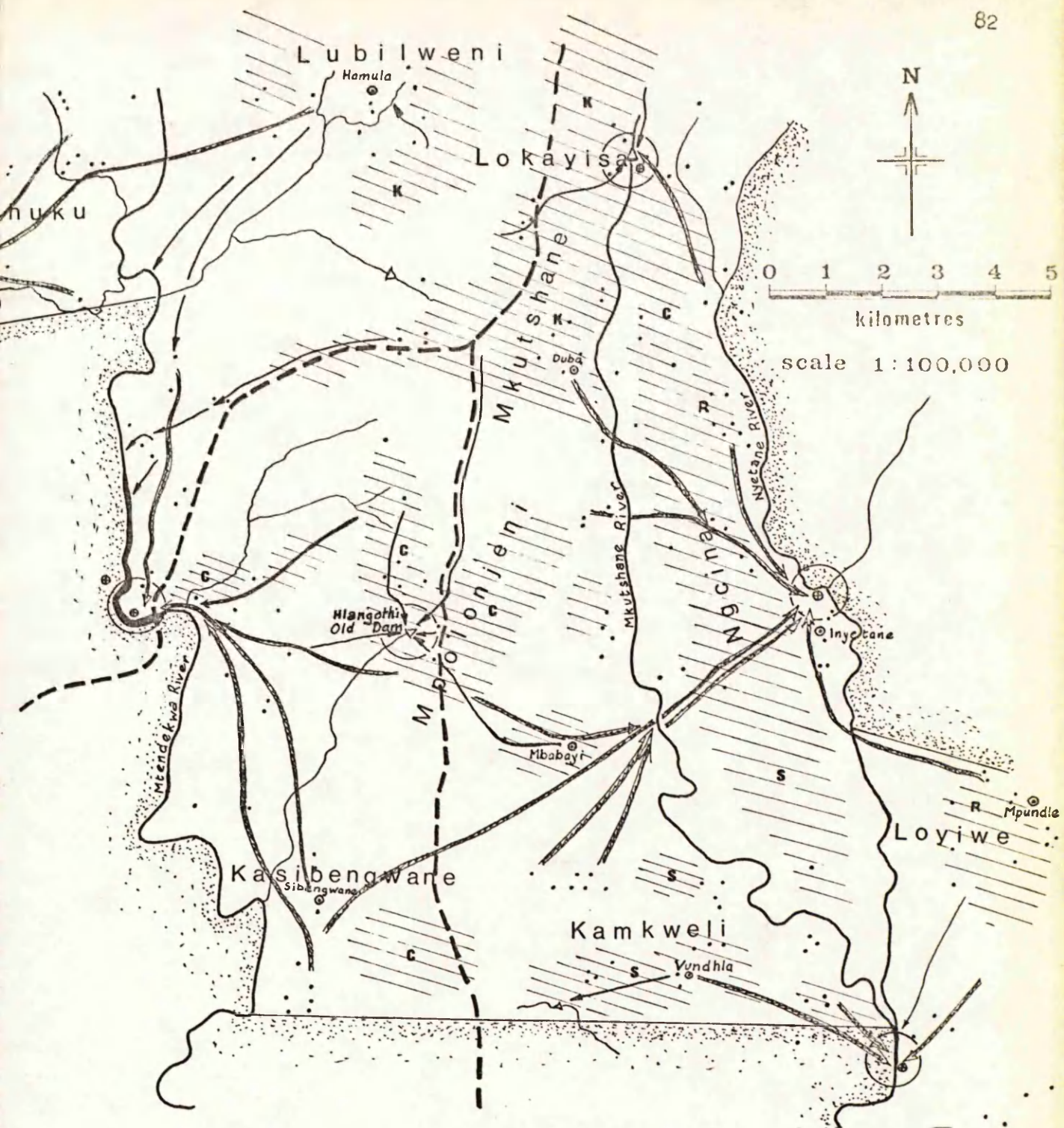


Figure 3.12 POPULATION, WATER SOURCES, CATTLE AND WATER-CARRYING ROUTES, c. 1947

The map shows the permanent water sources, homesteads and tracks visible on the 1947 air photographs which have been used as a basis for all subsequent maps. The distribution of population should be compared with that of 1966 (Figure 3.10), and the sparseness of population around Hlangothi Old Dam should be compared with the situation in 1971 (Figure 3.13). Note also that, in general, the population is concentrated in areas with favourable soils.

For the key to the symbols, see the opposite page.

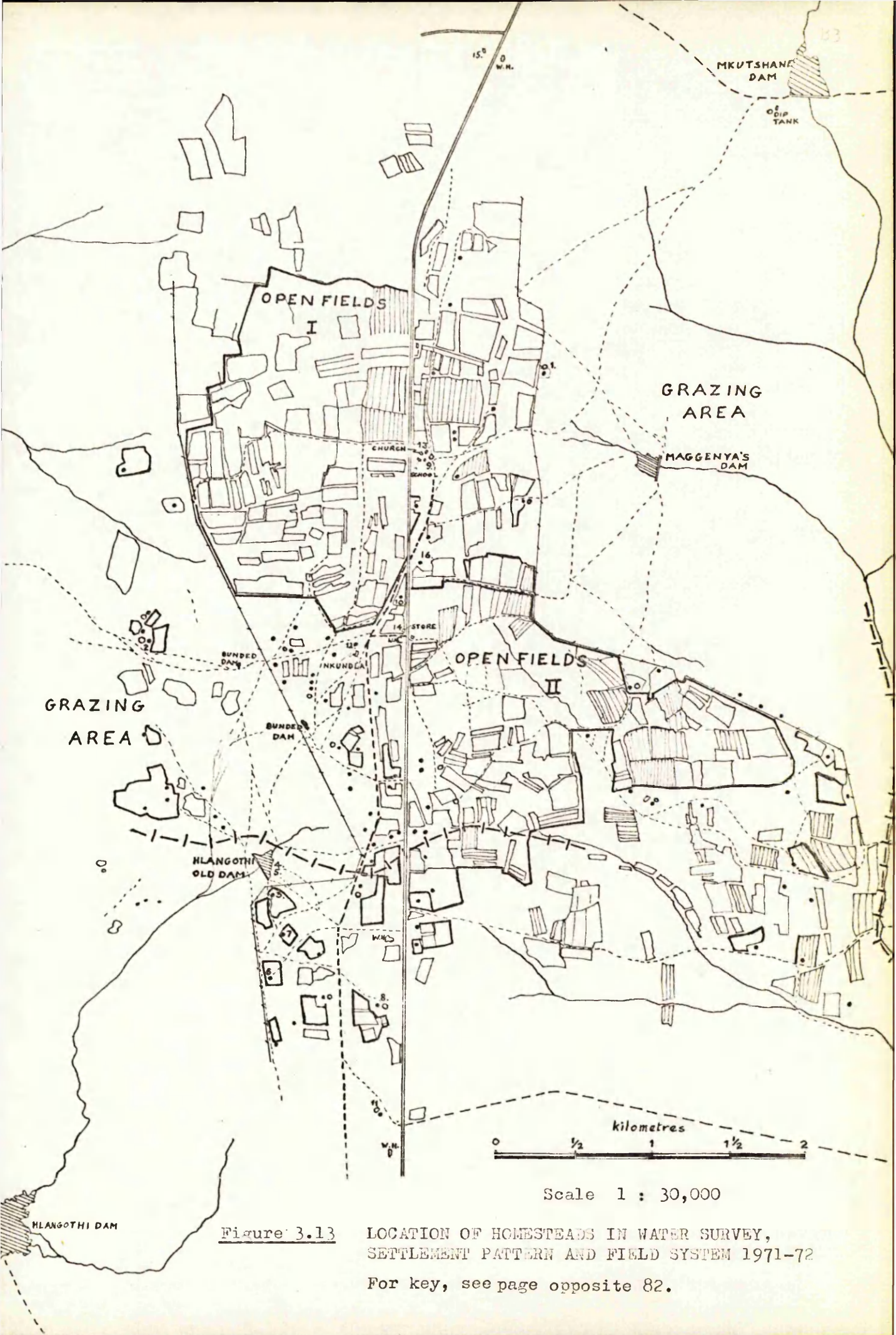


Figure 3.13

LOCATION OF HOMESTEADS IN WATER SURVEY,
SETTLEMENT PATTERN AND FIELD SYSTEM 1971-72

For key, see page opposite 82.

which show a large community (still known as Mpolonjeni) established near the dam. It seems that the permanent water source was sufficient to attract settlement from two chiefs' areas and produce the anomalous situation whereby present-day Mpolonjeni, although a coherent community in itself, is divided into two parts by the chiefs' boundary which runs near Hlangothi Old Dam.

During the 1950's and early 1960's Mpolonjeni became the most densely populated district in this part of the Lowveld. Whereas the Lowveld communities before this time had been very small and scattered, practising shifting cultivation, they now became much more similar to the more densely populated areas of the Middleveld, with permanently cultivated land. Thus, although the risk of crop failure with dryland farming in the Lowveld is as high as it has ever been, the present success of cattle raising, due to improved water supplies, has enabled a large permanent settlement to be established.

After the inception of the R.D.A. in 1966, the population became even more concentrated around Hlangothi Old Dam. The shop, the school and the regular bus service also encouraged centralised settlement. During the mid 1960's the main road was constructed, (though the old road (Figures 3.12 and 3.13) still provides a more important route for local communications), and several new dams were built to provide watering points for cattle in the recently established grazing areas (Figure 3.4). These water sources are also used by the inhabitants, but the settlement pattern is probably too well established especially now that grazing areas have been fenced, for these new sources to influence where people live. However, they have had a considerable effect on the traditional water carrying and cattle routes. Few people in Mpolonjeni are now more than 2 km. from a permanent water source.

The air photographs for 1947, 1961 and 1971 show how land use

has changed in this period. In the 1947 photographs there are widely separated plots, but by 1971 these had coalesced to form large expanses of almost uninterrupted cultivation. The main two areas of cultivation shown in Figure 3.13, i.e. Open Fields I and Open Fields II, are about 300 ha. and 400 ha. in extent, and are sited on soils derived from basalt, mainly the S-set soils of Figure 3.8. Although the K-set soils are more fertile, they are more difficult to work, and thus the choice of S-set soils for cultivation is a compromise between soil fertility and ease of working. This choice of the most suitable land for cultivation was made by Swazi farmers long before land capability studies began. The boundaries between cultivated and grazing land which were established by the R.D.A. plan, in general only confirmed the distinctions in soils made by the Swazi farmers.

3.6 The Rural Economy

The economy of rural Swaziland is often said to be "semi-subsistence" or a "transition economy" (Hughes 1964), because the members of the rural communities are no longer dependent on their crops and cattle alone for their existence, yet neither are they completely involved in the sort of money transactions associated with industrialised societies. About 80 years ago, the economy could be described as a subsistence one where money and extensive bartering of goods were unknown, but the influence of Europeans and the improved communications within Swaziland itself changed this. Now, in areas like Mpolonjeni, many of the men, during the slack time of the year in farming, go to South Africa or the urban areas of Swaziland to find employment. Thus many homesteads have a cash income of some sort, and this may be supplemented by the sale of crops and handicrafts. The existence of the shop, where household commodities such as washing powder, salt, sugar, bread, paraffin and children's clothes can be bought is indicative of a money economy. The

towns of Siteki (24 km) and Manzini (40 km) are accessible by daily bus services and provide most other shopping and agricultural facilities. In addition, money exchange is involved in payment of school fees, buying the locally brewed beer, in payments for carrying water and in contributions to community development projects. However, to offset these aspects of the money economy, the subsistence aspects are exemplified by the fact that the typical Swazi homestead group satisfies most of its own needs for labour, and the bulk of the day-to-day needs of the family are met from its own land.

Hughes (1964) has attempted to assess the total income of the rural population. His figures refer to 1960 and are now outdated, but they give some indication of the relative proportions of the "money" and "subsistence" sectors. In the period since Hughes' study, the rural economy has become more orientated towards the money sector. The components of total income are shown in Table 3.7. Hughes was able to obtain figures for the money sector (items 1 and 2) and the production subsistence sector was estimated as the value of "food grown and consumed" found by costing out the probable food consumption of the community (Table 3.8). It was hoped that this gave a figure comparable with the data for wages and produce sales. Income from the capital could not be estimated, but Hughes thought that it would probably amount to less than income from production.

Table 3.8

Average figures for "production income" for homesteads in the Lowveld.

	<u>Rand</u>	<u>Percentage</u>
Wages *	43.00	20.5
Other cash earnings	19.80	4.8
Value of "food grown and consumed"	<u>185.20</u>	<u>74.7</u>
Total	<u>248.00</u>	<u>100.0</u>

1960 figures (R1 = £0.5)

* This average figure hides clustering at the extremes of the scale. Thus, 41.7% of Lowveld homesteads had no wage elements in their cash incomes, and 45.0% relied on wages for four-fifths of their incomes.

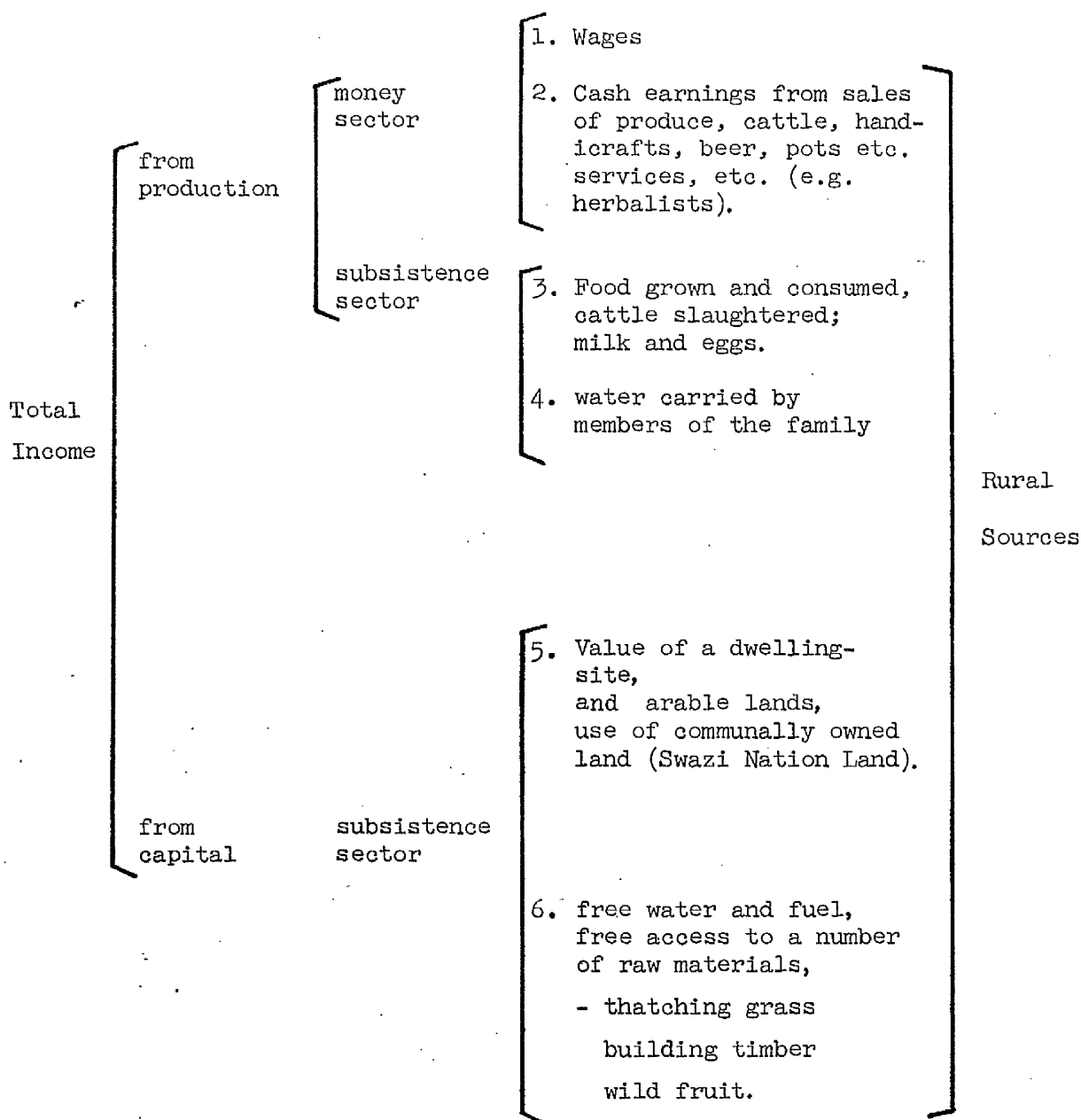


TABLE 3.7

THE COMPONENTS OF TOTAL INCOME IN A SEMI-SUBSISTENCE ECONOMY

Adapted from Hughes (1964)

An indication of the value of the "capital" in the subsistence sector may be obtained from some suggested compensation rates for dismantling homesteads and moving people to new areas. These were produced in 1970 for the first stage irrigation developments in the United Nations overall plan for water resources in Swaziland (FAO/UNDP 1970).

R20 for each homestead disturbance

R5 for each traditional, fully thatched wooden framed hut

R10 for each building of a more substantial nature

R2 for each acre of arable land

R5 subsistence allowance for each month in temporary resettlement (limit of 12 months).

Maximum compensation - R210

1970 figures (R1 \approx £0.6)

For comparison, a timber framed thatched roof home in Serowe, Botswana, was built in 1972 for a cost of R86. This incorporated purchased timber, door, door frame and window frames, and was essentially a much more substantial structure than its counterpart in Swaziland Lowveld.

3.7 The Agricultural Calendar - Hungry Times and Labour Peaks

Agriculture at Mpolonjeni revolves around the keeping of cattle and the growing of maize and sorghum. Cattle are regarded as a form of investment and a sign of social status, and are still required as "bridewealth" in traditional marriage ceremonies. Their use for meat and milk production is rather limited. Their chief contribution to the economy is to provide draught power for ploughing, sowing and cultivating the fields, and for pulling small sledges which can carry loads of up to about 250 kg. About a third of the cattle at Mpolonjeni are draught oxen, but donkeys are also used for this purpose. Using Daniel's (1964) figures, and assuming at least proportionate increases in the human and cattle population, the 1972 cattle population of

Mpolonjeni can be estimated at around 1,900^{*}. The total number of livestock units^{**} would be about 2,000.

Ownership of cattle is not evenly spread through the community. In 1960, it was estimated that 28.7 per cent of Lowveld homesteads owned no cattle, whilst 17.5 per cent owned herds with more than 40 cattle. Some herds were more than 100 strong, and over 46 per cent of Lowveld cattle were in herds greater than 40. This reflects the distribution of wealth and social standing within the community, though it should be remembered that some families have forgone them because their menfolk have gone to the towns of South Africa to work, or because they have other sources of income. For example, the herbalist at Mpolonjeni had decided to concentrate on his craft, and consequently fields for growing his raw materials were much more important than cattle. Such families may therefore be relatively more wealthy in money terms if not in cattle.

Ploughing is the first agricultural activity in each season, and takes place when the first rains have fallen - during the dry season, the soil is generally too hard for an ox-drawn plough to be usable. The short storm which fell at Mpolonjeni in mid August 1973 (Section 3.4) provided suitable conditions for ploughing.

Planting of the main crops follows ploughing as soon as the ground is judged to be moist enough to support sustained plant growth. This does not occur until the first really heavy downpour of the season, about 40-50 mm. in a day is considered a good "planting rain" (Murdoch 1968). Since ploughing and planting must wait upon a very uncertain

* This figure takes no account of the improved water supplies in Mpolonjeni in the 1960's. The cattle population may be 50% higher than this figure. More accurate estimates of the cattle population could be obtained from dip-tank records, but these were not available to the author.

** One livestock unit is equivalent to either one head of cattle, or one donkey, five goats or five sheep.

rainfall, their timing varies greatly from year to year. In a typical year, ploughing can begin in late September and planting in November. But sometimes, ploughing can begin in August, and planting may be delayed until January.

September to November is a time when men who have jobs in South Africa return to their families to help with these essential agricultural operations. The cattle are exclusively a man's interest, and any activity which requires their use is therefore the man's responsibility. Thus the men with outside employment remain in the same jobs for only six months of a year, and return to deal with all the cultivation requiring oxen.

Maize is the most important crop, and provides the staple food of the people. Melons and pumpkins are customarily grown in the same fields as the maize, underneath the main crop. Sorghum is the other main cereal grown. Being more drought-resistant than maize, it provides a substitute in dry years when maize crops frequently fail. Sorghum is also widely used for beer making. Other crops grown include beans and groundnuts, but probably only a third of the farmers plant fields with these.

The growing season for maize is just over four months, during the first two of which it is highly susceptible to competition from weeds. Thus from November to February weeding is the principal agricultural task. Ox-drawn implements are sometimes used, but efficient weeding depends on some hand-hoeing as well. Since each field needs to be weeded two or three times, this is a very labour-intensive operation. It is also an important one, because in the absence of any weed control, maize crop yields may be cut by as much as 40 per cent (Pacey 1973).

From fieldwork, it seemed clear that weeding is, in fact, seriously inadequate. Two possible reasons for this are that the labour force of the community is too small at this particular time of the year, and, that the nutritional standard of the people is so poor that their working efficiency is impaired. Jones (1963) has shown that in some Lowveld communities, food consumed in the early part of the growing season has a calorie content of only 55 per cent of what is required to sustain an adult in active work. This is because each family's stock of food from the previous harvest runs down during the dry season, and is sometimes entirely exhausted by November. Additional food is bought from local stores, but most families have limited financial resources, and have to cut the size of meals to try to make their stocks last. In the 1960 Swaziland Sample Survey, only 16.1 per cent of Lowveld homesteads reported a maize surplus; 29.4 per cent produced just sufficient, and 54.5 per cent recorded a maize shortage (Daniel 1964).

The poor nutritional situation is relieved somewhat after the rains begin, because as soon as the pastures recover from the dry season, the cows produce a little milk (Jones 1963). However, the only time when nutritional standards can be said to be at all satisfactory is in March, when the new harvest begins.

Harvest is a busy time, but not critically so, since the maize cobs can be left on the plant to dry. Harvesting sorghum is more urgent, because it is prone to attack by birds. The pumpkins and melons are last to be taken in, and depending on the original planting dates, this may be as late as mid June.

June, July and August are the driest months and a time of little agricultural activity. The people turn their attention to handicrafts, and house building and repairing (Kuper 1947). This is the period when the term "under-employment" is most appropriately applied, and

when the introduction of new productive activities would help to increase living standards. One obvious possibility is small-scale irrigation, which would not only provide continuing agricultural work in the slack period, but would help to fill the nutritional gap in November and December.

3.8 The Role of Water in the Rural Economy

The relevance of the agricultural calendar to the water supply problem is that those seasons can be identified when the labour involved in carrying water is a serious constraint on the productive capacity of the community. For much of the time, and especially in the dry season, the time and energy spent in carrying water may not be used for any other productive work; the "opportunity cost" may be almost nil. However, during the weeding period, water carrying probably reduces the labour potential for weeding very markedly. Fetching water and weeding crops by hand-hoe are both women's jobs. Carrying the family's water may only occupy a woman for one hour a day; but if her calorie intake is substantially below normal requirements, this one hour task may absorb most of her working energy, and she may need to spend the remainder of the day in relative inactivity. The importance of an adequate diet in relation to working ability has been shown by an International Labour Organisation study. The daily output of several groups of workers (from different regions) on a project in India was measured. One group was observed to give a daily productivity of 80 per cent greater than the average of other groups. When the diet of this particularly productive group of workers was investigated, their average daily calorie intake was found to be 4,500 compared to an average of 2,880 calories for the other groups (Dreiblatt 1972).

In order to assess the labour involved in carrying water, a number of women at Mpolonjeni were interviewed to find out what sources they used - and hence, what distance they carried the water - and how often they made the journey. Three ways of carrying water could be distinguished:

1. A 3-gallon (13 litre) bucket, or a 5-gallon (22 litre) oil drum can be balanced on a woman's head
2. A 44-gallon (200 litre) oil drum rolled along the ground by two women, or children
3. A 44-gallon oil drum carried on an ox-drawn sledge.

Because so many standard sized containers are used, it was a simple matter to estimate a family's water consumption from information obtained in the interview. Detailed figures are given in Table 3.9, and in Appendix 1. The homesteads of the people interviewed are shown in Figure 3.13. Here, it is only necessary to note that the average ^{use} daily water consumption of the families interviewed was about 7 litres per head, or around 50 litres per family. In cases where the water was carried by women on their heads, the average distance involved was 1 km from the home to the water source.

These conclusions correspond quite closely with the results of more elaborate surveys carried out in East Africa by White *et al.* (1972) and Warner (1969), though water consumption at Mpolonjeni was somewhat lower. It therefore seems reasonable to use other data given by White *et al.* to evaluate the importance of water carrying in the economy of Mpolonjeni. These authors estimated the energy (in calories) which is used by women in carrying water in rural communities. They then calculated the cost of food needed to provide this energy, and counted that as the money-cost of the water. This is an unrealistic approach, because people's food intake does not increase

Table 3.9

Summary of Water Consumption Survey at Mpolonjeni (see Appendix 1)

Homestead (see Figure 3.13)	Water Source	Distance (m)	Number of people in homestead	Approx. probable consumption (litres/head/day)
1. Gwebu	Mkutshane	2400	8	-
2. Zwane	{Hlangothi Old Sefutshani	1600 2400	19	5.5
3. Gordon	Hlangothi Old	320	8	4.5
4. Women at	Hlangothi Old	800	5-8	4.5
5. {interviewed		800	5-8	4.5
6. Nzimandze	Hlangothi Old	800	8	9.0
7. (No name)	Hlangothi Old	480	7	3.2
8. "Ten house"	Hlangothi Old	1600	-	-
9. Langwenya	{Sch. water-hole Maggenya's	320 1600	4	9.0
10. Spring	Bunded dam*	1000	6	9.0
11. Methule	Mbonga	4000	17	4.5
12. Nkundla (Builder)	Bunded dam*	650	3	9.0
13. Minister	own roof	10	6	13.5
14. Masuku	Bunded dam*	1000	10	18.0 ⁺
15. Teacher	own roof	10	-	-
16. Dlamini	Bunded dam*	1450	20	4.5

Average consumption for 106 -117 is 5.5 - 8.2 litres/head/day

Notes: ⁺ includes clothes washing at home

* The bunded dam source usually lasts until the end of April or beginning of May. Thereafter, until October, most people using this source would use Hlangothi Old Dam if they live to the west of the main road, and Maggenya's Dam if they live to the east.

in proportion to the volume of water that they carry. The position is that food intake is limited by supply, and people are forced by fatigue to reduce their activity until physical energy output matches calorie intake. Thus Jones (1963) was able to write:

" ... the least mental and physical energy expenditure was found in the Lowveld during the hunger period. The people sat around for a great portion of the day, sometimes drinking beer, sometimes without beer, in apathetic attitudes. "

It seems clear that the lethargy of the Swazi people so often reported by Europeans (see Liversage 1946 for a particularly denigrating description of the Swazi character) can more accurately be attributed to malnutrition.*

Using the figures given by White, Bradley and White, and by Jones (1963), the energy budget of an "average" 55 kg. woman may be expressed as follows:

	<u>Calories per day</u>
ENERGY INTAKE	
Requirements for women in Swaziland climatic conditions, but not allowing for the heavier tasks of the Swazi women compared to their European counterpart: 2,120 calories	
In November/December this is reduced to:	<u>1,248</u>
ENERGY OUTPUT	
Base rate - energy needed to maintain life when the woman is <u>inactive</u> :	800
Average energy used in carrying water is 240 calories - less base rate usage for time period involved:	200
Margin available for domestic work and agriculture:	<u>248</u>
	<u>1,248</u>

* One other important reason for the reported lethargy is the disease, schistosomiasis, which has a similar effect (Chapter 6).

This is a very rough calculation, and represents an oversimplified view of how energy is used in the human body, but it does serve to illustrate the energy cost of carrying water; almost half this woman's work potential is devoted to the task, and after she has cooked a meal and done other household duties, she is not likely to be fit enough to undertake strenuous agricultural work during the critical period when weeding is required. After harvest, food intake may be much greater and fetching water will have a much smaller impact upon a woman's other activities, but even then it will still require at least 15 per cent of her available energy.

There is a vicious circle in this situation. As long as people are malnourished in November and December, weeding will be neglected and crop yields will remain poor. This in turn means reduced rations in the last months before harvest, perpetuating the malnourishment which prevents efficient weeding.

Among the various ways of breaking this vicious circle, two involve water use: either (a) improve the water supply to release time and energy at the critical weeding period, or (b) introduce irrigation so that food crops could be grown during the dry season and up to the time when the main harvest is due. Neither measure would be sufficient in itself. If irrigation were thought to be desirable, then considerable agricultural extension work would be necessary to provide suitable crop varieties. Even with efficient weeding and good use of fertilizer, the maize crop will fail in those years when rainfall is significantly below average, and thus another solution might be to grow crops which are less susceptible to drought than maize.

However, with all these qualifications, it is still clear that an improved water supply might play a key part in developing the

the rural economy, just as past improvements have influenced the rural economy by allowing more cattle to be kept, and by influencing the settlement pattern.

CHAPTER 4

THE DIVERSITY OF SOLUTIONS

4.1 Introduction

The Mpolonjeni case study shows that people there rely on a great variety of water sources. Some are regarded as suitable only for specific purposes, such as washing clothes, and of course, some are available only for limited periods during the year. White et al. (1972) and Kirkby (1973) have noted similar patterns of use in other rural communities. In this chapter, these patterns are referred to as "multiple-source systems". This state of affairs is quite different from the conventional water supply situation in the developed world and in urban areas, where the water supply system consists of a single water source, or group of linked sources which, after treatment, feed into a pipe network to provide water of uniform quality serving all the different purposes for which consumers need water.

4.2 Multiple-Source Systems

In Mpolonjeni, all the families had a choice of water sources within an hour's walk of their home. The reasons why particular sources are preferred may be related to (a) economy of effort, (b) ^{perceived} water quality, (c) difficulty with equipment, and (d) social factors.

(a) Economy of Effort. This was probably the most important reason why a particular source was used. In general, the nearness and ease of access was the main factor, so that time and energy expenditure was minimised. If the nearest source was not used, then it was because one or more of the following qualifications applied.

(b) Quality. Some sources were regarded by some families as suitable only for washing. These were usually small stagnant pools. Thus people

had their own ideas of what was a healthy source, or more accurately, what was likely to be an unhealthy source. However, a much more common reason for choosing a source other than the nearest, was taste - when water was required for drinking, and hardness or ease of lathering - when water was needed for washing. These two considerations were very important for the people of Mpolonjeni, as explained in Chapter 5.

(c) Difficulty with Equipment. Very few of the sources near Mpolonjeni involved the use of machinery for getting water, and thus this reason for rejecting a source did not arise very often. However, it may be a factor where pumps for catchments tanks are concerned (Chapter 10), and it is probably the main reason why greater use is not made of rainwater collection from roofs. People were not confident of fixing guttering and erecting storage tanks, and their use with thatched roofs is still relatively untried.

(d) Social. Carrying water at Mpolonjeni involves a multitude of social contacts. Women sometimes go for water in pairs, or in larger groups when it is required for beer-making. As they walk along paths through the bush, and as they pass close to homesteads, they meet other people very frequently, with whom they almost always exchange a greeting. At the dam or other source from which they fill their buckets, they may meet women who have come from the opposite direction, and who otherwise, they might see only rarely. On days when washing is done, groups of a dozen women congregate at the water source which is customarily used for this. Communal washing is obviously a social function as well as a necessary practical function.

A woman's choice of the time she fetches water, the route she uses, and in extreme circumstances, her choice of the water source to which she goes will undoubtedly be influenced to some degree by the people she hopes to meet and those with whom she is not on good terms.

In nearly every case, though, people seemed to use the nearest "good" source, so social factors such as this, probably only have a slight effect on the ultimate choice. Relatively few homesteads are equidistant from two "good" sources, and it was not possible to investigate the factors influencing the choice in such cases.

The social value of all these activities is another aspect which should be considered. Again, the author can offer no real assessment of what would happen to social relationships if people all had individual supplies. There would certainly be some loss in social contact, but White, Bradley and White (1972) suggest that the communal function of water activities tends to be over-rated. This is a difficult judgement for a non-Swazi or non-African to make, however, since it is inevitably influenced by the values of his own culture - in this case by the more individualistic values of European/Western culture. In any case, other authors have taken a different view. Kirkby (1973) has tended to stress social factors, and has instanced a Mexican village, where ample water is available from wells which people could use for washing clothes in their homes. Instead of using this, the women take their washing to a stream several kilometres away which is better suited for washing as a group activity.

It is only in arid areas, or during extremely long dry periods that people are likely to be confined to one source. Everywhere also they have at least one alternative source, sometimes many more. Most of those consulted by White *et al.* in East Africa perceived two, three or four choices, and the maximum considered was five. As we have seen, many people take advantage of the choices presented to them. Having recognised the complexity of water use patterns, involving as it does environmental and human factors, agricultural and domestic activities,

and social and cultural habits, it is clear that water supply improvement is a much more difficult matter than just installing a small-scale, treated supply, which is simple to operate and maintain. Given limited capital resources, such a system would be unlikely to provide for all the needs of a community. Some possible deficiencies are:

- (a) the quantity of water available might be insufficient for bathing,
- (b) the taste of chlorinated water might be unacceptable,
- (c) there would probably be no provision for social activities, such as communal washing,
- (d) there will sometimes be cuts in the supply, due either to failure of equipment or poor social organisation, so people would have to revert to traditional sources.

There might also be sound environmental and conservation reasons why it would be unwise to rely on one source. Thus even if a conventional water supply system is installed and "accepted" by the community, there are several reasons why some diversity in the use of sources is likely to persist. In general, the new system would only supplement the existing range of choices, not replace them.

The implications of this conclusion affect the whole way of thinking about what sort of improvements are possible and what strategies should be adopted. This will be discussed later in this chapter, but first the existing multiple source water supply systems used in semi-arid rural areas of rural Africa will be reviewed. Points will be identified in these systems where improvements are most urgently required, and where modern water supply techniques have most to offer.

4.3 Water Sources and Water Quality

A river or spring can be used as a source of domestic water simply by dipping a bucket and carrying it home. In such cases, the

discussion of hydrology in Chapter 2 presents all the necessary information about the quality and reliability of water sources.

But even in the least sophisticated African societies, there are usually traditional methods of improving natural sources or of gaining access to concealed groundwater. Most of these traditional methods involve minor excavation work - digging small holes, or sometimes, proper wells; diverting streams into artificial channels; digging holes in the downstream embankment of dams to obtain "filtered" seepage water; or causing a current to clear sediment-laden water in a pool. With the possible water sources in a semi-arid area thus ranging from unmodified natural sources, through traditional techniques, to the products of modern engineering, it seems necessary to provide a brief general summary of all the usual water sources in semi-arid Africa.

Figure 4.1 gives a perspective of this large range of water sources by relating them to the hydrological cycle. The quality of water depends on where the cycle is "interrupted" to form a source of supply. In general terms, the direct interception of rain should provide the purest water supply, while more and more substances are collected by water as it flows over the ground, into streams, down rivers, and into reservoirs; or as it percolates through soil and rock to become groundwater.

Thus, as already indicated in Chapter 2, water in rivers and reservoirs is likely to contain organic and bacterial matter, dissolved minerals, and a sediment load. Groundwater is likely to contain even more dissolved minerals and possibly some bacterial matter, while in contrast, rainwater collected by gutters and a downpipe from an iron roof will be affected only by small amounts of dust or smoke particles from, for example, a grass fire, or by any slight dirt on the roof,

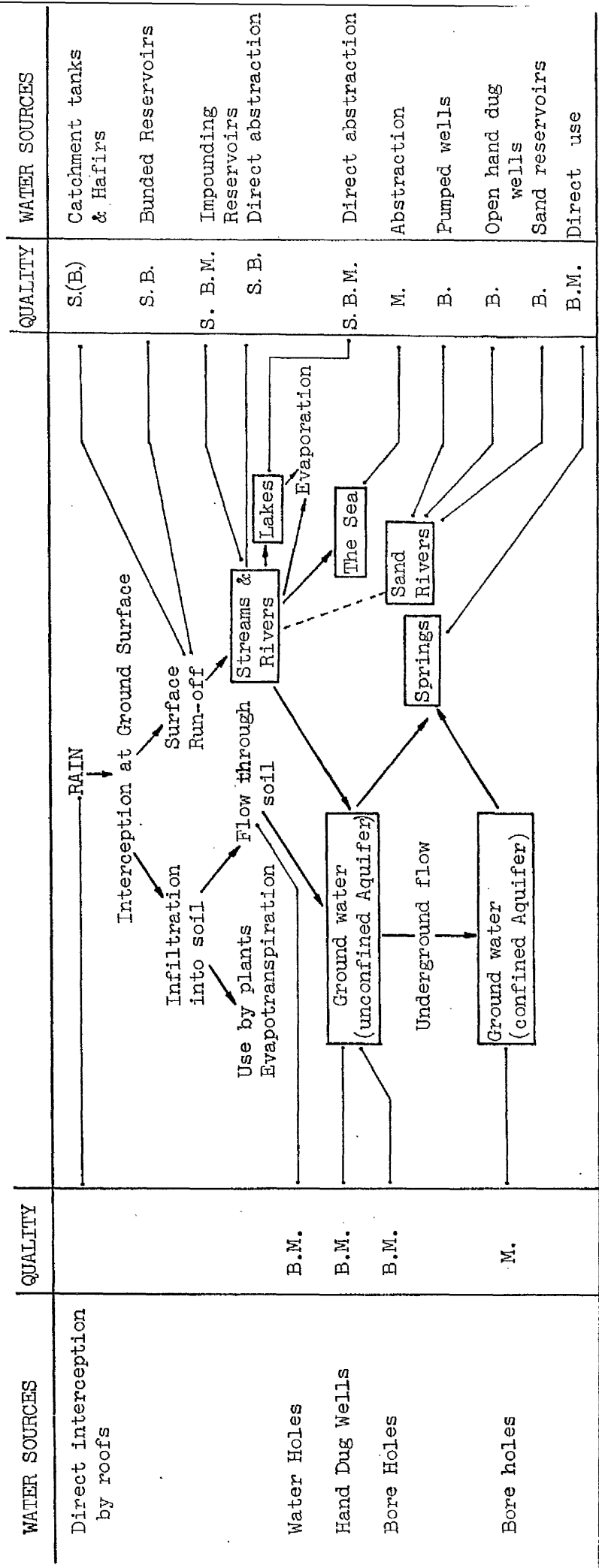


Figure 4.1 Water Sources and the Hydrological Cycle.

Water Quality Problems likely to be encountered.

- B. - Bacterial pollution
- S. - High sediment loads
- M. - High dissolved solids

Thus, intrinsically, rain catchment by roofs, or similarly protected areas, is likely to provide the purest untreated source of water that can be made available.

Figure 4.1 is intended to illustrate these general relationships between water sources and water quality. It is important to remember that a distinction is necessary between the initial quality of a source, and the actual quality of the water abstracted by the consumer. Although the initial quality of the water may be good, it can be adversely affected by storage conditions, the poor maintenance of storage works, or by the activities of water users. There is no need to review all the sources listed on this diagram, but only to draw attention to a number of differences which the diagram shows.

The first of these is the difference between surface water in streams and rivers, and surface run-off which occurs as an overland flow of water during heavy storms. A proportion of the water in rivers and streams may have come from springs or may otherwise have flowed through soil and rock before joining the river flow. Thus a significant content of dissolved minerals will be found in many rivers, but in overland flow, the water has much less contact with the ground, and so the mineral content of surface run-off is much less.

Techniques for collecting surface run-off include the catchment tank developed by the Intermediate Technology Development Group (ITDG), the hafir of Sudanese traditional technology, and the bunded dams common in Botswana. Catchment tanks and hafirs consist of excavations sited on slopes where natural lines of drainage converge. Bunded dams are formed by a low embankment laid out on a horseshoe plan, with the open side of the horseshoe facing up the slope. Chapters 8 and 10 give details of all these methods. In sources formed by all these means, dissolved minerals are likely to be less concentrated than in

streams and in impounding reservoirs.

Surface water in rivers and streams forms an immediate source, but often, the improvement of river water sources is attempted, using traditional techniques. In many parts of East Africa, people dig holes at the side of a river, and fill their buckets with water which has been partly filtered by seepage through sand or soil. In the many regions where sand rivers occur (Chapter 9), water sources can be formed, even when the surface flow has ceased, by digging holes in the deep sand of the river bed.

To this range of traditional techniques, more recent methods have added weirs and barrages for the direct off-take of river water; dams that impound the flow; and pumps connected with buried wells in the beds of sand rivers. But whatever technique is used to modify a river water source, it must be recognised that water quality in the rivers of semi-arid areas is often very poor both in terms of bacterial content, resulting from their intensive use, and in terms of dissolved and suspended solids.

The type of source known generally as a "water-hole" may collect both surface water and some ground water. A water-hole filling mainly from surface run-off can be compared with a catchment tank or hafir. In many cases, however, the persistence of water in these holes for long periods is the result of a significant groundwater contribution. The bottom of the hole may be below the water table at seasons when the water table is high, or it may intercept a perched water table. In the Swaziland case study, water-holes had often originated as borrow-pits for road building activities. They appeared to fill by leakage from perched water tables, with significant mineral content in the water (Chapter 2, Figure 2.4).

In discussing groundwater from wells and springs, it is important to note the distinction made in Figure 4.1 between confined and unconfined aquifers. Groundwater which is well protected by the overlying strata from bacterial pollution originating at the surface is generally considered to be in a confined aquifer, whilst groundwater in unconfined aquifers is vulnerable to such pollution. Sometimes this protection is afforded by a confining layer in the strictest sense of the term - an impermeable layer of rock above the aquifer which prevents all direct infiltration from above. Sometimes, however, the great depth of an aquifer may be sufficient protection in itself, because the surface water which serves to recharge it takes so long to percolate through the pores and fissures of the rocks above that few bacteria can survive the journey.

These general points about water quality are all indicated in Figure 4.1, where the letters in the margins denote the water quality problems commonly associated with the various water sources.

In the case study area at Mpolonjeni and in other nearby places, tests of water quality were made which illustrate these points. Testing procedures will be described in detail in the next chapter, but a selection of the results obtained is given in Table 4.1.

It should be stressed that Table 4.1 contains only sample measurements, not long-term records based on fully controlled sampling procedures. But there is no reason to think that a more elaborate series of measurements would give radically different answers - it would merely add more precision to the data given here. The figures confirm what has been said in Chapter 2 about the high levels of dissolved solids, suspended solids and bacterial matter which are to be expected in the water of rivers, streams and dams. In contrast, the table also indicates that very clean water may be obtained by the roof

catchment of rain waters and it shows the large concentrations of dissolved solids which are commonly found in water from bore-holes.

Table 4.1

Some Water Quality Data from the Swaziland Lowveld

Sample measurements taken in August 1973 - see Chapter 5 for details.

Water Sources	Suspended Solids mg/l	Dissolved Solids mg/l	Bacterial Pollution
<u>RESERVOIRS</u>			
Mkutshane Dam	200	270	High
Hlangothi Old Dam	1000	349	Moderately high
<u>CATCHMENT TANKS</u>	Negligible	90	Variable (see Chapter 5)
<u>ROOF TANKS</u>			
Minister's House	Negligible	-	Low
Mafutseni School	Negligible	-	Low
<u>BORE-HOLES</u>			
Magomba	Negligible	943	Low
Malindza	Negligible	871	Low
<u>WATER-HOLE</u>			
Borrow pit	200	647	High

4.4 Health and Water: Bacteriological Quality

The reaction of the consumers of water at Mpolonjeni to the greatly contrasting water qualities they find at different sources is strongly influenced by the dissolved and suspended solid content. These

are the factors affecting the colour and taste of water. But usually it is only the bacteriological quality of water which can affect the health of the consumer, and in these other respects, whether a sample of water is suitable for drinking and domestic use is really a matter of personal opinion. Obviously, if a water is full of sediment, highly discoloured and strong tasting, it would not be palatable, nor very useful for washing, but it would not necessarily be harmful to health, except perhaps to produce gastro-intestinal irritation. Human beings, and stock also, can become accustomed to large amounts of dissolved salts in water, and no generally applicable limit can be set, but clearly for each individual, there must be a limit set up by the rate salts can be excreted in perspiration and urine. Water with 1,000 mg/l of salt tastes strong but is bearable to those used to it. In fact, some people in North Mexico and Upper Senegal habitually use water with a common salt content of over 3,000 mg/l (Dixey, 1931). The WHO standards for dissolved solids set 1,500 mg/l as the "maximum permissible level", and 500 mg/l as the "highest desirable level". In Australia, 3,000 mg/l dissolved salts is considered safe for working horses, dairy cattle and pigs: 3,000 to 10,000 mg/l is safe for sheep and grazing cattle (Dixey 1931). Occasionally, high concentrations of particular dissolved salts can cause health problems. In parts of East Africa, excessive fluoride ions in groundwater lead to a disease of bones and teeth known as fluorosis (Latham 1965). The upper limit of fluoride ion concentration is considered to be 1.5 mg/l, but a regular dosage of 0.7 mg/l in warm climates is beneficial in preventing dental decay in children (Holden 1970).

The relationship between health and water supply will be discussed in later chapters, but it is necessary here to introduce the

most important factor in this relationship; namely, the bacteriological condition of the water. The greatest health danger associated with drinking water is that it may have been recently contaminated by sewage or human excrement. If the contamination has been caused by people suffering from infectious diseases such as dysentery or enteric fever, then the water may contain the living pathogens of those diseases. If this water is drunk by others, fresh cases of the disease may follow. There are also dangers associated with animal pollution but these are much less significant (Holden 1970, p.218.) It is not easy to isolate pathogenic organisms in routine water analyses. So, as is well known, it is usual to test for bacteria of the coliform group which originate in the large intestines of mammals. If these are found in quantity, it is generally assumed that the water has been recently contaminated by warm-blooded creatures, and there is the possibility that the sample also contains pathogens. Thus the use of coliform bacteria as a pollution indicator provides a margin of safety.

The growth of coliform bacteria depends on a number of factors including temperature, sunlight, presence of metal traces, and the pH of water, but the bacteria are unable to withstand extra-intestinal conditions for long. Although they can survive for some weeks in soil and water, they do not flourish but become progressively less numerous and eventually die (Holden 1970). The qualification about "recent" contamination usually refers to a period of a week at the most.

In this discussion on the quality of water sources, the important point concerning the bacteriological condition of the source is whether it is vulnerable to pollution by human and animal excrement. It is clear that almost all surface water is vulnerable, and indeed the evidence of animal pollution around the reservoirs in Mpolonjeni was most obvious. This can only be avoided by prohibiting all animal and

human activity within the catchment areas of surface sources.

For the areas of Africa considered here, this course is conceivable for only the smallest controlled catchments, such as those for small catchment tanks and rainwater collected from roofs. Even then, the possibility of pollution by birds should not be completely dismissed (Holden 1970, p.218).

Since shallow and unconfined groundwater is replenished directly by surface waters, it too is vulnerable to pollution. The risks associated with groundwater are generally less because of the natural filtration provided by soils and rocks, and because the time interval between original pollution of the surface water and its abstraction from the spring or well is usually too long to reduce considerably the harmful bacteria. Because there is no direct connection between surface water and water in confined aquifers, the bacteriological risks associated with deep groundwater and confined aquifers are very small indeed, though some examples of infection have been recorded which resulted from unusual geological conditions (Holden 1970, Dixey 1931).

These points are borne out by figures quoted by White et al. (1972) on the basis of a large number of bacteriological tests in East Africa. Measuring bacterial pollution in terms of a faecal coliform count per 100 ml sample, they found that most boreholes, which penetrate the deeper strata, gave coliform counts of less than 2; the shallow wells in more accessible aquifers gave figures between 8 and 256. The very heavy pollution of major rivers, as compared to groundwater sources, is shown up by a range of coliform counts of between 500 and 8,000.

But even though the groundwater itself is potentially pure, pollution may occur at the sites of the wells. Unless wells and boreholes are designed to prevent the intrusion of matter from above,

a serious situation may arise, because many people tend to use each well, and stock are often watered there. Wells fitted with pumps are usually much easier to protect than open wells, but even with the latter, some protection against dirt or surface water finding its way into the well is afforded by a parapet and apron around the opening. If pumps are fitted, it is equally important that they should be of the self-priming type or at least have a valve to prevent water draining back, otherwise poor quality surface water may have to be used to get the pump working. In the absence of such precautions, shallow groundwater sources are often a greater danger to health than open surface water, because contamination is concentrated at one point and there is little movement of water to disperse it.

4.5 Choice of Sources in Existing Multiple-Source Systems

Having reviewed the range of water sources used in various parts of semi-arid Africa, we may refer again to Mpolonjeni in the Swaziland Lowveld, and the Palapye-Serowe area of Botswana (Table 4.2).

In Mpolonjeni, surface water stored in impounding reservoirs provides a major part of the water supplies. Roof tanks and water-holes are also used to a limited extent. There are three bore-holes in neighbouring communities, which are rarely used even by people living near them except as a last resort. In contrast, the Botswana villages rely predominantly on groundwater for their supplies, with surface water providing only supplementary sources. This is a reflection of the better taste of groundwater and the low reliability of surface water sources. Thus the villages of Ratholo and Matlakola (Figure 4.2) seem originally to have relied mainly on springs in the southern slopes of the nearby Tchwapong Hills. There are also water-holes and pans (shallow, seasonal lakes) in the area but these are unreliable. In the course of

Table 4.2

Examples of Two Multiple Source Water Supply Systems

P = permanent source (year round)

Water Sources (See Figure 4.2 for Botswana communities)	SWAZILAND	BOTSWANA
	Mpolonjeni	Ratholo Matlakola Mahalpitsa
RAIN	collected in tanks at 5 homes. Quantity suffi- cient for drinking and cooking	No collection from roofs observed.
- direct interception by roof		
SURFACE RUN OFF		
- catchment tanks	-	Tried at Matlakola and Ratholo for watering gardens
- bunded dams	2 very small ones, one used by cattle, the other for domestic supplies. Neither permanent	Used for watering cattle, rainy season only.
STREAMS, RIVERS, LAKES	P	
- impounding reservoirs	Major source of supply for domestic use and cattle. Piped supply under construction.	Small one near Matlakola used seasonally for watering cattle.
- direct abstraction from streams	Important for families near Mkutshane River. Seasonal.	Transient streams only.
- direct abstraction from lakes	-	Pans provide a seasonal supply at some distance: used for cattle.
SUB SURFACE & SURFACE RUN-OFF		
- water holes	Used for clothes washing	Seasonal watering of cattle.
SPRINGS		
- direct use	None existing	Originally important for all uses. No longer permanent sources.

Table 4.2 (Contd)

Water Sources (See Figure 4.2)	<u>SWAZILAND</u> Mpolonjeni	<u>BOTSWANA</u> Ratholo Matlakola Mahalpitsa
GROUNDWATER		P
- unconfined aquifer hand dug wells	-	Used mainly for watering cattle
- confined aquifer boreholes	P Two nearby 1. Ngcina - brackish. domestic water. cattle use only 2. Magomba - dry season use.	P Major source of

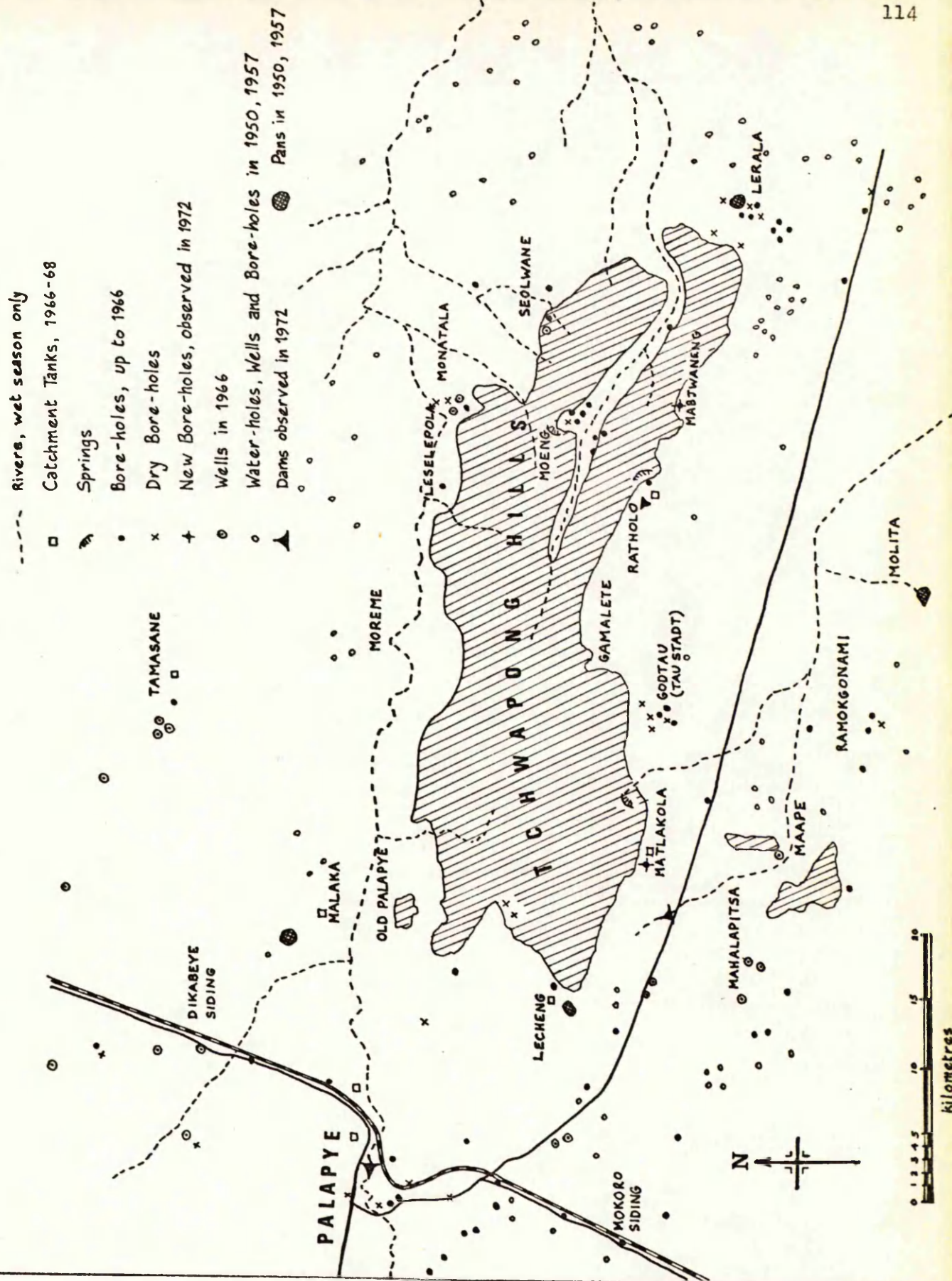


Figure 4.2 WATER SOURCES AROUND THE TCHWAPONG HILLS, EAST-CENTRAL BOTSWANA

This map is based on a Geological Survey of the Southern Ngwato Water Development, 1966, and maps of the Directorate of Overseas Surveys (D.O.S. 547) of Bechuanaland, 1957 & 1958, and personal observations.

time, hand-dug wells were established by the villagers between Mahalipitsa and Matlakola, and bore-holes were drilled by the government. In the late 1960's a number of bunded dams were built, and some catchment tanks, to try to make more use of surface water (ITDG 1969). The catchment tanks were initially successful, but failed to become well established because of poor social control (Chapter 10). The bunded dams are still used as wet-season drinking points for cattle.

The reason why some people choose some sources in preference to others have already been noted. In considering policies for the improvement of multiple source systems, a number of factors have to be borne in mind which can be grouped under three headings.

1. Physical Considerations. These include the practical and technical limitations on the use of each source: namely, the quantity of water available; its quality, its distance from the point of use; the reliability of the supply; and sometimes even the monetary cost of water.
2. Social Considerations. These include the part played by water activities in the life of the community, and also the organisation and social control over the use and maintenance of supplies. Again, technical factors are involved in the operation and maintenance of water schemes, and some sources lend themselves to individual ownership and control (e.g. roof tanks), whilst others must be used and maintained communally.
3. Water Conservation. Water from various sources is available for different periods of the year. There are many opportunities for water conservation and for spreading failure risks if multiple source systems are used.

This last point requires further explanation. In developed countries the term "conjunctive use of resources" is applied to

situations where multiple source systems are deliberately employed to make the best overall use of available water (e.g. supplementary river flow from groundwater), and reduce the risks of failure. Midgley and Pitman (1969) have argued that failure risks need to be more carefully assessed in semi-arid regions (such as South Africa), and that higher risks should be accepted for all water use except drinking water and the supply to key industries. This is another example of how the whole situation should be reassessed for the different conditions of semi-arid regions. The low failure risks accepted for temperate climates can only be assured by very large storage volumes and by accepting high evaporation losses from reservoirs. Of course, "conjunctive use of resources" is already practised in a limited way and without conscious planning in the multiple source systems of rural communities. Surface waters are used whilst they are available, during and after the rainy season. Leaking dams may also, accidentally, be serving a useful purpose by recharging unconfined aquifers and thus reducing evaporation losses. A long-term objective in the semi-arid areas ought to be to move from existing multiple source supplies to a more technologically advanced conjunctive use of resources.

4.6 Strategies for Improvement

Some consideration of the way people choose their sources of water, and a review of the choices open to them, enable conclusions to be drawn concerning strategies for improving supplies. The most important conclusion is that even with a sophisticated water scheme, some diversity in the use of other water sources is likely to persist for the sound reasons already noted. A new scheme would only supplement the existing range of choices.

It is also clear that many people already recognise different qualities of water, and are prepared to ration themselves so that their

most valued supplies last through the dry period. Thus, those families which collect rain water from roofs realise that it cannot satisfy all their demands and therefore restrict its use to cooking and washing dishes. For full bathing and washing of clothes, poorer quality water is used, often at the water source. Of course, the self-imposed discipline required for rationing depends on the character of the individual, or at least the head of the family, whether such a person is naturally thrifty or reckless. But the general attitudes to situations such as rationing are strongly influenced by traditions and the examples of a few key people in the community; and disciplined habits are more likely to be adopted if each family has control over at least some of its water supplies, as is the case with rainwater catchment with roof tanks.

In thinking of strategies for improvement, it is worth considering not only the diversity of sources, but also the different uses for which water is required. Indeed, multiple source systems are partly the result of the need for various classes of water. If, for example, water for drinking and cooking was considered the greatest deficiency, then one method of improving the situation would be to devise systems for intercepting rainwater, always recognizing that such a system would not fulfill the water needs for other uses.

Thus, it is unrealistic, and unnecessary, to think of a "final solution" which replaces all the traditional sources and satisfies all requirements. It is better to start with these sources, identify their deficiencies, and think of ways they can be "upgraded". Such a strategy might involve a piped water scheme which includes water treatment, but this should be seen only as one part in a programme of improvements. Other parts of the programme may depend on social changes in the community and would not be instantaneous, whilst further improvements

would involve better fencing of water sources so that cattle were excluded completely from some sources and had access to others at particular points or periods during the day.

This latter type of improvement fits into the pattern of a broad rural development policy. The implications and consequences of water supply improvements will be discussed in Chapter 6. At this stage, the major deficiencies of the existing multiple source systems will be identified and possible improvements considered. The starting point here is the physical limitations on water use noted above. These were quantity, reliability, quality, distance and cost, and it is in these areas that technical changes can have a significant effect. The first step should be to establish an order of priorities distinguishing between improved quantities of water, greater reliability in supply, better water quality or reduced distance between sources and points of consumption.

The Mpolonjeni case study, and the Botswana situation suggest that the most urgent quantity problems, as they affect simple existence in these areas, have been solved in the past few years by "crash programmes" of dam building and well drilling. The problem in most semi-arid areas has been questions of reliability, quality and distance. Water quality has received the greatest emphasis here, and it has been noted that, while bacteriological quality is considered most important by public health authorities, the local people are more conscious of the taste as it is affected by dissolved minerals and suspended solids. The complaints most often voiced by people at Mpolonjeni concerned the muddiness of water and the taste at some sources. The distance of sources, and the extra walking distance imposed during the dry season when some of the more convenient sources are no longer available, were less often stressed. Women were more conscious of the distance factor,

because they carry almost all the water, but the whole community was aware of the taste and appearance problem. It seemed then, that the people's first priority in water supply improvement would be better quality as reflected by taste and appearance. The second priority would be greater reliability and convenience. This assessment may be too strongly influenced by the male point of view, and it is quite likely that a woman would reverse this order and put reliability and convenience as the first priority.

In the Botswana villages referred to before, however, the groundwater is more palatable than in Mpolonjeni; it is more accessible, and it is accepted as the main source of supply. Since the groundwater is always clean, the chief priority should logically be to improve the reliability of sources, and to reduce the distance water has to be carried to the people's homes. However, it should be pointed out that this conclusion was not verified by asking people.

Again, much would depend on how priorities in the community are established. Parker (1973) quotes the case of a village in Ghana where the women were anxious to see water-carrying reduced, and where several houses with corrugated iron roofs could have guttering installed very cheaply to provide a supply by rainwater interception. Very little was done however, partly because putting up the guttering depended on the men in the community, and they felt no urgency about reducing the amount of water which needed carrying.

In both the Botswana and Swaziland communities mentioned, the priority as conceived by the water supply engineer would probably be to improve the bacteriological quality of the water, without necessarily improving the other factors, but as we shall see in Chapter 6 the evidence of improved health resulting from the availability of small quantities of safe water is slight. And remembering the philosophy of

user-choice outlined in Chapter 1, whereby the desires of the people in these communities are respected, even though the experts "know better", then the strategy adopted should be the one which is most acceptable to them and therefore most likely to be successful.

Once an order of priorities has been established on this basis, suitable strategies can be worked out. These strategies will often have to be chosen with a view to the way they will fit in with the total water system. The range of possible strategies is illustrated in general terms in Table 4.3. In later chapters it will be shown that there are empirical relationships between the quality of water used by people and the distance from source to point of use; in general, the nearer the source, the more water is used. Thus, deciding what strategy to adopt may affect more than one "problem area". There are other examples to show that these limitations on water use are very closely interrelated. However, the "quality factor" is somewhat different from the others, and can be taken separately.

Figure 4.3 shows the strategies and possible techniques for improving water quality, and Figure 4.4 shows the relative effect of various treatment processes on water quality. For developing rural areas water improvement by prevention seems to be the most appropriate strategy to adopt. Simple measures such as fencing, and the provision ~~such~~ of drinking troughs could significantly improve the bacterial quality and turbidity of the water. But the success of such measures depends mainly on human factors and they are likely to be rejected by engineers who foresee apparently intractable social problems arising from this sort of approach. However, only when preventative measures have been exhausted should treatment be considered.

Idelovitch (1973) has suggested that rural dwellers can be conveniently divided into two groups:

Table 4.3

Strategies for the Improvement of Existing Multiple Source Systems

<u>Problem Area</u>	<u>General Strategy</u>	<u>Technology</u>
<u>Limitations on Water Use</u>		<u>Examples of types of equipment available</u>
Quantity	increase capacity of existing sources	
	develop new sources	boreholes/wells, roof tanks, catchment tanks, dams.
Quantity/reliability	increase storage capacities	bigger dams
	better water conservation: e.g. evaporation reduction	sand-filled reservoirs floats or mono-molecular films on reservoirs storage in aquifers conjunctive use
Reliability	design for low maintenance attention to social control of supplies better servicing	
Distance	pipeline or canal new sources nearest point of use resettlement of people	roof tanks, boreholes, wells
Quality - general	see Figures 4.3 and 4.4	
Quality/reliability	new nearer and cleaner service sources with built in filters	roof tanks beehive tanks

Figure 4.3

Strategies for Improving Water Quality

→ Strategies

by Prevention of "pollution"

Stopping large concentrations of salt from building up.
 Reduction of sediment problems
 Prevention of bacterial pollution

Techniques

Collect surface water only
 Reduction of evaporation

Flush out reservoirs

Soil conservation measures
 Protection of wells and springs
 Careful siting of wells in unconfined aquifers

Fencing of reservoirs
 Provision of drinking troughs for cattle

Improved storage and transport of water

by Treatment

Treatment related to suspended solids, and bacteria

Destroy bacteria

Boiling
 Disinfection
 Chlorine
 Ozone
 Iodine

Remove solids & Bacteria

Slow sand filter
 Coagulation
 Sedimentation
 Filtration (rapid)

Removing solids only

Desalination
 Aeration
 "softening"

Treatment related to dissolved solids.

Removing dissolved solids

"hardening",
 Fluoridation

Additions

see Figure 4.4

Attribute (a)	Aeration (b)	Coagulation and Sedimentation (c)	Lime-Soda Softening and Sedimentation (d)	Slow Sand Filtration without (e)	Rapid Sand Filtration Preceded by (f)	Disinfection (Chlorination) (g)	Simple Storage with Protection of Source (h)
Bacteria	0	++	(+++) ^{1,2}	++++	++++	++++	++
Color	0	+++	0	++	++++	0	+
Turbidity	0	+++	(++) ²	++++ ³	++++	0	++
Odor and taste	++ ⁴	(+)	(++) ²	++	(++)	++++ ⁵ -- ⁶	0
Hardness	+	(--) ⁷	++++ ¹¹	0	(--) ⁷	0	0
Corrosiveness	+++ ⁸ -- ⁹	(--) ¹⁰		0	(--) ¹⁰	0	0
Iron and manganese	+++	+ ¹²	(++)	++++ ¹²	++++ ¹²	0	0

(1) When very high pH values are produced by excess lime treatment; (2) by inclusion in precipitates; (3) but filters clog too rapidly at high turbidities; (4) not including chlorophenol tastes; (5) when break-point chlorination is employed or superchlorination is followed by dechlorination; (6) when (5) is not employed in the presence of intense odors and tastes; (7) some coagulants convert carbonates into sulfates; (8) by removal of carbon dioxide; (9) by addition of oxygen when it is low; (10) some coagulants release carbon dioxide; (11) variable, some metals are attacked at high pH values; (12) after aeration.

Figure 4.4 COMMON WATER CHARACTERISTICS AFFECTED BY WATER
TREATMENT PROCESSES
(Fair, Geyer & Okun 1971)

The column (h) has been added by the author. The relative degree of effectiveness of each process is indicated by the number of plus signs (+) up to a limit of four; adverse effects are shown by minus signs (-) also to a degree; and indirect effects are shown by parentheses placed round the signs. Limitations and other factors are explained in the footnotes.

- 1) Those for whom the first improvement in the natural state of water supply has not yet been made.
- 2) Those who are beyond the first stage of improvement and have perhaps a piped system, but need further improvement.

The people of Mpolonjeni probably come within the first category, though many dams have improved the water supply situation. Similarly, most people in the semi-arid areas of Africa discussed in this thesis come within this category. Idelovitch suggests the following treatment processes which would be appropriate for this category:

Surface Water	Groundwater
1. No treatment	1. No treatment
2. Boiling	2. Boiling
3. Plain sedimentation	3. Chlorination
4. Slow-sand filtration	

Boiling is effective in destroying all pathogenic organisms, but to carry this out successfully ^{it is not sufficient} merely to bring the water to the boil; at least five minutes boiling is required (Williams and Mann 1973). The taste is changed, since the oxygen in the water is expelled, leaving a "flat" tasting water. Boiling also has some effect on greatly speeding the settlement of suspended solids. This treatment is generally considered an emergency measure, and not one which would be expected to be accepted as "normal" for most rural peoples (Mpolonjeni case study), though it is apparently normal practice in parts of Uganda (Warner 1973).

Figure 4.4 shows the relative effectiveness of plain sedimentation and slow-sand filtration. Indeed, the latter is the best all round treatment process, and because of other factors, such as unskilled maintenance requirements and low cost materials, this seems the most suitable process for rural areas provided the suspended solids content

of the original source is not high (WHO 1970). Plain sedimentation may be regarded as a separate treatment operation where larger suspended particles, such as sand and silt, are allowed to settle by gravity alone; or it may be regarded as the treatment carried out by natural storage of waters in reservoirs and tanks. The natural processes occurring in stored water can be very effective in reducing turbidity (by settlement of solids), and the bacterial pollution caused by coliform organisms (Holden 1970). Water is an unnatural habitat for these organisms and they die off faster than they multiply. However, storage alone may not be as effective a treatment in semi-tropical lands, because of very great sediment problems with clay soils, and because the temperature of water will be much higher (possibly up to 30°C). These factors could affect the bacterial growth significantly (Chapter 5).

Chlorination and sand filtration are positive treatment processes, which in some circumstances will provide significant improvements to water quality. However, as pointed out earlier, more appropriate solutions for rural developing areas are the preventative measures, which are intended to reduce the likelihood of sources becoming polluted, and "natural" processes which rely on natural purification by simply storing the water, or which attempt to introduce natural filtration into the collection-storage-use cycle, for example, catchment tanks and sand reservoirs. The "appropriate" techniques which are discussed in Chapters 8, 9 and 10 will be thus mainly concerned with devising improved sources of water.

CHAPTER 5

WATER QUALITY TESTS AND THE MPOLONJENI CASE STUDY

5.1 Introduction

The fieldwork for the case study area at Mpolonjeni was carried out in two instalments, in June 1972 and in August 1973. During the first of these periods the main object was to study the amount of water which people used, the distances they carried it, the methods of carriage, and the purposes for which it was used.

However, during this work, casual observation showed that, most water sources were both very turbid and affected by cattle. A common complaint of people living in Mpolonjeni, and especially of visitors to the area from other parts of Swaziland, concerned the quality of the water they had to use. Some sources were said to taste salty or bitter, some were very dirty, and with others it was difficult to lather soap. By virtue of living in Mpolonjeni, the author was able to obtain direct experience of some of these problems. In addition to having to boil every drop of water used (this was not common practice among the Mpolonjeni people), there were difficulties in cooking with sediment-laden water, and having to endure the sickly-sweet taste which suspended clay produced when the water was used for making tea.

During the second period of fieldwork, one main purpose was to identify those characteristics of water which are likely to affect the user's appreciation and to try to relate these to actual qualities of water from a variety of sources. No formal survey of users' assessments was made. The following discussion is based on observations and conversations with people living in Mpolonjeni. Through having to explain the reasons for bacteriological and chemical analyses, the author was able to reach some general conclusions about what quality of water was acceptable and desirable.

There was great divergence of opinion, and direct observations of water sources used did not always tally with users' remarks. For example, although the borehole water at Magomba (to the north west of Mpolonjeni) was said to be for domestic use only, there was clear evidence in the form of fresh dung, that animals, probably goats, had regularly forced their way inside the fenced area to obtain water. As another example, water from the borrow pit, which during June 1972 was said by some to be fit only for washing, was being used in August 1973 for normal domestic purposes. It is probable that some people express opinions which are contrary to their actions. This is a problem with all questionnaire surveys and particularly so in places where "government" people are viewed with suspicion.

When people in Mpolonjeni talked of "good" and "bad" water, they were usually referring to its appearance and taste. A clear, pleasant tasting water was considered healthy, whilst a cloudy, bitter or salty water was unhealthy. This assessment, without further knowledge of the bacteriological quality of the water, is eminently sensible. Where a choice had to be made between a clear but unpleasant tasting water, e.g. borehole water, and a cloudy but pleasanter tasting water, e.g. reservoir water, then the latter was usually preferred. Thus the borehole water at Magomba was used only when alternative surface sources had dried up. Some people expressed concern about having to use the same sources as cattle. But although health risks were perceived on this account, little was done to minimise the risks, such as restricting cattle to particular areas of the reservoir shore line. This would require communal action, but any concerned individual could ensure that he or she took water from a part of the shore line which was not used by cattle. It was usual practice to obtain water in the early morning before the cattle were watered. In this way

better quality water was obtained, not because a greater period of time had elapsed since the last pollution by cattle, but because cattle had not stirred up the mud.

Although the influence of water quality in relation to general health was appreciated in Mpolonjeni, the main aspects of quality which were considered important were appearance, taste and hardness. A question often asked by people was whether it was not possible to devise some simple method for removing "cloudiness", "hardness" and "saltiness". None of these qualities is of primary importance to a public health engineer who is chiefly concerned with the bacteriological condition of the water.

Similar perceptions of water quality were found by Warner (1969a) in Tanzania. The explanations for "bad quality" water were nearly always that the water was "dirty". Complaints that water was "diseased" or "polluted by animals" were less common.

It is probable that people make good intuitive choices about water quality without being able to explain their choice satisfactorily. In these cases, complaints about taste and appearance may just be an attempt to explain an instinctive judgement. In parts of Kenya, the usual practice is to avoid pools of standing water, but to look for a source of moving water, if necessary, artificially creating an overflow channel in a pool or dam (Shamala 1973). Sometimes, holes are deliberately dug in the downstream walls of dams, in order to obtain "filtered" running water (Kenya Water Department, 1973).

There seemed to be no obvious preference for moving water at Mpolonjeni, though small stagnant pools were avoided. Observations showed that all the reservoir sources were significantly polluted by animals. The tests carried out in August 1973 were intended to find out how polluted these sources were, and how they compared with other types

of sources in the area. Because the other aspects of water quality are very significant for the people, it was also important to investigate the influences affecting appearance and taste, and again compare various types of source. The purpose of this chapter is to describe the efforts made to assess:

- a) bacteriological quality of water
- b) suspended solids affecting mainly appearance, but also taste
- c) dissolved solids affecting mainly taste and hardness.

The scope of the tests was severely restricted by limited laboratory facilities and it was felt that the best use of time and resources was to try to obtain an indication of water quality at as great a variety of sources as possible. Thus, in general, single bacterial tests were performed on samples from reservoirs and water-holes, rainwater catchment tanks and roof tanks, boreholes and river water. Most of these sources were within the Mpolonjeni area, but the catchment tank, borehole and river samples came from surrounding areas. Some sources were tested more than once and at different times, but the range of sources tested enabled the different types to be compared, and this was considered more important than being able to reach a definite conclusion about all aspects of water quality at one particular source.

The approach adopted here is consistent with the general theme of this thesis, namely that the chosen methods should be appropriate to the needs of communities like Mpolonjeni. It will already have been appreciated that people in this type of rural community rely on a great variety of water sources at different times of the year and for different uses. One of their present needs is for some improvements in the water supply, even if it appears to be only marginal. The best way of achieving this is by studying the current situation on a broad basis, selecting

the most suitable sources for improvement, rather than by amassing a lot of (for this purpose) largely irrelevant data about the chemical and bacteriological composition of one particular source.

The location of the sources tested are shown in Figure 3.3 for those outside Mpolonjeni, and Figure 3.9 for those within the study area (Chapter 3).

5.2 Bacteriological Tests on Water in the Swaziland Lowveld

According to usual practice (WHO 1971), an isolated bacteriological test is rarely of value in indicating the extent of pollution of any source. Even a series of tests on the same raw surface water source is of little value because of the wide variations that can occur - due, for example, to changes in climatic conditions. However, by including the complete range of sources at Mpolonjeni and taking samples under varying conditions, it was possible to make a useful general assessment of differences between the categories of sources, without being committed to specific conclusions about any one source.

The methods adopted for the tests lent themselves to this sort of approach. "Millipore Coli-count Water Tests" were used; these are a variation on the membrane filtration (M.F) technique for bacteriological examination of waters which is a standard method (Millipore 1973 (a), Millipore 1973 (b)). The Coli-count water tester consists of a presterilised filter material containing a dehydrated nutrient media. When immersed in a water sample, a measured amount, 1.0 ml, is drawn through the filter and hydrates the media. The bacteria are retained by the filter, and after the whole filter pad and media have been incubated for 18 to 24 hours at 35°C, each individual organism develops into a visible colony. The device is designed for

detecting coli-form bacteria^{*}, and this is done by comparing the colour of the colonies with a colour range chart provided by the Millipore Corporation (Plate 1). Blue, blue-green, or green colonies indicate coli-form bacteria. The Coli-count test is not yet a standard method, but it is said (Millipore 1973 (b)) that field tests show good agreement with standard M.F. techniques. Mara (1972) has concluded that similar "dip-slide" techniques are useful for determining the extent of river pollution in developing countries where laboratory facilities are limited.

The Water Testers in Use

The Coli-count water tester method was used successfully for Swaziland waters, though consistent incubation temperatures could not always be achieved. The Coli-count water testers were incubated in a controlled temperature room at the Lowveld Experiment Station, Big Bend. The maximum obtainable temperature was 34°C, but low outside night temperatures, and artificially induced night-day cycles, sometimes meant that the incubation temperature fell as low as 19°C. It is not thought that these fluctuations seriously affected the results, but only increased the overall incubation time. Eighteen hours seemed to be about the most suitable incubation period at the higher temperatures, for identifying the coliform colonies.

The Coli-count water testers suffer the same drawbacks as the M.F. techniques, and so a number of further points need to be made:

1. It was not always easy to identify the coliform bacteria. Many non-coliform colonies appeared, and the coliform group usually made up only a small proportion of the total numbers. The blue colonies were easy to identify, but often there were large numbers which seemed to fit

* Since these water tests were carried out, the Millipore Corporation have introduced a similar technique for detecting faecal coliform bacteria.

Table 5.1
Results of Coli-count Water Testers

No. of Sample	Water Source	Date 1973	Time of Day hrs	No. of Colonies	Remarks
<u>Reservoirs</u>					
1	Mkutshane	2/8	1645	TNTC	T, ~ 1500 yellow-green colonies
2	Mkutshane	8/8	1630	23	many hundreds "
3	Mbonga	6/8	1430	4	about 500 other colonies
4	Mbonga	17/8	1230	3 D	many hundreds yellow green colonies
5	Mbonga	18/8	2100	7	T, sample stored 12 days
6	Maggenya's	6/8	1100	8	4 - 800 yellow-green
7	Maggenya's	6/8	1100	30	" "
8	Maggenya's	6/8	1100	2 D	Diluted sample of No.6, about 50 colonies
9	Hlangothi Old	2/8	1545	20	T, discoloured background
10	Hlangothi Old	17/8	945	27	T
11	Hlangothi Old	17/8	605	3	T, discoloured background
12	Hlangothi Old	18/8	1545	9	Sample 11, but stored in sun 24 hrs
13	Mafutseni	15/8	1030	65	Sample from storage container at school
<u>Catchment Tanks</u>					
14	Maphatinduku	10/8	1100	3	Many hundreds non-coliform growths
15	Secusha School	15/8	900	95	Some yellow, but few non-coliform growths
<u>Roof Tanks</u>					
16	Minister's House	13/8	1500	Zero	Few growths
17	Mafutseni School	15/8	1030	1	Only 9 growths

Contd....

Table 5.1 (Contd)

No. of Sample	Water Source	Date 1973	Time of Day hrs	No. of Colonies	Remarks
<u>Bore-holes</u>					
18	Magomba	13/8	1030	Zero	No growths
19	Malindza	15/8	1230	Zero	Many non-coli form growths. Sample from storage container from a home.
<u>Taps - Piped System</u>					
20	Ngcina Tap 2	15/8	1530	Zero	Water from storage tank
21	Ngcina Tap 2	17/8	1340	2	Storage tank recently filled
22	Ngcina Tap 5	17/8	1340	6	" " "
23	<u>Water-hole</u>	13/8	1515	60	Many non-coli form growths
24	<u>River Usutu</u>	16/8	1430	15	30 in yellow-green range

TNTC - too numerous to count

D - diluted samples

T - temperature fluctuations during incubation

into the pale green yellow end of the colour range.

(Plate 1'). The "colour" of these colonies was influenced by the colour of the background. This varied from yellow through to pale green, pale blue and brown, depending on the water sample. Where doubt about the colours occurred, colonies were classified as non-coliform (Table 5.1).

2. The problem of identifying colonies was particularly difficult when turbid water was sampled. Apart from the discolouration of the background, it is possible that solid matter prevented the measured volume of water from being drawn through the filter. Thus the colony counts for turbid samples might be under-estimates of the true situation.
3. Most of the surface waters contained many non-coliform bacteria, which tended to interfere with the growth of the coliform colonies. Dilution of the sample reduces this problem, unless the number of countable coliform bacteria then falls too low to produce a significant result. Thus coli-count testers are not suitable for waters containing few coliform bacteria in the presence of non-coliform organisms.

Some of these problems are recorded in the summary of results (Table 5.1) and are evident from Plate 1, which shows a representative selection of the Coli-count slides after incubation. Seven categories of source were examined in 24 separate tests.

Interpretation of Results

Each Coli-count water tester detects the number of coliform bacteria in the 1 ml. sample passed through the filter. Thus the information which this provides about the general quality of the source

is limited. The number of coliform bacteria will be subject to statistical variations, and replicate counts of the same water sample will not usually give the same number of organisms. The manufacturers (Millipore 1973 (a)) say that Coli-counts attain statistical validity in waters which average 10-15 coliforms or more per millilitre (1000-1500 coliforms per 100 ml of sample). Assuming that the field test results of Coli-counts are in good agreement with those obtained by standard M.F. techniques, then similar statistical variations should apply. The Ministry of Housing and Local Government, England and Wales (1969) gives the following 95 per cent confidence limits for the true number of coliform organisms detected by M.F. techniques:

$$\text{The upper limit} \approx C + 2 (2 + \sqrt{C})$$

$$\text{The lower limit} \approx C - 2 (1 + \sqrt{C})$$

where C is the count of organisms, C being greater than 20. For counts of less than 20, the following values of limits are suggested:

Membrane Count	95% Confidence Limits	
	Upper	Lower
1	5.6	0.025
5	11.7	1.6
10	18.4	4.8

Thus 20 colony counts seems to be the lowest desirable number for significant statistical interpretation. Only eight of the tests produced counts of more than 10, and in this respect the tests may be considered to be unsatisfactory. However, the limits suggested above do allow confidence limits to be applied to counts between 1 and 20. These were found by interpolation and the 95 per cent confidence limits for the tests are shown in Table 5.2; with the range of values of coliform bacteria per 100 ml samples.

Table 5.2

Analysis of Results

No. of Sample	Type of Source	No. of Colonies	95% confidence limits		Bacteria range per 100 ml		Coliform Bacterial Pollution	Visual assessment Non-coliform bacterial growth
			Upper	Lower	Upper	Lower		
1		T.N.T.C.	-	-	-	-	(High)	High
2		23	36.6	11.4	3660	1140	High	High
3		4	10.2	1.5	1020	150	Moderate	High
4		3*	8.6	1.0	8600	1000	High	High
5		7	14.8	2.7	1480	270	Moderate	High
6		8	16.2	3.0	1620	300	Moderate	High
7	RESERVOIRS	30	44.9	17.1	4490	1710	High	High
8		2*	7.1	0.6	7100	600	Moderate	High
9		20	32.9	9.1	3290	910	Moderate	High
10		27	41.3	14.6	4130	1460	High	High
11		3	8.6	1.0	860	100	Low	High
12		9	17.8	3.7	1780	370	Moderate	High
13		65	85.1	46.9	8510	4690	High	High
14	CATCHMENT	3	8.6	1.0	860	100	Low	Moderate
15	TANKS	95	118.5	73.5	11850	7350	High	Low
16	ROOF	0	-	-	-	-	Low	Low
17	TANKS	1	5.6	0.025	560	25	Low	Low

Contd...

Table 5.2 (Contd)

No. of Sample	Type of Source	No. of Colonies	95% confidence limits		Bacteria range per 100 ml		Coliform Bacterial Pollution	Visual assessment Non-coliform bacterial growth
			Upper	Lower	Upper	Lower		
18	BORE	0	-	-	-	-	Low	Low
19	HOLES	0	-	-	-	-	Low	Moderate
20	TAPS	0	-	-	-	-	Low	Moderate
21	PIPES	2	7.1	0.6	710	60	Low	Moderate
22	SYSTEM	6	13.3	2.3	1330	230	Moderate	Moderate
23	WATER HOLE	60	79.5	42.5	7950	4250	High	High
24	RIVER	15	26.2	6.3	2620	630	Moderate	Moderate

TNTC - colonies "too numerous to count"

* - sample diluted x 10

Bacterial Pollution classification - High lower limit 10,000 colonies/100 ml
Low upper " 1,000 colonies/
 Moderate all others - intermediate

Although it is difficult to interpret these results, some classification can be made; a suitable dividing line being 1000 colonies per 100 ml. Three groups are distinguishable and are classed as "high", "moderate" and "low" bacterial pollution relative to each other (Table 5.2). All the samples from reservoirs, apart from No.11 about which there is some doubt, can be classified as either "highly" or "moderately" polluted. Similarly, the groundwater specimens (18 and 19) and those from roof tanks (16, 17) show low bacterial pollution. Two of the tap samples (20, 21) from the piped system have "low" pollution, whilst the third (22) just falls within the "moderate" category. This intermediate "moderate" category also includes the river sample (Figure 5.1).

Conclusions

A number of conclusions can be drawn from these results. Firstly some general points about the use of Coli-count water testers and the qualities of water available to people in the rural communities of the Swaziland Lowveld will be made. These will be followed by specific conclusions about individual results.

The Coli-count water testers have proved, subject to the limitations already mentioned, to be a useful technique in assessing the general bacterial quality of the water available in areas where laboratory facilities are limited, though in many cases, the colony counts obtained did not exceed the desirable minimum of 10 to 15 colonies. However, because some samples proved somewhat inconclusive, whilst others gave significant results, it was possible to introduce a ranking of the sources into degrees of "pollution". It is also necessary to consider what meanings the results have on a wider scale.

The sources tested cover a range of 0 to 12,000 coliform organisms per 100 ml sample, which is generally a higher range of

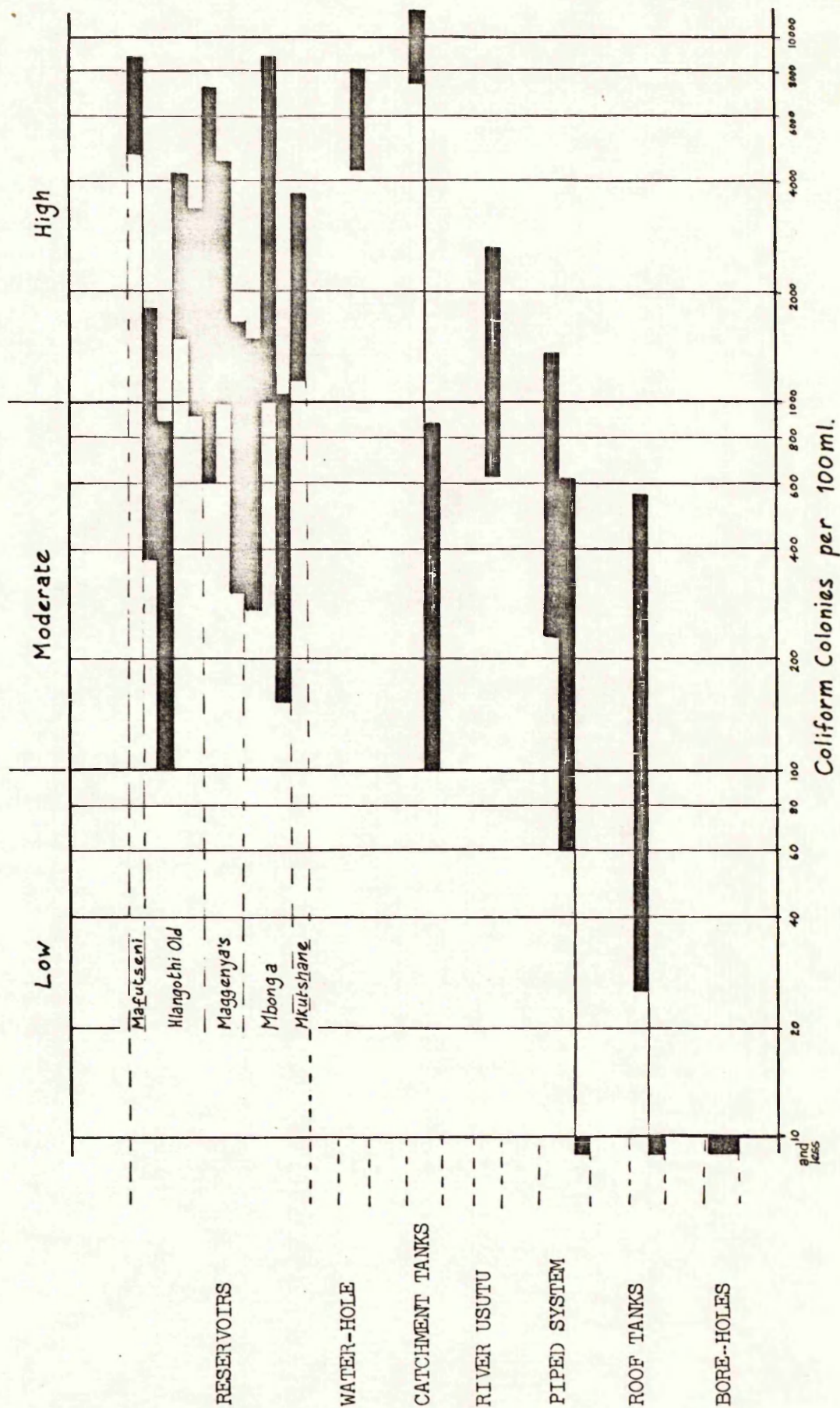


Figure 5.1 COMPARATIVE COLIFORM BACTERIA POLLUTION IN THE SOURCES TESTED

pollution than in impounding reservoirs in Britain, but lower than main rivers. Holden (1970) gives some examples of coliform counts per 100 ml. for impounding reservoirs and rivers in Britain. The range of values is:

Impounding reservoirs	2 - 365	coliform colonies/100 ml
Rivers	1100 - 100,000	" " "

By these standards, the reservoirs in Mpolonjeni are comparable to "moderately" polluted British rivers, but in view of the large quantities of effluent received by British rivers from towns and industry, the Mpolonjeni reservoirs are "grossly" polluted sources for a dispersed rural community. These high levels of pollution are not surprising when it is remembered that all the open water sources had cattle droppings around the fringes, and that cattle were allowed to wander into the water at places where domestic water was collected. All the samples from reservoirs were taken from points which were used by cattle and people, the only exception being samples 3, 4 and 5 at Mbonga dam. Here water samples were taken as near as possible to the pump intake of the Ngcina piped water supply; this point was inaccessible to cattle and was not used by people.

It is not possible to say precisely how the bacterial quality of these water sources varies during different seasons of the year. When the tests were conducted it was the dry season and only permanent water sources were available; consequently, relatively small bodies of water were being used more intensively, and this would tend to increase the coliform bacterial pollution. At other times of the year many more sources are available, and less intensive use should mean that the coliform bacterial condition of the sources would improve. However, heavy rains cause large inflows of sediment and organic matter into the reservoirs, providing more favourable conditions for

bacterial growth. This, and higher water temperatures, probably means that the overall bacterial condition of the sources would remain fairly constant.

Although the worst Mpolonjeni waters are only moderately polluted sources in terms of typical raw waters, they fail by a long way to meet the W.H.O. standards (WHO 1971) for drinking water. W.H.O. concedes that small community supplies with no distribution system cannot be expected to meet the standards of piped and chlorinated supplies, but suggests that it should be possible to "reduce the coliform count of even a shallow well to less than 10 per 100 ml. Persistent failure to achieve this should, as a general rule, lead to condemnation of the supply." On this basis all the sources tested would be condemned, except the borehole supplies and possibly the rainwater from roof tanks. Mpolonjeni waters would thus be classified as "inadequate" from water quality criteria alone.

The test results (Figure 5.1) show that a distinction can be drawn between qualities of open-surface waters (reservoirs and water holes), and the ground water sources (boreholes) and protected rain water supplies (roof tanks); the river water appears to be intermediate. Thus, these results agree well with the general discussion on water quality and sources which appears in Chapter 4, and the specific points which follow about some of the tests, although not conclusive in themselves because of the small number of tests, are consistent with the general pattern.

1. The piped supplies at Ngcina (tests 20, 21, 22) are an improvement on the quality of water taken from Mbonga dam (tests 3, 4, 5). The only treatment involved is filtration through sand (not slow sand filtration), coagulation by "alum blocks" and sedimentation in the storage reservoir. The bacterial condition is probably most improved

by simple storage, and test 3 which was performed on water stored in the reservoir for at least ten days, showed a lower coliform count than Nos. 4 and 5 which tested the water soon after the storage reservoir had been re-filled.

2. The results for the catchment tanks (14, 15) appear as anomalies in the classification of quality; test 14 gave a low count, whilst test 15 gave the highest of any of the tests. The water from catchment tanks, which are described fully in Chapter 10, is vulnerable to surface contamination. Some local conditions may account for the high count of No.15. It is known that the tank had been empty for some time, and the pump out of action because a pipe had split. The day before the test, heavy rains had partially filled the tank, and the pipe was repaired immediately before the sample was taken. Thus the sample was taken from freshly stored surface water which was run-off from a school playground, and the pipework had been handled several times. Either of these factors could have caused the contamination. The count was so high by comparison with other obviously polluted sources, that a particular incident seems to be the most likely cause.

Comparisons with other Data

There are no published results of bacteriological tests on rural water supplies in Swaziland, though occasional tests are performed (Friedman, 1973). Some data are available for sources in the semi-arid North Eastern Province, Kenya (Kenya Water Department, 1973): for a rural piped supply at Ismani near Iringa, Tanzania (Kreysler 1969); and for two other areas in East Africa (White et al 1972). In every case high levels of pollution are reported for open surface sources which are shared by both human and cattle population. White et al. found that "protected" springs and boreholes gave lower faecal coliform counts, and Kreysler showed that the sedimentation tanks in the Ismani

scheme, which are the only form of treatment, did significantly reduce the coliform count per 100 ml from an average of 501-2000 colonies for the raw river water to an average of 33-128 colonies for water from the communal taps.

White *et al.* (1972) suggest that for tropical sources, coliform counts at 36°C incubation temperature are not a reliable index of pollution, since it has been known for many years that free-living coliform organisms in the tropics grow at this temperature. Thus coliform bacteria tend to be diluted by numerous saprophytic bacteria. Faecal coliform counts based on an incubation temperature of 44.5°C are preferred; even these are subject to the same limitations but to a lesser degree, and they have the disadvantage of being much more difficult to carry out in the field. Kreysler (1969) found that samples of water used in the household were much more polluted than those taken from the stand pipes (501-2000 coliform colonies per 100 ml compared to 33-128 colonies for most tap samples). He attributed this difference to:

- a) water being stored 1 to 6 days in open containers which are rarely cleaned,
- and b) the water in these containers often reached incubation temperatures leading to multiplication of the organisms already in the tap water.

Two of the Mpolonjeni samples (Nos. 5 and 12) were deliberately stored before colony counts were taken (Table 5.1). In each case, the colony counts were higher for the stored sample than for the equivalent fresh sample. The Malindza borehole sample (No.19) was taken from water which had been stored in a house for an unknown period. Although no coliform organisms could be detected in this sample, the overall bacterial condition was very much worse than the

other borehole sample (No.18) which appeared to be completely sterile.*

Obviously no firm conclusions about the effect of storage can be made from these instances, but this question of bacteriological activity and the temperature of the water in tropical and sub-tropical climates is worthy of further examination. Sources in temperate climates undergo a self-purification process just by being stored (Holden 1970), but the processes involved may be considerably modified by temperature changes. The day temperature of the surface sources in Mpolonjeni for the winter months varies from 15-18°C (Clay 1973) which is not excessive by standards for temperate climates, and thus the results obtained for this study are unlikely to be greatly affected. On a similar topic, it would also be useful to know how bacteriological activity was affected by the high turbidities encountered in some of the Mpolonjeni sources.

5.3 Appearance of Water: Turbidity

In June 1972, the water in all the reservoirs was very turbid, which must have made washing clothes very difficult. In August 1973, the situation was much improved - probably because during the previous month there was no rainfall, and hence, no sediment laden run-off. However, the two smaller reservoirs, Hlangothi and Maggenya's, were considerably reduced in volume, so that the continual stirring of mud by cattle and people in the shallow water had affected the whole source. Water samples from any point were very turbid.

Because local people must inevitably judge water quality largely by taste and appearance, samples of the water were systematically tasted by the author as discussed below, and notes on turbidity and other aspects of appearance were made at the time when the samples were taken

* Two weeks after the test on this sample, the coli-count water tester developed a fungal growth.

Table 5.3

Field Tests on Water Samples from Sources in the Swaziland Lowveld -

Appearance: turbidity

Source	A P P E A R A N C E			Turbidity by matching (mg/litre)	
	Appearance of Sample	Apparent Colour (Hazen Units)	Initially	After standing	
RESERVOIRS					
Sefutshani Dam	fairly turbid				
Hlangothi Old Dam	extremely turbid	≥ 70	1200	600	
Mkutshane Dam	turbid	15			
Mbonga Dam	clear	5	150	0	
Maggenya's Dam	green slime	20	1200	600	
Mafulutseni Dam	very turbid	≥ 70			
Water Hole	extremely turbid	≥ 70	1200	400	
CATCHMENT TANKS					
Maphatinduku	clear	5			
Secusha School	slightly turbid	10			

(Table 5.3). In addition, two more controlled observations of the appearance of water samples were made.

The first of these, relating to turbidity, was based on the use of four tubes containing a measured quantity of clay soil from Mpolonjeni dispersed in distilled water. When these standard tubes were thoroughly shaken, the water within them closely resembled water samples taken from the reservoirs. A rough measure of turbidity could be obtained by "matching" them with similar tubes of reservoir samples. The amounts of soil in the four standard tubes were as follows:

1. 150 mg/litre
2. 400 "
3. 600 "
4. 1200 "

Water samples were generally taken from the top 5 cm of the water source. This surface water should clear first as sediments settle, and should therefore show a lower turbidity than water at greater depths. With some samples, however, it was observed that considerable amounts of sediment were deposited in the sample containers within an hour. In most of the dams, the water had been agitated not long before the samples were taken, either by humans and cattle, or by the wind, so that even water near the surface had not fully cleared. For this reason, the matching of samples to standard tubes was repeated when the initial settlement appeared to be complete. This second "match" was assumed to give a measure of the turbidity which could be expected to persist in reservoir water under stable and wind free conditions. These values will be discussed below.

A second assessment of the appearance of water samples was made by measuring their "apparent colour". None of the samples was very strongly coloured, though because of the high turbidity and suspended

solids contents of some of the samples, the apparent colour as measured, was high. The Hlangothi Old Dam samples, even after standing, gave readings greater than 70 Hazen units. The equipment used was a "Lovibond Comparator". Glass discs are available which match the colours of Hazen solution for colours from 5 to 70 units, a clear solution being used for comparison (Holden 1970). The results for "apparent colour" shown in Table 5.3 are another indication of turbidity and suspended solids. All sources apart from the reservoirs and catchment tanks gave readings less than 5, which indicates that they were clear and largely free from suspended matter.

Suspended Solids

Although the term "turbidity" has so far been used in a general sense to denote the appearance of water which contains dispersed soil particles, the term can be used with a more exact meaning to denote a cloudy appearance due to colloidal material in the water; this persists indefinitely, in contrast to the effects of suspended particles which settle within a few days. The turbidity of water at Mpolonjeni is primarily due to the soil which is washed into the reservoirs as a result of erosion. Much of the soil consists of material which can be described loosely as sand and silt, consisting of particles larger than 0.002 mm diameter which carry no electrical charge, and which settle in still water with a terminal velocity given by Stokes' Law, assuming the particles approximate to spheres. This rate of settlement is used by soil scientists as means of analysing soils. All suspended sand and silt in the top 15 cm of a reservoir should have settled within 8 hours.

Ordinary filter paper will retain particles of 5×10^{-2} mm. The size of colloidal particles ranges from 10^{-6} mm to 10^{-3} mm. For spherical particles of the size 10^{-3} mm in diameter, sedimentation

rates can be around 1 cm/hr, but as the particle size decreases the sedimentation rates become very low, e.g. for particles of 10^{-5} mm the rate is around 0.7 cm/year, clearly these rates are almost impossible to detect, and convection currents and other interferences will prevent settlement.

Settlement of clay particles is a complicated process, partly because of their very small size - capable of passing through most types of filter paper - but also because they carry a negative charge. If positive ions such as H^+ , Ca^{++} or Al^{+++} become attached to clay particles, their charge is neutralised, and they tend to coalesce or flocculate, and settle fairly quickly. When sodium ions are present in the water, however, they become attached to the clay particles and flocculation may be prevented. The sodium ions set up complex interactions with bi-polar water molecules and the effect is one of dispersing the clay particles. The loose structures formed by the clay particles, sodium ions and water molecules together give rise to colloidal behaviour (Mysels 1959).

It is impossible to draw a sharp distinction between suspended clay and colloidal clay in reservoirs at Mpolonjeni, and this makes a clear statement of the "suspended solids" content of the water extremely difficult. Clay particles vary considerably in size. Some are heavy enough to settle slowly regardless of any marginal colloidal behaviour, while others are so small that settlement would scarcely be noticeable in a limited time, even with no electrical charge effects. The only clear distinction that can be drawn is between material which is retained by specific grades of filter papers, and the residue left by the evaporation of the filtrate. The latter includes dissolved salts as well as colloidal matter. To avoid ambiguities, it seems best to use the term "filtered solids" to describe material retained by the filter paper,

because this quantity may not agree precisely with "suspended solids" as defined or measured other ways.

Experiments to assess these quantities for a number of water samples were carried out by the author at the Lowveld Experiment Station in Swaziland, and were repeated for samples brought back to Manchester. The results are expressed more readily as a diagram (Figure 5.2). Work in Swaziland was hampered by lack of vacuum filtration equipment and a precision balance. Manchester measurements are generally more reliable than Swaziland ones, which are best regarded as indicating the order of magnitude. In both Swaziland and Manchester tests, Whatman No.1 standard filter papers were used.

The visual estimates of turbidity mentioned previously, which were based on a number of standard clay suspensions, can be related to the laboratory results as shown in Figure 5.2. The figures given refer to the initial turbidity. The estimates of "turbidity after standing" (Table 5.3) should correspond approximately to the "colloidal clay". Thus, for the Hlangothi Old Dam sample, the diagram (Figure 5.2) suggests that there were 500 mg/litre of "colloidal clay". The corresponding estimate of turbidity made by matching the sample with standard suspensions was 600 mg/litre (Table 5.3).

In a further effort to elucidate the behaviour of suspended and colloidal clay in reservoir water, experiments were carried out for the author using soil from Mpolonjeni which had been sent to the National College of Agricultural Engineering for analysis. The soil came from a number of points in the catchment area of Maggenya's Dam, and included one sample of black loam, and another more typical of the dark clay soils of the area.

Weighed samples were dispersed in measured quantities of distilled water, and a hydrometer was used to measure the amount of soil in

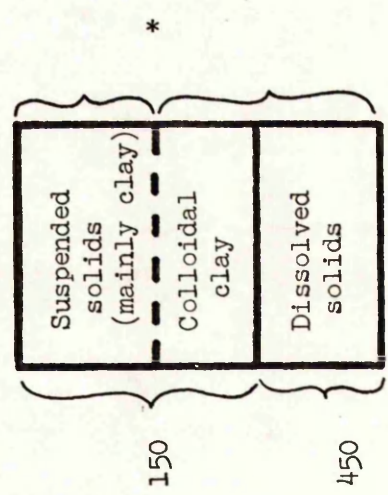
Figure 5.2

Suspended and dissolved solids in samples from Mpolonjeni sources (mg/litre)

(a) MBONGA DAM

Turbidity Estimate

By subtraction dissolved solids approximately

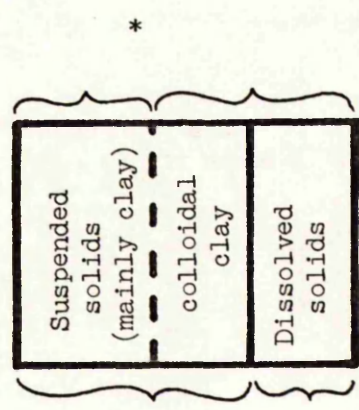


Filtered solids
67 (Swaziland measurement)
17⁺ (Manchester measurement)
Residue on evaporation
533 (Swaziland measurement)
606 (Manchester measurement)

(b) HLANGOTHI OLD DAM

Turbidity estimate
1200

By subtraction
< 800

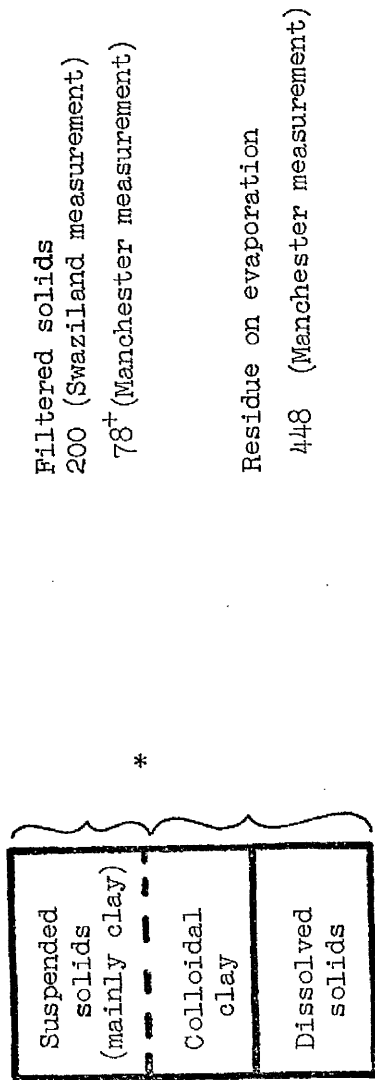


Filtered solids
701 (Manchester measurement)
Residue on evaporation
1380 (Manchester measurement)
(contained considerable suspended and organic matter)
Total 1025
(Swaziland measurement)

Contd..

Figure 5.2 (Contd)

(c) MKUTSHANE DAM



Filtered solids
200 (Swaziland measurement)
78⁺ (Manchester measurement)

Residue on evaporation
448 (Manchester measurement)

* "Filtered solids" corresponds approximately with "suspended solids", but not exactly, since there is no sharp distinction between suspended clay and colloidal clay.

+ Lower figures due to vacuum filtration at Manchester.

suspension at regular intervals after dispersion was complete. The results showed a rapid settlement of material during the first 8 hours after the suspension was allowed to stand. The coarser components of the soil had settled during this time, leaving only clay in suspension. Thereafter, and for the next 10 days, settlement continued more slowly. Towards the end of that period, evaporation of the suspensions was effectively concentrating them, so that measurements were less reliable. However, they did suggest that settlement of the clay never entirely ceased, although it became very slow indeed.

Efforts were made to see whether the settlement of the clay fraction could be described by an exponential decay function of the form:

$$m = m_0 e^{-t/T}$$

where m is the mass of clay in suspension

m_0 is the original mass of the soil

T is the time required for a fixed proportion (65%) of the clay to settle.

Quite good agreement between this equation and the observed results was found with $T = 10$ days in one case, and $T = 25$ days in another case. The suspended material in reservoirs at Mpolonjeni is likely to behave in a similar way. Thus, when a storm brings a lot of sediment-laden water into a reservoir, a significant reduction may be expected after a period T - that is, after about 10 to 25 days. In the dry season, when storms are infrequent, turbidity should be consistently low, except on the fringes of reservoirs where cattle wade in and stir up the mud.

In the dry season of 1973, it was observed that water in the large reservoirs was relatively clear (see Mbonga Dam, Figure 5.3), although small reservoirs were so badly affected by cattle that water was always very turbid.

Finally it should be noted that one of the samples in the settlement test was dispersed using "calgol" - a dispersing agent containing a large concentration of sodium ions. Settlement of this sample ceased after about 40 hours, leaving about 5 g/litre of clay in the water, presumably in colloidal form. The calgol would have released a far higher concentration of sodium ions than would be found in any of the reservoirs, but the behaviour of this sample does help to illustrate the colloidal nature of clay in this respect. In the actual reservoirs, calcium ions are far more plentiful than sodium ions (Section 5.4): the sodium absorption ratio (SAR) is likely to be relatively low, so that only a small percentage of the clay forms a colloid in the water rather than a suspension.

5.4 Dissolved Solids and Chemical Analyses

The main influences on the taste of the water from sources in Mpolonjeni are dissolved minerals. Surface waters are usually relatively free of dissolved solids, but ground waters, especially in semi-arid areas are severely affected. Estimates of the amounts of dissolved solids in Mpolonjeni surface water, however, showed that these were also significantly affected.

Table 5.4 shows the results of experiments for a variety of sources (see also Figure 5.2). Measured samples were evaporated to constant weight in previously weighed beakers. Because of the moderate accuracy of the balance available, the tests performed in Swaziland can only be considered to give approximate values. Since some samples still contained considerable suspended and colloidal matter, the results are more accurately termed "residue on evaporation".

The sample from the Usutu River contained a comparatively small proportion of dissolved solids; this is consistent with other analyses

Table 5.4

Field Tests on Water Samples from Sources in the Swaziland Lowveld - Taste - dissolved solids
(all tests performed in Swaziland except where otherwise stated) (See Figure 5.2)

Source	Taste	Residue on evaporation mg/l	pH	REMARKS on sources and sample
<u>RESERVOIRS</u>				
Sefutshani Dam			8.3	Washing point
Hlangothi Old Dam	E	1380 ¹ 1025	6.5	Watering point, dung nearby
Mkutshane Dam		448 ¹	8.5	Watering point, dung nearby
Mbonga Dam	slight M	606 ¹ 533	8.8	weed growth, pump intake
Maggenya's Dam	E-M	200	8.5	surface slime, dung nearby
Mafutseni Dam	E		7.0	
			6.5	small muddy source
<u>WATER HOLE</u>				
<u>CATCHMENT TANKS</u>				
Maphatinduku	N-E		8.0	clear, sample contained dead insect, frog in tank
Secusha School	slight M	268	6.7	slightly turbid, swimming grubs
<u>ROOF TANKS</u>				
Minister's house	N		6.0	cool, clear
Mafutseni Sch.	N		6.0	clear, said to contain "snails"

Contd..

Table 5.4 (Contd)

Source	Taste	Residue on evaporation mg/l	pH	REMARKS on sources and sample
<u>BOREHOLES</u>				
Malindza	M	466	9.5	slight sediment, hand pump
Magomba	M		7.9	clear, dung nearby
<u>PIPED SUPPLY</u>				
Ngcina w.s.	N	658	7.6	clear
River Usutu	G	65	7.6	watering and washing point

Key to tastes: E - earthy, M - minerals or salty, N - neutral, G - good (aerated)

1 - Manchester measurement

of Usutu water (FAO/UNDP 1970). But most of the surface sources contained amounts which are far higher than those encountered in British sources. Holden (1970) quotes figures for some impounding reservoirs, the highest total solids (i.e. dissolved and suspended) being 385 mg/l. All but one of the other examples have a total solids content of less than 100 mg/l. The WHO standard for dissolved solids is 500 mg/l - maximum desirable limit (WHO 1971). Although many of the Mpolonjeni samples exceed this amount, they are well below the WHO "maximum allowable limit" of 1500 mg/l, but borehole sources in the Lowveld often approach this limit and occasionally exceed it by great amounts (Table 5.5). The results for dissolved solids in surface water suggest that the general points, made in Chapter 4, about the accumulation of salts in reservoirs in semi-arid areas are borne out in practice.

Taste

Table 5.4 shows an "outsider's" assessment of the taste of water from Mpolonjeni sources. Samples were tasted by the author and two other Europeans. Some of the samples were boiled before tasting, which tended to produce a rather "flat" taste, and in other cases the appearance of the water unavoidably influenced the assessment, but the general conclusions were that the borehole waters tasted strongly of minerals (i.e. slightly salty or metallic) and were disliked. The water from the dams sometimes tasted of minerals, but sometimes had a sweetish-earthly taste due probably to suspended solids. The water samples from roof tanks, catchment tanks and the Usutu River were preferred. A ranking of tastes by a non-local palate would be as follows:

Table 5.5
Analyses of Water from Sources in the Swaziland Lowveld

Chemical Analyses	River Usutu	Bore Holes			Dams		
		Malinda	Mpaka Range for four sources	Big Bend Bar R	Siteki	Siteki	Mhalatuzane River Tribut.
Date	Mar 57 Feb 70	28/4/67	?	23/10/73	8/2/73	13/6/73	31/12/70
Approx flow cu.secs	4,000 400						
Dissolved solids (105°C)	170 36	1123	1034-1073	4560			
Suspended solids (105°C)	690		5.0 - 17.6				
pH	7.0 7.3	8.75	7.9 - 8.1	7.3	7.8	7.4	
Total alkalinity (CaCO ₃)		686	53	756	61	68	
Total hardness (CaCO ₃)		492	326 - 332	2239	43	44	
Calcium (Ca ⁺⁺)	8 2	90.0	131 - 143	430	8.0	8.3	9.24
Magnesium (Mg ⁺⁺)	4 3	64.8	71 - 72	283	5.6	5.6	6.74
Sodium (Na ⁺)	11 4	18.3					17.49
Potassium (K ⁺)	12 1	81					0.97
Chloride (Cl ⁻)	9	195	229 - 243		39	38	
Sulphate (SO ₄ ⁻⁻)	11	12	24 - 43		1	1	
SOURCE	FAO/UNDP 1970	Min. of Power, Works & Communications, Swaziland			Min. of Power, Works & Communications, Swaziland		

1. River Usutu
2. Rainwater
3. Tapwater (Ngcina Water Supply)
4. Catchment Tank
5. Reservoir water
6. Water-hole
7. Bore-hole water

The relative positions of intermediate sources varied slightly according to the taster, but local people would almost certainly agree with the overall pattern. The tapwater from the Ngcina water supply (source - Mbonga dam) had a dissolved solids content as high as the reservoir water, but because its appearance was better, its taste also seemed improved.

This assessment of tastes is in general agreement with the comments of people living in Mpolonjeni. Bore-hole water was invariably disliked. The two samples of bore-hole water tasted by the author were particularly unpleasant, and it seems hardly surprising that other sources were sought. There was often disagreement about water from catchment tanks; some people complained that it was salty. Because of the taste of bore-hole water, people were frequently suspicious of all groundwater sources, and this may be one reason why the water from catchment tanks was sometimes considered unfavourably.

Hardness

Some simple comparative tests on the "ease of lathering" soap were made. The rainwater sample was easiest, followed by the catchment tank sample. The bore-hole water was most difficult. The catchment tank water was said to be good for washing, presumably because it was both fairly clean and easy to lather, qualities which taken together are rare for Lowveld sources.

Chemical Analyses

Data on the chemical analyses of the Usutu River water and some Lowveld bore-hole samples are available, but analyses of Lowveld reservoir water are scarcer. Limited information on three types of source is available (Table 5.5), but none is within the study area. Tests for total hardness and total alkalinity were carried out in the field on samples from Mpolonjeni reservoirs and these were repeated, with more accuracy, on three samples brought back to Manchester (Table 5.6).

In Britain, water containing 250-350 mg/l Ca CO_3 is classified as "hard", whilst water containing 50-100 mg/l Ca CO_3 is "moderately soft". (Thresh, Beale and Suckling, 1958). On this basis, the water in Mbonga and Mkutshane Dams is hard, and that in Hlangothi Dam is moderately soft. The differences in hardness (and in alkalinity) can be explained by the differences in the geology and the soils of the catchment areas.

The table below shows the constituents of the rocks making up the two main types of geological formations in the Swaziland Lowveld. In the area to the east of the main road in Mpolonjeni, which includes the catchment areas of Mbonga and Mkutshane Dams, the rocks are mainly basic (basalts and dolerites), while to the west, including the Hlangothi Dam catchment area, they are acid to intermediate sedimentary types.

Chemical Composition of Rocks (Murdoch and Andriesse 1964)

Percent	<u>Acid to Intermediate</u>		<u>Basic</u>	
	Ecce Sandstone	Cave Sandstone	Basalt	Dolerite:
SiO_2	82.3	83.5	46.1	50.4
Al_2O_3	8.8	-	22.3	13.3
Fe_2O_3	3.2	-	10.1	5.2
FeO	-	-	3.6	8.5
MgO	1.6	-	2.9	5.6
CaO	0.4	0.7	5.6	10.7
Na_2O	-	1.6	3.4	2.6
K_2O	3.7	1.4	1.5	1.2
Other	1.5	-	5.0	2.0
<u>Total</u>	101.8	(87.2)	100.5	99.5

Table 5.6
Laboratory Analysis of Water Samples brought back from Swaziland

Mpolonjeni Reservoirs

Chemical Analyses mg/l	Hlangothi Dam	Mbonga Dam	Mkutshane Dam
Residue on evaporation	1380 *	606	448
Suspended solids	701	17	78
pH	6.9	7.5	7.4
Total alkalinity (CaCO_3)	14	57	58
Total hardness (CaCO_3)	57	309	275
Calcium (Ca^{++})			
Magnesium (Mg^{++})			
Sodium (Na^+)	22	102	98
Potassium (K^+)	12	9	10
Chloride (Cl^-)	19	24	17
Sulphate (SO_4^{--})	too low to detect	To low to detect	too low to detect

* Residue contains considerable suspended and organic matter.

The analyses of soils derived from these two rock types (Murdoch 1968; Pacey 1973) show similar differences in the constituents. The greater calcium and magnesium content of the basic rocks and soils largely accounts for the greater hardness of the Mbonga and Mkutshane water. The differences in sodium content can also be accounted for in the same way (Table 5.6).

Because of the difficulties outlined earlier, it is not easy to say how much of the residue on evaporation for the Hlangothi sample is due to dissolved solids, but from the hardness considerations mentioned above it is likely that there would be fewer dissolved solids in this source compared with Mbonga and Mkutshane. The qualities of dissolved solids detected in the reservoirs are sufficient to give the water a mineral taste, but the analyses of the water (Table 5.6) do not reveal any constituents (such as excessive chlorides and sulphates) which are likely to give any source a particularly salty or bitter taste.

In June 1972, several people claimed that water from Maggenya's Dam was "salty" or "bitter". This opinion was so widespread that particular attention was given to investigating this source, and seeking an explanation. It was originally thought that the unpleasant taste could be due to run-off water from soils with a high salt content (sodium chloride), and that the concentration of salt was increased by high evaporation losses. It is improbable that the dam has ever overflowed, so this latter reason remains valid, but estimates of the dissolved solids in a sample from this source were somewhat lower than the other sources on the basic soils (Mbonga and Mkutshane), and the sodium ion content of the sample from this source was also slightly lower. Analyses of soil samples from Maggenya's Dam catchment area did show that the proportion of sodium chloride was higher than other samples in the area, but the amount was still not sufficient to have

any strong influence on the quality of the water (Pacey 1973). The matter is further complicated by a complete reversal of opinion by people living near the dam. In August 1973, water from Maggenya's Dam was preferred to that from Mkutshane, because it was softer. The author could not detect any unusually unpleasant taste in the water at this time, and so it must be concluded that the unpleasant taste of 1972 was merely transitory, and possibly caused by decaying vegetable or animal matter.

5.5 Conclusions - Water Quality at Mpolonjeni

The chemical constituents of the Mpolonjeni sources do not present health problems, though the high turbidities and high mineral content cause inconvenience and discomfort and may affect health indirectly.

Most of the reservoirs in the Lowveld are not long established, but already it seems clear that in most cases, the water is not active biologically and is not especially suited for fish life (Clay 1973). Aquatic life in the sources investigated seemed very slight. There was evidence of some weed growth in Mbonga and Mkutshane Dams, but the catchment areas of these dams are within the area of basic soils and rocks, and the run-off water is likely to provide more favourable conditions for plant growth (Bellinger 1973). It is also possible that the high turbidities and widely fluctuating water levels also inhibit plant growths in the other reservoirs.

The overall bacteriological activity of the sources can be deduced by the total number of colonies (coliform and non-coliform) on the Coli-counts of samples. The number of coliform colonies by itself is an indication of the level of human and animal activity. No attempt was made to estimate the total colony count, but a visual assessment was

made (Table 5.2). In general, high coliform counts were visible when the total number of colonies was high, and thus it was not possible to relate the degree of pollution in these sources to specific human and animal activity. Only in the case of the catchment tank sample, number 15, did coliform colonies account for the great majority of the total number of colonies, thus confirming the suspicion that the high coliform count in this case was the result of a specific and recent, pollution incident.

CHAPTER 6

THE CONSEQUENCES OF WATER SUPPLY IMPROVEMENTS

6.1 Introduction

Any change in the water supply arrangements of a rural community will have far-reaching consequences in many aspects of life. As well as specifying the actions needed to bring about technological change, planners, designers and engineers between them must attempt to predict the consequences of the proposed change. Very few of these consequences will be wholly beneficial, or completely adverse; the difficulty is to make a complete assessment of the net beneficial consequences or "benefits", and the net adverse consequences, or "costs", so that the final outcome may be predicted. But before dealing separately with "costs" and "benefits" of rural water supplies, it is necessary to think of all the factors involved and then consider the beneficial and adverse consequences of each. In this chapter, the consequences of water supply improvements will be discussed. Firstly, the extent and influence of water supply on a rural community will be outlined, and then the consequences will be classified so that the most important and immediate effects are identified. The types of consequence will be discussed in general terms, and specific points relating to Swaziland mentioned.

6.2 Water Supply and the Rural Community

For the first part, some of the methods used in the realm of design technology can be usefully applied. In Chapter 1 it was suggested that water may be regarded as a problem at the systems level. In considering all design work, it is possible to distinguish three other levels of problem solving activity, each with its own distinct methods

(Jones J.C. 1970). They range from component design with the narrowest scope, to political actions which affect whole communities.

Table 6.1
Levels of Problem Solving Activity and Solutions

<u>Level of problem solving activity</u>	<u>Types of solution and design method</u>
Community	<div> <div> Social & Political Action Political campaigning National economic planning land resource planning </div> </div>
System	<div> <div> Integrated Rural Development Community Development </div> </div>
Products	<div> <div> ? </div> </div>
Components	<div> <div> Engineering feasibility studies Traditional Design Procedure (e.g. drawings specifications) Research & Development Calculation, Drawings Trial & Error technique e.g. activities of craftsmen and technicians </div> </div>

Many of the unsolved problems of societies (e.g. traffic or environmental problems) are associated with the "systems" level, which is the link between "products" and "community" levels. The systems level is beyond the scope of traditional design methods, but below the level of effective community action. Concepts such as community development and integrated rural development have attempted to fill the space from the community level and methods such as engineering feasibility studies have extended traditional design procedures to try to cope with systems problems, but neither approach has been completely successful.

Innovation at the systems level requires freedom not only to alter drastically the components and products that make up a system, but also the organisation of the community that the new system is to

serve. In developing countries, one major difficulty has been that the rural communities encountered by planners and engineers are usually quite alien to them. Instead of recognising this state of affairs, these "experts" are inclined to treat the communities as being similar to those with which they are familiar. The design of new systems then, resolves itself into the familiar design of items at the products and components levels.

The particular design methods used in this section dealing with water supply at systems level combines "brainstorming" and "taxonomy" (Jones J.C. 1970, p.274 and p.350 respectively). This consists of writing on cards any, even remotely relevant, thoughts on the problem. Ideally, this process should be carried out by a multi-disciplinary team of people, so that a wide variety of views is obtained. The cards are then grouped into categories and sub-categories of information until a final classification is achieved which satisfies all the cards and all the categories.

The classification in Figure 6.1 is the result of this exercise for "improvement of water supply of a rural community in Africa". Even if the classification is not fully comprehensive, it has enabled the boundaries of the problem to be extended, and reduced the risk of pre-conceived ideas dominating the thought processes. The potential influence of the water supply improvement is emphasised, and the main problem areas are identified. Conventional civil engineering is concerned with only a part of the whole problem, though the civil engineer should be aware, especially when working in a developing rural area, of the other aspects.

Some of the consequences of water supply improvement are evident from the "evaluation" section of the classification; and those arising from the "implementation" section are detailed in Figure 6.2.

FIGURE 6.1

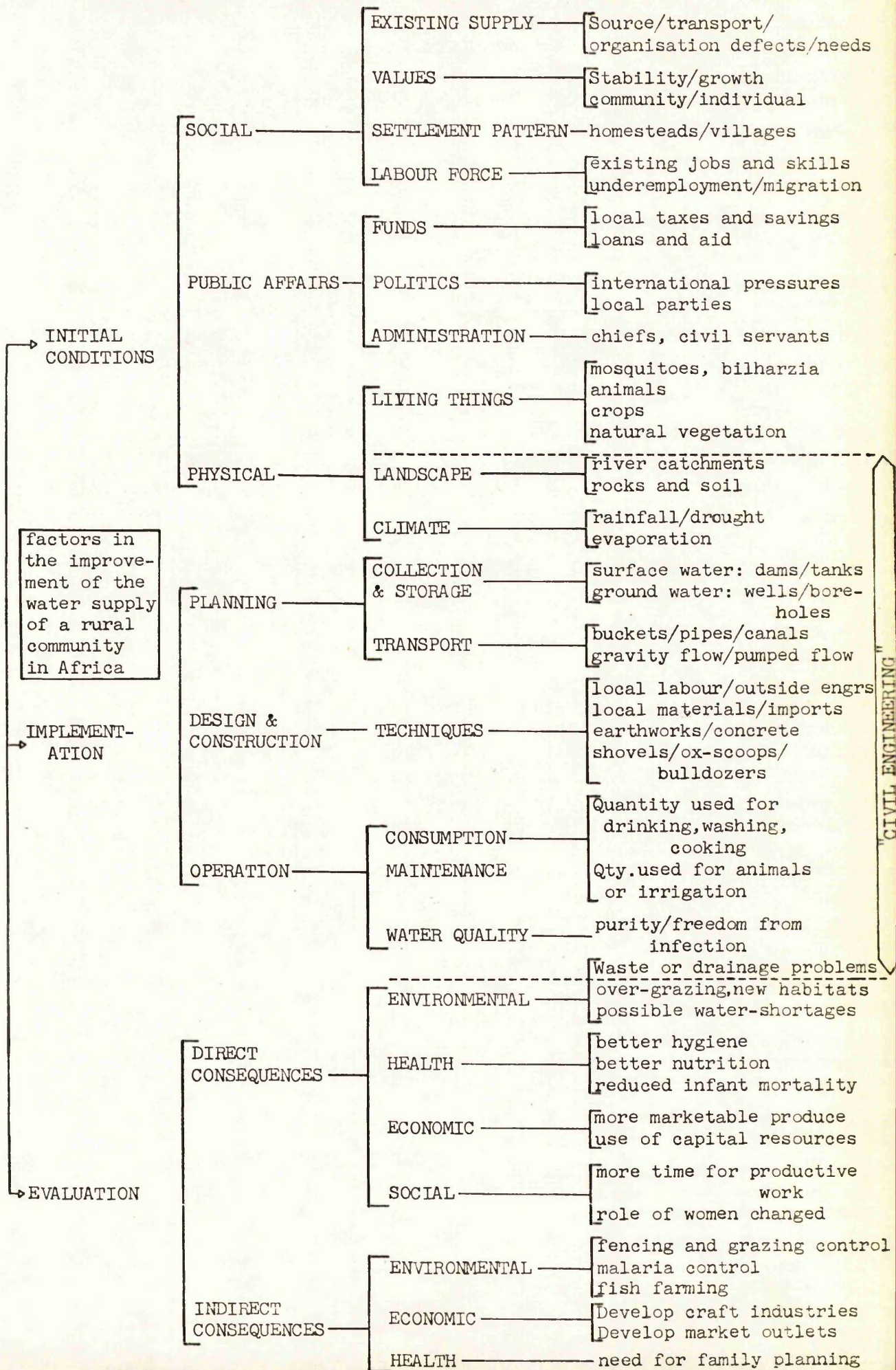


Figure 6.2

CONSEQUENCES arising from the IMPLEMENTATION of an improved water supply
in a rural community in Africa

1. Improved methods of COLLECTION & STORAGE

affects habitat of living things

- consequences: a) influence on soil erosion
b) increased mosquitoes
c) fish in reservoirs

malaria control
measures needed

opportunity for
fish farming

also affects balance of water resources

- consequences: a) possibility of water shortage
elsewhere or in the future

water conservation
plans

2. Improved TRANSPORT of water

affects time spent by women in carrying water

- consequences: a) possible change in role of women
b) more time for cooking,
cultivating crops etc.
c) more leisure

community
development

need for rural
industries, or
handicrafts to
reap benefits
from extra time
and energy of
people - inter-
mediate technology
applications

3. increased CONSUMPTION of water

affects drinking, washing, cooking etc.

- consequences: a) better hygiene
b) waste and drainage problem

also may affect animals' drinking and
irrigated crops

- consequences: a) better nutrition
b) more marketable produce
c) overgrazing near animal
drinking points

need for health
education to teach
value of hygiene

improve sanitary
arrangements

4. IMPROVED WATER QUALITY

reduces spread of typhoid, cholera, dysentery,
bilharzia

- consequences: a) better adult health and
capacity for work
b) reduced infant mortality

fencing and other
improvements in
animal husbandry
to prevent
overgrazing

develop market
outlets

5. TECHNIQUES used in constructing new system

affect degree of involvement of local people

- consequences: a) interest in maintaining
and developing works
b) skills & knowledge required

need for family
planning and child
welfare service

"intermediate
technology"
construction
methods

affects economic viability

- consequences: a) capital and skills available
for developing project

It is also clear that an improved water supply will affect many of the "initial conditions" of the classification of Figure 6.1. But although the potential impact of an improved water supply is now apparent, a closer look at some of the direct consequences (Figure 6.2) shows that a complete range of other services, such as grazing control, welfare services, sanitary arrangements etc., may be required at the same time if the benefits of the water project are to be realised.

Warner (1969b) investigating rural water supplies in Tanzania, has identified 30 beneficial changes which could result from improved water supplies and these are summarised in Table 6.2, an example of each type of change being given. Many of Warner's benefits could be classed as socio-political changes, and in fact only 12 of the 30 are directly attributable to improved water supplies. Most are changes which could occur if any community works were undertaken.

This in no way belittles the potential impact of water supply improvements, but it does emphasise the point that water supply, in common with other infra-structural developments, cannot be considered in isolation. The benefits of any change are going to depend on changes in other sectors, and this will make the identification of benefits and costs very much more difficult, and hence the final economic assessment much less reliable. It is now clear why "integrated rural development" is necessary, and why water supply is considered a necessary but not sufficient condition for development* (White et al, 1972, Burton 1973, Carruthers 1970).

* It is doubtful if there are many necessary and sufficient conditions for "development". Labour and land would seem to be two such conditions, and on the social level, some sort of will or driving force seems essential. Even capital, which is the most often quoted constraint is not sufficient as the experience of the oil-rich Middle Eastern countries has shown.

Table 6.2

Selection of Hypothetical Benefits from Improved Supplies (Warner 1969b)

Benefit	Factor to be measured	Details of Measurement or Investigation	Some possible constraints affecting benefit
1. <u>Health</u> (6) e.g. reduced incidence of diarrhoea	Records of diarrhoea treatment at village dispensary	dispensary records statements of villagers	diagnostic capabilities medicine available education
2. <u>Productivity</u> (7) e.g. improved live-stock condition	Quality of livestock	herd sizes market weights Veterinary reports	Grazing areas Disease control
3. <u>Education</u> (3) e.g. Acquisition of new skills	Level of skills	Job training for water projects Subsequent use of skills	Size of project Attitude of villagers
4. <u>Self-reliance</u> (5) e.g. greater local involvement in development projects	Participation in development projects	Types of projects Frequency of participation Size of projects	Attitude of villagers Transport available Time available to villagers
5. <u>Modernisation</u> (3) e.g. greater acceptance of technology as a means of improving life	Attitudes towards technology	Attitudes of villagers	Attitudes of villagers Past experience Education

6. <u>Ujaama Socialism</u> (3)					
e.g. greater sense of socialistic ownership of water supply	Attitudes towards ownership of water supply	attitudes of villagers	attitudes of villagers education		
7. <u>Equality</u> (2)					
e.g. reduced disparities of effort in obtaining water	Time devoted to water carrying	time per household total household water consumption manpower available	manpower transport design		
8. <u>Democracy</u> (1)					
Greater democratic participation in decision making	Participation in decision making	activities of village Development Committee Activities of Cooperatives Statements of villagers	Time available to villagers Past experiences Attitudes of villagers		

In order to assess the consequences of an improved water supply it is necessary to make some assessment of the present situation so that comparisons on a "before" and "after" basis can be made. Ideally, a number of rural communities would be selected for a "base-line" study in which all the factors affecting water supply would be measured, and then the communities would be re-visited at intervals over several years to record the changes which followed from the installation of improved water supplies. It would be necessary to use some similar communities without improved supplies as a control. Such a course of action is fraught with difficulties, since: a) it would be impossible to isolate the consequences of water supply improvements from those of other changes; b) some of the consequences might not manifest themselves until a number of years had passed; c) it would be morally wrong to leave untreated obvious health risks to people in the control communities in order to observe the effects of a non-improved supply; and d) no two communities are sufficiently similar to be compared with precision, and unless very large numbers of villages were studied to obtain statistical uniformity, the "improved" and the "control" communities would show divergent trends for purely idiosyncratic reasons, e.g. because of the different personalities in different communities. Nevertheless, useful data can result from imperfect "before" and "after" studies as Warner's (1969a, 1969b) work has shown. Table 6.2 suggests how he would set about measuring the changes which could occur. Heijnen and Conyers (1971) have produced a similar set of 14 hypothetical benefits relating to water supply improvements, and although they are aware that there could also be adverse effects, it would be better to think of all the consequences rather than restricting the thought to benefits alone.

The consequences of water supply improvements can be classified into two main groups, "social" and "economic". There are two other categories which are embraced by both these groupings, but which are so

important that it is useful to consider them separately; these are "health" and "environment". The "health" consequences may have social aspects, e.g. reduced suffering resulting from the improved health of users of the new supply, and "economic" aspects, e.g. because of their improved health water users now have greater productive capacities. Similarly, "environmental" consequences will have social and economic components. In the remaining sections of this chapter the consequences of water supply improvements will be dealt with under these four headings: "health", "social", "economic" and "environmental".

It is also clear that some of the consequences of water supply are direct, whilst others are indirect, that is secondary or tertiary effects for which inputs other than water supply are required. Thus, each of the four groups has been sub-divided into first, second and third order consequences, and these are defined as follows:

First order - consequences which result directly from improving water supplies, and are largely independent of other inputs. These are clearly dependent on the water supply being used, but beyond that no further changes are required from water users.

Second order - consequences which only emerge when a water supply improvement is accompanied by other inputs which influence the system.

Third order - consequences not associated with water supply as such, but which are likely to result from most improvements of infra-structure, of which water supply is one example.

The overall classification is shown in Table 6.3 which includes some examples of each type and order. This classification should not be expected to be absolute, because the dividing lines between types and orders is not always distinct.

Table 6.3

The consequences of water supply improvements

<u>Consequences</u>	<u>1st Order</u>	<u>2nd Order</u>	<u>3rd Order</u>
<u>Type</u>			
<u>Health</u>			
See Table 6.7			
% reduced by water improvement	reduction in	reduction in	reduction in
70% 1st order	e.g. typhoid	water washed	T.B.
40-70% 2nd order	cholera	diseases	malaria
40% 3rd order	guinea worm		
<u>Social</u>			
	more time available	reduced suffering	awareness of technology.
	more energy available	increased school	village resettlement.
	washing and bathing	enrolment	role of women changed.
	customs change	new activities	
	equality between	for women	
	water users		
<u>Economic</u>			
	more time for production	expansion of water	increased G.N.P.
	work	using activities.	Bus service
	reduced cost of water.	better livestock.	
		small scale irrigation.	
		fish farming.	
<u>Environmental</u>			
	reduction in water table.	risk of soil erosion.	waste disposal problems
		water unavailable for	other users.
<u>1st Order:</u>	consequences which result directly from changing water supplies, and are largely independent of other inputs.		
<u>2nd Order:</u>	consequences which require other inputs for them to be effective, but which are still water dependent.		
<u>3rd Order:</u>	consequences not directly associated with water supply, but result from most improvements of infrastructure.		

There is a temptation to think that the identification of three types of consequence also introduces a ranking in terms of immediate measurable effects and long-term non-measurable effects, in the way that "costs" and "benefits" in economic evaluations are divided into primary, secondary and intangible categories (Chapter 7). There are some analogies in this classification, but inspection of the Table 6.3 shows that first order consequences are relatively few, and although they are "unavoidable", it is the second and third consequences which are often more significant.

As an example, consider health consequences. The prevalence of diseases such as typhoid and cholera is greatly reduced by improving water supplies alone, and is therefore a first order consequence. However, a much more serious part of the total health problem in semi-arid African countries is presented by water-washed diseases (mainly skin and digestive disorders), which are associated with low water use, and/or ignorance of hygiene. In many places both shortcomings occur (Section 6.3). By making water supplies more plentiful and accessible, greater water consumption would be encouraged, but a complete solution to this particular health problem also requires a complementary input of health education. In this respect, reduction in water washed diseases is a second order consequence, but because these diseases constitute a greater health problem, the overall impact of the second order consequences is more significant than that of the first order consequences.

The effects of water supply improvements on diseases such as tuberculosis, which is perhaps the most serious health problem in Swaziland (Annual Medical Report, Swaziland 1971), are third order. The incidence of tuberculosis is associated with poor and restricted housing conditions. Improved water supplies constitute one of the

many factors contributing to better living conditions, and although the part played by water supply may be small and difficult to measure, the health problem is of such a magnitude that, again, the impact is significant.

These points are further discussed in the section below.

6.3 Health Consequences

Health benefits, usually non-quantified, are the main justification for water supply improvements. The general influences of water supply on health are well-known, and public health text books (e.g. Fair, Geyer and Okun 1973) often quote figures for the reduction in deaths from water-borne diseases such as typhoid, which are said to accompany water supply improvements. However, for scattered rural populations in developing countries, where small communities are accustomed to drinking poor quality water, and where outbreaks of typhoid are confined to small areas and numbers, few firm conclusions on the specific relationships between health, water quality and water customs can be made. Bradley (1971) has said:

" Many diseases can certainly be reduced by improving domestic water supplies, but no qualitative data on the degree of improvement needed are available. "

There are several careful and authoritative studies on record which have shown "no benefit at all from improvement in village supplies. " Thus we should be warned not to expect too much. Bradley went on to remark: "Probably more than just water is needed - a change in habits ? health education ? - it is not yet clear."

The most comprehensive assessment of health benefits and water supply in African developing countries is that by White, Bradley and White (1972). In this book, the authors have reviewed studies of water

related diseases in many parts of the world and have attempted to relate them to East African conditions where few studies have been undertaken, and where data on incidences of diseases are also scarce. Water related ailments have been divided into two groups by White et al (1972).

- a) infective disease such as cholera and typhoid which are definitely connected with water quality,
- b) non-infective diseases such as cancer and artherosclerotic heart diseases, which are now known to vary with water quality (e.g. hardness of water is associated with the incidence of heart disease) but as yet, the relation is poorly understood.

This second group are not of immediate concern for developing rural areas. Infective water diseases are classified as shown in Table 6.4 .

Group I Water-borne Diseases

The public health engineer is most concerned with this category since incidences of such diseases have been shown to be affected by water quality using "classical" epidemiological techniques. Cholera and typhoid are two common examples and these are contained in group I(a); the main consideration being that water should be free of the pathogenic organisms causing these diseases. Other diseases in this category, such as paratyphoid, amoebic dysentery, infectious hepatitis and gastro-enteritis have been shown to be water borne on occasions, but either the relationships are not clear, (e.g. infectious hepatitis) or the infective dose is so much greater (e.g. paratyphoid), that White et al have classified these diseases as "non-classical" water-borne, belonging to group I(b). Virus infections are often said to be associated with drinking water, but only in the case of infectious hepatitis is the evidence conclusive (Mosley, 1967). It seems probable that non-classical

Table 6.4

A Classification of Infective Diseases related to Water
(adapted from White, Bradley and White)

Category	Example	Condition most affecting transmission or infection
1. Waterborne, a) classical b) non-classical	typhoid infectious hepatitis)) Water quality
2. Water-washed a) superficial b) intestinal	trachoma, scabies <u>shigella</u> dysentery)) Water quantity
3. Water-based a) water-multiplied percutaneous b) ingested	schistosomiasis guinea worm))) Water access
4. Water-related insect vectors		
a) water-biting	Gambian sleeping sickness) Water
b) water breeding	Onchocerciasis) environment

diseases are also frequently spread by means other than the water route.

Group II Water-Washed Diseases

The diseases of this category are those associated with personal hygiene and therefore depend on the quantity and availability of water rather than its quality. Skin or superficial infections are classified as II(a) and the intestinal diseases as II(b). The qualitative evidence for the reduction of the latter category as water is made available is good, but the degree of reduction is uncertain. The evidence for this view rests mainly on studies of Shigella dysentery in migration camps of California (White et al 1972). The diarrhoeal diseases, including gastro-enteritis, are a major cause of death amongst young children in many parts of Africa and much of this problem could be related to water availability. The skin infections are rarely fatal, but they are extremely common and account for one third of admissions for water related diseases to hospitals in East Africa, and two thirds of out-patients (White et al 1972). Related to these are the inflammatory eye diseases, of which trachoma is the most common, and a major source of blindness in East Africa. Indeed, blindness is far more widespread in Africa than in Europe, largely because of this disease.

Group III. Water-based Infections

Schistosomiasis (bilharzia), an example of III(b), affects between 100 and 200 million people in tropical and sub-tropical countries (Barrett 1972). The life-cycle of the parasitic blood fluke is a complicated one which requires a six-week intermediary period in a water snail host. The adult schistosome may live within the human host for several years, and its eggs are discharged in the urine.

The original infection depends on contact with water containing the infected snail hosts (the parasites enter the body through the skin), but the overall transmission of the disease to other people requires

the life-cycle of the parasite to be maintained by pollution of water sources with human waste. In this respect, control of the disease would appear to be best effected by the improvement of sanitation so that human urine cannot reach any water source, thus interrupting the cycle. And since the original infection can occur through any type of water contact, such as bathing, washing, irrigation farming, the effect of improving water supplies will not be dramatic unless it can be made certain that only improved supplies will be used for all activities. This is most unlikely to be the case. Schistosomiasis also affects horses and cattle (VITA 1970), and thus the possibilities of infecting water sources by this route would remain even if human pollution were prevented. If water supply improvements consisted of building new dams, then the possibilities of transmission of the disease are further enhanced. Indeed, an increase in schistosomiasis is one of the adverse consequences of many irrigation developments (Barrett 1972).

Group IV Water Related Insect Vectors

The significant feature in the transmission of these diseases is the physical environment of the water source (White G.B. 1969). The flight range of the mosquito is sufficiently long to make it unlikely that the provision of improved water supplies will greatly affect the health of water users, though as with schistosomiasis, adverse health effects could result, if improved supplies took the form of reservoirs or roof tanks, allowing mosquitoes to breed nearer the homes of water users.

Implications for Semi-Arid Areas and Swaziland

On the basis of these considerations, White, Bradley and White have estimated the potential reduction in water-related diseases by introducing "excellent" water supplies (presumably of WHO standards) to people in East Africa, and related these reductions to the records of

deaths, inpatients and outpatients to be found in hospital records. A similar exercise has been carried out with the data on diagnoses given in the 1971 Annual Medical Report for Swaziland, and the results are presented in Table 6.5.

White et al stress that their estimates of percentage reduction are still rather arbitrary, and that analyses of this type on hospital records will not be very reliable, but given the general lack of data on this subject, the figures provide some guide as to what could be expected by introducing excellent supplies. The Swaziland figures are likely to be more reliable in this respect; because of the good communications within the country, it is estimated that 60 per cent of the population attend hospital outpatients departments and rural clinics (Swaziland Annual Medical and Sanitary Report 1971). In Swaziland, approximately 10.3 per cent of outpatient diagnoses were dental caries, compared to the East African figure of 1.5 per cent. This may indicate that dental disorders are more common in Swaziland, but a more likely explanation is that dental services there in general are more active. Apart from this large difference, which seems to have distorted the Swaziland figures (Table 6.6), the patterns of disease in Swaziland and East Africa are similar, and thus it is reasonable to apply the analyses and some of the conclusions of White et al to Swaziland. The effects of gastro-enteritis, accounting for almost 12 per cent of the hospital recorded deaths in 1971, and the widespread prevalence of water-washed diseases (group II) are clear. As in East Africa, disregarding "dental caries", the proportion of water related infections preventable by providing excellent water supplies is around 50 per cent. This is assuming that excellent water supplies affect "deaths", "outpatients" and "inpatients" diagnoses in the same proportion.

So far this discussion has dealt with the present incidence of

Table A

Type	Page reduction if supply excellent	Diagnosis	Diagnoses as a page of			
			Deaths		Inpatients	
			No.	%	No.	%
Ia	80	Typhoid	3	0.382	87	0.478
Ib	40					
Ia (IIb)	50	Bacillary dysentery	3	0.382	90	0.494
Ia (IIb)	50	Amoebic dysentery	7	0.891	132	0.726
IIIIa	80	Urinary schistosomiasis	-	-	45	0.247
IIIIa	40	Intestinal schistosomiasis	-	-	4	0.022
IIa	40	Ascariasis	-	-	30	0.165
IIa	40	Tick-bite fever	-	-	3	0.016
IIa	50	Dermatophytosis (tinea)	-	-	7	0.038
IIa	80	Scabies	-	-	25	0.137
IIa	70	Inflammatory eye diseases	-	-	107	0.588
IIa	40	Otitis externa	-	-	14	0.077
(IIa)	10	Dental caries	-	-	31	0.170
Ia, IIb	50	Gastroenteritis, 4wk - 2yr	51	6.489	1229	6.757
Ia, IIb	50	Gastroenteritis, over 2yr	42	5.344	746	4.101
IIa	50	Skin & subcutaneous infection	-	-	522	2.870
TOTALS			107	13.615	3072	16.886

Table B

"Water-related infections" identified in the Annual Medical Report (1971) but not specifically included in the original table of White et al. (1972)
(Columns as above)

IIa	50	Leprosy	-	-	8	0.044
Ib	10	Infectious hepatitis	10	1.272	91	0.500
IVa	10	Malaria	1	0.127	20	0.110
IIa	20*	Tapeworm	-	-	10	0.055
	50*	Other helminthic and hydatid diseases	-	-	9	0.049
	50*	Other infective and parasitic diseases	-	-	7	0.038
	50*	Other eye diseases	-	-	101	0.555
IIa	50*	Other diseases of the skin	2	0.254	117	0.643
TOTALS			13	1.653	363	1.994

TOTALS - Tables A and B	127	15.286	3435	18.189
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TOTAL DIAGNOSES Swaziland 1971	786	18189
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IIa	40	Louseborne typhus	Water related infections mentioned by White <u>et al.</u> , but not identified separately in Annual Medical Report, Swaziland 1971. Most will be included in tables A and B above.
Ia	80	Leptospirosis	
IIa	70	Yaws	
IIa?	60	Trachoma	
IVb	80	Gambian sleeping sickness	
IVa	10	Yellow fever	
Ia, IIb	50	Diarrhoea of the new born	

* proportions estimated by the author

Table 6.5 contd.

Total Diagnoses		Deaths	Inpatients	Outpatients
No.	%	%	%	%
347	0.398	0.23	0.29	0.24
275	0.316	0.19	0.25	0.16
88	0.101	0.45	0.36	0.05
870	0.998	0.10	0.20	0.80
49	0.056	-	0.01	0.02
1408	1.616	-	0.07	0.65
17	0.020	-	0.01	0.01
141	0.162	-	0.02	0.08
200	0.230	-	0.11	0.18
1543	1.771	-	0.41	1.24
363	0.417	-	0.03	0.17
8984	10.311	-	0.02	1.03
4982	5.718	3.25	3.38	2.86
3319	3.809	2.67	2.05	1.91
2169	2.489	-	1.44	1.25
24755	28.412			
20	0.023	-	0.02	0.01
54	0.062	0.13	0.05	0.01
24	0.028	0.01	0.01	0.0
241	0.277	-	0.0	0.05
84	0.096	-	0.02	0.05
105	0.120	-	0.02	0.06
485	0.577	-	0.28	0.28
1835	2.106	0.13	0.32	1.05
2848	3.267			
27603	31.679	7.16	9.37	12.16
87133				

Proportions of Total Diagnoses Preventable by Providing Excellent Water Supplies

Table 6.5 Preventable Water Related Infections in Swaziland

Proportions of diagnosed diseases in Swaziland (Annual Medical Report 1971) due to water related infections, and proportions preventable by providing excellent water supplies - based on the classification and estimated reductions of White *et al.* (1972).

Table 6.6

Comparison between Swaziland and East Africa - Water
Related Infections

- A Proportion of water related infections compared with the total number of diagnoses
- B Proportion of water related infections preventable by providing excellent water supplies

	<u>Deaths</u>		<u>Inpatients</u>		<u>Outpatients</u>	
	Swaziland %	E. Africa %	Swaziland %	E. Africa %	Swaziland %	E. Africa %
A	15.3	11.2	18.9	11.8	21.4*	21.0
B	46.8	52.4	49.6	51.8	52.1*	51.8

* If dental caries is included, these figures are 38.4 and 31.7 %

water related disease and the expected reduction by providing excellent water supplies. However, there is still very little information and even few hypotheses on the intermediate relationships between health and water supply. It is these which are important for this study for two reasons:

- i) the incidence of water-washed diseases is likely to be higher in semi-arid areas where water is scarcer,
- ii) the degree of water supply improvements which can be anticipated for semi-arid areas is severely limited, and falls far short of "excellent".

What health consequences can be expected if water supply is less than excellent? Theoretical upper limits can be placed upon aspects of reliability (i.e. 100 per cent reliable) and quality (all strictly water-borne diseases could be eradicated by ensuring that drinking water was free from pathogens), but no such upper limit can be placed on the "quantity" of water which must be used to avoid water-washed diseases. White et al suggest a daily consumption of between 20 and 60 litres per head is necessary to reap the health benefits from reducing water-washed diseases. Presumably, people in a hot, dry semi-arid climate would require consumption levels at the upper end of this range. It is now widely accepted that if people have to carry water home from a communal source more than 30 metres away, then the per capita daily consumption is rarely more than 15 litres (White et al., 1972). (The average Mpolonjeni figure was around 7 litres). This figure of 15 litres is regarded as an insufficient quantity to obtain significant health benefits, and is the main reason why individual connections are recommended for the Kenya water supply programme (Kenya/WHO 1972). However, most of the studies of water consumption (e.g. White et al 1972, Warner, 1969a, 1969b) make little allowance for water used at the source in washing

and bathing. Crawford (1969), investigating water use at communal points, found that the water carried home accounted for only half the total amount drawn from the source. The Mpolonjeni study has shown that women do most of their washing at the source, and the majority of the younger people bathed at the same source. Under these circumstances, it is not practical to work out a daily per capita consumption for people living in rural areas, but it would seem that the "take home" consumption is not a true reflection of water use. Perhaps a figure two or three times this amount is a better estimate, which would then usually fall within the 20 to 60 litre range of White et al.

In urban areas, people have fewer choices of source and less opportunity for washing clothes at the source, and the "take home" consumption is likely to give a better estimate of total use. Again, if communal points are used, consumption is rarely more than 15 litres per head per day (White et al 1972). This suggests a lower level of water use than in rural areas. If this is so, then the reduced water consumption ought to manifest itself in a greater incidence of water-washed diseases compared to rural areas. However, it is unlikely that data on this topic are available, and a potential greater incidence of water-washed diseases may be offset by improved health services and health education in the urban areas.

The main conclusion of White, Bradley and White is that the volume effect of water has a much wider influence than water purity, and that the diseases affected by volume (group II), though less severe, are much more common than group I diseases (Table 6.7). That the volume of water used is more important to the health of people in developing rural areas than its quality, is a proposition contrary to most public health thinking.

The eradication of water-washed infections requires a daily

	Group	Commonness	Severity	Chronicity	Volume Effect	Purity Effect	Infection Route	% Reduced by Water Improvement	Health Consequences Order
Cholera	Ia	(++)	+++			↓ ↓ ↓	D	90	1
Typhoid	Ia	+	+++			↓ ↓ ↓	D	80	1
Leptospirosis	Ia	±	++			↓ ↓ ↓	DB	80	1
Bacillary dysentery	Ia(IIb)	++	++		↓ ↓	↓ ↓ ↓	D	50	2
Amebic dysentery	Ia(IIb)	+	++	++	↓ ↓	↓ ↓ ↓	D	50	2
Tularaemia	Ia		++			↓ ↓ ↓	D	40?	2
Paratyphoid	Ib	±	++		↓	↓ ↓ ↓	D	40	2
Infectious hepatitis	Ib	++	++	+		↓ ↓ ↓	D	10?	3
Enteroviruses (some)	Ib	++	++			↓ ↓ ↓	D	10?	3
"Gastroenteritis"	Ib, IIb	+++	+++		↓ ↓ ↓	↓ ↓ ↓	D	50	2
Skin sepsis	IIa	+++	+	+	↓ ↓ ↓	↓ ↓ ↓		50	2
Skin ulcer (chronic)	IIa	+++	+	++	↓ ↓ ↓	↓ ↓ ↓		40	2
Trachoma	IIa	+++	++	++	↓ ↓ ↓	↓ ↓ ↓		60	2
Eye inflammation	IIa	+++	+	+	↓ ↓ ↓	↓ ↓ ↓		70	1
Scabies	IIa	++	+	+	↓ ↓ ↓	↓ ↓ ↓		80	1
Yaws	IIa	+	++	+	↓ ↓ ↓	↓ ↓ ↓		70	1
Leprosy	IIa	++	++	++	↓ ↓ ↓	↓ ↓ ↓		50	2
Tinea	IIa	+	+		↓ ↓ ↓	↓ ↓ ↓		50	2
Otitis externa	IIa	±	+		↓ ↓ ↓	↓ ↓ ↓		40	2
Louseborne typhus	IIa	±	++		↓ ↓ ↓	↓ ↓ ↓		40	2
Louseborne relapsing fever	IIa	±	++		↓ ↓ ↓	↓ ↓ ↓		40	2
Ascariasis	IIa	++	++	+	↓ ↓ ↓	↓ ↓ ↓		40	2
Urinary schistosomiasis	IIIa	++	++	++		↓ ↓ ↓	B	80	1
Rectal schistosomiasis	IIIa	++	++	++		↓ ↓ ↓	B	40	2
Guinea worm	IIIb	(++)	++	++		↓ ↓ ↓	D	100	1
Yellow fever	IVa	±	++					10?	3
Onchocerciasis	IVa	++	++	++				20?	3
Malaria	IVa	+++	++	+				10?	3
Gambian sleeping sickness	IVb	+	+++	++				80	1

NOTE: Indications of commonness refer to East Africa, except for cholera and guinea worm. Both of these important infections happen to be rare in East Africa, and a global frequency is given in parentheses.

Table 6.7 Relation Between Water Supplies and Infectious Diseases (White, Bradley & White 1972)

A column indicating the order of the health consequences has been added on the following basis:

70% - 1st order, 40-69% - 2nd order, 40% - 3rd order.

per capita consumption of between 20 and 60 litres, and a complementary input in the form of health education. Because at least one other input is required, the reduction in water-washed infections is a second order consequence of water supply improvements. It has perhaps been too readily assumed that, because these quantities of water were available within a kilometre of the home, people would use sufficient quantities of water, and thus, that water-washed diseases are exclusively a result of poor hygiene: since this is a matter of personal responsibility, it is one which can best be influenced by health education. It now seems clear that where people have to fetch water from some distance, insufficient quantities of water are used with great care, but for a less exacting existence, and for a more certain way of reducing water-washed infections, a better answer is to make greater quantities of water more readily accessible and encourage greater use by this means. White et al have estimated that by encouraging greater use of water, without considering how it is used, water-washed diseases can, on average, be reduced by 50 per cent.

The public health engineer is not usually concerned with the volume of water used as it affects health; instead, he is more interested in water purity, because for communal sources, this is a factor which is beyond the control of any individual or family. Because those diseases which are affected by water purity alone are not readily associated with personal responsibility, reduction in those diseases may be considered first order consequences.

It is assumed that people regularly using polluted sources establish some sort of immunity to water-borne infections. If this is the case, are there any health consequences, affected by purity alone, which will follow an improvement in water quality? Even if water quality is improved there will be occasions when the new supply is out of service,

and people will be compelled to use perhaps polluted sources again, but there seems to be little evidence that intermittent use of such sources would be a greater health risk than continuous use (White et al 1972). The point here is how long does the "acquired immunity" last?

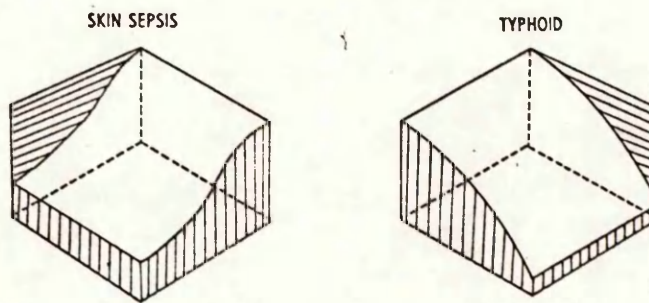
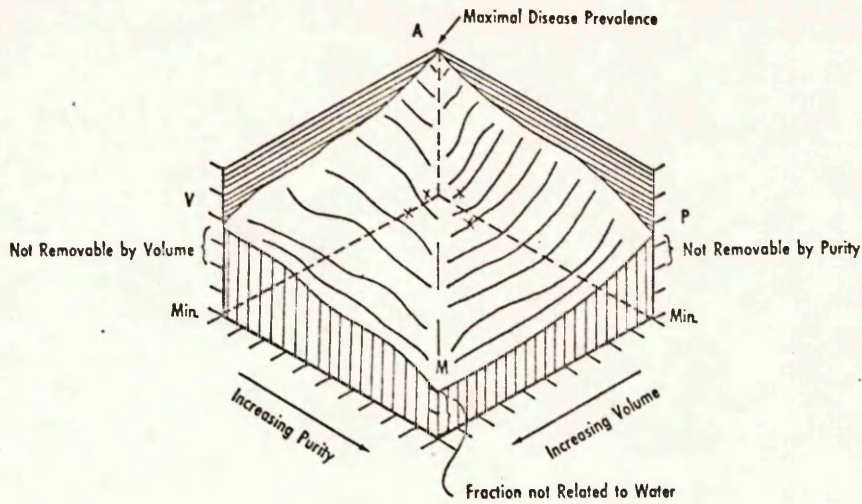
Although it can be postulated that improving water quality would have little effect on the health of rural communities, this "immunity" has been acquired at the expense of an extremely high infant mortality rate. In Swaziland, the infant mortality rate in 1960 was estimated at 147 per 1000 live births - more than seven times the figure for England and Wales for the same period (Jones 1963). A large proportion of these deaths (around 20 per cent), is caused by infantile gastro-enteritis (Table 6.5, and Jones 1963), and if half of these could be prevented, then the consequences for children's health could be very significant. Carruthers (1970) recording a case study from Kenya where chlorinated supplies had been introduced, reports a significant improvement (50 per cent) in the health of the children in the case study community compared to the "control" community. The health of adults in both communities however, was little changed. The long term implications of this effect are a further increase in population, and a need for family planning services. The urgency of the need for family planning campaigns to accompany improvements in child health arises from the fact that Swaziland, the country of the case study, had already one of the fastest population growth rates in the world - about 3 per cent per year.

In view of the complicated nature of the health-water supply relationship, it is obviously difficult to predict the health consequences of improving water supplies. Since "theoretical" values cannot be given to aspects of quality, quantity and reliability which can be associated with health levels, many more case studies are required if health consequences are to be predicted accurately. However, the general case

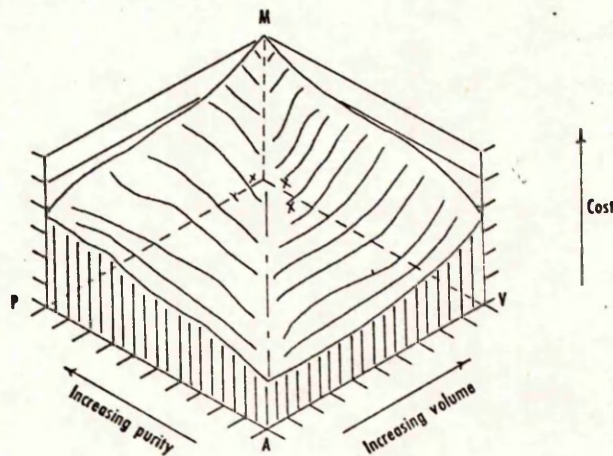
can be illustrated in a way (Figure 6.3) which helps to clarify the overall picture.

In Swaziland, according to the Second National Development Plan (Swaziland Government 1973), the most serious health problems of the country are related to water supply and sanitation. Among the most prevalent diseases is schistosomiasis which is said to affect 90 per cent of people in the Lowveld and Middleveld; typhoid is endemic; tapeworm is widespread, and gastro-enteritis is a serious problem among young children. Malaria is now no longer a major hazard, but it remains a latent threat especially after very wet summers. These statements are in general agreement with the hospital records (Table 6.5), though schistosomiasis is clearly a much greater problem than the records suggest. This is probably due to the characteristics of the disease, which induces lethargy in the infected person and lowers his resistance to other infections. Since most sufferers are infected at an early age, and live with the disease for most of their lives, the effects will not be apparent to them, and it will often be difficult to convince these people that they are ill. However, because of the infection and means of transmission, improvement of water supplies alone will not greatly affect the incidence of the disease. Even sanitary measures by themselves have been shown to have little effect (Swaziland Medical Report 1971). Most control programmes now attempt to destroy the snail population and couple this with social measures to reduce human contact with infected water, but only limited success has been achieved (Barrett 1972).

Improving the availability of water to people in Swaziland would have an immediate effect on the water-washed diseases, and this should be the first priority as far as health is concerned. The effects of improving quality would be longer term and less obvious. The "classical" water-borne diseases (group I(a)) are mainly a problem when larger concentrations of populations are restricted to one or two



(a) Relation of disease prevalence to water: the general case; skin sepsis; and typhoid.



(b) Relation of cost to water water purity and volume.

Figure 6.3 RELATIONSHIPS BETWEEN HEALTH AND WATER SUPPLY
(White, Bradley & White 1972)

Improvements in water quality and volume in individual systems will not follow a smooth curve as shown above, but are likely to be made in definite stages, e.g. slow sand filter and at a later stage chlorination. But since the effects of improving water quality are not immediate, but may require several years to manifest themselves, it is probable that the effects of these step changes will be "smoothed out".

sources.* These conditions seldom apply in Swaziland and thus water quality should receive less emphasis. However, even in rural areas there are occasions when large numbers of people congregate. At Mpolonjeni, the school now (1973) has 245 pupils and the Nkundla will accommodate meetings for several hundred, so that a case could be made for taking special care with the bacteriological quality of water supplies to these places. A far more effective precaution, however, would be to control sanitation (Section 6.6).

6.4 Social Consequences

The social consequences of improving water supply are the most difficult to assess, since they depend so much on the subjective views of the assessor. This being the case, final judgment on these points should be left entirely to the water users, and this of course is an important part of the "user-choice" philosophy (Chapter 1).

Fetching and using domestic water is primarily the activity of women. Warner (1970) estimated that 85 per cent of the total time spent in carrying water in rural Tanzania was that of women and/or children. The same is true in Swaziland, though it was observed at Mpolonjeni that men play a bigger part, using ox-drawn sledges or carts to carry 200 litre drums of water. Oxen belong to the man's sphere of activity in the community, and hence they undertake this work, but men never normally carry the buckets by which most families are supplied, and indeed, they usually never learn to balance buckets on their heads as the women do.

* Fair and Geyer (1956) give figures for typhoid outbreaks in the U.S.A. for different size communities. The greatest morbidity in outbreaks is associated with communities of 500-1000 people to 2,500-5,000 people. The reason for the reduction in the larger communities is greater vigilance and better treatment methods. For rural communities, reduced contact of water users is suggested as the reason.

For these reasons it is the life of women which is likely to be most immediately affected by changes. The only first order consequences are the greater convenience of nearer and more plentiful supplies. Washing and bathing habits may be changed, and in some circumstances these could be considered adverse effects.

Second order consequences are more numerous, and would include reduced suffering as a result of improved health, and increased school enrolment because children are released from fetching water. Many of the social consequences, such as those postulated by Warner (Table 6.2) are socio-political and are really an indication of the level of activity in the overall field of rural development. These consequences therefore, are third order.

As with health, the first order consequences appear relatively insignificant compared to the potential benefits of second and third order consequences. It is mostly these benefits which are the long-term objectives of rural development and which contribute to improved well-being, and there are probably few other physical developments which can have greater impact.

The overall problem in community development is "education" in its widest sense - that is, helping people to become aware of their abilities and showing them how to realise their potential. The enlarged sphere of activity open to a woman who has been freed from the labour of carrying water can be seen in this light. But the actual construction of a community water supply, involving voluntary labour, and preceded by village meetings for planning the work, is also an educative process.

The social benefits of projects run on these lines are sometimes seen as a major justification for a programme of improvements (Tanzania Second Five-Year Plan, 1969), but they are still essentially side effects; the primary purpose of the projects is essentially to relieve hardship and promote health and well-being.

Clearly social consequences do not lend themselves to easy measurement. Warner (1969, 1970) attempted to measure changing attitudes in several Tanzanian villages, some of which had water supply systems constructed during the study period. Villagers were asked a series of questions, and a 10 per cent change of opinion in the samples of "before and after" opinion was considered significant. The results, although not conclusive, suggest that water supply does have some influence on the attitudes of villagers, but perhaps longer time periods are necessary. Others (e.g. Carruthers 1970, and Kreysler 1969) report case studies where water supply has played a prominent part in a whole series of village developments, including school extensions, clinics, irrigation schemes and better housing.

The two questions to be asked about the social consequences of a water supply improvement are therefore as follows:

- i) How will the role of women be changed ?
- ii) What impact will improved supplies have on community development ?

Few special studies have been made with a view to answering such questions, but some tentative views were formed when the general situation in Mpolonjeni, Swaziland was examined. Most women there still spend over an hour a day fetching water, and water supply improvements could lead to considerable savings in time. This could be of benefit in the women's other duties - domestic work or agriculture - or it could be devoted to leisure or to new activities, such as handicrafts, or a women's association.

With the distant prospect of a family planning service and smaller families, a greatly changed social role for women can be foreseen. Some people envisage that women will play a key role in rural development (Warner 1969, Mitchnik 1972). In Swaziland, women already carry a

heavy responsibility for agriculture as well as domestic work, and it has been said that "To educate a male is to educate an individual. To educate a female is to educate the nation." (Gamedze, 1971).

However welcome these changes may be in general, some men in the community undoubtedly dislike the prospect, and somewhat resent water supply improvements which liberate their women-folk. They have been known to ask what the women will do with their time when relieved of water carrying duties (Dlamini, 1972). One policy meeting in a village to discuss water attracted a preponderance of women, and it was commented that, "the women are more active in pressing for water supply improvements, but the men in general are not very interested." (Mkhabela, 1973).

On a more mundane and immediate level, changes in washing and bathing habits are to be expected. As already noted (Chapter 4), these activities have a social function in Swaziland, and it is perhaps significant that no washing was observed at the five new communal water points at Ngcina (near Mpolonjeni). There are plans for shower baths in this scheme, and the women have also requested that facilities for washing clothes be provided. One wonders whether there was sufficient prior consultation about this point. Further evidence of a positive attitude is that at least four families had expressed interest in having individual connections installed at their own cost. Thus, the new water supply has already assisted in the erosion of the present social habits. Changes like this might appear inevitable as the community develops, but the people ought to be aware of the long-term effects.

The comparison between Ngcina and Mpolonjeni in terms of overall community development is also interesting. The main difference is that Mpolonjeni seems to have suffered because it has been without an effective chief in recent years. Mpolonjeni was chosen as the centre of the R.D.A. and the site for the Nkundla. A water supply scheme is under construction and a building for women's activities has been finished. The

Nkundla and water supply are still incomplete, and the women's association has not yet been established. At Ngcina, Chief Makhosini Dlamini has managed a most impressive list of developments over the past three years. Apart from the water supply scheme, other projects carried out on a self-help basis with government assistance with materials include school class-rooms, a storage shed for the farmers' co-operative, a women's building, quarters for the veterinary assistants and a clinic. Longer term plans include a secondary school, a large general store and offices. The Chief offered beer incentives for those who contributed labour, and imposed a fine of one bag of mealies* each on those who would not help. Even people from outside the Chief's area, but who would benefit from the projects, were induced to contribute. Work on the water project continued at weekends when the supervising Ministry of Agriculture officer was away.

Clearly the influence of the Chief, which is the only significant difference between the two neighbouring communities, has provided the impetus for the projects at Ngcina, and these have now snowballed into sustained activity towards development. The Chief has apparently been less interested in promoting purely agricultural developments (Chapter 7), and it may be that his main purpose is to increase his authority in the area, and extend his influence at the Swazi National Council, but whatever his motives, active leadership is necessary in community development. It is not possible to isolate the influence of the water supply scheme, but since the other projects have been concerned with buildings (and disregarding at the moment, the problems of staffing and whether they are being properly used), it is expected that the water supply development has had a different sort

* One sack of maize cobs is worth about £1.80.

of influence. Some community members are now experienced in pipe-laying and jointing; one member has been appointed to look after the pump installation; and most community members have had first-hand experience of what is involved in such a project - in the supervision, the construction, and the underlying engineering principles.

One of the prime intentions of the Rural Development Area schemes in Swaziland is that the scattered population should coalesce into well-defined villages enabling health and education services, and incidentally water supplies, to reach a greater number of people. Providing a central water supply with a relatively limited distribution system is one method of encouraging this centralisation. The enclosure of grazing land, as part of the RDA programme at Mpolonjeni, has already had the effect of concentrating the population (Chapter 3), but the intrinsic characteristic of the Swazi way of life, namely isolated family homesteads, has still been largely retained. No well-defined village area exists.

It is difficult to predict the social effects of the piped water schemes at Mpolonjeni and Ngcina, but the experiences at another Rural Development Area, Ebulanzeni in the Highveld (Swaziland, Ministry of Agriculture 1969) where a piped system was installed and a village site planned, suggest so far that spontaneous centralisation is unlikely to occur.

A similar approach to small-scale centralisation has been adopted in Tanzania with the Ujaama villages, but behind this concept, there is a political philosophy which has apparently been taken up from within the people of these communities.

This is a far stronger driving force for collectivisation than that offered as the potential benefits from an improved water supply. The evidence from the Rural Development Areas in Swaziland

is that they are an outsider's concept, and not one likely to be accepted by the rural Swazi people without an equally effective political philosophy to accompany it.

6.5 Economic Consequences

The direct economic consequences depend largely on the original purpose of the improved supply. If it can be shown that water is the only constraint affecting developments of water-using activities such as small-scale irrigation, rural industries, or livestock production, then the consequences of improvements will be first order. Under these circumstances where a definite demand can be identified, the evaluation of any improvement is relatively simple, since a monetary value can be assigned to the goods produced, and hence the contribution of the water.

However this thesis is mainly concerned with those rural communities, where there is a clear "need" for improved domestic supplies but the demand, as such, is ill-defined. In these communities, it is hoped that water supply improvements will stimulate developments in irrigation and other rural industries, but any developments in these fields will be mainly desirable side-effects which require other inputs to complete fruition. In the classification of consequences (Table 6.3) these economic consequences will be second order.

On this basis, as with social consequences, the first order effects are very few. The most obvious economic consequence is that the cost of water may be changed. Depending on the policy adopted, people in rural areas may, for the first time, be expected to pay for water, or at least contribute towards the maintenance and operation of the installation (Chapter 7). The other first order consequence is that time and energy spent in carrying water will be different, and assuming there are savings, these could be put to productive work. It

could be that the time spent fetching water actually increases after supplies are improved. For example, if a nearer source is provided, a woman may make more journeys, thereby enabling her family to use greater quantities of water and reap the health benefits of increased water use, but at the same time she sacrifices more of her valuable time. If the new source is a tap, she may also have to spend time queuing. Generally though water supply improvements would be expected to save carrying time.

These first order economic consequences would appear to conflict with social consequences, for if all the time and energy saved were put to purely productive work, the social consequences could be very much reduced. It is most unlikely that all the time and energy savings would be put to productive work as White et al (1972) have assumed in their evaluation of water supply improvements. A more realistic proposition would be to assume that a woman would allocate the time savings to productive work, household duties and leisure in the same proportions as previously, i.e. before her supplies were improved. One difficulty here is to assess "productive work" in a semi-subsistence society. Another is to decide the economic effects of spending more time on cooking, cleaning and washing.

Parker (1973) studying water use in south east Ghana asked women how they would apportion time savings if a new water supply saved them 12 hours per week. Warner (1969a) carried out a similar exercise for nine Tanzanian villages. The responses were :

	Ghana	Tanzania
Productive work (generally agriculture)	57%	43%
Household duties	35%	45%
Other activities including leisure	8%	7%

It seems reasonable to assume that about half the time savings would be put to productive work. But since labour is often the greatest

restraint on agricultural production during key periods, there will be occasions in the year when perhaps all the time savings will be put into farming, and the subsequent economic effects could be substantial.

Parker (1973) has made a series of benefit/cost studies for a variety of water supply schemes (mainly catchment systems) for a Ghanaian village. All show a positive ratio (the range was 1.01 to 6.08) with his figure of 37% of time savings used productively. Not surprisingly, the schemes with the most favourable ratios were those which provide storage for a very limited supply of water, i.e. rapid depletion systems, which make possible considerable savings in time during the peak agricultural periods, but do not attempt to provide a constant supply throughout the year, especially during slack agricultural periods. Parker's analyses, as he pointed out, neglect the benefits of a constant supply of clean water. Indeed, they are really exercises in evaluating the time of people in semi-subsistence economics, and the fact that water is involved is largely incidental; it could equally have been some other household commodity such as firewood. This may seem a rather narrow approach, but the exercises do demonstrate that water supply improvements considered from the point of view of time savings alone, should have beneficial economic effects.

The costs of the water supply schemes in Parker's work were in terms of the prices of materials used. If the general productivity of labour rises relative to the price of materials, the attractiveness of the schemes would increase proportionately. If, on the other hand, material costs increase faster than the value of people's time, then the projects would become less favourable. An often quoted view is that the gap between the rich and poor countries of the world is actually increasing. If this is generally true, then water supply schemes which

use imported materials would become less favourable.

The second order consequences are legion and are related to all water-using activities. Some of these are shown in Table 6.3. In most African rural communities water is rarely the main constraint on further activity. Irrigation farming is not very widely practised in traditional communities in southern Africa, and even when excess water is available for small-scale supplementary irrigation, as in some Tanzanian villages, the opportunities have not been taken (Berry & Kates 1970).

There are considerable quantities of water available from the Mpolonjeni reservoirs (Chapter 8), but the only irrigation which is being carried out on these is by an individual farmer with a small area below one of the dams of some 700 m^2 which is fed by two seepage channels from the toe of the embankment. It is likely that lack of knowledge of the equipment required and capital are the main constraint on further activity because there does seem to be a general awareness of the potential of irrigation in Swaziland. The Headmaster of the school at Mpolonjeni is prepared to pay 25c (about 15p) each week for a 200-litre drum of water for his private vegetable garden, and he has made similar arrangements for the school garden. When the Mpolonjeni piped water supply is complete (Chapter 10), vegetable production at the school is likely to increase. In other parts of Swaziland, irrigation using diversion furrows from streams is much more common than Europeans originally suspected. It is thought that the water abstracted by Swazis for traditional agriculture amounts to only 5 per cent of the total abstractions from streams and rivers (Hitchcock 1972). But considering the scale of Swazi agriculture compared to the large European irrigation plantations, this figure suggests that, given favourable circumstances, many more Swazi farmers would take up small-

scale irrigation. The author observed one small, communal irrigation system near Mbabane. A mountain stream with a flow of about 2.5 l/sec was channelled about 4 km down the valley and served several fields.

The provision of domestic supplies would not greatly affect irrigation prospects. The most that could be anticipated is that if people had a reliable supply near their homes, they would grow dry season vegetables. The author's observations in Swaziland suggest that this is not an unrealistic hope. Once vegetable gardens had been established, the way would be open for supplementary, or full irrigation, on a larger scale.

The provision of water for livestock is the other main way in which water supplies could improve agricultural production. Carruthers (1970) reports a case study from Kenya where the number of grade cattle increased by 66 per cent in 4 years (3,640 to 6,025) after a piped water supply had been installed. The control community, without an improved supply, showed only a 36 per cent increase. Milk sales and pig sales showed similar differences when the two communities were compared. Ample water at the homestead is necessary if grade cattle are to be kept in the densely populated highland areas of Kenya; firstly because this obviates the energy absorbing walk down to the reservoirs, usually through tick infested vegetation, and grade cattle are particularly vulnerable to tick borne disease. Secondly, clean water at the homestead enables good dairy practices to be maintained.

Carruthers also reports another case study where the provision of piped water had apparently no effect on the numbers of grade cattle. This again demonstrates that livestock production is a potential benefit; other complementary inputs are required to realise the benefit.

The situation in Swaziland is somewhat different. The number of cattle owned by a Swazi is often an indication of his social status,

and there is little "livestock production" as such, but more livestock "accumulation". Even milk production is very low. It has already been suggested (Chapter 3) that the existing improvement of water supplies around Mpolonjeni has led to rapid increases in stock numbers, with subsequent damage to grazing land. If water were made available at the homesteads in sufficient quantities to water large herds, it is likely that stock numbers would increase further, but there would be few economic benefits from this, because only a small fraction of the stock would be sold, and damage to the environment would be exacerbated. However if water supplies are planned in conjunction with the veterinary services so that better grade stock are introduced, the bulls are kept separate from the remainder of stock, and livestock production is encouraged, then economic benefits could result.

Other water-using cottage industries in Swaziland appear to be relatively scarce, and this is consistent with Warner's experiences in some Tanzanian villages (Warner 1969a). Swaziland has suffered from its proximity to the industrial centres of South Africa. What traditional industries existed, such as tanning, ironwork etc. have now been made superfluous by the cheaper products available from South Africa. Pottery still continues on a small scale, but in general, the retail markets are too small for this type of industry. It is thought that this factor is a much greater constraint on development than lack of water. Botswana is another story. Because of its isolation from industrial centres in southern Africa its traditional industries have survived much better, and are being strengthened, especially around Serowe, where a pottery has been recently established. The prospects for more immediate economic benefits from water using industries in Botswana would appear to be much brighter.

At Mpolonjeni, the only activities which required water near the home were beer-making, brick-making and general house repairs.

These would all benefit from improved supplies, and presumably those families who make beer for sale would be able to show some economic benefits, but of course, the overall consequence for the community might be adverse.

One other major group of second-order economic consequences are those associated with health improvements. Here, White et al (1972) have suggested that there have been several misleading statements on economic benefits brought about by improved health. They quote a report whose authors claimed that the construction of "safe water supplies" in rural areas of Venezuela would produce an 800 per cent net return on capital. But closer scrutiny of the results shows that the "loss" in production due to water-related ailments such as diarrhoea also included the 1 to 2 year age group who comprised more than half the total number of sufferers. Another defect in the analyses was that all the potential labour released by improving supplies was assumed to be used productively. Rees (1972) reports a much more pessimistic account of water-supply investment in Puerto Rico. Only after 10 years and a low discount rate of 4 per cent, did benefits exceed costs.

Parasitic infections, such as schistosomiasis, have recently been shown to have few adverse effects on agricultural labour productivity in St. Lucia (Burton 1973). The authors of this study concluded that sufferers of schistosomiasis were not able to work as efficiently as other people, but they offset this by working longer hours so that their weekly earnings were maintained at the same level as non-sufferers. Improving water supplies in this situation would not produce any economic benefits, but of course the leisure time of the schistosomiasis sufferers is adversely affected, and it is difficult to predict what the longer-term, or third order economic consequences might be for them.

White, Bradley & White (1972) extended their study of health and water supplies (Section 6.3), by trying to estimate the present cost of treatment for preventable water-related diseases. They arrived at a figure of \$0.09 (about 4p) per person per annum, but this was for those who actually received treatment. They estimated that the total cost of treatment would treble if all those who were within walking distance of hospitals and clinics and were in need of treatment also received it. Their figures are necessarily uncertain because of the unreliable data upon which they are based, but they were able to show with authority that the cost of preventing the water-related diseases by other methods (e.g. a course of injections for schistosomiasis) was invariably much more expensive than improving supplies.

The assessment of third order economic consequences is even more nebulous. Some possible effects are given in Table 6.3. The influence of water in the way of life of a rural community is so far reaching that water supply improvements must have some tangible effect on virtually every other activity, though it may not be easily measured or even identifiable. Thus even though a water supply has apparently failed and had no impact on the health or economic development of a community, it would be naïve to think there had been no lasting effects. Apart from recognising that these effects exist, it seems that nothing at this stage can be done to plan for them in anything other than very general terms by deciding what are the long term objectives of improvements and developments.

6.6 Environmental Consequences

The sort of scale envisaged in water supply developments, and the sparsely populated areas considered, preclude the environmental "eyesores" and pollution problems associated with industrialised

societies. The environmental effects in semi-arid rural areas will probably not manifest themselves for several years, but they can be equally damaging to the economic potential of these areas.

One possible environmental effect is the lowering of the ground water table due to excessive pumping from wells. There is concern about this at Serowe, Botswana (Lowry 1972), and problems have arisen in this way in southern India. The long-term effects of over-pumping also exacerbated water shortages in the Sahelian zone of West Africa during the drought of 1971-73 (Harrison Church 1973). In the Swaziland Lowveld, the level of water in the bore-hole at Ngcina is falling roughly 30 cm every three years (Tsabedze 1973), and other small confined aquifers have often been over-pumped and abandoned (Swaziland, Geological Survey Annual Report 1969).

Water shortages caused by over-exploitation of groundwater, or encountered downstream of an impounding reservoir, are first order consequences of water supply projects. Among second order consequences, one of the most important in semi-arid areas arises from the fact that stock-watering facilities are often associated with the provision of new water sources, and this has a considerable influence on the number of stock kept, and on their movements. The planning of domestic and stock water together is an explicit policy in the "low potential" areas of Kenya, i.e. generally semi-arid area (Kenya/WHO 1972), and is a practice which is taken for granted in many other semi-arid areas of Africa.

The effects of this practice were observed by the author in the Serowe/Palapye area of Botswana, and in the Mpolonjeni area of Swaziland, and they have been studied in greater scientific detail in the Kisongo catchment, Tanzania (Murray-Rust 1971). Fosbrooke (1973) has described the effects in Botswana. In all areas, small dams provide

water for cattle and the livestock, though in Botswana, many animals are also watered at hand-dug wells. In every case, there are well trodden routes along which the beasts walk each day as they come for water, and there are large trampled areas around each drinking point (Plate 10). All grass in these areas is closely nibbled as well as being trampled by the cattle, and where goats are kept, plant life, apart from the taller bushes, is systematically eliminated. This leaves the soil very vulnerable to erosion, and may very greatly modify the run-off characteristics of a catchment area. This seems to have happened in the catchment area of Hlangothi Old Dam at Mpolonjeni, where exceptional run-off was observed by the author after a dry season storm in August 1973 (Chapter 3).

In the Tanzania study, Murray-Rust not only investigated over-grazing and soil erosion in a catchment area, but also recorded the sediment deposited in the reservoir fed by this catchment as a result of erosion. He noted that the construction of the reservoir had led to an increase in the number of cattle kept locally, but in the drought of 1969, many of these animals died even though there was still some water in the reservoir. Before the dam was built in 1960, the number of cattle in the district was limited,

" by the availability of dry season water, but by 1970

the controlling factor was grass supply. "

The estimated economic life of the reservoir was estimated at 15 years because of high sedimentation rates which had been increased by inadequate stock control. After 1975, when the reservoir will cease to be a reliable dry season source, the stock carrying capacity of the area will drop to a lower level than that of 1960,

" as the grazing area has been reduced during the existence of a permanent supply within the catchment. Thus within 20 years the economic potential of the area will have been

reduced through the provision of dry season water

followed by uncontrolled increases in stock population. "

Murray-Rust concludes that soil erosion studies are able to play an important part in the planning of new reservoirs, and because of the high rates of sedimentation, and considerable evaporation losses, it is important to consider alternative sources of water supply.

It seems likely that similar processes are occurring at Mpolonjeni. The author's own observations on the ground are consistent with the types of soil erosion processes described by Murray-Rust. This problem, although related to water supplies, is clearly a basic one of grazing control and land management, but if one of the "benefits" of water supply improvement is greater livestock numbers, then careful thought should be given to the siting, selection and control of water sources.

In an even broader sense, the environmental consequences of improved water supplies involve all aspects of water management and soil conservation. This requires maintaining a careful balance between all types of source, and taking into consideration the effects of soil conservation measures. These can be expected to reduce sedimentation rates in impounding reservoirs, but they can also decrease the surface run-off and thus reduce the potential for surface resources (Republic of South Africa, Development Atlas 1966).

One third order consequence which arises when water supply is discussed is the possible need for sanitation. This is a third order consequence, because waste problems are associated with high density populations and more complex living styles. It tends to be assumed in the West that an improved supply of water also entails the development of drains and sewers to carry away the waste. This situation in many developing countries differs from that in most Western countries, however, because water-borne sewage systems do not exist. This is

still largely true even in large and sophisticated cities (e.g. Tokyo), but in most rural areas, water-borne sewage is not even a distant possibility. The problem is thus limited to the disposal of water which has been used for washing and other household tasks.

Assuming that the greatest water improvements which can be expected at a place like Mpolonjeni will be similar to the individual connections recommended for the high and medium potential areas of Kenya (Kenya/WHO 1972), consumption might rise to about 70 litres/head/day. For a large family, this would certainly present a waste disposal problem, but not one requiring elaborate sanitation. Some form of drainage could be envisaged which allowed waste water to be used for kitchen gardens.

An urgent need for sanitation in rural Africa is therefore not going to arise as a consequence of water supply improvement. There is an existing problem of sanitation, however, even before water supply improvements begin. In the absence of proper lavatories (pit latrines and aqua-privies) at Mpolonjeni and many other places, human excrement is deposited at any suitable place in "the bush". Consequently, a large proportion of surface run-off can be affected and diseases spread among the population as a result. Because of the dispersed population, and large number of water sources, the risks of major outbreaks of water-borne diseases is relatively small (Section 6.3). But the incidence of water-washed parasitic infections (e.g. tapeworm) and of the water-based parasitic infections (e.g. schistosomiasis) is increased by inadequate sanitation. To counteract these dangers, it is necessary to promote sanitary education, and construct lavatories so that human excrement is sealed from human and animal contact, and direct contact with surface water is prevented.

CHAPTER 7

THE COSTS OF WATER SUPPLY AND ECONOMIC ASSESSMENTS

7.1 Introduction

In this chapter, the various aspects of the costs of water will be considered in three main parts:

1. the present costs that people pay for water in various situations,
2. the costs of water supply improvements undertaken in parts of Africa,
3. some questions about the financial and economic evaluation of water supply improvements.

7.2 The Cost of Water

The range of prices that people pay for water is very wide, and as usual, the "economics of scale" operate to the disadvantage of the poorer members of society who can only afford to pay for smaller quantities when it is actually needed. In Table 7.1, prices paid in various parts of the world and for different types of community are shown.

The purchase of water from vendors is essentially a feature of urban life. Water from traditional sources in rural areas is generally regarded as a free resource. In southern Africa, the customary law of most indigenous peoples indicates that a man acquires a "right of avail" to land through membership of a community, i.e. of a chiefdom. Included in this right of avail to land are a number of subsidiary rights, of which "right of water" for domestic use, irrigation and cattle, and "right of access" to water over other land are two. Other subsidiary rights are to "pasture", to "delve"

Table 7.1

Prices paid for water in various situations

Place	Prices U.S.\$ per m ³			Sources
	Price charged by water vendors	Non-metered supplies	Metered Domestic	
Dacca	1.11 - 2.22		0.09	World Bank (1971)
Kampala	1.55 - 3.86		0.18	" "
Typical German City	-		0.11 - 0.19	" "
Blantyre	0.26* - 0.52 ⁺		~ 0.15	Present author
Kyeni (Kenya) communal pts. individual connections		~ 0.18 ~ 0.40		Kenya/WHO (1972)
Nairobi			~ 0.14	" "
Mpolonjeni (Swaziland)	1.50**			Present author
Mochudi (Botswana)	1.50**			Present author

* resale price by municipal authorities

+ resale by water vendors (officially illegal)

** price of a 200 litre/drum brought by sledge or cart. In 1973, some people quoted prices up to 35 c for a 44-gallon drum (200 litres).

(i.e. mine or quarry), to "hunt", and to "collect" (wild vegetables, firewood etc) (Hughes 1967). This basic cultural difference between Europeans and southern African peoples over the nature of ownership of property and resources is one obvious point of friction in relations. Thus it is now easier to understand the resentment felt by many people in Swaziland over the "land concessions" made to Europeans during the 19th century (Chapter 3). A European's interpretation of his rights is quite different from the Swazi's "right of avail" described above, and this may also reveal itself when payments for water are considered.

The prices for water in rural areas quoted in Table 7.1 refer, in the case of Kenya, to piped supplies which have been installed by government departments. Where communal points are provided, the consumer first signs an agreement, and then pays a monthly rate. Enforcement of payment for water sales at communal points, unless they are continuously manned, is notoriously difficult. At Kyeni, only 11 per cent of the amount due has been collected. For individual connections, supplies are not metered, but a monthly rate is paid which is set at a rate to recover capital and operational costs. Even though redress can be made against non-payers by curtailing individual supplies, it is estimated that collection of payments is only about 50 per cent successful (Kenya/WHO 1972).

The prices paid for Mpolonjeni refer to amounts paid by people to neighbours for fetching a 44-gallon (200 litres) drum, usually by ox-drawn sledge. The cost of this water is similar to that charged by vendors in the cities but of course the quality is very much worse. This gives some indication of the price some people in Swaziland (and also Botswana) are prepared to pay for water, though this statement should be qualified in view of what has been said about customary law, by noting that 25 cents is a usual fee for the hire of an ox team and sledge, and

thus the payment is almost certainly the cost of transport rather than the cost of water. The people in Mpolonjeni who pay for water in this way are those who are generally better off than most but who do not own cattle; examples are the store-keeper, the headmaster of the school and the herbalist. Whether these people would be prepared to pay similar amounts if water was provided near their homes is a matter of conjecture, since there are no precedents in Swaziland. Certainly most of the poorer people in the community would baulk at the idea of paying even an apparently nominal amount for water, though much would depend on the attitude taken by the chief. Many communities are prepared to contribute money and labour for community development schemes, and pay for maintenance costs.

Another method of estimating the costs of water is to consider the proportion of the total income which is spent obtaining it. A middle income man in Nairobi spends 8 per cent of his income on water for himself and all his dependents. This is more than his payments for transport, fuel and household equipment. For an unskilled man the proportion is up to 10 per cent. In Dar-es-salaam the figures are much lower, 2.5 per cent and 3.4 per cent respectively (White et al 1972). Data on water sales at communal points, obtained by the author from the records of the Blantyre Town Planning Unit, Malawi, suggest intermediate values of 2.6 and 5.2 per cent.

These figures are difficult to compare with a rural community like Mpolonjeni, since few people there have a regular cash income. However, using the data presented in Chapter 3, it is possible to estimate the total income (i.e. wages, other cash income and production income) of the better off families in the Lowveld at around R480 (1964 figure). Assuming a per capita, daily consumption for a high income family of 14 litres, and the 1972 cost of 0.125 c per litre (Table 7.1),

this gives a yearly expenditure of R44 for a family of seven. Allowing for the possibility that the "hire cost" of 25 c for carrying a 44-gallon drum may have risen over the intervening years, the proportion of total income spent on water is similar to the higher percentage figures mentioned above for urban areas.

Carruthers (1973b) has suggested that an ideal water service would be one where, among other conditions, the annual cost to the user does not exceed 5 per cent of his annual cash income. The range of values for water costs in non-ideal services would appear to be about 1 per cent to 10 per cent of income. In some cases the upper limit may be 15 per cent, and in extreme drought conditions the figure would be even higher. It is of course difficult to apply monetary assessments of this type to semi-subsistence societies, but since there is doubt (Chapter 6) about the influence of water on the way of life and the contribution of water supply improvements to further community development, such figures give some indication of the overall magnitude of the effects.

One final method of estimating the "costs" of water is to measure the amounts of time and/or energy expended in fetching water. Warner (1969b) and a number of other writers at Dar-es-salaam (BRALUP 1969-73) have tried to assess the time allocated to carrying water, but have not converted them into "costs". White et al (1972) assessed the energy consumption of carrying water and converted them into food costs and arrived at an answer. This method is misleading since it involves an ergonomic measurement rather than an economic one. It is extremely unlikely that people in rural areas would eat more food in order to carry more water. These authors found that some women spent as much as 20 per cent of their daily calorie intake carrying water (Chapter 3).

At some Tanzanian villages Warner (1969a, 1969b) measured the distance to the sources, the time to make the trip and the number of adult trips for water each day. The average round trip ranged from 1.0 to 5.6 miles and took between 40 mins and $3\frac{1}{2}$ hours. With more than one trip per day some families spent as much as 7 hours a day collecting water. Warner's data has been presented in graphical form in Figure 7.1. The general trend is clear and hardly surprising. But on the same axes, the Mpolonjeni data (Appendix 1) has also been plotted. There are fewer results for Mpolonjeni, and only one family lives more than $1\frac{1}{2}$ km from its source, but the distinction between the two sets of data is clear; families in Mpolonjeni spend much less time fetching water. This may be because of a lower per capita consumption, but the greatest difference is clearly the method of transporting water. In Mpolonjeni many families can bring a week's supply at one move by using ox-drawn sledges and 200 litre oil drums.

7.3 Capital Costs of Water Supply Developments

It is difficult to present an overall view of the cost of water supply developments since many factors are involved. The costs will depend on the design criteria adopted, e.g. consumption figures, quality standards, design periods, on the initial conditions of climate and the density and settlement patterns of population; and on what methods are employed, e.g. labour-intensive or capital intensive techniques, self help or paid labour, groundwater or surface water sources, pumped or gravity flow systems. To add to these factors, there are complications of exchange rates, and inflation, so that direct comparisons between water supply developments at different times and in different regions are not possible. However, in order to obtain some indication of the range of costs which can be expected for various types of development in different places, the capital costs per capita of a

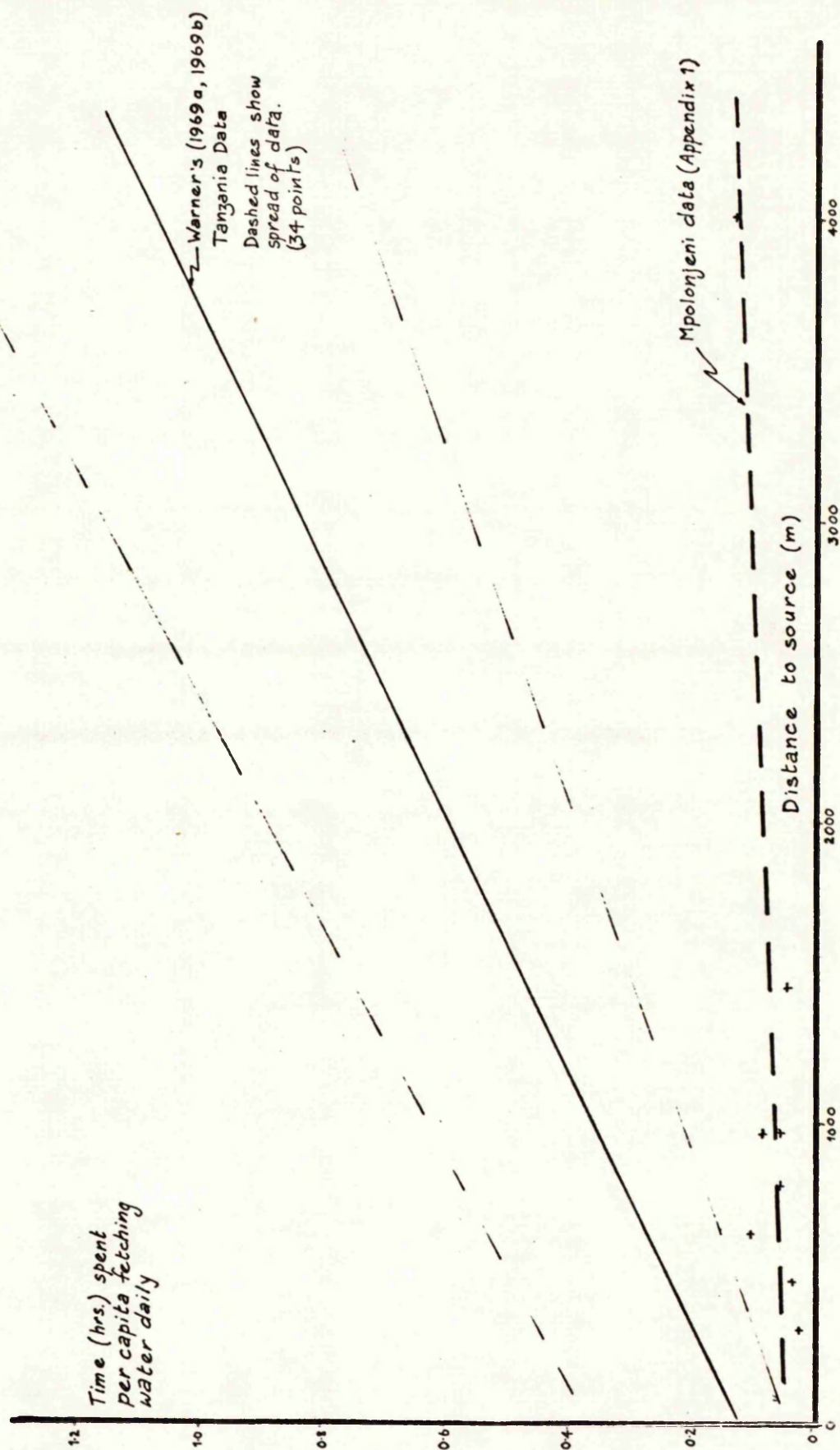


Figure 7.1 TIME SPENT CARRYING WATER, AND DISTANCE TO THE SOURCE - TANZANIA AND SWAZILAND

number of schemes in Africa have been presented with other details in tabular form (Table 7.2).

Unit capital cost per capita was chosen as the basis of comparison since this is a more useful guide to considering what actual costs might be for a particular settlement or region than say, costs per unit of water supplied. The latter basis of comparison generally only serves to show that larger scale projects show economies of scale. The data given in Table 7.2 refers to schemes of 1969-73 and also includes estimates for future schemes, but the figures given make no allowances for carrying exchange rates and inflation, nor do they include operational costs. The capacity of the schemes range from 15 to 70 litres/head/day.

The information presented in the table refers to rural areas of Africa, and some attempt has been made to define three types of rural area, based primarily on population density and distribution. Clearly, per capita unit costs will increase where sources are scarcer and less reliable, and more storage has to be provided (Chapter 2). This will be the case in semi-arid regions.

Unit costs will also increase when population is dispersed and distribution becomes more difficult. For the countries considered in this thesis, population levels tend to be a reflection of the climate, and to a lesser extent, topography. Moisture, as measured by the moisture index is often the limiting factor on the size of population that land can support, where dry land agriculture is practised. Of course, many other factors, especially in recent times, have affected rural population levels, but in general, semi-arid areas are more sparsely populated than land in the humid zones. Thus a ranking of unit costs for rural water supplies will take some account of different climatic zones.

Unfortunately, the criterion of population density used for

Table 7.2
Capital Costs per capita and Population Density for Water Supply Developments
in some African countries

Country and Location	Source	Service	Treatment	Capital cost per capita			Source of information and notes	
				£				
				Population Density				
				High 2 100/km ²	Medium 2 50 km ²	Low 2 30 km ²		
MALAWI								
Chambe	streams	S, G	none	1			(1)	
Rural areas	wells			← 1.25			(2)	
KENYA								
WHO estimates for supply programme	various	I, S	Cl, SSF	5.5	7.5		(3)	
	"	S		3.0	3.6			
	dams, etc.	X	none			3.5		
Thegegne	stream	S, G			4.8		(4)	
Nyabondo	stream	S, P		3.0			(4)	
TANZANIA								
Rural areas	various	S, X	usually none	←	7.45		(5)	
Rural areas	various	S, X	"	1.1	2.9		(6)	
	dams etc.	X	"		1.2	2.9	(6)	
Mainly rural	various	S	"		8.2		(6)	
Rural areas	"	X, S, P, G	"		7.4	11.3	(7)	
Rural areas	wells	X	none		0.65		(8)	
"	various	S	none	←	1.5		(8)	
SWAZILAND								
Zemphi	borehole	S, P	None		6 - 12		(9a)	
Mapobeni	river	I, S, P	full		15 - 30		(9b)	
Ngcina	dam	S, P	PF			4.3 - 8.6	(10)	
Mpolonjeni	"	S, P	PF			4.2 - 8.6	(10)	
Ebulanzeni	"	S, P	PF		3		(11)	
Rural areas	streams, springs	X, P, G	SSF		←	1 - 3	(12a)	
Rural areas	springs	G	protection		←	0.45 - 0.9	(12b)	

Key to symbols:

- S - stand pipes, X - no distribution, P - pumped scheme
 G - gravity scheme, Cl - chlorination, SSF - slow sand filter
 PF - primary filtration

Sources of information and Notes

- (1) Robertson (1970) - self help, materials only
- (2) De Lonza (1973) - community of 300
- (3) Kenya/WHO (1972) based on family size of 6
- (4) Carruthers (1970) range of costs £1.40 - £18.50 1965-70
- (5) Holloway (1970) based on consumption figures of 30-70 l/head/day and communities of 1000 - 6000
- (6) Warner (1973) borehole schemes highest cost, followed by pumped and gravity piped supplies
- (7) Warner (1970) self-help materials only, communities of 200 and 500 people
- (8) CTDF (1972) (a) family size of 5-10. (b) settlement of 15 families
- (9) FAO/UNDP (1970) self-help
- (10) Oxfam (1973) self-help, excludes piping
- (11) Swaziland, Ministry of Agriculture (1969) self-help, excludes piping (a) self-help
- (12) Swaziland Ministry of Local Government & Administration (1972) (b) self-help total of 116

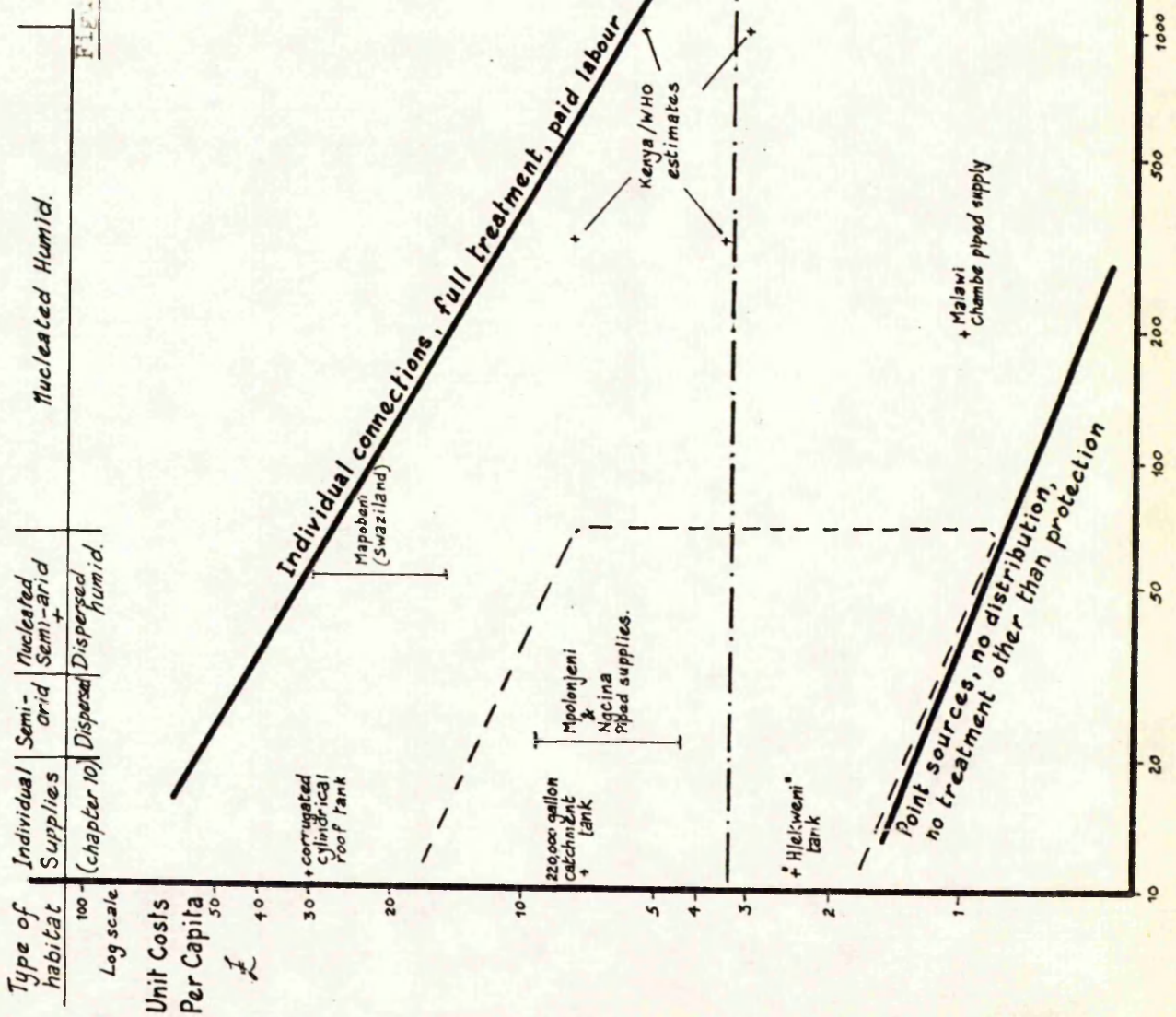
regions reveals little about the distribution of population. Semi-arid Botswana, in terms of overall population density, is very sparsely populated; but it does have nucleated settlements of several hundred people. Swaziland has few nucleated settlements, but compared with most other African countries it is densely populated. Where a specific limited area is considered, population density will be more closely related to settlement pattern. For example, there are few places in the Swaziland Lowveld where more than 50 people are living in any one square kilometre. For the villages of Botswana, the population density will often be more than 100 people per square kilometre.

In spite of this limitation, a comparison of unit per capita costs in terms of population density does help in assessing the likely costs for a particular area. In Table 7.2 three broad categories have been suggested - high, medium and low. These correspond to approximate population densities of 100 or more people per square kilometre, around 50, and less than 30 respectively*. In Kenya, the rural area have been officially divided into three ecological zones, depending on the agricultural potential of the areas. The population densities largely correspond to this classification; the high density areas are associated with land of high agricultural potential, and the low potential areas are the semi-arid and less densely settled regions.

In order to give a simplified view of the relationships between unit per capita costs and population density (and settlement pattern), the information given in Table 7.2 has been presented in graphical form in Figure 7.2. A selection of the projects listed in the table has been included to indicate the boundary lines which represent the

* For many of the projects listed in Table 7.2, there is insufficient information about the places they serve to give details about population density.

Figure 7.2 PER CAPITA COSTS AND POPULATION DENSITY



The per capita costs for water supply developments are probably a minimum for the population density of around 500 - 1,000 persons/km.² As the population densities increase, then per capita costs start to rise again because of difficult conditions for distribution and the higher standards adopted for urban settings. Typical West African urban costs are £10 per head (Stern 1971); future supplies in Nairobi may cost £30 per head (Kenya/WHO 1972).

The area bounded by the dashed lines is the main area of concern for this thesis.

two extremes in water supply development. The lower end of the population density scale, about 10 people per square kilometre, has been included to represent individual family supplies.

Of course, the data used for Figure 7.2 is necessarily approximate, but the general trends should be clear. Associated with the lower line will be all the factors which go towards minimising capital cost, for example:

1. low level of sophistication in service and distribution - point sources only with no distribution or treatment, gravity schemes rather than pumped,
2. cheapest materials - usually local materials,
3. lower design standards and shorter design periods
4. self-help methods and thus only material costs considered
5. labour intensive methods
6. speed of construction is less important

The upper line indicates the most capital intensive solutions and the greatest levels of sophistication. Water supply developments of this type become increasingly, and usually prohibitively, expensive at low population densities; certainly such cost levels would be beyond the capabilities of most indigenous rural dwellers in Africa. For these people reduced standards and lower levels of service are considered inevitable, but even so, the per capita costs for even the minimal service are still higher than individual connections and better services for high density dwellers.

The average expenditure of the WHO ten year programme (Chapter 1) of approximately £3.30 per head will provide only modest improvements for people in sparsely populated areas. Figure 7.2 also suggests that the individual family supplies, as exemplified by catchment tanks and roof tanks (using commercially available guttering and a 1000-gallon

corrugated iron tank) and described in Chapter 10 are not as unrealistically expensive as some writers have assumed (e.g. White *et al.*, 1972).

The problem area for water supply developments is thus within the range of population densities up to 50 people per square kilometre (this allows for the nucleated settlements in semi-arid areas of the type encountered in Botswana), and a capital cost of up to £15 to £20 per capita. The extent of the problem is shown dotted in Figure 7.2.

It is anticipated that unit costs will increase for future developments since it is often the easy (i.e. low cost) projects which have already been undertaken, or which will be given priority in the immediate future. Warner (1970) accepts this view but believes that a concerted programme of water supply improvements would lead to considerable organisational savings, and better methods which ought to reduce cost levels.

White *et al.* (1972) have identified six types of habitat in East Africa, ranging from low density urban settings to dispersed rural communities, and have estimated "annual use" costs for six types of improvement. The first class includes individual family supplies such as a roof tank or well. The range continues from these through to community improvements of well and springs, to pipelines and standpipes (with or without treatment of the water), and finally to full treatment and multiple tap systems within the home. Their figures indicate that for any type of dispersed community, whether it is in a semi-arid or humid environment, the costs of improvement beyond a communal standpipe system are prohibitively expensive. Their assessment of health benefits, using the methods outlined in Chapter 6, for each class of improvement suggest that the health benefits of a treated supply from a communal standpipe system are no greater than the anticipated health benefits of individual supplies. The reasons for this conclusion

follow from the discussions of the relative merits of sources in Chapters 4 and 5. An individual family supply, whether it is rain-water collected from a roof, or a well, yields generally good quality water which because of good social control can be protected from secondary pollution. Any pollution which does occur is confined to a small number of users, so that the possibility of transmission of infections is reduced. On this basis alone, individual family supplies would seem to be a good prospect for dispersed settlements.

With sufficient data on all the component costs of water supply development - such as extent of distribution, design standards etc., it would be possible to draw a family of curves on the axes of Figure 7.2, showing how component costs vary with different types of habitat. A rough theoretical assessment of how the costs of storage (or source works), distribution and treatment are affected by different types of settlement pattern can be made.

Capital costs for treatment will be fairly similar for all types of improvement and will not be greatly affected by the settlement pattern. The Kenya Community Water Supply Programme, for example, allows only £0.25 per capita for treatment in all its estimates (Kenya/WHO 1972). This represents some 3-8 per cent of the total per capita cost. The relationship between costs and storage is a cubic function, so that there are considerable advantages in supplying as many people as possible from one source. The costs of distribution, on the other hand, depend on the area to be served. At some stage, depending on the distribution of population, the advantages of a single source will be more than offset by the greater distribution costs involved. Since there is a greater variation in the areas involved in water supply developments, than the number of people to be served, the distribution costs will tend to have an overwhelming influence on the costs of water supply developments. Thus, although the source works for schemes in a semi-

arid area of Botswana are likely to be greater than for a humid zone, the fact that settlements in Botswana are nucleated will mean that distribution costs will be lower than those for any sort of dispersed community, and subsequent total costs of the supply will tend to be lower.

One fundamental decision for water supply improvements concerns the extent of distribution. There will be some point depending on the density and distribution of population when the high costs of providing individual supplies and storage (e.g. catchment tanks) will be matched by extra distribution costs of a public piped supply. This point will also depend on climatic conditions. On a purely empirical basis, using the data of Table 7.2 and Figure 7.2 the critical population density for the Swaziland Lowveld would appear to be about 30 people per square kilometre.

Of course, one alternative solution when distribution costs are high is to resettle the population, and this is one of the main purposes of the Rural Development Programme in Swaziland. It is interesting to note that it is not only in developing countries that this policy has been suggested. A report for the Ministry of Housing and Local Government (1968) concluded that the least cost solution for improving water supplies in a rural area of Shropshire (South Atcham) was large-scale resettlement of the population from farms and small communities into the larger existing communities. In many ways, the problem considered is similar to that of communities like Mpolonjeni. The overall population density of South Atcham is slightly higher, but there are more nucleated communities each with its own separate supply system. The main reason for "improving" supplies was that the present situation of several separate systems failed to meet the current standards on water supply, though there was no evidence presented of

what adverse consequences were expected of this, such as poorer health of the people served by the "sub-standard" system.

7.4 Economic Evaluation of Projects in Developing Countries

So far, the cost of water has been discussed solely in terms of the prices people are willing to pay, or have to pay, and the capital costs of a range of particular projects. The "economics of water supply" as understood by water engineers and economists is unlikely to have much meaning to people in rural communities. Thus "opportunity costs" of time savings, "energy expenditure" in fetching water and "marginal costs" of water are terms which mean little to people, but which can be used to describe every-day situations which people are aware of. What will be appreciated is the time spent in fetching water, feeling too tired to go for more, and perhaps having to pay a neighbour in cash or kind for delivering water. Economists and engineers should beware of becoming too detached from the human situation in these matters, and should refrain from trying to impose alien economic criteria.

It is sometimes suggested that peasant communities make the most efficient use of the time available. This is probably true for static societies. Traditional solutions to problems which have evolved over many generations will not fall far short of the most efficient practice attainable in the light of the technical knowledge of that time (Holstein 1970). Few societies remain in this situation. Objectives, and therefore problems, are changing. Parker (1973) reports that women in villages in south east Ghana no longer make the most efficient use of their time for collecting and storing water. In the circumstances where "conditions are changing too rapidly for experience to be assimilated by informal, unsystematic methods, but slowly enough to permit the formulation of a model applicable to both the recent past and relevant future, and to permit

the accumulation of the data needed for estimating the parameters of the model " (Holstein 1970), systems analysis, sophisticated economic assessments and mathematical models may be useful tools, especially in the field of environmental engineering. Economic criteria such as opportunity costs, cost/benefit ratios and systems concepts may be helpful for describing the implicit understandings of people in rural communities of how they apportion their time. The relevance of a model for rural water supplies will be discussed later in the chapter (Section 7.5).

It should be noted that gross inefficiencies in the use of resources is not something which is confined to subsistence rural communities. Casual observations of Western societies reveal that family life in particular is often inefficiently organised in purely economic terms. The costs that some people are prepared to pay for such indeterminate things as "convenience", "freedom of movement" etc. are value judgments and will depend on the personal opinions of the assessor, but for each particular case, the "value judgment" can be assigned a monetary value by checking to see how much is being paid for it.

Warner (1970) has used typical figures for rural water supply schemes in Tanzania to make this calculation. With initial costs of 200 Tanzanian shillings per person (about £12), equipment is written off over a period of 20 years. Interest rates are about 8 per cent and annual maintenance and operational costs are 10 shillings per capita. If the government or other authorising body is prepared to meet these costs so that water is provided free, it is effectively saying that the value of the project to itself is at least 30 shillings per person per year. So even if the benefits of the project are largely social, and cannot be individually quantified, the people who planned the

scheme implicitly assumed that the non-quantifiable benefits had a value of this amount. The views of the consumers may be different, and some of them may not think it worthwhile using the new supply if they were expected to pay 30 shillings a year, but any consumer who uses the water, and pays the economic cost, confirms the judgement of the planner.

Economic Evaluations and Developing Countries

The full evaluation of water supply developments should take into account all the consequences which been discussed in Chapter 6. In practice, only those consequences which can easily be given a monetary value are fully considered, and even this is a recent trend.

In the past, water supplies in urban areas have been installed on the basis that the consumer eventually pays the full capital and operating costs. In rural areas, when outside bodies helped with the improvement of water supplies, it was usually for purely humanitarian reasons. These situations existed during relatively stable conditions, where future urban developments were mainly extensions of existing systems, and where the rural areas were neglected, and considered to contribute little to the economy as a whole. Now, many cities in developing countries are having to cope with rapidly expanding populations for which the existing water and sewerage systems are either non-existent or completely inadequate. Such enormous sums of money are required for new developments, often so far beyond the means of the city or the nation, that external aid is sought from such agencies as the World Bank, who make definite conditions about how the money should be spent. (World Bank 1971). Outside the towns, rural development is now regarded as a major requirement for the future development of the country as a whole. Expenditure on rural water supplies is seen as

one important input which can contribute to the overall development objectives, and thus there is now much more concern on how effective expenditure on rural water supply is, compared to other agricultural, educational and health inputs.

It is foreseen that water supply and sewerage projects will be increasingly subject to the evaluation techniques used for transportation projects (Jackson 1971). Since individual charges are rarely made for road users, the direct indicator of benefits is absent. This is also the case when nominal charges are made for water supply, or when it is considered to be a social service and water is supplied free of charge. Under these circumstances, sophisticated cost-benefit analyses can be employed to ensure that resources are wisely allocated.

At this stage it is necessary to make a distinction between cost-benefit and cost-effectiveness (Peters 1971) and also to distinguish between financial and economic evaluations.

Cost Benefit Analysis involves a very much more fundamental approach, which takes into account all the benefits and costs, ascribing quantitative values to as many as possible, and finally arriving at some rate of return on the money invested. The boundaries for this type of exercise are almost limitless. A cost-effective study is less far reaching and ambitious since it does not attempt to pass full judgement on the soundness of the project. Instead it attempts to rank a number of projects in terms of value for money. The boundaries for this study are well-defined.

The distinction between financial and economic evaluation also depends on how the boundaries for assessment are chosen.

Financial evaluations treat the project as an independent enterprise, and include all the cash flows that an "accountant would take with his books of the enterprise" (Rangely 1968). Such factors as

inflation, import duties, taxes etc. would be accounted. This approach is only really relevant to the operation of private firms, and can tell us little of value about a water project.

An economic evaluation generally has a regional or a national basis and should therefore exclude internal transfers which occur in the form of inflation, subsidies etc. The costs and benefits should be those which are directly attributable to the project, and not those which would have occurred in any case.

The great problem with these evaluations is deciding what should be included. Inevitably there are tendencies to restrict the problem boundaries for economic and cost-benefit evaluations, since this will make them more manageable; and with financial evaluations and cost-effective studies there are temptations to extend the problem area because so many questions appear unanswered.

Cost-benefit techniques of project appraisal have been developed for Western economies which are based on relatively homogeneous societies. They have proved useful in cases where no clear-cut decision was obvious, and have enabled some assessment to be made of social factors. However when the same methods are applied to projects in developing countries, there are very serious limitations unless the terms of reference are changed.

Cost-benefit analysis takes into account three types of costs and benefits (Table 7.3). The direct and indirect costs and benefits are fairly straightforward to deal with, but the intangibles are more difficult since they cannot be evaluated in monetary terms. Either they are matters of opinion, for example, appearance, or they are costs and benefits which are difficult to analyse, for example, safety or health improvements, that no quantitative assessment can be made. The recent trend has been to narrow the area of intangibles by devising

Table 7.3

Summary of Costs and Benefits Taken into Consideration
in Economic Evaluations (Rangley 1968)

*Benefits**Primary or direct benefits*

All incremental net gains that arise directly from the project, i.e. the difference between the net gains 'with' and 'without' the project. In practice, benefits ascribed to a facility are limited by alternative least cost means of meeting the same need. Thus the direct benefits of a hydro-electric power project may be the incremental profit from power sales, though in effect the direct benefits cannot exceed the cost of thermal or other least cost and feasible methods of generation.

Secondary or indirect benefits

Incremental gains in secondary activities that arise out of the implementation of the project, i.e. rice milling in an irrigation project area. From a purely economic and national standpoint secondary benefits have little meaning unless the level of secondary activity for a given capital investment is unusually high. From a regional standpoint, secondary benefits have more significance and should be evaluated wherever primary benefits show marginal economic viability, provided regional development is a stated aim.

Intangible benefits

Benefits that cannot be assigned a monetary value either because they cannot be measured or because they have no market value. They should be described in the project report.

*Costs**Primary or direct costs*

All goods and services that are expended in order to construct and operate the project. These include all costs of project preparation, engineering and supervision, and payments made in respect of construction works. (In DCF procedures, interest on capital expenditure both during and after construction is excluded.)

Secondary or indirect costs

The costs involved in the production of the secondary benefits. The precise treatment of these costs can be laborious and it is usually possible to proceed directly to net secondary benefits, i.e. the profitability of rice milling in the region being known, the net incremental benefits can be taken by proportion.

Associated costs

All costs incurred by the primary beneficiaries. In the case of irrigation development, for example, these are the associated farming costs that are deducted from gross production value (GPV) to produce NPV which is then treated as the primary benefit.

Intangible costs

Costs that cannot be assigned a monetary value and must be described in relation to intangible benefits.

other techniques of assessment. Thus intangibles for alternative projects can be compared using a points scoring system with an arbitrary maximum and minimum. Intangibles can also be evaluated indirectly by comparing them with items which have an accepted market value.

Comparing the economic conditions of the West and the developing world, we would find that construction costs for a particular project would be fairly similar - higher labour costs would be matched by lower material costs, but the direct and indirect benefits would be much lower since the markets are very much smaller. The intangibles, on the other hand, are likely to be much greater since there are few precedents for large scale developments, and because in general these would be unevenly noted (Table 7.3); it is only the very large-scale developments which receive favourable consideration. Only those projects which fit into the Western economic pattern are acceptable. A project such as the Volta Dam in Ghana fits the "Western economic pattern" since it produces cheap electricity for aluminium smelting for the assured markets of America and Europe.

As it becomes more difficult to find projects which produce acceptable rates of return, development economists have introduced a number of factors which influence the cost-benefit balance by taking into consideration the special conditions of developing countries. For example, "shadow prices" for local labour and foreign exchange are used, which are meant to reflect the real cost to the countries of these items. In countries with unemployment or under-employment problems, the opportunity value of labour can be very small in relation to the wages payable. Similarly, artificial currency exchange rates in countries with trade balance problems under-rate the cost of materials and labour from abroad.

The ultimate test for approval in cost-benefit analyses is that the rate of return should equal or exceed the opportunity cost

of the money invested, i.e. the earning capacity of that money if allocated to some other form of resource development. At the present time, this opportunity cost is around 16-17%, and the Overseas Development Administration (O.D.A.) of the British Foreign Office expects the opportunity cost criteria to be applied to all its major development projects (Lawrence 1973). This may appear sensible when a specific sum of money is to be invested, but if this approach were to be adopted on a wide scale it would make nonsense of any ideas about the real development of a poor country's peoples and resources. On this narrow, short term basis, the best course of action for a Third World country would seem to be to invest in say property development in the cities of Europe and North America.

The present economic evaluation criteria, if rigorously applied to all situations works towards increasing inequality between the rich and the poor; between urban and rural life. A poor, dispersed rural community in a semi-arid land is not likely to receive favourable attention.

Assessment of Rural Water Supplies

From the previous section it is apparent that two questions about the assessment of water supplies need to be asked. These can be dealt with separately, though as with cost-benefit and cost-effective studies they are not completely independent of each other.

- 1) Do rural water supplies contribute significantly to the overall objective of "rural development and well-being" - or is it better to invest in other sectors, such as directly in health and education, to achieve this aim ?
- 2) Assuming rural water supplies are a good investment, what are the most effective methods for putting a rural water supply programme into operation ?

In relation to the first of these points, some authors have argued that rural water supplies are not a good investment (Irwin 1971, Alexander Gibb & Partners, 1973), yet this is contrary to the current policies in many African countries. The most recent Development Plans for Kenya, Tanzania and Swaziland place emphasis on the social and economic benefits of rural water supplies. In Tanzania rural water supply is basically a social service with economic ramifications, and the Development Plan allocates 11 per cent of Central Government expenditure to this service, compared with 2.8 and 8.0 per cent on health and education respectively (Warner 1970). In this instance, the case for rural water supplies has been accepted without much recourse to economic analysis, and Burton (1971) has suggested that there has been over investment.

Water supplies are a politically loaded issue, in the same way that housing and health are, and hence it is not surprising that the principle of water supply improvements should be readily accepted. It is often suggested that the final decision on subjects like water supplies will always be a political one (Chagula 1971, Carruthers 1970, Kuiper 1971), but political decisions are greatly influenced by economic and social analysis, and in this respect any attempts at such analyses are useful.

The main problem with assessments of this type is that the effects of water supply improvements are so complicated and diverse (Chapter 6), that it is very difficult to deal with them quantitatively. For urban supplies and large scale irrigation projects, the proportion of the water used for domestic purposes is relatively small. The water used by industry and crop production can be given a market value; that used for domestic purposes is more readily placed in the category of "intangibles" but the effect of neglecting this small proportion in the final assessment is small.

For rural supplies, the great proportion of water use is concerned with the fundamentals of simple existence, and thus any quantitative assessment would require assessing all the elements which make up the business of living. This is a very tall order, and one that could not be made on the present bases of assessment. It is also questionable whether it is even desirable, since the results would inevitably be largely value judgements, e.g. of whether improved health is a better objective than a broader education. The final assessment ought to be made by people concerned after they are fully acquainted with the range of possibilities.

It was noted in Chapter 1 that very little information exists about people's aspirations. Heyer, Ireri & Moris (1971) have made a study of rural development in Kenya, and compared the actual spending on self-help projects with the priorities for self-help projects as listed by farmers (Table 7.4). Local people often provide more than half the cash contributions. The first table shows that "education" accounts for more than 60 per cent of resources devoted to self-help projects, whilst water and road projects receive 3.5 and 1.9 per cent respectively. When farmers were asked what the priorities should be (as opposed to the projects encouraged by government), "health" was considered the most important, and roads were thought to be as important as education. Water supplies, as opposed to dams, did not seem to be very important, whilst there was little interest in agricultural projects. In enquiring about aspirations, there are obviously conflicts between personal and communal responsibilities, and to say that a project is necessary, and then be prepared to pay and work on it may be two different things. Care must also be taken to ensure that a representative opinion is obtained. In Kenya, farmers, presumably male, were asked their opinion. If women were asked, then water projects might have been given greater prominence, and roads less.

Table 7.4
Self-Help Projects in Kenya - Averages from a Survey
of 14 Districts

(a) Percentage of Total Cash and Materials in each field, self-help projects

	<u>Education</u>	<u>Health</u>	<u>Social</u>	<u>Water</u>	<u>Roads</u>	<u>Agriculture</u>	<u>Other</u>
% age	63.2	13.9	2.9	3.5	1.9	7.3	6.2

(b) Percentage of Respondents listing the following self-help projects as priorities

	<u>Education</u>	<u>Health</u>	<u>Roads</u>	<u>Water</u>	<u>Agriculture</u>	<u>Other</u>
Primary	56	74	65	55	3	12
Secondary	69	72	65	49	3	12
Centres						
Maternity						
Roads						
Bridges						
Dams						
Water supplies						

Source: Adapted from data given by Heyer, Ireri & Moris 1971. Rural Development in Kenya
Inst. of Development Studies, University of Nairobi, 1971.

In Mpolonjeni, the concern for educational facilities was very obvious. As in many other developing countries, education is seen as the key to success, and a release from rural life. Water supply also seemed to be important, but this may have been a false impression because this was the main concern of the author. Agricultural projects were given low priority. For example, Chief Makhosini Dlamini of Ngcina who has proved himself very active in promoting self-help projects for school classrooms, a clinic, a water supply system, and a shed for the farmers' cooperative, had rejected a scheme for trials of a battery operated pesticide spray for cotton (Treen 1973). This may have been because of local conditions, objection, or it may be a sign of a basic feeling of people living in communities like Mpolonjeni and Ngcina that their present under-privileged position is due solely to lack of education, and inadequate facilities in which to operate their satisfactory social and agricultural system. Holleman (1964) also noted this lack of interest in agriculture, and commented that people in Swaziland regard agriculture as a basis for existence, but not a basis for development.

One final method of gauging the importance of rural water supplies is to relate it to the amount people are prepared to spend. This was dealt with more fully in the section on the costs of water (Section 7.2). Carruther's (1973b) suggestion of 5 per cent of annual income is probably a reasonable assessment of the overall contribution of domestic water supplies towards the development objectives.

The issues involved in assessing rural water supply developments can be clarified by referring to the systems concept introduced in Chapter 1. Most of the discussion in this chapter so far has concerned "the national economy" as the system and has looked at the value of water supplies from a governmental point of view. Several reasons

have been put forward why conventional economics are of little use in trying to achieve the development objectives suggested in Chapter 2. National economies are not run in the interests of rural people and poor people, and conventional economics contain little to counteract this tendency.

Most economic arguments convey either capitalistic or socialistic value judgements. Once the fundamental objective of "rural development" has been accepted - a political decision supported by economic and social analyses - then investment in water supplies will follow naturally. The problem of assessment then resolves itself into a cost/benefit (or input/output) assessment for a system at a community or family level. The assessment is immediately made easier because the system does not now need gross simplification in order to be understood.

It can be argued that where foreign aid is necessary to carry out water supply development, the donors may impose some conditions about economic assessment. For small projects this is not usually a problem, since they do not compete for capital in the same way as large projects do. Aid agencies who donate funds for self-help projects are often charitable organisations (Oxfam, Christian Aid, etc) for whom social benefits are sufficient evidence that money is well spent. When larger sums are required for water supply programmes, then in the case of Tanzania's programme, which is supported by the Swedish International Development Agency, a well-defined list of development objectives (mainly social) seems to have been sufficient justification for the support (Westman & Hedkvist, 1972). The World Bank is now proving more flexible about applying the strict economic criteria. Better identification of benefits is required, and "well justified rural water projects (would) merit Bank support." To date none have been

presented to the Bank, " the reasons which cause governments to neglect urban water and sewerage needs apply with even greater force to rural areas." (World Bank 1971).

Choosing the community as the system for assessment of water supply improvements essentially means that the most cost-effective solution is sought. However, policy decisions about the level of service which is desirable still have to be made. Otherwise the poorer sparsely populated rural areas would suffer at the expense of the high potential areas just as in the past rural development in general has suffered at the expense of urban development. One of the problems is to persuade aid-donors that funds ought also to be allocated to those areas where the benefits will not be immediately obvious (Ricardo 1973).

7.5 Cost-Effective Water Supplies & Mathematical Models

The community or family system considered may be described qualitatively in terms of its general characteristics and inter-relationships as described in Chapter 6. In this way its wholeness and complexities may be appreciated. The choice of the most appropriate water supply development would probably arise out of some intuitive judgement as the one most likely to be absorbed by the system, yet introducing subtle changes.

Alternatively, the inputs and outputs of the system may be quantified so that an input/output ratio or cost/benefit ratio can be obtained. This is the basis of cost/benefit studies like Parker's (1973) which has shown favourable ratios when considering time savings alone (Chapter 6). White *et al.* (1972) have quantified health benefits on a points system so that the relative effects of different types of supply can be compared.

Parker's study is the most useful since he considers improvements which could be met mainly or entirely by the people of the village he

studied. If we say that people act intelligently to optimise their use of resources, then in principle, their behaviour must be capable of being rationalised in economic language.

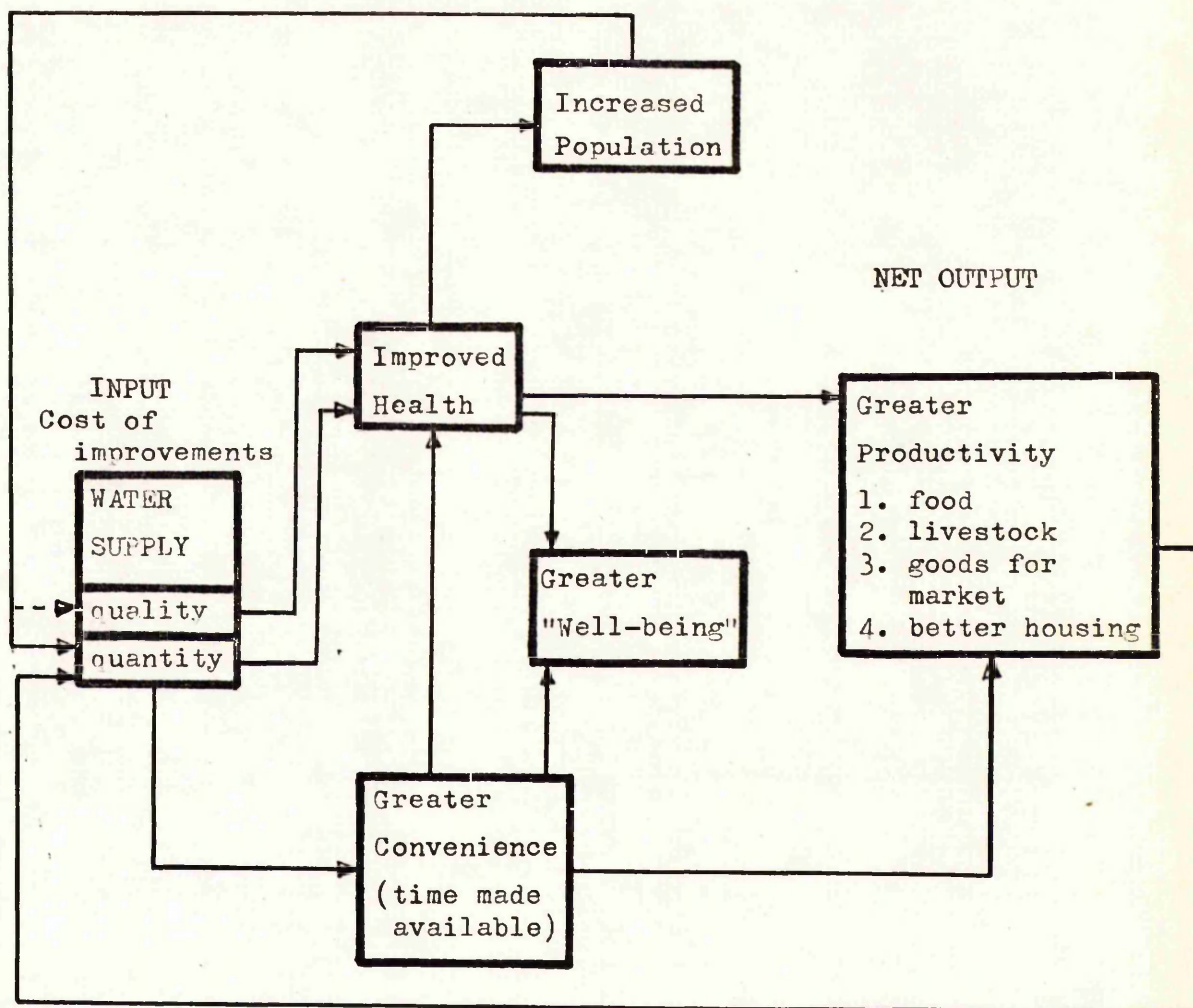
An extension of the simple input/output study is to consider the effects of the output on a new input, i.e. a feed back loop. For this, a mathematical model can be useful provided that it attempts to answer the correct question. For example, a mathematical model could be used to optimise the design and operation of a hospital, but if the ultimate objective is to improve the health of the majority of people (by preventative means) then a hospital is not the most appropriate solution.

The form that a mathematical model might take for a rural community has been tentatively put forward (Figure 7.3). It should be stressed that this model has not been tried, but it provides a starting point for further development. The relationships required for each step have been listed, and some of these which are now fairly well established have been shown as a series of figures (Figure 7.4).

The central feature of the model is greater well-being, for which water supply is only one input. It should be remembered that water-supply system is really a sub-system of all those contributing towards greater well-being. In benefit/cost terms, the ratio net output/input ignores output in terms of greater well-being, and for a first stage it would be better to neglect this output and consider it part of the intangibles.

Conclusions

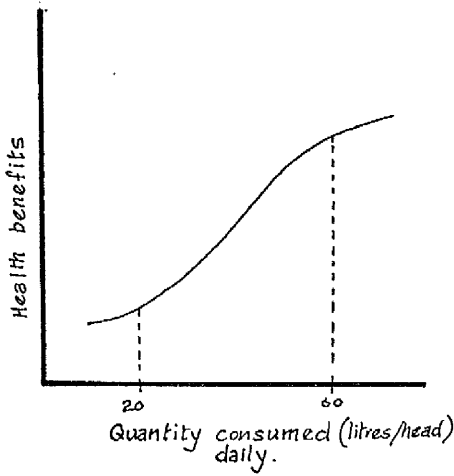
A benefit/cost ratio is a valid method of assessing water supply developments for the community or family system, though as noted above the final solution of dealing with intangibles has not been found. Value



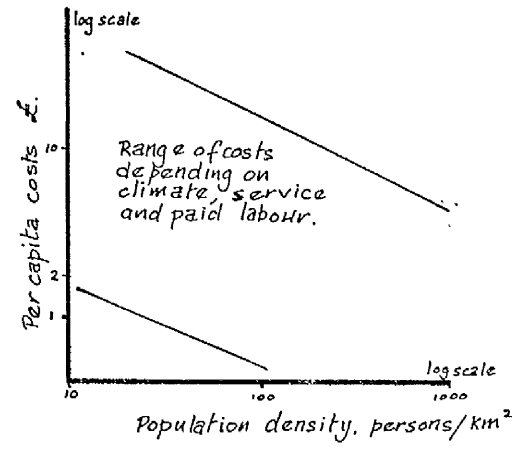
Relationships required

- (1) Health is affected by quantity and quality of water used (White et al. 1972).
- (2) The quantity of used is influenced by the distance from the home to the source.
- (3) Better health means greater ability to work.
- (4) Time savings resulting from a nearer source mean more time for productive work.
- (5) Improved health and rising living standards lead to an increased population.

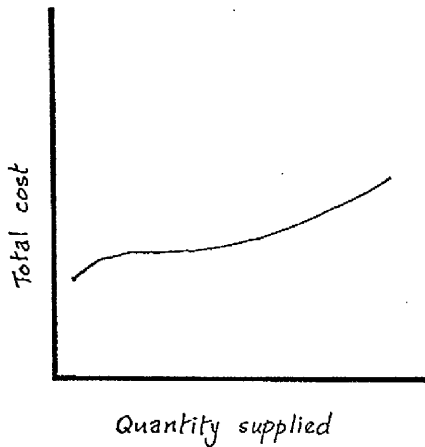
Figure 7.3 AN OUTLINE FOR A MATHEMATICAL MODEL FOR WATER SUPPLY AND A RURAL COMMUNITY



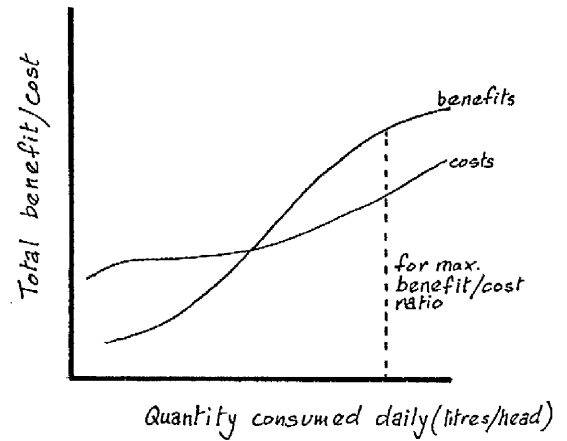
(a) Health and Quantity



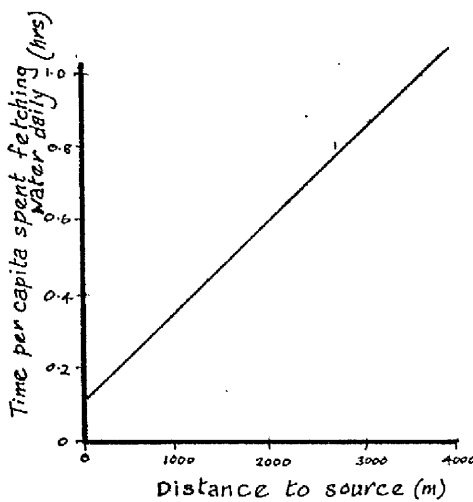
(b) Per Capita Costs and Population Density



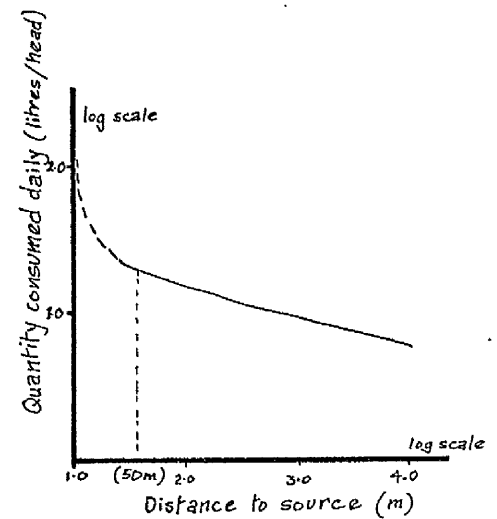
(c) Total Cost and Quantity supplied



(d) Total Benefit/Cost and Quantity (Carruthers 1973a)



(e) Time spent carrying water and distance to source



(f) Quantity and Distance to Source

Figure 7.4 RELATIONSHIPS FOR USE WITH THE PROPOSED MATHEMATICAL MODEL (Figure 7.3). For health-quantity-quality (Figure 6.3)

judgements play a very important part in the assessments. At a local level these may be satisfied by holding meetings to discuss developments and planning for the user-choice system (Chapter 1). At a national level, political processes will be necessary.

The costs of water supply development have been shown to be critically dependent on the population density. For the population densities of the Lowveld of Swaziland, piped supplies can only supply relatively few people. If the majority of people are to benefit from improved supplies, then individual supplies will have to be given more consideration.

CHAPTER 8

WATER SUPPLY TECHNOLOGY IN SEMI-ARID AREAS

PART I : DAMS

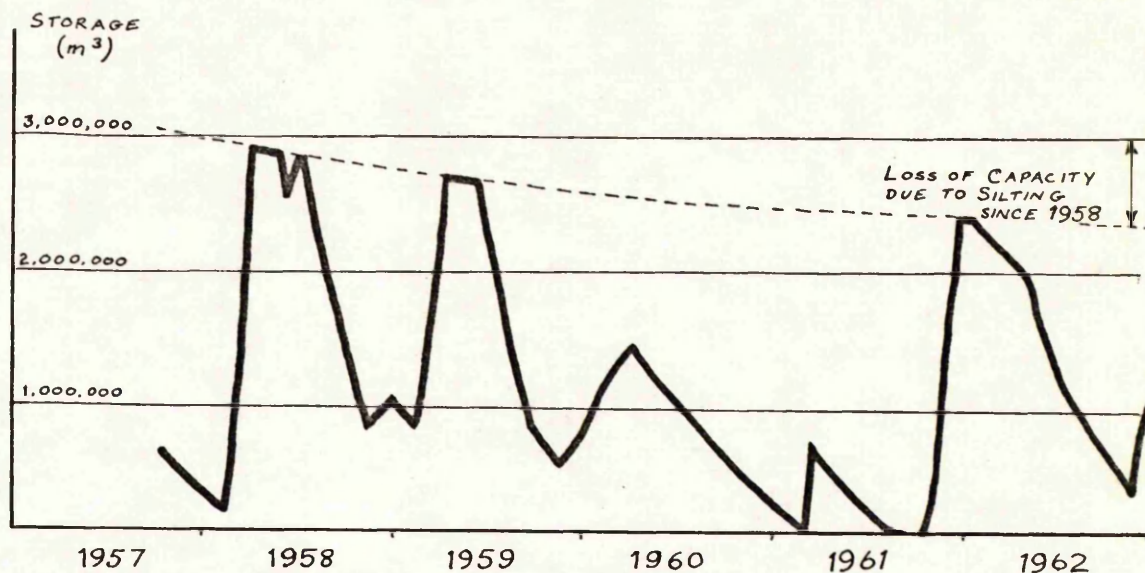
8.1 Introduction

Small earth dams are widely used in southern and eastern Africa for watering cattle and for the supply of domestic water to villages and isolated farms. But it is not always appreciated that these dams provide a very inefficient form of water storage. In the Lowveld region of Swaziland, the annual loss of water from small dams may amount to 50 per cent of the volume collected.

The reasons for the inefficiency of dams in semi-arid areas have already been discussed, and may be summarised as follows:

- (a) seasonal rainfall,
- (b) rainfall is unreliable and run-off even more so; when rainfall in the Swaziland Lowveld is 20 per cent below average, run-off is reduced by almost 40 per cent,
- (c) high evaporation losses
- (d) loss of capacity by silting.

All these effects and the problems they cause are illustrated by Figure 8.1. The large seasonal variations in the volume of water stored by these dams is clearly seen. In the semi-arid areas of southern Africa, dams tend to fill between December and March and empty during the rest of the year. In drought years, inflow is greatly reduced. The Tanzanian dam (Figure 8.1) failed completely in 1961, leading to the loss of irrigated crops and the abandonment of irrigated land by the farmers. The careful records of this dam also show how its capacity has been reduced by the settlement of eroded soil carried down from the catchment (Berry & Kates 1970).



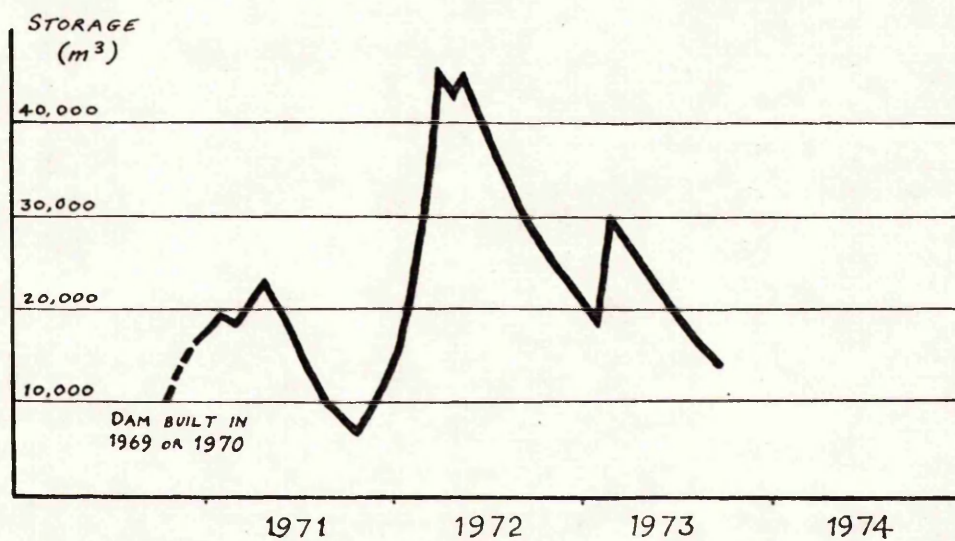
IKOWA DAM, TANZANIA

mean annual rainfall over catchment 610mm

mean annual run-off over catchment 90mm

a water supply for irrigation is taken from the dam: draught about 3,000 m^3 /day during growing seasons.

source: Berry & Kates (1970)



MAGGENYA'S DAM, SWAZILAND

source: Farrar & Pacey (1974)

Figure 8.1 STORAGE STATES OF TWO EARTH DAMS AT VARIOUS DATES

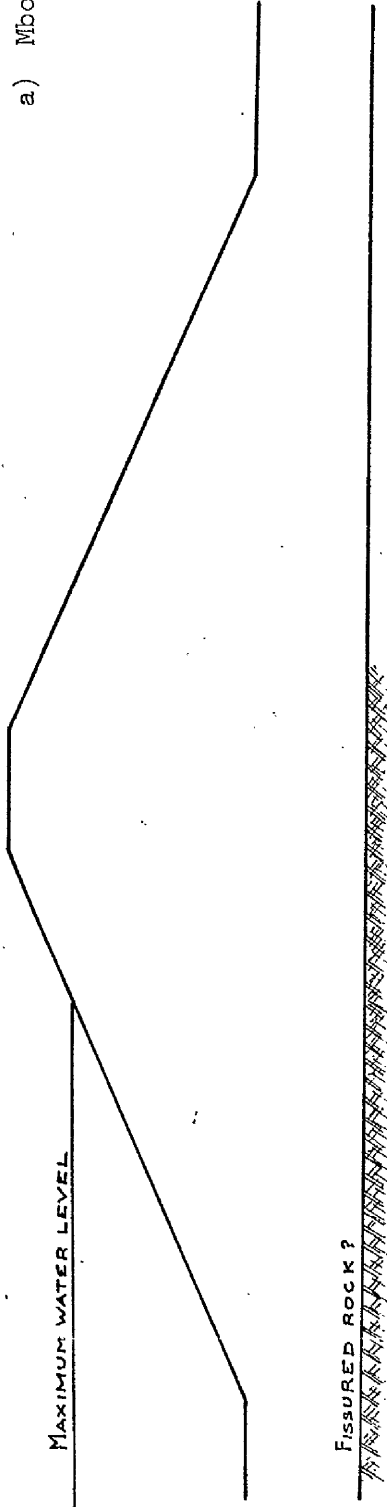
To some extent, it is possible to allow for the disadvantages of a seasonal and unreliable rainfall by careful reservoir management, and assignment of priorities for the various water uses. This was the approach adopted by Midgley and Pitman (1969) in their assessment of water resources in southern Africa, including Lesotho and Swaziland. A major part of this chapter is devoted to the application of Midgley and Pitman's methods to the five small earth dams at Mpolonjeni. These authors were mainly concerned with large reservoirs in which water levels could be continuously recorded, and where outflows could be frequently and precisely adjusted. In considering small village-scale dams, none of these conditions prevail, and thus one objective of the chapter is to assess the relevance of Midgley and Pitman's methods in these circumstances, and to consider what kind of water budgeting techniques can be devised.

8.2 Earth Dams at Mpolonjeni

Of the five dams investigated, four were constructed to a similar design during the mid 1960's. The other, Hlangothi Old Dam, was built in the 1940's, and a comparison of the 1961 and 1971 air photographs suggests that the capacity of the dam was increased in the intervening period, though there was no evidence of these alterations when the dam was visited in August 1973.

A typical cross-section of the newer dams is shown in Figure 8.2a. It will be seen that Hlangothi Old Dam (Figure 8.2b) has a less massive section and a much narrower crest. This dam is built from the local soil, which is the "black tropical clay" (Chapter 2). This soil poses a number of problems in dam construction, because of shrinkage and cracking as it dries out. The newer dams are constructed from a crushed, weathered basalt, which is a much more predictable material, but one which is relatively permeable, and there are significant seepage losses from all these dams. Hlangothi Old Dam is anomalous in several respects

a) Mbonga Dam



Scale: 1:200 vertical & horizontal

b) Hlangothi Old Dam

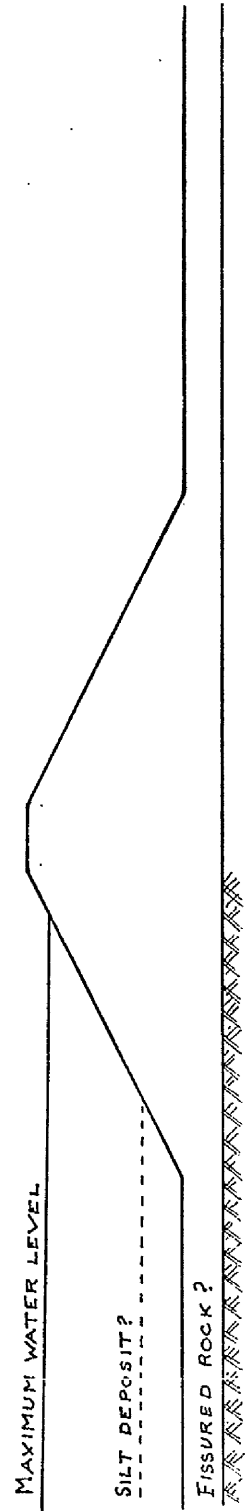


Figure 8.2 CROSS-SECTIONS OF MBONGA & HLANGLOTHI OLD DAMS AT THEIR DEEPEST POINTS

and a separate section will be devoted to it.

The plans and sites of the dams are illustrated in Figure 8.3. These show the water-line in September 1971 when the air photographs were taken.

The capacities of the dams

Contour intervals on the 1:50,000 maps are 50 feet; consequently it was not practical to estimate the capacity of a dam by deducing its shape from contours. Instead, field measurements of the length of the dam wall, and the maximum depth of water were made (Table 8.1). These could be related to measurements taken from the 1971 air photographs, and thus it was possible to obtain an estimate of what the water surface area would be when the dam was full.

The simplest type of area-capacity relationship is one which assumes a triangular shaped section for all planes. This gives:

$$A = kd^2 \quad \text{and} \quad V = \frac{kd^3}{3}$$

where A is the area of the water surface

V is the volume of water in the reservoir

d is the depth of water at the deepest point, and

k is a constant.

From this it can be shown that :

V is proportional to $A^{2/3}$ and

$$V = \frac{Ad}{3}$$

The dams at Mpolonjeni were built across concave sided valleys, and the above relationship would tend to underestimate capacities. A more satisfactory formula was given by Midgley and Pitman (1969) as being typical of many reservoirs in South Africa:

V is proportional to $A^{5/3}$ or: $A = bV^{3/5}$

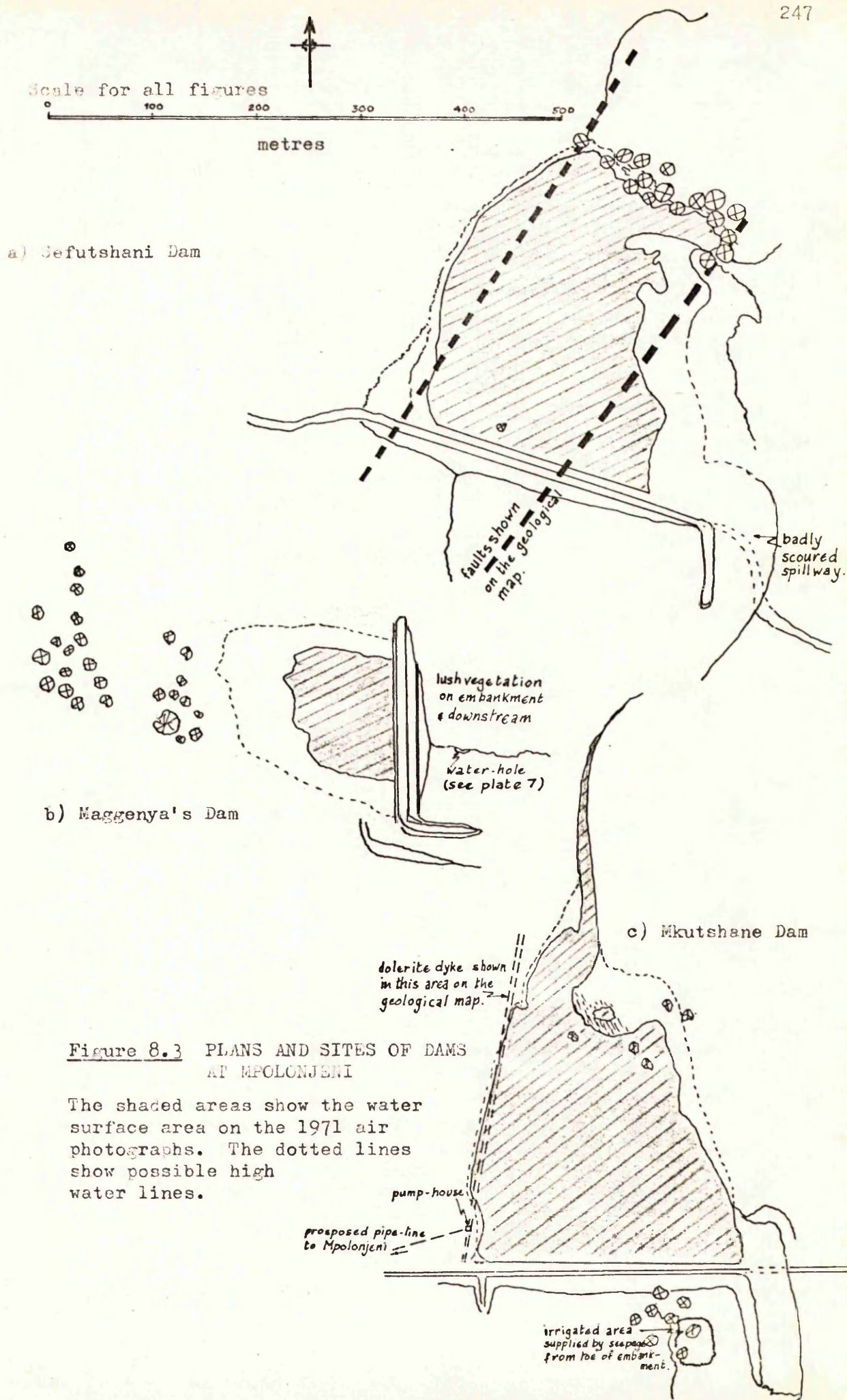


Figure 8.3 PLANS AND SITES OF DAMS AT MPOLONJENI

The shaded areas show the water surface area on the 1971 air photographs. The dotted lines show possible high water lines.

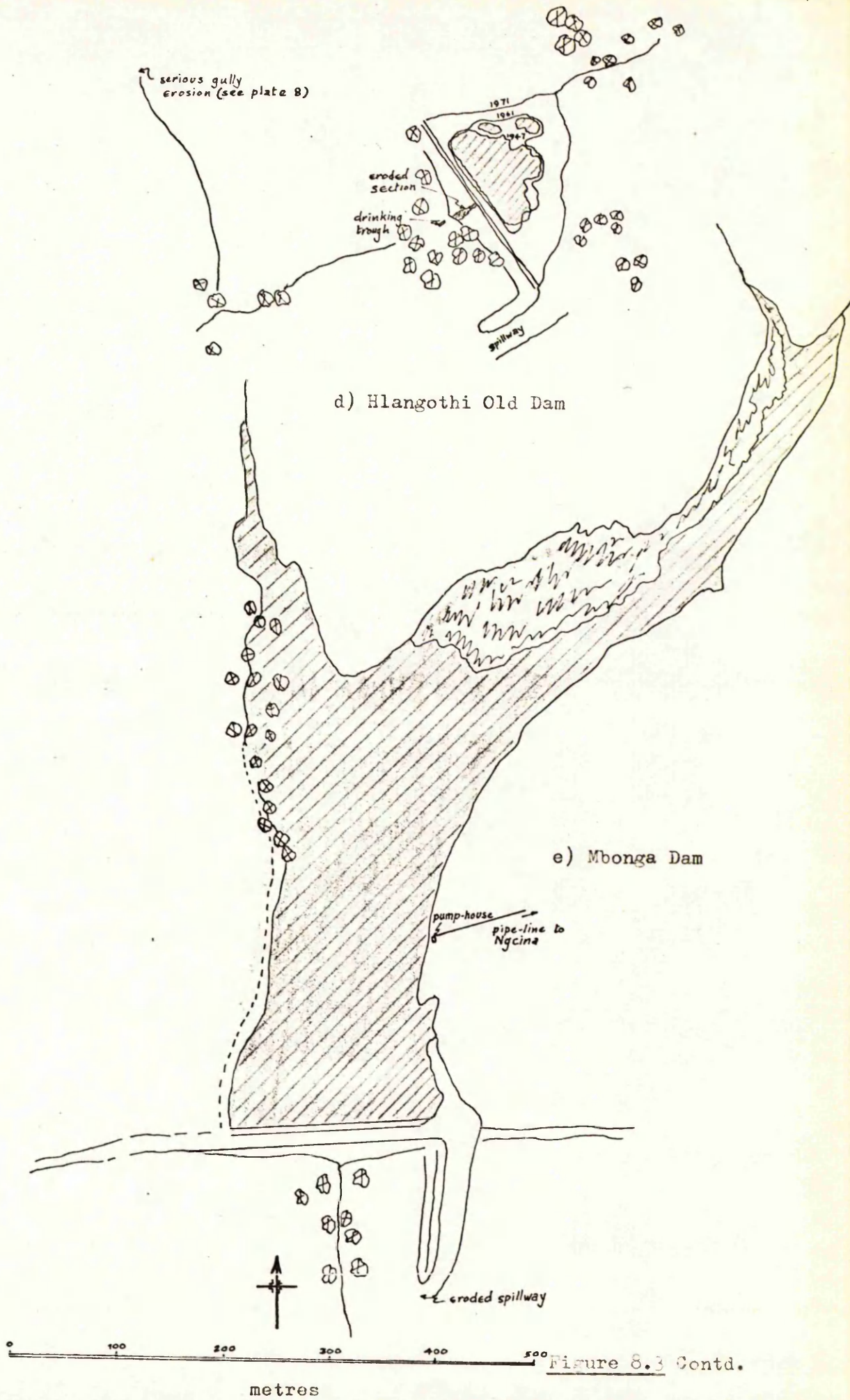


Figure 8.3 Contd.

metres

Table 8.1
Field Measurements and Area-Capacity Relationships

DAM	Embankment length (m)	Max. depth of water (m)	Free-board (m)	Water surface area when full (m ²)	Capacity $V = \frac{2Ad}{5}$ (m ³)	Constant 'b'	Live Storage (m ³)
Sefutshani	305	6.8	1.7	68,000	185,000	47	166,000
Mkutshane	260	6.5	1.7	53,000	140,000	43	126,000
Maggenya's	207	3.65	1.7	33,500	45,000 ¹	n.a.	40,000
Mbcnga	220	4.7	1.7	110,000	206,000	79	185,000
Hlangothi Old	200	3.7	0.6	15,300	22,800	37	20,500

Note 1. The formula $V = \frac{2Ad}{5}$ does not apply to this dam because of topographical irregularities.

This gives the capacity-area-depth relationship of:

$$V = \frac{2Ad}{5}$$

Using the maximum values of d and A obtained as described above, the constant b can be evaluated for each dam, and capacity-area curves drawn (Table 8.1 and Figure 8.4).

Although this relationship generally gives satisfactory results, the specific irregularities of some sites sometimes makes it rather approximate. In the case of Maggenya's Dam, an attempt was made to allow for a large flat area which only became flooded at high water levels. This area was observed on the ground, and its effect on the surface area of the water could be seen in the air photographs.

A further refinement is also needed because not all the water in a reservoir can be effectively used. When the water falls below the suction head of the pump for the Ngcina supply at Mbonga Dam, for example, the remaining unusable capacity is "dead" storage. For dams where cattle are watered, the dead storage will be very small, since cattle can go on drinking even when only a shallow depth of water remains. In practice, however, the bottom of the dam would become a useless mud bath before such a low level was reached. For the purposes of calculation, dead storage has been set at 10 per cent of total capacity, and hence live storage is 90 per cent (Table 8.2). This value also allows for some reduction in capacity due to silting.

The current 1:50,000 map of Mpolonjeni (1966 edition) shows only Hlangothi Old Dam. With the aid of the air photographs taken in 1971, the other dams were located on the contoured map, and catchment areas were delineated and measured.

From local knowledge of run-off conditions (Chapter 3), estimates of the mean annual run-off (MAR) were obtained for each catchment. Midgley and Pitman (1969), whose work provided the basis for these

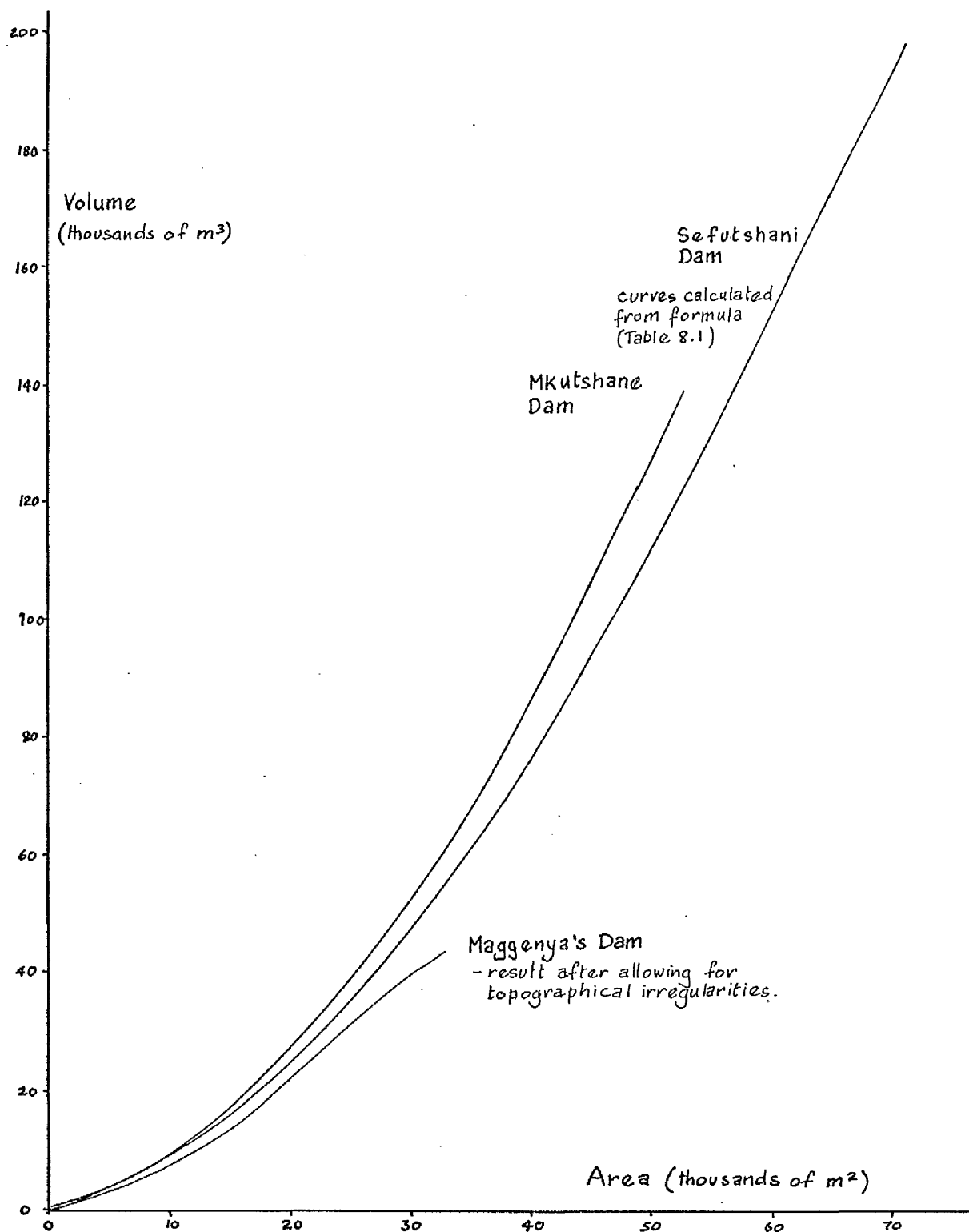


Figure 8.4 AREA - CAPACITY RELATIONSHIPS FOR MPOLONJENI DAMS

Table 8.2

Catchment Areas, Mean Annual Run-Off, and Gross and Safe Draughts

DAM	Catchment area (ha)	Estimated MAR (mm)	Estimated MAR (m ³)	Live storage in terms of MAR %	Midgley & Pitman's graphs		
					Recurrence interval 20yr.	Gross draught (% mean flow)	Safe draught (m ³ /month)
Sefutshani	1580	26	411,000	41	60	20,500	11,500
Mkutshane							
low flow conditions	800	30	240,000	52	65	13,000	7,000
flood condions	1200	30	(2)	(2)			
Maggenya's	170	16 ⁽¹⁾	27,000	148	94	2,100	0
Mbonga							
low flow conditions	2800	26	730,000	40	58	35,000	21,000
Hlangothi Old	90	30	27,000	76	76	1,700	200

Notes (1) The low run-off in this catchment has been discussed by Pacey (1973).

(2) Calculations for Mkutshane Dam refer to low flow conditions only.

estimates, suggests that vegetal cover is perhaps the most significant influence on run-off. Thus mean annual run-off estimates were adjusted according to the relative proportions of grazing and cultivated or fallow land in the catchment areas. The final step in assembling the basic data on these dams was to express the capacities as a percentage of the run-off produced by their catchments (Table 8.2).

In the absence full-field surveys, large scale maps (e.g. 1 : 10,000 or 1 : 5,000) or stream gauging records, these data are necessarily approximate. It is doubtful whether refinements to the data obtained could produce any increase in accuracy, and so when the data were presented elsewhere (Farrar & Pacey 1974) refinements were sometimes omitted. But since the main purpose here is to explore the relevance of more sophisticated methods to small dams, some changes have been made. The data presented here differ from those previously produced in the following ways:

- (a) in basing calculations on live storage rather than total storage,
- (b) in defining the catchment area of Mkutshane Dam. A smaller and probably silted dam upstream overflows during flood conditions so that Mkutshane Dam receives almost all the water from a catchment area of 1200 ha. In low-flow conditions, however, the smaller dam ceases to overflow, and the Mkutshane catchment is effectively reduced to 800 ha,
- (c) in dealing with Mbonga Dam, the problem occurs because in flood conditions it receives overflow from Mkutshane (and from Maggenya's Dam should that ever overflow - an unlikely event),
- (d) in calculating the capacity of Mbonga Dam, a better measurement of the depth of water has been used than was available previously,
- (e) the water surface area of Hlangothi Old Dam was checked by field measurement in August 1973.

8.3 Supply Capabilities of the Reservoirs

From their computer analysis of recorded river flows in southern Africa, Midgley and Pitman identified a series of characteristic

drought regions. For each region they produced a co-axial diagram relating gross draught from a reservoir, recurrence interval, month of the year and storage requirement. Using the diagram relevant to Swaziland, the estimates of gross draught for each of the reservoirs and a recurrence interval of 20 years are shown in Table 8.2. In each case the critical storage condition occurs at the end of April.

The gross draught represents the total outflow possible with the stated risk, and includes evaporation, seepage and leakage. In order to estimate the "safe draught", i.e. that which can be utilised, evaporation and seepage losses have to be assessed and subtracted from the gross draught. Midgley and Pitman (1969) have provided a second graph for making this calculation. Given the mean monthly evaporation (in mm), the initial water surface area and the dead storage, the mean monthly volume of water lost can be read directly from this graph. Where seepage losses are important, they are incorporated by expressing them as a mean monthly fall in water levels, using the same units as evaporation. Seepage losses are then added to evaporation, and the graph is used as before. The way seepage losses were estimated in this case is described below; the results of the completed calculation are shown in Table 8.2 (see also Table 8.6).

An alternative way of calculating the safe draught of a reservoir is by performing a step-by-step solution of the general storage equation for the critical low flow sequence with a chosen recurrence interval. Sefutshani Dam was chosen to illustrate this exercise for a known or simulated low-flow sequence which occurs on average once in 20 years.

The storage equation may be written as follows:

$$S_b = S_e + U_m + E_m + P_m - I_m$$

in which S refers to the storage state,
 I to inflow,
 U to useful draught,
 E to evaporation loss, and
 P to seepage loss.

The subscripts b and e refer to the beginning and end of the month, and m to the average for the month.

The calculation proceeds in reverse chronology, starting with Se set equal to the dead storage. For Sefutshani Dam, this has been assumed to be $18,500 \text{ m}^3$. The total storage is also known - $185,000 \text{ m}^3$ - so a value of Um - the safe draught - has to be found and appropriate values of Em and Pm obtained to satisfy the chosen low-flow sequence. The values for the low-flow inflow, evaporation, and seepage were obtained as described below.

Low-Flow Sequence

At this stage it is necessary to make some qualifying remarks about the validity of the low-flow sequence method in general for assessing the draught of a reservoir. The basis of the method is that the probability of the reservoir emptying is the same as the probability of the low-flow sequence. For most practical purposes, i.e. moderate relative demands, this is a reasonable assumption, but as White, J.B. (1967) has pointed out, this is not so when relative demand is high. In this study, demands are around 60 per cent of MAR, and the errors involved are likely to be small.

Midgley and Pitman provide low-flow sequences for each of their drought regions. The region of which Swaziland is a part also includes parts of Natal and the Eastern Transvaal. It is doubtful whether average data for such a large area can be safely applied to a small area of the Swaziland Lowveld. However, during the United Nations study of water resources in Swaziland (FAO/UNDP 1970), data relevant to the Usutu basin were obtained. Midgley and Pitman determined long-term mean annual run-off in areas where river gauging records were scarce by using a direct ratio between these areas and a base station where long-term records did exist. The United Nations study refined this technique to take into consideration

variations in recorded flow, and developed a model based on comparisons of standard deviations.

In the Table 8.3 below, the inflow sequence for the recurrence interval of 20 years was provided by Midgley and Pitman, whilst the monthly distribution is that given in the FAO report. The chief limitation of these figures is that they are based on flow records of major rivers, like the Usutu, and it is clear that the behaviour of small upland catchments, such as those at Mpolonjeni, is quite different. The Usutu has a perennial flow, while no flow at all occurs in most Lowveld catchments for weeks at a time. In general, the flow records of an upland river should show a sharp peak while the volume of flow in a mature river rises and falls much more gently. Major rivers have a larger groundwater flow, and their catchments have long times of concentration and include areas with a variety of rainfall characteristics. In Swaziland Lowveld conditions, all these factors help to give the major rivers a greater dry season flow than can be expected in upland catchments.

Ideally, a low-flow sequence record for the particular catchment would be used. In the absence of stream gauging records for the smaller catchments in the Lowveld, it was decided to use the Midgley and Pitman figures and the flow distribution obtained in the United Nations study. The FAO/UNDP drought flow distribution, in fact, suggests a more even distribution than the equivalent figures given by Midgley and Pitman, but since the latter are average figures for a very large region, and the former are specific to the Usutu and its tributaries, the combination referred to above was considered more suitable.

Table 8.3

Low-Flow Sequence for Sefutshani Dam - Recurrence Interval of 20 years

MAR = 26 mm Catchment area = 1580 ha.
Therefore MAR = $41.1 \times 10^4 \text{ m}^3$.

Cumulative deficient flow as percentage of MAR

Year 1	inflow 40.3%	year 1 inflow (m^3)	16.5×10^4
Year 2 cumulative	inflow 111.1%	year 2 inflow	19.1 "
Year 3 cumulative	inflow 192.9 %	year 3 inflow	33.6 "

Table 8.3 Contd.

Average percentage of annual flow in each month of drought years

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
% age distri- bution	4.9	8.7	14.2	15.3	15.0	11.7	8.7	5.8	4.5	4.2	3.6	3.4
Inflow $m^3 \times 10^3$												
Year 1	8.1	14.4	23.4	25.2	24.8	19.3	14.4	9.6	7.4	6.9	5.9	5.6
Year 2	9.1	16.6	27.1	29.2	28.6	22.4	16.6	10.9	8.6	8.0	6.9	6.5
Year 3	16.5	29.2	47.7	51.4	50.3	39.3	29.2	19.5	15.1	13.4	11.5	10.8

Evaporation

Net evaporation losses are obtained by subtracting expected rainfall from gross evaporation, but the difficulty arises of what recurrence interval of evaporation variation can be associated with a specific recurrence interval of low-flow sequences. It is unlikely that a sequence of net evaporation having a 20year return period would coincide with a deficient flow sequence of 20year return period. Whatever joint frequency analyses are likely to reveal, the error in estimating net evaporation is only likely to be 2 to 3 per cent (Midgley and Pitman 1969). These authors therefore suggest that the net evaporation rates are assessed by subtracting from average gross evaporation, a rainfall value given by all those years for which annual rainfall is below average.

It is not clear whether the authors are thinking of monthly or yearly averages, but in any event, the data for Mpolonjeni are inadequate for this operation. Thus it was decided to assess net evaporation by subtracting from the estimated mean evaporation data (Table 3.1 Chapter 3) deficient rainfall figures which apply to the Lowveld as a whole. The figures used are given in a Swaziland Department of Agriculture bulletin (Lea, Murdoch and Cornish-Bowden 1965) and refer to 38 years of Lowveld records. By inspecting monthly rainfall records for the period 1927-1965,

these authors abstracted those figures which showed that on average, one year in four, the rainfall in each particular month would fall short of the figures given in Table 8.4.

Obviously the total yearly rainfall produced by this method has little meaning, since the monthly rainfall figures are not related to any one year. The evaporation figures given in column 3 of Table 8.4 are probably too extreme, and as result the net evaporation is likely to be an over-estimate. However, as pointed out earlier, the low-flow sequence method is quite speculative for Mpolonjeni dams, and errors in evaporation will not greatly affect the result.

Table 8.4

Extreme Open-Water Evaporation at Mpolonjeni (net)

Month	Estimated mean open-water evaporation (mm)	Rainfall in the Lowveld; 1 yr in 4 it will fall short of these amounts (mm)	Extreme net evapora- tion coinciding with low-flow sequence (mm)
Oct	120	21	99
Nov	144	36	108
Dec	166	46	120
Jan	168	45	125
Feb	140	36	104
Mar	128	28	100
Apr	100	15	85
May	73	10	63
June	60	5	55
July	65	3	62
Aug	94	5	89
Sep	112	13	99
Totals	1370		1109

Two distinct evaporation rates can be identified:

	Average net evaporation mm/month
April to August	71
September to March	122

The actual evaporation losses for any storage state of the reservoir may now be obtained with the aid of the area-storage curve (Figure 8.4) to produce storage-evaporation curves as shown in Figure 8.5.

Seepage losses

Seepage losses through and under the dam wall are more difficult to assess, since they require a detailed knowledge of the construction materials, and the geological conditions in the immediate vicinity of the dam

The qualitative evidence for substantial seepage losses from all the Mpolonjeni dams is very clear. During August 1973, and after two months with virtually no rain, vegetation in the downstream areas of the dams was invariably lush when compared with the surrounding areas. Fever trees, which are good indicators of moist ground conditions, were even more prominent. Trees and bushes were sometimes very well established on the embankments themselves. The ground immediately downstream was often marshy, and at two dams, Maggenya's and Mkutshane, there was standing water. That at Maggenya's was used by the local people as a washing point (Plate 7). At Mkutshane Dam, two channels of water appeared from the toe of the embankment. The flow of water was sufficient for one enterprising farmer to have established an irrigated plot of some 700 m². Bananas, paw-paws, tomatoes, beans and maize were growing.

A theoretical quantitative assessment of seepage at Sefutshani Dam was obtained using the principle of flow nets. Figure 8.6 shows the flow net for the deepest section when the dam was full. The use of flow nets in this way requires a number of assumptions about Sefutshani Dam:

1. the soil from which the dam is constructed is homogeneous,
2. there is no impermeable or semi-permeable core to the dam, nor is there any toe drainage on the downstream embankment,*

*There was no evidence of a core or drainage toe at any of the dams. The description of seepage water already given suggests that this assumption is not unreasonable. An attempt by the author to elicit construction details from the Ministry of Agriculture met with no response.

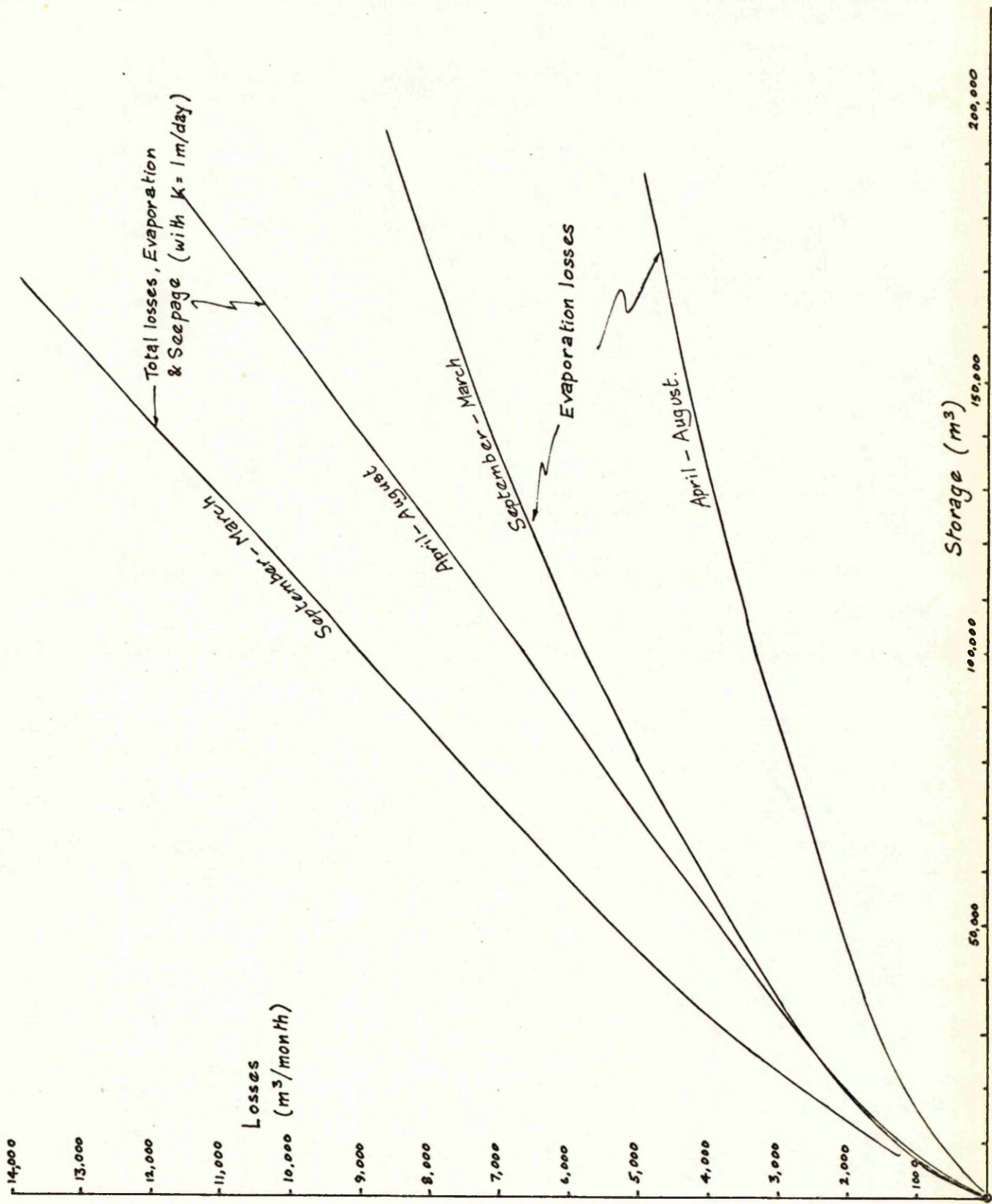


Figure 8.5 EVAPORATION AND SEEPAGE LOSSES WITH STORAGE STATE - SEFUTSHANI DAM

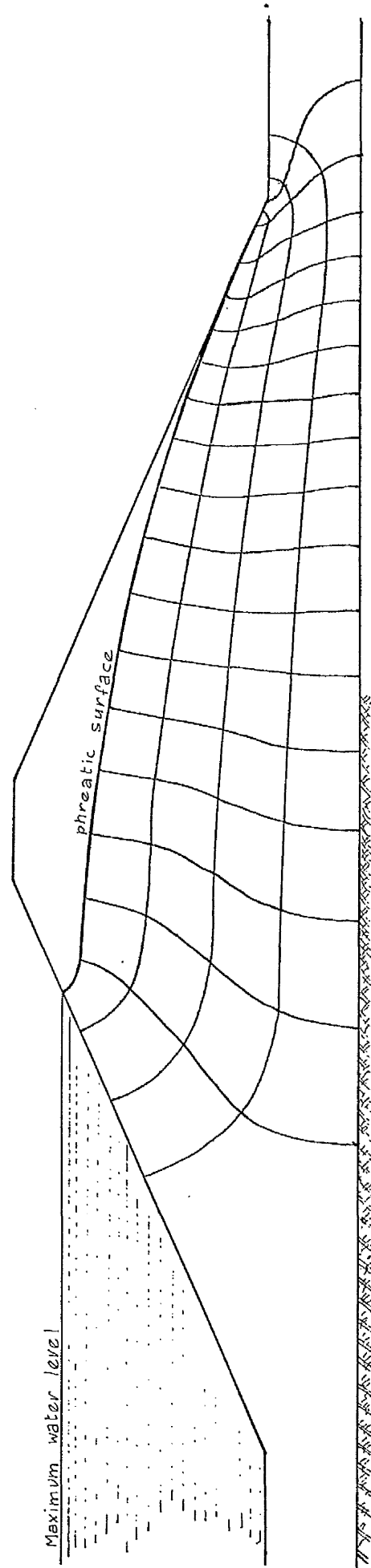


Figure 8.6 FLOW NET FOR SEPUTSHANI DAM - THE DEEPEST SECTION WHEN THE DAM IS FULL

3. the dam has soil foundations which have the same permeability as the embankment. From a knowledge of local geology and soils, the depth of the soil to the impervious rock at the deepest section is assumed to be 3 m.

The phreatic surface was determined according to the analyses given by Sowers (1962). It should be noted that it leaves the downstream embankment some distance above the toe. For safety reasons, it is desirable that the phreatic surface be contained completely within the embankment; a drainage toe is one method of achieving this.

The seepage flow (q) per unit length of embankment is given by:

$$q = K h \frac{M}{N}$$

where M is the number of flow channels,
 N is the number of potential drops,
 h is the total head,
 K is the permeability of the material.

The seepage flow for that section of Sefutshani Dam shown in Figure 8.6 is 1.62 K per unit length of embankment. The total flow through and under the embankment may be determined by drawing a series of flow net diagrams for different sections of the embankment and for different storage states. In fact, two other water depths were chosen - for half and quarter reservoir capacity - and two other cross-sections were chosen - at a distance of 30m and 70m from the centre section. The values obtained at the different cross-sections were taken to be average values for those parts of the embankment for which they were representative. In this way, the contribution of the various sections to the total flow were assessed as follows:

	%age of seepage flow	%age of dam length
Centre section	24	12
Intermediate section	23	22
Abutments section	53	66

Total losses for Sefutshani Dam for the three storage states were then calculated to be:

	<u>Storage (m^3)</u>	<u>Seepage Losses</u>
Full	185,000	229 K
Half	93,000	100 K
Quarter	46,000	48 K

The problem now is to estimate a value of K. All the dams were built from materials in the vicinity, mostly excavated from the beds of the reservoirs themselves, so increasing capacity somewhat; these materials may be summarised as follows:

- (a) Mkutshane, Maggenya's and Mbonga Dam - crushed weathered basalt; semi-pervious material with K likely to fall in the range 0.001 to 10.0 metres/day (Capper & Cassie 1969).
- (b) Sefutshani Dam - crushed ecca sandstone; some clay from Z - set soil; K probably in the same range as above.
- (c) Hlangothi Old Dam - clay loam soil; low value of K except where cracked as a result of drying out (see Section 8.4).

An attempt to measure seepage and leakage losses at Maggenya's Dam was made by Farrar and Pacey (1974). The method was to observe storage states at different times, e.g. during fieldwork in June 1972 and August 1973 (Chapter 3). All other inflows and outflows were accounted for; the deficit was attributed to seepage and leakage losses. The result was an estimate of seepage losses of 130 to 140 m^3 per day, while the corresponding flow net estimate for seepage was 50K to 60K. Thus if all the losses were accounted for by seepage, K is approximately 2.5 m/day which is a very high figure. In fact, all the dams appear to lose some water by leakage to groundwater. This may be particularly important at Sefutshani Dam, where the geological map shows two faults crossing the site of the reservoir. At Mbonga

and Mkutshane Dams, the geological maps show several dolerite dykes running approximately at right angles to the dam embankments. As shown in Chapter 3, dykes can influence the movement of water to groundwater. Although no dykes are shown near Maggenya's Dam, it is quite likely that dolerite intrusions exist there as well. This whole region of the Lowveld is riddled with dykes, but only when they are easily seen in the river valleys do they appear on the geological maps (Chapter 3, Figure 3.6)

Losses by leakage are almost impossible to estimate, but are likely to be proportional to ground area covered by water. They will thus tend towards a constant reduction in depth per day.

Faced with these uncertainties, either of two simplifying assumptions may be made so that at least a reasonable approximation for the safe draught of the dam can be obtained. Farrar and Pacey (1974) assumed seepage and leakage losses at a constant reduction in depth per day, and related all the dams to the observed behaviour of Maggenya's Dam. Seepage and leakage losses were therefore taken as about 3.3 mm/day at Maggenya's and 4.3 mm/day at Sefutshani Dams. The alternative is to assume that all the losses take place as seepage, and to use a value of K large enough to cover any leakage. For the solution of the storage equation the latter assumption has been made, with K set at 1.0 m/day. At most storage states this gives a slightly lower total loss than that suggested by Farrar and Pacey.

Total losses from Sefutshani Dam are plotted in Figure 8.5, where seepage losses calculated for various storage states have been added to the net evaporation loss calculated previously.

Solution of the Storage Equation for Safe Draught

The solution of the storage equation starts with a consideration of the storage state at the end of the 3-year low-flow sequence. For the chosen recurrence interval the reservoir should fail at the end of

the critical month - in this case October. At the end of "year 1" the storage in the reservoir will equal the dead storage. The storage state at the end and beginning of the month (or the end of the previous month - September) is calculated by adding on to the dead storage the evaporation and other losses (Figure 8.5) and the assumed safe draught, and subtracting the sum from the inflow. This process is continued month-by-month until the storage reaches a maximum equal to the total storage capacity of the dam.

It is necessary to use a trial-and-error method to establish a figure for the draught (U_m). In this case, a preliminary inspection indicated that the required value was between 12,000 and 13,000 m^3 per month. The final calculation of the water budget for a draught of 12,600 m^3 per month is shown in Table 8.5, where the critical storage for failure occurring on average once in 20 years is given as 181,600 m^3 at the beginning of May, 30 months before the failure actually occurs. This value of 181,600 m^3 is sufficiently close to the total capacity of Sefutshani Dam (185,000 m^3) for the value of U_m , 12,600 m^3 per month, to be considered the safe draught. It should be noted that the calculations must be continued beyond local maxima. Obviously, a further trial could be performed so that the "maximum storage" coincided exactly with the dam capacity, but the approximations involved in the estimate of seepage do not warrant this accuracy.

Results obtained by the above "step-wise" solution of the water budget should be similar to the results obtained by the graph method mentioned previously, since both incorporate critical flow data which are basically the same. The step-wise method is slightly more refined, since it takes into account seasonal variations in evaporation. Comparative results obtained by the two methods are shown in Table 8.6 for three of the dams.

Table 8.5

Solution of the Storage Equation for Sefutshani Dam

	Inflow Im	Storage Se	Evaporation Em	Seepage Pm	Storage Sb
Oct	8,100	18,500	2,100	600	25,700
Sept	5,600	25,700	2,500	700	35,900
Aug	5,900	35,900	1,800	1,200	45,600
July	6,900	45,600	2,000	1,400	54,700
June	7,400	54,700	2,300	1,700	63,900
May	9,600	63,900	2,500	2,000	71,000
Apr	14,400	71,400	2,700	2,200	74,500
Mar	19,300	74,500	4,900	2,300	75,000
Feb	24,800	75,000	4,900	2,300	70,000
Jan	25,200	70,000	4,700	2,200	64,300
Dec	23,400	64,300	4,400	2,000	59,900
Nov	14,400	59,900	4,200	1,800	64,100
Oct	9,400	64,100	4,400	2,000	73,700
Sept	6,500	73,700	4,800	2,300	86,900
Aug	6,900	86,900	3,100	2,800	98,500
July	8,000	98,500	3,400	3,200	109,700
June	8,600	109,700	3,600	3,600	120,900
May	10,900	120,900	3,800	4,000	130,400
Apr	16,600	130,400	3,900	4,400	134,700
Mar	22,400	134,700	6,800	4,600	136,300
Feb	28,600	136,300	6,900	4,600	131,800
Jan	29,200	131,800	6,700	4,400	126,300
Dec	27,100	126,300	6,500	4,200	122,500
Nov	16,600	122,500	6,400	4,100	129,000
Oct	16,500	129,000	6,700	4,300	136,100
Sept	10,800	136,100	6,900	4,600	149,400
Aug	11,500	149,400	4,200	5,200	159,900
July	13,400	159,900	4,400	5,700	169,200
June	15,100	169,200	4,600	6,100	177,400
May	19,500	177,400	4,700	6,400	181,600
Apr	29,200	181,600	4,800	6,600	176,400
Mar	39,300	176,400	8,000	6,900	164,100
Feb	50,300	164,100	7,700	5,900	140,000

Recurrence interval - 20years, Useful draught - 12,600 m³/month

Table 8.6

Estimates of Safe-Draught at Three Dams (Failure 1 in 20 years)

Dam	Graph Method (Midgely & Pitman 1969)			Step-wise Method
	Gross Draught from Table 8.2	Mean Total * losses assumed	Safe Draught	
	(m ³ /month)	(m ³ /month)	(m ³ /month)	
Sefutshani	20,500	8,700	11,800	12,600
Mkutshane	13,000	6,000	7,000	8,300
Maggenya's	2,100	4,000	0	0

* Calculated from the Midgely and Pitman diagram with the following estimates of seepage: Sefutshani Dam 4.3 mm/day consistent with the calculations made above. Mkutshane and Maggenya's Dams respectively, 2.5 mm and 3.3 mm per day, as estimated by Farrar and Pacey (1974). These seepage losses must be added to the total mean evaporation when the diagram is used, and total losses in the table include evaporation.

These two methods give consistent answers. But, as pointed out earlier, they are derived from low-flow sequences which have been obtained from records and simulated records of major river flows which are fed by large catchments. The small catchments considered here are likely to behave much more erratically.

Thus for the same recurrence interval, low flow records like that given in Table 8.3, but for a small upland catchment, would show a lower percentage cumulative inflow and a wider distribution of monthly inflows. In particular, run-off for the winter months June to August would usually be negligible during drought years, whilst the three summer months, December to February, would each contribute over 20 per cent to the total yearly flow (Figure 8.7).

There is insufficient reliable data to perform a new stage-wise solution to the storage equation, using a modified form of low-flow sequences. But the sensitivity of the worked example to even small changes to "safe draught", and very rough figures for a low flow

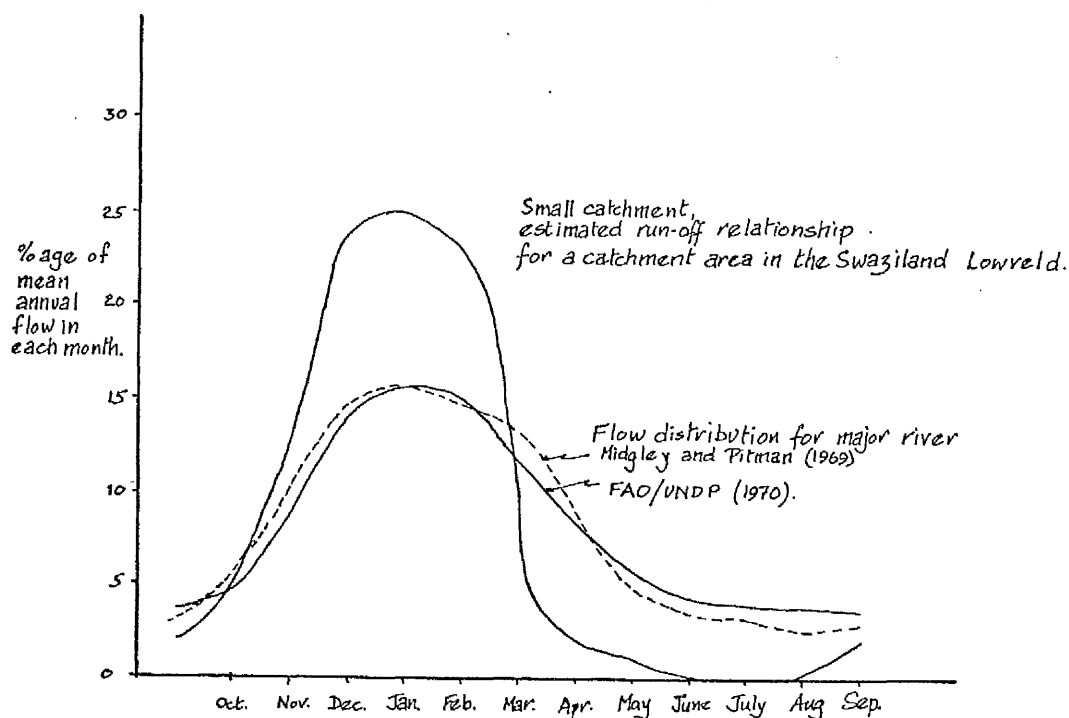


Figure 8.7 . COMPARISON BETWEEN FLOW DISTRIBUTION OF A SMALL UPLAND CATCHMENT IN THE SWAZILAND LOWVELD AND A MAJOR RIVER

The flow distribution for the small catchment is estimated from rainfall and run-off relationships. The curves for the major river are given by Midgley and Pitman (1969) and FAO/UNDP (1970)

distribution like that shown in Figure 8.7 suggest that values of "safe draught" already obtained may be around twice as great as the true value.

This section has illustrated the problems of using Midgley and Pitman's methods for village-scale dams. Few African countries can be expected to have data available to allow estimates of safe draught to be obtained accurately and with confidence in the result. It is clear that any "appropriate technology" approach developed to enable small dams to be more efficiently used will have to be less dependent on detailed hydrological records. It is suggested that charts should be developed for this purpose which incorporate a pessimistic estimate of seepage losses and of low-flow behaviour. These graphs would be more approximate than those given by Midgley and Pitman, and should not attempt to include safe draughts for very low risks, such as 1 in 50 or 1 in 100 chances of failure. Obviously, a separate graph would have to be produced for each geologically distinct region, because of different seepage and leakage behaviour. Such graphs would only provide crude estimates but at present there is no satisfactory method for estimating the safe draught of these small dams.

8.4 A Note on Hlangothi Old Dam

Because it has for a long time been the most convenient source of water for many people at Mpolonjeni, Hlangothi Old Dam is of considerable social importance. It was built at an unknown date between 1942 and 1947, following the first serious water development programme to be carried out in the Swazi National areas of the Lowveld which was inaugurated in 1931 (Roberts, 1942). The dam might therefore be expected to contain more than 25 years of silt deposits, and to have a greatly reduced capacity. However, the air photographs suggest that

the dam was reconstructed at some time between 1961 and 1971. The main embankment was made longer and higher, and the area occupied by the water increased considerably. It seems probable that the sediment layer was excavated from the dam during this reconstruction, and it is possible that the black clay soil out of which the present embankment is built consists partly of material obtained from this source. However, no information has been obtained about this from the relevant authorities, and it is impossible to give more detail than could be observed on the site.

The embankment at this dam is built of very much more impermeable material than that of any of the other dams discussed, with the coefficient of permeability (K) perhaps in the region of 10^{-3} to 10^{-5} metres/day. However, the clay which contributes to this low permeability is liable to cause shrinking and cracking as the soil dries out, so there may be circumstances when more water can pass through the embankment than the low value of K suggests.

At a point midway along the embankment, a collapse has occurred, and more than half the section of the dam has disappeared. It was possible to examine the structure of the dam at this point, and confirm that it was homogeneous.

When water levels in the dam are high, water overflows at this damaged section, and it seems clear that over-topping of this kind is the explanation for the present shape of the hole in the embankment. The profile of the eroded section (Figure 8.8) is that of a straight drop spillway complete with stilling basin, which overflowing water would create for itself. Also the fact that all the material from this hole has been removed and completely dispersed over a wide area is further indication of extensive over-topping.

The question therefore arises as to whether over-topping was the original cause of this partial failure. No damage is visible in

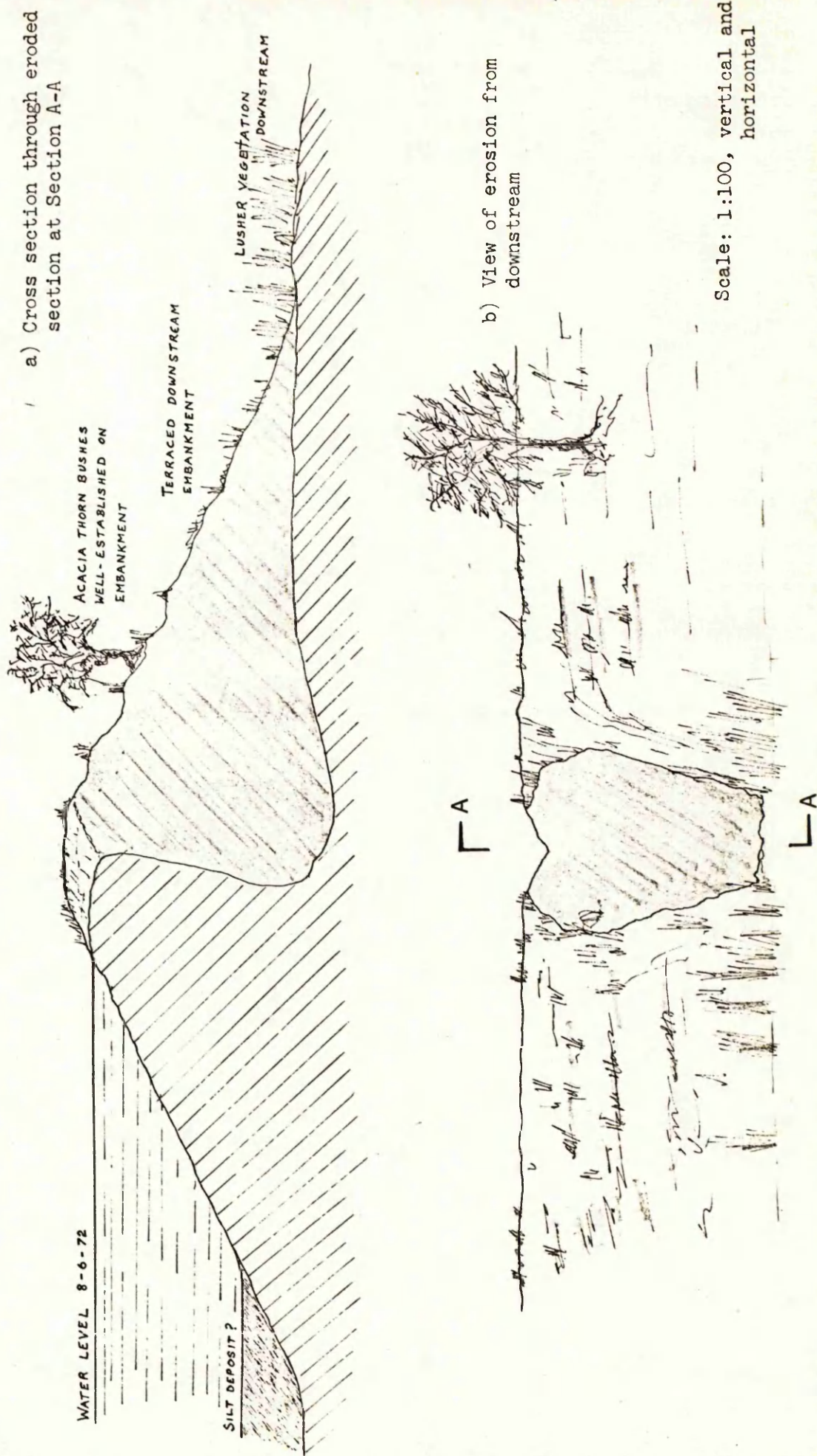


FIGURE 8.8 SKETCH SHOWING EROSION OF HLANGOTHI OLD DAM - observed June 1972 and August 1973

the air photograph taken in September 1971, but when the site was visited in June 1972, the erosion looked as if it had been quite recent. The water level was only 3 or 4 cm below the minimum needed for over-topping, and the eroded soil surfaces were moist. When the site was re-visited in August 1973, little change was to be observed except that the eroded soil surface was now dry and brittle. The failure of the embankment must therefore be seen in the context of the exceptionally high rainfall of the 1971-2 season, which is estimated to have produced more than twice the average amount of run-off (Chapter 3). The maximum capacity of this dam is $22,800 \text{ m}^3$, and run-off in its catchment may have been about $50,000 \text{ m}^3$. Extensive overflow is therefore likely to have occurred, and because the spillway was overgrown, water levels could easily have risen to a point where over-topping would begin, with consequent erosion of the downstream face of the embankment.

This raises the question of why over-topping occurred only at one point. Clearly, this was a weak spot which was immediately exploited by an unusually high water level. The initial depression in the crest may have been due originally to the trampling of cattle, or to some other apparently trivial reason. It may be significant, however, that this dam has a narrow crest - only 1.7 metres wide.

This may be the result of increasing the dam capacity; the height could have been increased by adding to the original profile. Or it could be because the dam was re-built using a bulldozer, probably supplemented by hand labour. In either event, the earth may not have been properly consolidated, and the original depression where over-topping occurred could have been the result of uneven settlement.

An alternative explanation of the failure of Hlangothi Old Dam rests with the black clay soil used in its construction. When this type of soil dries out, it shrinks and large cracks develop. The year

1970-71 was of near average rainfall, but the previous year had been very dry. It is possible that during the dry period, when the water level in the dam was very low, the clay soil had dried out sufficiently for vertical cracks to develop in the upstream and downstream slopes.

It has already been demonstrated (Chapter 3) how quickly water levels in Hlangothi Old Dam can rise following a storm. Thus a vertical crack near the top of the upstream embankment might initially allow water to leak through to dislodge some soil. The loss of water would not be large, but when the crack healed with the swelling of the soil, there may also have been some downward displacement of soil, leaving a depression on the crest for water to overtop.

A more complicated explanation for the failure in the structure depends on the phenomenon of piping - the process of internal erosion of the soil mass by seepage water through and under the dam. Piping manifests itself first on the rear embankment in the washing out of fines from the soil mass. The increasing flow of water through one preferred channel eventually forms a continuous opening from the front slope with the subsequent collapse of the earth above it. These effects need not lead to the total failure of the dam, for the partial collapse could effectively seal the pipe. The end result would be a slump in the crest and a series of minor collapses on the downstream slope which would have been obliterated at Hlangothi Old Dam by water overtopping.

A material which is as homogeneous and impermeable as the cotton soil appeared to be would not normally be susceptible to piping (indeed piping is much more likely to occur at the other Mpolonjeni dams). But the conditions described above where large cracks appear in the soil in very dry weather could precipitate piping. Because of the nature of the soil, any cracks which might have developed would not be detectable once the soil had swollen. Piping in clay soils can also

be increased by the presence of sodium ions in the water, which has the effect of encouraging dispersal of the clay particles. The results of tests described in Chapter 5 suggest that this is unlikely to be a problem at Mpolonjeni, but where run-off water is saline, as in parts of Western Australia, piping failures are more frequent (McKenry 1967).

One final point to consider is the steel pipe which passes through the dam very near to the collapse and which originally supplied a cattle drinking trough. This is a potential source of danger; internal erosion and channelling could occur along the length of the pipe. The steel pipe was not visible in the eroded section, and there is no evidence which suggests that it was involved in the collapse.

8.5 Implications for Dam Construction and Maintenance at Mpolonjeni

The mechanisms of the failure of Hlangothi Old Dam which have been suggested could be explored in greater detail by model tests in the laboratory. Clearly the black cotton soil is not the most suitable material for dam construction at Mpolonjeni but using the alternative material, weathered basalt, is likely to mean that a significant proportion of water stored is lost by seepage. It would obviously be useful if the advantageous properties of the two materials could be combined.

The usual method of doing this would be to make an impermeable clay core within a weathered basalt dam. The main practical difficulty is to ensure that the clay core is properly constructed; preferably there would also be a core trench dug down to impervious rock. Proper puddling and compaction of the clay are required, to achieve low permeability and to ensure that the weathered basalt and clay core settle to the same extent.

There are two obstacles to achieving these results in the Swaziland Lowveld. Firstly the bedrock is fissured in many places

near intrusive dolerite dykes that it might be difficult to find an impervious foundation. Secondly, dams have to be constructed in the dry season, when it may be difficult to find sufficient water, and harness sufficient labour and equipment, for puddling the clay.

The problem could be overcome by accepting a much narrower clay core than usual, perhaps only 1 metre across. This could be dealt with by manual labour and "puddled" by cattle, whilst earth moving machinery deals with the basalt material on either side. In this way it should be possible for the manual labour and the machinery to work at comparable rates to produce a dam which is structurally sound but also less vulnerable to seepage losses.

Maintenance of Mpolonjeni Dams

The immediate problem for the existing Mpolonjeni dams is one of maintenance. Unless steps are taken to repair Hlangothi Old Dam, and clear and deepen the spillway to ensure that overtopping does not occur again, the dam is doomed to total failure during the next rainy season with more than average rainfall.

In the longer term, regular maintenance needs to be properly organised. None of the dams at Mpolonjeni was adequately fenced to prevent cattle trampling the embankment. With the newer dams, which have wide crests and a liberal freeboard, this is possibly less urgent than at Hlangothi Old Dam, where the downstream slope is "terraced" in parts by cattle tracks.

At all the dams, trees and bushes were growing on the embankment, their roots may provide other channels for seepage water. Spillways also need attention. At Sefutshani Dam, there was serious erosion during the 1971-72 season and the spillway should be repaired and widened. At Mbonga Dam, the spillway has been eroded where the water returns to the valley bottom. This is at some way downstream of the embankment and is not likely to affect the safety of the dam yet.

The maintenance problems of earth dams are experienced in many other African countries. Holloway (1970) has reported "a limited number of failures of low earth dams" in Tanzania. The causes were either spillways failing under flood conditions, or 'piping' through the embankment. The latter type of failure could almost always be attributed to inadequate compaction, or lenses of permeable material being included in the clay core.

In Kenya, a survey of 19 dams in a drier part of the country, revealed that 18 needed immediate attention. The maintenance required ranged from cutting back of vegetation to complete reconstruction. (Kenya, Water Department, 1972). The survey team noted erosion, seepage, and sagging in embankments, but the most common feature requiring attention was spillways. Sixteen of the dams had choked, silted or badly scoured spillways, and four out of the five "washouts" of embankments which had occurred could be attributed to poorly functioning spillways.

Dams are sometimes washed away in the Swaziland Lowveld, but in general, spillway problems are less there than in other semi-arid areas. In Botswana, concrete spillways are provided in most recent dams (Oxfam 1969). In some instances it is impossible to provide complete protection against erosion without considering concrete. Where the spillway is continued along the valley side, as in the Mpolonjeni dams, some elaborate drop structure would be required. In these circumstances, where concrete would normally be necessary, West (1971) has suggested that it might be cheaper to merely increase the capacity of the dam - the cost of a relatively small increase in height - so that the dam capacity approximated to at least one year's average annual run-off. If this were done, and assuming that the water taken from the reservoir each year was a sizeable proportion of the stored volume, i.e. either

water used, or lost from seepage and evaporation, the dam would be most unlikely to overflow. The design of Maggenya's Dam at Mpolonjeni, the capacity of which is 148 per cent of the mean annual run-off, meets these conditions, probably inadvertently since run-off in its catchment is very much less than the average for the area.

8.6 Bunded Dams

The dams so far discussed consist of straight embankments built across small valleys, and are filled by the streams which flow in these valleys during the rains. Another type of dam which is found throughout the semi-arid areas of Africa is one which can be built across gently sloping land to catch run-off water before it reaches a stream. There are two small dams of this type at Mpolonjeni, which provide more conveniently situated sources than the larger impounding reservoirs in the valleys. But in Botswana, where the topography does not offer many good sites for conventional dams, this type of storm water collection is now very widely used. The shapes of these dams vary with the sites, but a typical Botswana example built on land with an even and regular slope would consist of a bund built on a horseshoe-shaped plan with the arms pointing up the slope and thus defining the catchment area (Figure 8.9).

In the two dams at Mpolonjeni, the horseshoe is very much less pronounced, the bund being more gently curved, while at Serowe in Botswana, advantage was taken of two natural hillocks to build a straight embankment which looks like a very crude impounding dam.

Many bunded dams were built in Botswana by hand labour during the drought years of the 1960's, and they are often referred to as Ipelegeng dams. This name refers (in the vernacular) to the food-for-work scheme operated in 1966-67 through which construction was organised.

The material for the bund or embankment of these dams is usually taken from the centre of the enclosed area, thus increasing the

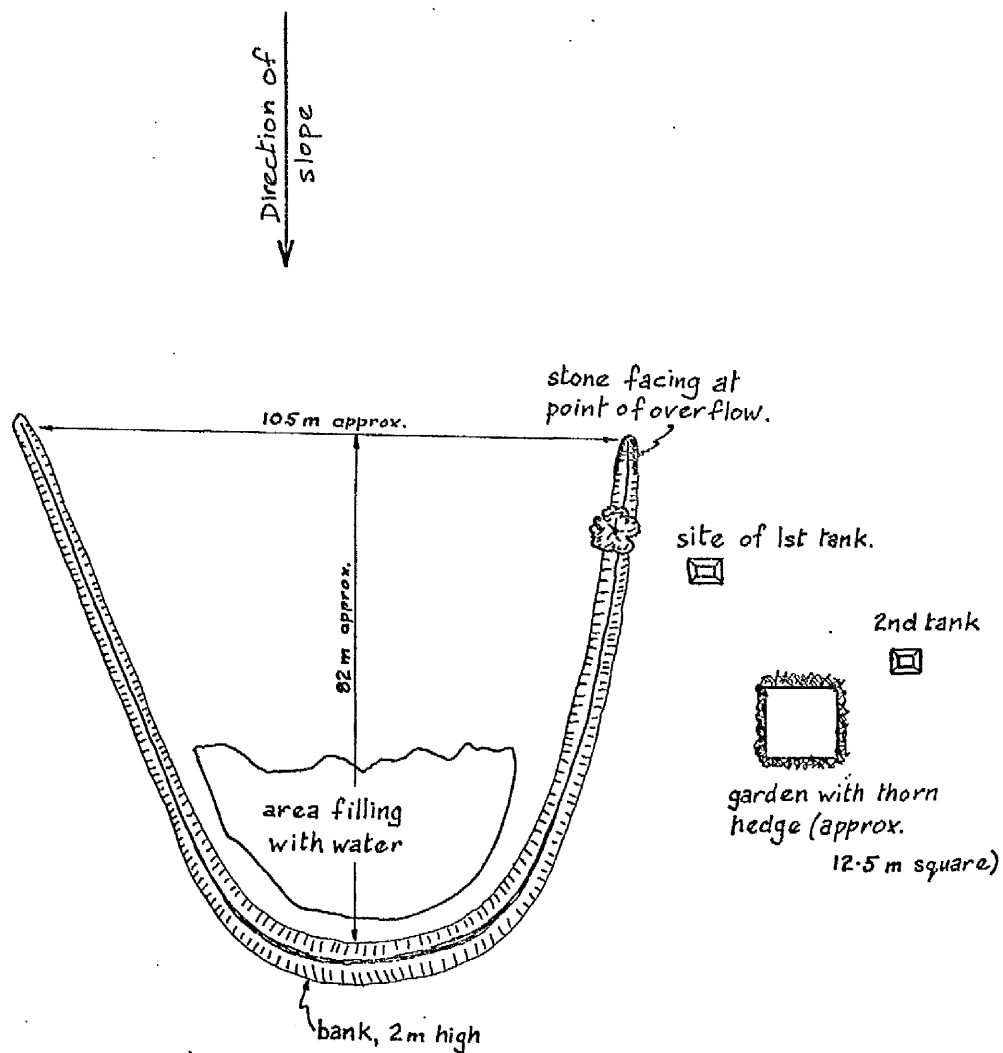


Figure 8.9

PLAN OF A BUNDED DAM - RATHOLO DAM, BOTSWANA

The dam was built in the 1960s by Ipelegeng labour (a food-for-work programme for famine relief). The dam was dry in June 1972.

The first catchment tank was destroyed by water overflowing from the bunded dam. The second tank was intended to have to have a butyl lining, but the tank was unusable in 1972.

total capacity. Even so, the water is usually very shallow, and rarely exceeds 2 metres depth. Ratholo Dam (Figure 8.9) was built on land sloping approximately 1° , and the horseshoe extends for about 85 metres. Thus when water is overflowing the spillway, the greatest depth of the reservoir would be 0.85 metres. After allowing for the excavation, this might be increased to 1.2 metres. The Serowe dam referred to earlier is a much larger structure. The height of the embankment at its deepest point is 4.9 m, but the spillway level is only 2.1 m. The maximum amount of water which the very small catchment is likely to produce is only 1.2 m. (These figures were obtained by plotting field observations on the official large scale map of Serowe Town and assuming a high value of run-off - 75-100 mm - from the average rainfall of 460 mm, see Table 2.1 Chapter 2).

Obviously this particular dam is over-designed, and a lot of manual labour has been wasted, but the shallow depths of bunded dams in general are important because open water evaporation in this part is likely to be in excess of 1500 mm. Evaporation alone would therefore empty both these dams in less than a year. With seepage losses and water consumed by cattle, it is clear that these dams will retain water for only a few months each year. In June 1972, Ratholo Dam was dry, while Serowe Dam contained 0.5 metres which would probably have lasted until July. With higher rainfall and lower evaporation in Swaziland, water in the small bunded dams there lasts longer. In 1971-72, water in one Mpolonjeni dam lasted until late June, but in an average year it dries up in April.

Except for one bunded dam at Mpolonjeni which is used extensively for domestic water, it is significant that these dams are used mainly for cattle. The animals are grazed on different areas during different seasons, especially in Botswana, and it is common practice to use grazing close to a bunded dam during the rains and soon after, and

later moving the herds to a permanent water source.

Bunded dams can make a useful contribution in this way, but they are a very inefficient method of storing water. In some parts of Botswana, they might have a more useful function in terms of groundwater recharge. At the village of Tamasana near Palapye, for example, cattle sheep and goats are watered at a group of seven hand-dug wells in an area of 3 to 4 ha. In June 1972, the water level in one well was observed to be about 15 m below the surface (This figure would include draw-down). The top soil in the area is sandy and apart from some trees, completely devoid of vegetation. It seems likely that all the sand and/or soft sandstone strata above the water table are highly permeable. Thus a bunded dam in the vicinity could be expected to leak to the aquifer, so raising or maintaining the water table, while sometimes providing a temporary water source for the cattle independent of the wells. A bunded dam intended to function in this way would need to have a layer of gravel spread over its floor so that the trampling would not create an impermeable puddled "pan".

One advantage of bunded dams is that they are small enough to be built by hand-labour aided sometimes by ox-drawn scoops. However as the dam-building programme in Botswana continued, larger dams were needed; and with the drought over, it was no longer so essential to provide work for large numbers of people. Thus the programme now includes some earth-moving machinery (Oxfam, 1968-69). Reports suggest a careful balance between manual labour and earth moving machinery is a more satisfactory arrangement (see Gibberd (1969) for a comparison between manual and machinery methods for bunded dam construction in Botswana). The dams being built in this programme are designed to fill with average to good year's rains and thereafter to hold water for at least two drought years. In view of the high seepage losses which can be expected, and the high

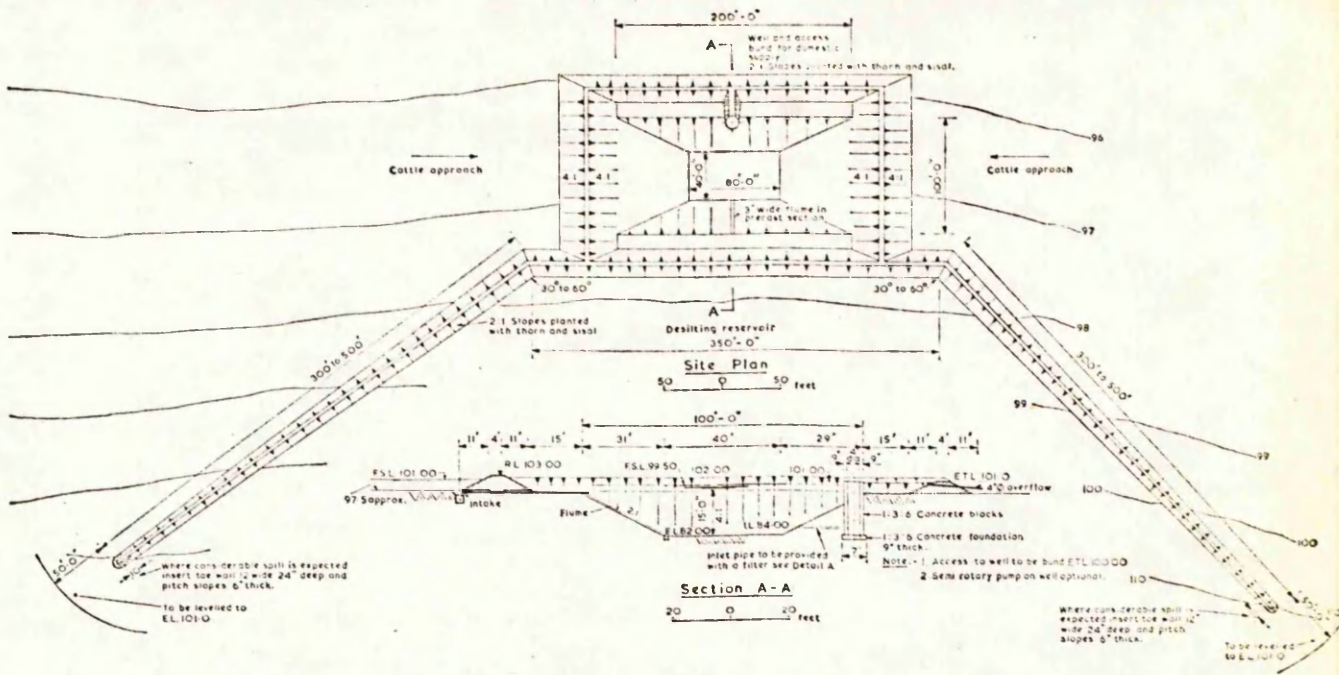
evaporation losses in Botswana's climate, these dams must be quite substantial structures and must be carefully sited. Most are conventional impounding dams rather than bunded dams. The average capacity of the 27 dams which had been built by the end of 1969 was $81,000 \text{ m}^3$. One dam of about this capacity, near Mochudi, was examined in June 1972. Its design differed from the Swaziland impounding dams only in having a concrete and brick-built spillway in the centre of the embankment, rather than an earth spillway in the valley side.

8.7 Charcos

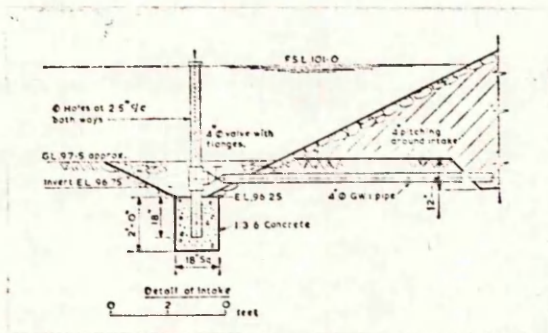
A modification of the bunded dam principle, and one that clearly shows the link between bunded dams and catchment tanks (Chapter 10) is the charco. Holloway (1970) has described its uses in Tanzania, and Figure 8.10 gives details of a typical site plan. According to Holloway, a charco giving a permanent supply would need to be sited in an area with a relatively well distributed rainfall of about 760 mm annually. A catchment area of about 12 ha would be needed, and the soil should be sufficiently impervious for the main tank to retain water. This tank is $1\frac{1}{2}$ million gallon capacity (about $6,800 \text{ m}^3$) and is supplied by a pipe from the collecting dam which acts as a desilting basin. Water is drawn off from the tank through a well point, and may be pumped by hand to cattle troughs.

Seepage losses are fairly small, the concentrating of water in a storage tank provides a more efficient method of storing water than the usual bunded dam. They also provide better quality water because most of the sediment will be retained in the collecting dam.

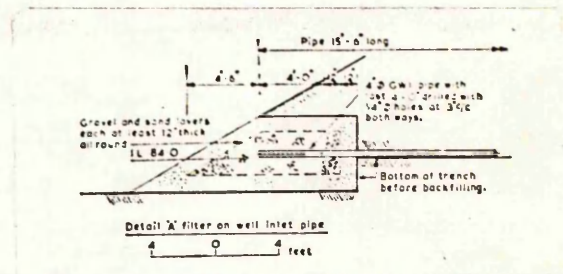
Holloway gives no details of cost, but says they are "a cheap means of supplying well-distributed water points in cattle country, where other naturally occurring sources are unobtainable". Examination



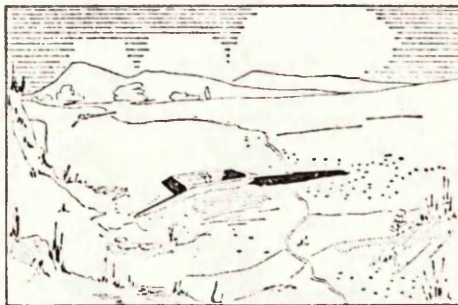
a) Site plan



b) Detail of intake



c) Detail 'A' filter on well inlet pipe



d) Sketch

Figure 8.10 DETAILS OF THE CHARCO (Holloway 1970)

of the Figure 8.10 shows fairly elaborate methods for the intake from the collecting dam and the intake to the well point. These probably improve the quality of water appreciably, but they are not the sort of construction which could be undertaken by communities on a self-help basis without extensive technical assistance. It is also clear that large amounts of earth moving are needed. In fact, charcos require a bunded dam and a catchment tank. Experiences of the Ipeleg ng labour programme for constructing bunded dams in Botswana suggest that self-help, labour-intensive methods were not very successful (Lowry 1972, Shirley 1973). And the experiences of Moody (1973) in Swaziland in promoting simple catchment tanks which require a much smaller excavation suggest that charcos in their Tanzanian form are too big to be tackled as community development projects.

The success of charcos depends on the properties of the soil which is excavated to make the tank. In sandy soils seepage losses would add to evaporation losses, and it is doubtful whether a water source could be made to last through the dry season (Tanzania and other African equatorial countries are more fortunate in this respect, in that they have two rainy seasons, separated by two shorter dry seasons). Albany-Ward (1971) has reported on some Sudanese experiments to reduce seepage losses from small catchment tanks and charco-type open reservoirs. Various types of clay linings were tried but the cheapest and most suitable were those which used layers of mud and polythene sheeting. Thin polythene sheeting (250 gauge) was laid on mud, this was covered by a mud layer and a thicker layer of polythene was applied (1000 gauge), which was finally covered by 0.5 in. of backfill. The first two layers of mud needed impregnating with insecticide to prevent termites attacking the polythene. The problem with clay linings was finding large quantities of dry season water

for preparation of the clay. The mud polythene technique is the basis of the linings of the catchment tanks built in Botswana and Swaziland, as will be described in Chapter 10.

The cost of the lining was estimated at £0.427 Sudanese/m² (about £0.51 sterling/m²). The unit costs for useful storage capacity of lined and unlined charcos were as follows:

Lined charcos	£0.80 Sudanese/m ³	(about £0.96)
Unlined charcos	£0.60 Sudanese/m ³	(about £0.72)

The cost of lining is fairly small and can probably be justified by the amount of water saved.

8.8 Conclusion - More Efficient Utilisation of Dams

The dams at Mpolonjeni have been costed using the procedures recommended for use in Rhodesia (Department of Conservation and Extension 1962), and the construction costs of Mkutshane and Maggenya's Dams at 1968 prices are estimated as £5,000 and £2,000 respectively. In terms of capacity this works out at £0.04 and £0.045 per m³, as compared with £0.039 per m³ paid for 27 dams in Botswana (Oxfam, 1969). These figures are deceptively low because so much of the capacity is that occupied by evaporation and seepage. With good management and a risk of failure of once in 20 years, Mkutshane Dam could provide a safe draught amounting to 60 per cent of the water stored in an average year (Farrar & Pacey 1974). Thus it can be argued that only 60 per cent of the capacity is of practical use, and hence the unit capital costs should only be £0.07 per m³. These cost estimates do not include the overhead costs on equipment and the engineering services. More realistic figures are obtainable from a Kenya water conservation programme (Kenya, Water Department 1973), which when broken down over a five year period gives an average cost of £9,200 for each dam of the planned 160 in the programme. The average capacity of the dams is

45,000 m³ - about the same as Maggenya's Dam. Unit costs for the Kenya Dams would thus be £0.20 per m³ in terms of total capacity and perhaps £0.3 per m³ if losses are considered.

This is still a small investment for water storage, however, so it might be argued that the gross inefficiencies of conventional earth dams are acceptable because of the small amounts of capital involved.

Like so many simple economic arguments, this point of view is short-sighted. In the long term, water resources are likely to be the principal limiting factor in the development of semi-arid areas. Large scale irrigation is being practised in the Lowveld, and there are plans to extend the scale of operations. Small dams at Mpolonjeni will deprive the irrigation schemes of water and the dams are therefore justified only if they are used as fully as possible.

Innovations which might lead to more efficient use of dams fall into two categories - firstly changes in design and construction, and secondly changes in the way water is used. Three suggestions have already been made which can be included in the first category:

1. the use of clay cores in Swaziland dams to reduce seepage losses,
2. the development of bunded dams to form charcos,
3. the use of small dams in Botswana for groundwater recharge.

Other ideas, such as the use of floats to reduce evaporation and the development of sand dams, will be discussed in Chapter 9.

Groundwater recharge seems to be one of the most efficient ways of using small dams in some of the more extreme semi-arid and arid countries. In Saudi Arabia, for example, where open water evaporation is as high as 3,000 mm per year, dams have been designed which hold back the flash floods occurring during storms, and then allow water to

be released at a slow enough rate for it to infiltrate the soil and percolate to groundwater. Crops may be grown in the recharge area, and water stored in the aquifer is available via wells (Shaikh 1971).

In the Maharashtra state of India, small dams have been built on permeable ground, so that water flowing into them will percolate to the aquifer before evaporation has taken too great a toll. These dams are similar in shape and size to the ones in Swaziland which have been described, with earth embankments about 200 metres long, but with masonry and concrete spillways. During two years (1968-70), 24 such dams were completed using hand labour, with up to 6,000 people employed at any one time. As a result, water is again obtainable from wells in the area which had dried up through over-exploitation of the aquifer (Oxfam 1971).

These groundwater recharge schemes may be valuable, but it has not been possible to develop the idea very far in this thesis, mainly because geological conditions in the area studied in detail did not offer much scope for groundwater supplies. For Mpolonjeni, it seems more fruitful to think of ways in which the water of the dams may be better used. This means managing the draught taken from dams so that benefits are maximised and the evaporation penalty is kept to a minimum. Midgley and Pitman (1969) have discussed ways of doing this based on calculations of the risk of a supply failure. The method may be illustrated by using their graphs for further calculations on Mkutshane Dam. Previously (Tables 8.2 and 8.6), the safe draught was estimated only for a 20-year recurrence interval. Taking other recurrence intervals, the safe draught of Mkutshane Dam with an average risk of failure once in:

5 years	is	11,400 m ³ /month	
10	"	9,000	"
20	"	7,000	"
50	"	5,600	"
100	"	4,600	"

In Britain it is usual to insist on very low risks of supply failure for all types of water use; but Midgley and Pitman (1969) have argued that in semi-arid areas, this policy would lead to very inefficient utilisation of reservoirs because of the low draughts which must be observed if recurrence intervals of 50 or 100 years are aimed for. People in semi-arid areas cannot afford this level of insurance. A more economical policy is to allocate priorities to different types of water consumption, and supply low-priority consumers on a high-risk basis.

The choice of recurrence interval is always a difficult one but at Mpolonjeni two categories of water use can be envisaged:

1. high priority - essential supplies for domestic use and stock, since the latter are basic to the Swazi way of life,
2. low priority - water for some form of irrigation.

The dams at Mpolonjeni, with the exception of Maggenya's can easily meet the high priority demands. Bearing in mind the severe consequences of a water supply failure in a semi-arid area, it is reasonable to assume a recurrence interval of 1 in 50 years for this category. This may still seem a low risk, but it should be remembered that although a reservoir is only expected to fail once in fifty years, there will be several occasions when failure is very near. The traumatic effects caused by near failures may themselves cause suffering.

The low priority water could be assigned to intensive irrigation of cash crops. But the water available would only serve small areas of land which would be very expensive to develop. Intensive irrigation farming would also require a complete new way of life for the Swazi farmer, and results of experiments in this sphere which are at present being carried out in the Lowveld are not encouraging (Browning 1973). A better solution would be to consider supplementary irrigation of established crops. This would entail growing dry season vegetables and

irrigating maize - the staple crop. This is contrary to accepted irrigation practice which uses expensive water to grow the most valuable crops (Clark 1967). The solution proposed for Mpolonjeni would be an extension of the existing farming pattern. It could also be adopted on a wider scale, and the effects of failure of the water supply on crop production would be less catastrophic. Low priority water could be given a recurrence interval of 1 in 10 years.

The problem with the village-scale dams considered here is that the methods for assessing water availability are inadequate for distinguishing between a safe draught with a 50-year recurrence interval and one with a 10-year interval. For example, great doubts are cast on the above list of safe draughts for Mkutshane Dam when it is recalled that the low-flow sequence used to arrive at these figures was questioned as being unrepresentative of a small upland catchment in the Lowveld. If a more suitable low-flow sequence was substituted, the safe draught for a 20-year recurrence interval may have been $3,500 \text{ m}^3/\text{month}$, which according to the list above would satisfy a risk of more than 1 in a 100 years.

Given these difficulties, what seems to happen in practice is that there is often no attempt to estimate safe draughts for rural dams. In some cases, draughts are kept so low that there is an enormous safety margin, which is wasteful in terms of both water losses and returns on capital invested. Other dams, in contrast, are used intensively until they dry up, and then cattle and people go further afield, and use a less convenient source of water.

What could be useful in planning water utilisation would be a simple method for estimating draughts which did not depend on unobtainable data. It would necessarily give very crude estimates of the safe draught, but it would be possible to weight the method so that the margin

of error was between a 10-year recurrence interval and a 50-year one. This would then eliminate the need for highly extravagant safety margins while at the same time limiting the risk of frequent and extended supply failures.

Using Midgley and Pitman's work as a basis, it is possible to envisage a simplified version which relies on a more realistic assessment of a likely low-flow sequence. This would give gross draughts and a uniform rate for seepage and leakage losses would have to be used, perhaps 90 mm/month (3 mm/day), a figure which is close to the observed seepage loss at Maggenya's Dam, and comparable to the result from the flow net calculation described earlier. Evaporation for an area like Mpolonjeni can be estimated with reasonable confidence at 1370 mm/year, or 114 mm/month. Thus it should be possible to obtain a reasonable estimate of safe draught by subtracting the estimated losses, in this case 204 mm/month, from the gross draught.

Of course there are difficulties of how people in a rural community can gauge the quantity of water they draw-off each day. Clearly the length of time that the valve is open is one form of assessment, but this would have to be linked to some sort of depth gauge in the reservoir so that variations in head were taken into account.

Another approach to the better utilisation of the dams in this area would be to clear all the dead vegetation - tree stumps, shrubs etc - from the flooded area, so that net fishing could begin. The clearing of trees is something which is best done before flooding, but the reservoirs at Mpolonjeni could still be redeemed by tackling the problem during the dry season when water levels are low.

Most parts of the Swaziland Lowveld are served by dams of this kind, many of which have been constructed in the last fifteen years. The objective in the period when the Lowveld was being extensively

settled for the first time was to provide water sources for cattle, and as a secondary consideration, people. This objective having been largely met, the policy should now be to develop the reservoirs so that they play a bigger part in the economic life of the community.

CHAPTER 9

WATER SUPPLY TECHNOLOGY IN SEMI-ARID AREAS

PART II : STORAGE IN SAND

9.1 Introduction

The previous chapter was devoted to small dams and bunded reservoirs in Swaziland and Botswana because these are the most prevalent form of water collection and storage in these semi-arid parts of Africa.

But dams were shown to be in-efficient because of the large evaporation losses from open reservoirs, and because of seepage. Where classical dam sites are rare, and this is the case for most of the semi-arid areas of southern Africa, increasing the capacity of a reservoir eventually leads to no corresponding increase in yield, since with larger surface areas, evaporation losses are excessively high. However, the yield of the reservoirs in the areas studied was not a serious problem; most of the reservoirs were also seen to have a great deal of un-used capacity, especially in relation to the scale of domestic water supplies and stock watering.

The purpose of this chapter is to consider a form of water storage in which the problems of evaporation loss are controlled. In the following chapter, storage system will be discussed which match supplies more closely to domestic requirements, and which achieve low or "intermediate" cost levels by avoiding investments in unused capacity.

9.2 Experiments in Evaporation Control

The most obvious form of evaporation control is to store water underground, and this is done in a relatively uncontrolled way by groundwater recharge schemes. It is also the basis of the main section of this chapter (section 9.3). Another method is to reduce the effects of wind by creating some form of windbreak around the water surface area. Reductions of up to 9 per cent have been claimed in some experiments (Frenkiel 1965), but if the windbreak is a form of vegetation, the evapotranspiration losses from this will also have to be taken into account.

The final method for reducing evaporation is to cover the water surface. Where the reservoir is very small, a roof may be considered, but for most practical cases, the covering consists of materials floated on the surface of the water.

Polythene films have been tried with little success, the material becomes inundated with dirt and sinks. Microscopic beads have also been used, but they are seriously affected by wind, and there is the possibility that the spinning of the beads, which exposes more wetted surfaces to the atmosphere, may actually increase evaporation.

Larger polystyrene balls have been used successfully for tanks, but the expense and affects of wind render them unsuitable for larger reservoirs.

Most research in recent years, generally the 1950's and 1960's, has been centred on the use of mono-molecular layers of the fatty alcohol series of compounds(eg. cetyl alcohols). There have been difficulties in devising equipment for spreading the layer, and once broken, the layer does not easily reform. As with the use of floats, the main problem is to maintain an effective layer for long periods in other than calm conditions. Frenkiel (1965) quotes results of a series of experiments in Australia. For various wind speeds, the savings resulting from evaporation control wereas follows.

Winds up to 5 m.p.h.	-	savings	40%
" "10 m.p.h.	-	"	10-20%
" "15 m.p.h.	-	"	zero.

Results such as these are sufficient, according to Frenkiel, to establish a firm economic basis for worthwhile savings in extremely arid zones where water demands are high.

Apart from wind, recreational pursuits or fishing activities may also affect the performance of mono-molecular layers. There are also questions about their effects on aquatic life. Doubts about the toxicity to fish of the compounds used and interference by such mono-molecular layers to oxygen transfer from the atmosphere to the water have now been shown to be largely unfounded. But hexadecanol, one of the more popular constituents for the monomolecular layer, does encourage the growth of some types of bacteria (Frenkiel 1965).

9.3 Storage in Sand

In previous chapters, mention has been made of "sand rivers" in semi-arid areas, in which deep sand in the river beds retains water long after surface river flow has ceased. By digging into these sand deposits, a water source can be created which will last through the dry season, and in some cases the supply is sufficient for the needs of towns (Plate 9, White R.J. 1971). The people of Mahalapye in Botswana have obtained their water in this way for many decades, and Windhoek, the largest town in Namibia, is supplied from a sand river.

In areas where sand rivers are not a regular feature, it has long been observed that sediment which builds up behind a weir or barrage may hold water for a considerable time after the river has dried up. This has happened with small weirs in Kenya, and has also occurred in the Swaziland Lowveld at a point where the Mtendekwa River meets a natural barrage formed by a dolerite sill.

The water in these surface deposits is protected from evaporation, and so a reliable supply can frequently be obtained where bodies of open water of similar size quickly dry up. If the types and amounts of sediment deposit can be controlled to provide sand-filled reservoirs, this would lead to a much more efficient way of storing surface water.

The ideal conditions for developing this type of storage are in river channels where floods carry high sediment loads, and where the sediment consists mainly of larger particles. In many parts of Botswana, Namibia and western Rhodesia, the most prevalent top soils are of a type known generally as "Kalahari sand". Natural erosion is high in these areas because of the sparse vegetation and the occasional very intense storms. The sediment load of the rivers consists of

uniform size, and these are an ideal medium for water storage. The particles are small enough to be swept along by flash floods, thus allowing a rapid build-up of deposit when the floods subside, but large enough to provide sufficient space for water movement between individual particles when water is abstracted. Sediment-laden run-off is increased in areas where overgrazing has occurred. Good land and water management would work to counteract this effect, but where this is not possible, the storage of water in sand is one way of putting an apparently adverse feature to good use.

In the Swaziland Lowveld, by contrast, sediment loads in rivers tend to be lower, because more prolific vegetation and the cohesive clay soils resist erosion. Rainfall is more evenly distributed compared with other semi-arid areas in southern Africa, and this, and the run-off characteristics of the ground surface, mean that flash floods are less common. Thus the build-up of sediment behind a barrage is likely to be slower, and because of the prevalence of clay, the material is much less permeable and less suitable for the storage and subsequent abstraction of water. The western Lowveld suffers more erosion and has sandier soils than the eastern Lowveld, and it is perhaps significant that the sand river conditions which have developed, for example, in the Mtendekwa River, are in the western part of the region.

The availability of water stored in sand

The retention of water in a sand river from one flood season to the next is due to the frictional resistance to flow through the sand, and not to the presence of any underground rock barrier above the normal rock level. Under these conditions Darcy's equation for the rate of flow (Q) through a porous medium may be used :

$Q = K.S.A.$ Where S is the slope of water surface,

A is the area of the medium through

which water is flowing, and

K is the coefficient of permeability in
a horizontal direction.

Thus the main factor influencing the availability of water at a shallow well point in a sand river or sediment-filled reservoir is the coefficient of permeability (K) of the sediment. All sediment deposits in rivers vary considerably, and experimental determination of K is preferred, but the value of the coefficient is mainly dependent on the porosity of the soil and the shape and size of the voids; the main factor affecting these is the size of the particles. Minor influences on the coefficient of permeability are temperature, (which affects the density and viscosity of the water), the degree of aeration of the water, and sodium salts which can reduce permeability by "associating" with clay particles and thus increase the resistance to flow (Chapter 5).

The effective size of sand particles found in the sand rivers of the Gwanda District of Rhodesia range from 0.25 to 0.80 mm for which the range of coefficients of permeability is 58 to 640 m/day (Morton 1958). The effective size is defined as the mean diameter of a particle such that 10 per cent (by weight) of the sand is composed of smaller particles, and 90 per cent of larger particles.

Wipplinger (1958) found that storage of water in sand was also feasible with particle sizes ranging from 0.11 to 0.28 mm diameter. This is probably the minimum range for uniform sand particles to achieve significant yields from shallow well points, i.e. up to 6 m in depth.

In practice, river beds consist of many strata of fine and coarse sand, interlaced with silt layers, and, depending on the soils of the area, clay layers. The permeability of fine silts and clays is 100,000 times less than that of sands, but even if they interrupt the infiltration of water into the river bed, it may often be possible to obtain water from the more permeable sand strata. But if the major part of the deposit consists of silts and clays, although the water content may be high, it will be virtually impossible to extract it.

9.4 The efficiency of storage in sand

Both Morton (1958) and Wipplinger (1958) have investigated the efficiency of water storage in sand compared with open storage, mainly as it affects the evaporation losses.

Evaporation from fully saturated sand is extremely rapid during the first few days. This is because the water near the surface is subject to the same conditions as open water, and the volume lost will be similar; but because the sand particles occupy most of the space, this volume lost will result in a rapid reduction in depth. If open water evaporation is E_o , and the porosity of the sand is n , the drop in water table will initially approximate to (E_o/n) . As the water level falls however, the sand protects the water from the effects of sun and wind, and evaporation becomes much less. In a region where E_o was 1800 mm/year or about 5 mm/day, Morton (1958) observed water levels in sand falling at initial rates of 50 mm/day and 80 mm/day, depending on the grade of sand. After a few days, evaporation was much slower, and after a month, the total fall in the water table was 250 mm and 340 mm. Thereafter the drop in water levels was constant at around 8 mm/month. Wipplinger (1958) found that evaporation virtually ceased after three months, when the top 3 ft (0.9m)

of a sand-filled reservoir would be completely dried out.

The depth of sand being considered is defined as H_s ; the depth of water in the sand is h . The fall in water level in the sand which is due to evaporation may be called E_s . Initially this is closely related to (E_o/n) , but it declines as (H_s-h) increases. Thus:

$$E_s = f(E_o, n, [H_s-h])$$

Neglecting seepage losses, Wipplinger derived equations for the storage efficiencies of water in an open reservoir, and water stored in a similarly shaped sand-filled reservoir. The shape assumed was in fact an inverted pyramid, so that:

$$a = ch^2$$

$$\text{and since, } V = \int adh$$

$$V = \frac{1}{3} ch^3$$

where h is the maximum water depth at any stage of reservoir depletion, a and V are the corresponding area and volume, and c is a constant.

Open storage

Further definitions required are :

T_d - the service period - the time of rainless period for the reservoir to go from full to empty.

F_o - the storage efficiency - the total draw-off during the service period divided by the maximum storage capacity.

H_s - the maximum depth of water when the dam is full

E_o - the open water evaporation per unit time

V - the full capacity

For a time interval δt and a height change of δh , the volume which evaporates is $E_o ch^2 \delta t$.

The volume drawn off is $F_o \cdot \frac{V \cdot \delta t}{T_d}$

The total volume change is $-ch^2 \delta h$

$$\text{i.e.} \quad -ch^2 \delta h = F_o \cdot \frac{V \cdot \delta t}{T_d} + E_o ch^2 \delta h$$

Integrating between $t=0$ and $t=T_d$, $h=H_s$ and $h=0$,

$$\text{and substituting} \quad V = \frac{1}{3} c H_s^3$$

$$\text{then} \quad \frac{3T_d \cdot E_o}{F_o \cdot H_s} \left(1 - \frac{T_d \cdot E_o}{H_s}\right) = \tan^{-1} \frac{3T_d \cdot E_o}{F_o \cdot H_s} \dots\dots(1)$$

In this integration, E_o has been assumed to be constant, though infact, it varies from season to season. Figure 9.1 shows open water storage efficiencies for two different evaporation rates.

Storage in sand

Exactly the same reasoning can be applied to the sand-filled reservoirs, except that the volume of water which evaporates is :

$$n_1 E_s ch^2$$

and the volume drawn off is :

$$F_s n_2 V_s t / T_d$$

the subscripts referring to the sand-filled reservoir

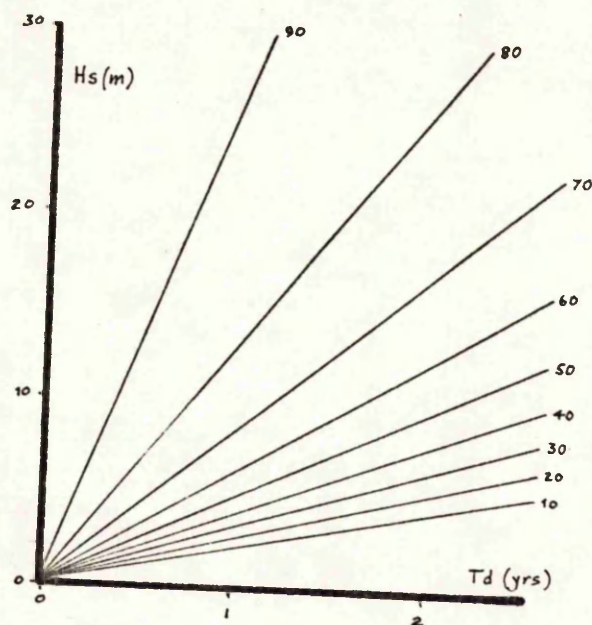
n_1 is the average water content of the sand at the end of the flood season, and

n_2 is the specific yield of the sand with original water content n_1 .

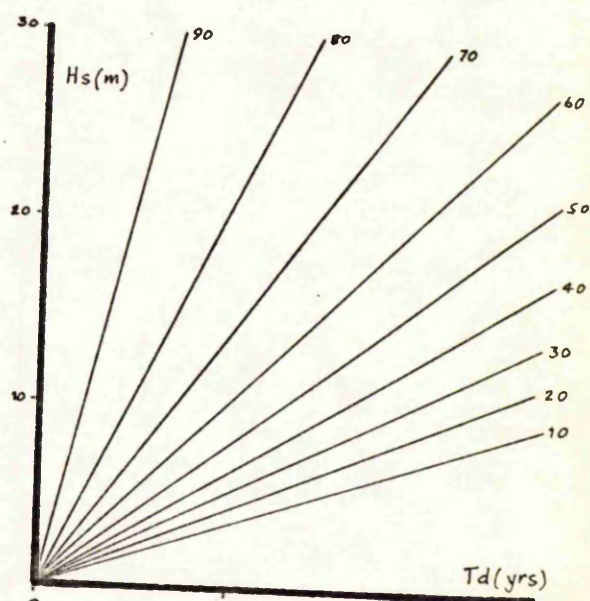
After exceptionally good floods n_1 will be the same as the porosity of the sand n .

With these additional factors, an equation could in principle, be obtained in the same way as equation (1) for open water reservoirs.

Figure 9.1 THE EFFICIENCY OF OPEN WATER STORAGE

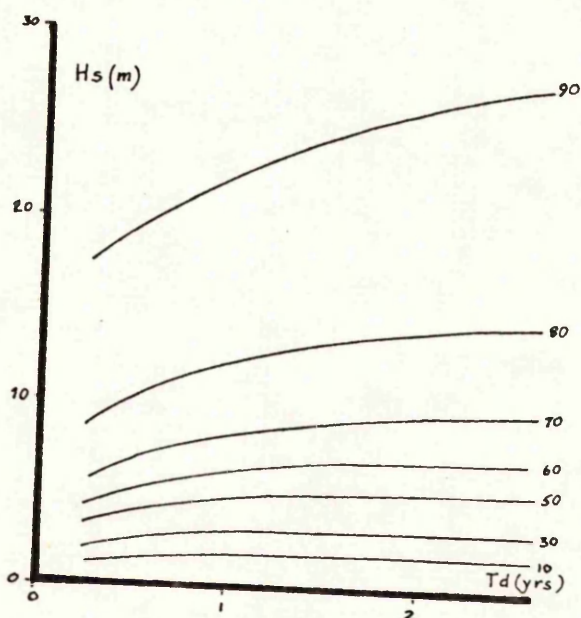


(a) Evaporation $E_0 = 1500 \text{ mm/year}$



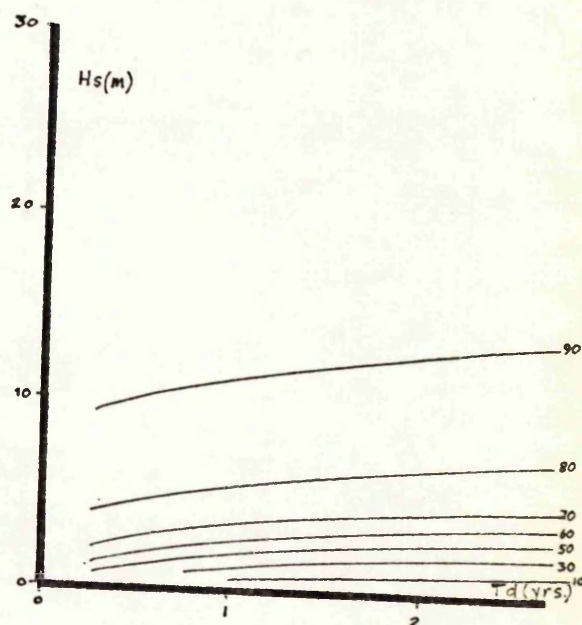
(b) Evaporation $E_0 = 2500 \text{ mm/year}$

Figure 9.2 THE EFFICIENCY OF WATER STORAGE IN SAND



Sand such that:
water content before refilling
specific yield

(a) $n_1 = 0.40$
 $n_2 = 0.25$



(b) $n_1 = 0.40$
 $n_2 = 0.25$

Fig. 9.1a The assumption is that the top 0.9 m of sand is completely dried out in 0.25 years between rainy seasons if no water is extracted (Wipplinger 1958).

Fig. 9.1b The same assumption as above except that the top 0.6 m of sand is completely dried out in 1 year i.e. Morton's (1958) findings.

However, E_s cannot be taken as a constant during the initial stages and the integration is not possible. Presumably because he anticipated this problem, Wipplinger made use of his observations that the top 3ft (0.9m) of sand would dry out in a time T_e (about 3 months) and after that no evaporation would occur. T_e replaced E_s in the equations, and the equations for storage efficiency were derived as follows :

The maximum yield is obtained with instantaneous extraction, when $T_d = 0$ and $T_e = 0$ and is V_{sn_2} . If $T_e \rightarrow \infty$, T_d will equal 0.25 years and the useful yield will be reduced by :

ReV_{sn_2} where $Re = \frac{\text{volume of top 0.9m.}}{\text{total volume of sand}}$

$$\text{i.e.} \quad Re = 1 - \left(\frac{H_s - 0.9}{H_s} \right)^3$$

For intermediate values of T_d , the useful yield will be reduced by an amount proportionate to T_e .

$$\text{i.e.} \quad \frac{T_e}{0.25} ReV_{sn_2}$$

$$\therefore \text{The useful yield of the upper 0.9m} = ReV_{sn_2} \left(1 - \frac{T_e}{0.25} \right) \dots (2)$$

The useful yield of the lower part, $(H_s - 0.9)$ is :

$$(1 - Re)V_{sn_2} \dots \dots (3)$$

From equations (2) and (3)

$$T_d = T_e + \frac{1}{\left(\frac{H_s}{H_s - 0.9} \right)^3 - 1} \times \frac{1}{\frac{1}{T_e} - 4} \dots \dots (4)$$

The storage efficiency $F_s = \frac{\text{useful draw off}}{\text{volume of water absorbed}}$

Considering (a) the basin before replenishment, the top 0.9 m is dry, and below, $n_1 - n_2$ is the volume of retained moisture.

(b) the basin on replenishment, a fraction n will be absorbed in the upper 0.9m, and a fraction n_2 in the portion below to bring the total water content to n_1 .

$$\text{From this, } F = \frac{T}{T_d - T_e + \frac{n_1}{n_2} \left(\frac{1}{\frac{1}{T_e}} - 4 \right)} \dots\dots(5)$$

Using equations (4) and (5), storage efficiencies for sand storage are represented by Figure 9.2. The first of these Figure 9.2 (a) uses Wipplinger's observations for T_e ; the second Figure 9.2 (b) has been produced using values of T_e which are consistent with Morton's observations in an area where open water evaporation is around 1800mm/year. Both figures are drawn using values of specific yield (n_2) of 25 per cent, and the water content of the sand at the end of the day season (n_1) as 40 per cent.

These graphs may be compared to those obtained for open storage (Figures 9.1). The comparison is not very exact, since different types of approximation are used in the two cases. In particular, Wipplinger's time period T_e has been regarded as a constant, whereas it depends on the climatic conditions which also determine E_o . When these results are reassessed in terms of climatic conditions, graphs, of which Figures 9.3 and 9.4 are examples, can be obtained.

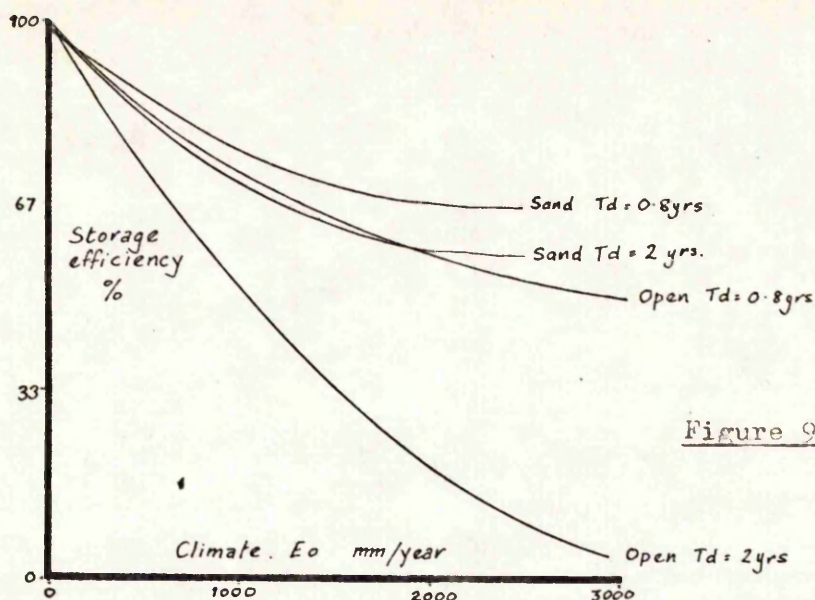


Figure 9.3 STORAGE EFFICIENCY AND CLIMATE

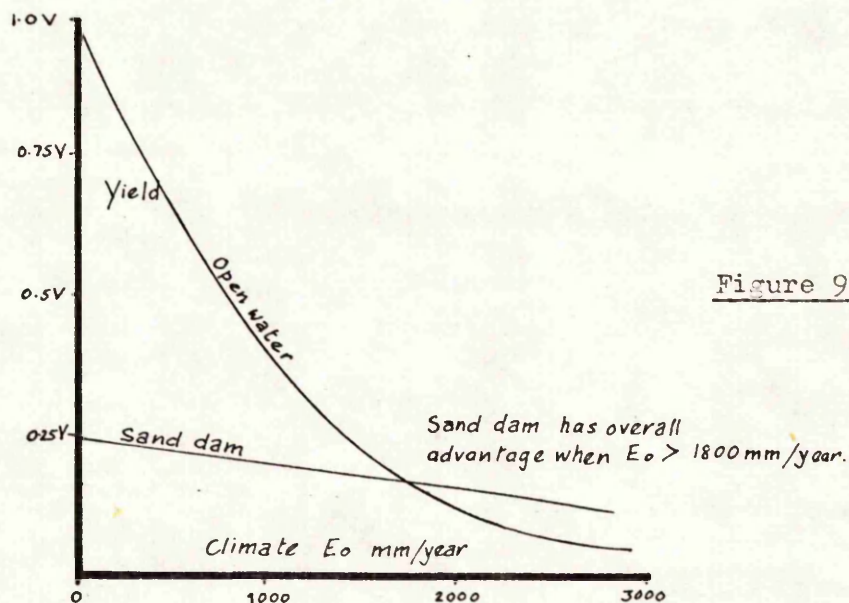


Figure 9.4 YIELD AND CLIMATE

These graphs refer to open and sand dams of similar size and 7 m deep, and have been drawn using the data from Figure 9.1 (for open storage) and Figure 9.2a for sand storage. The curves for sand storage are necessarily approximate since the equations for sand storage do not include a specific term for open water evaporation, but instead, include actual observations for the value of T_e . However, the shapes of the curves are indicated to show more clearly the difference between open storage and storage in sand.

This shows more clearly how the disadvantages of open reservoirs are much greater in climates where E_o is large.

If reservoir depths are greatly increased, then open storage efficiency improves, but this is not a practical solution for small scale developments in regions of low relief. For shorter service periods, the advantages of storage in sand are less evident. Always assuming that conditions permit the construction of sand-filled reservoirs, there will be particular values of evaporation, service period, and reservoir depth when storage in sand becomes a worthwhile proposition.

It should be remembered that although storage efficiencies are very much higher with storage in sand in semi-arid climatic conditions, the volume of water stored is much less. If the actual quantity of water stored is to be greater with sand storage, then for sand of a specific yield of 25 per cent and similar service periods, the storage efficiency must be approximately four times that for open storage. However, any improvement in storage efficiency is significant, if the excess water, which would otherwise be lost by evaporation, is put to good use.

9.5 "Sand dams"

Wipplinger considered how artificial sand-filled reservoirs could be built by controlling the type and rate of sediment deposit during flash floods.

When a dam, or barrage, is built across a sand river, the next flash flood will deposit much of its sediment load in the upstream basin, where the flow velocity is reduced. This process will continue with succeeding floods until the dam is completely filled with sediment. Successive increases in the height of the dam will eventually produce a sediment-filled reservoir.

The ideal deposits, as explained earlier, are gravels and coarse sand. The very fine sediment can be prevented from being deposited by designing the height of the dam in stages, so that the flow velocities through the basin are sufficient to transport the fine sediments over the crest of the dam, but still retain the coarser sediments. Inevitably, compromises in the design of the stages have to be made. If only gravel sand coarse sands are retained, then the build up of the sand storage is a very slow process. Consequently, the finer sands and coarser silts have to be accepted, and only the fine silts and clays rejected. In addition, it is not practical to increase the height of the dam for each individual flood, but only in stages which last a number of seasons. The first flood after an increase in height will deposit a proportionately greater quantity of fine sediment, whilst towards the end of the "life" of the stage, some of the finer sands will be carried over the dam crest.

In spite of these drawbacks, Wipplinger (1958) and Lawrence (1971) report the success of these dams in Namibia. The dams usually consist of four or five stages built over a period of ten years, during which 3 to 5m depth of sediment is deposited. Very minor floods may not overtop the dam and thus all the fine sediment will be deposited in these cases, but the next minor flood will tend to scour the basin and improve the filtration.

A cross-section of a typical construction is shown in Figure 9.5. The wall has to be of a slightly more massive section than for open storage reservoirs in order to withstand the increased pressure of saturated sand. As well as reducing evaporation losses, "sand dams" have some other advantages over open storage :

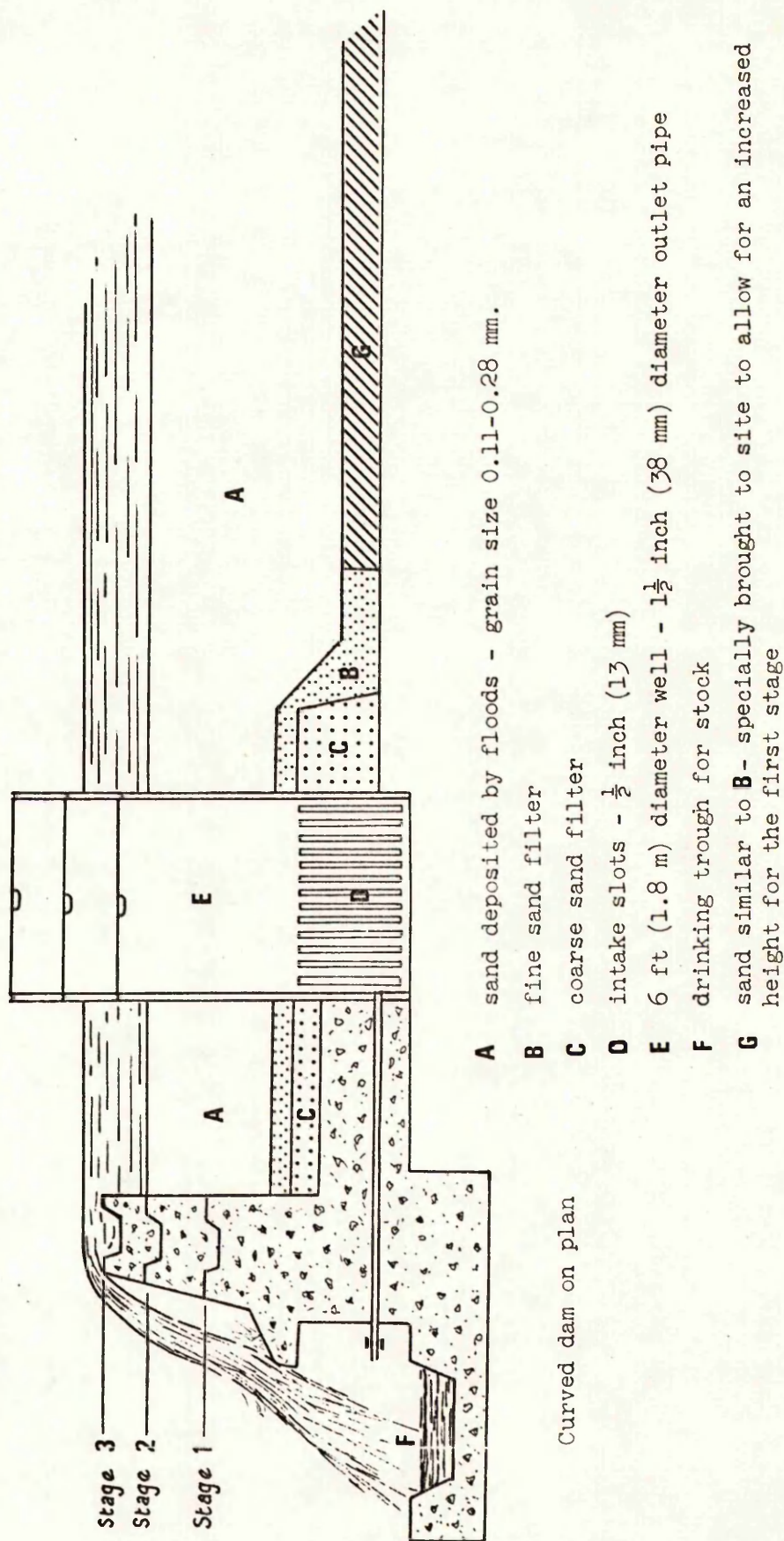


Figure 9.5 CROSS-SECTION OF A SAND DAM THROUGH THE WELL POINT, SHOWING STAGE CONSTRUCTION
 (based on a diagram by Wipplinger 1958)

- 1) the storage capacity is not affected by silting,
- 2) the supply is filtered,
- 3) since the original volume of water stored is smaller, downstream users are less affected,
- 4) sand dams can be built on porous foundations, and used to regulate river flow.

The stage-wise construction may also have advantages in making the best use of scarce resources, and reducing the risk of uncontrolled increases in stock numbers.

In situations where sediments consist of unfavourable silts and clays, it might still be possible to make use of the build up of sediment in open reservoirs. Permeable strata would be deliberately included before the build up of sediment occurs. For example, drains could be laid, and water could be extracted from a number of well points which have drains radiating from each one. Provided the wells tapped permeable strata, significant yields could be obtained. Similar measures may also have to be taken to improve infiltration into the sediment bed.

There are a number of analogies here in the field of water supply practice. If the "permeable strata" consisted of specially constructed linked cavities, then the system would be similar to the "beehive" catchment tanks (Chapter 10). There are also examples, including large-scale ones, where quality is improved by extracting river water from well points in the river banks.

CHAPTER 10

WATER SUPPLY TECHNOLOGY IN SEMI-ARID AREAS

PART III : SUPPLIES ON A DOMESTIC SCALE

10.1 Introduction

Water supply improvements for villages and small communities in the semi-arid areas of Africa have taken many forms, but it is possible to distinguish four main categories.

1. Wells and boreholes have been particularly favoured by some charities, voluntary agencies, and government departments concerned with public health, because they hold a promise of tapping a bacteriologically pure water source, and because they can be developed quickly, and in the case of wells, at low cost.

2. Small piped water schemes drawing water from dams and rivers are less common, but are now being increasingly developed in Kenya, Tanzania, Malawi and Swaziland.

3. The simple provision of small dams has been seen as a major improvement in itself in poor and drought-stricken regions like parts of Botswana (Chapter 8).

4. In Botswana, Swaziland, and perhaps a few other places elsewhere, there have been experiments with catchment tanks, few of which have been wholly successful.

Wells have not been given much emphasis in this thesis, partly because the area where most fieldwork was done had poor groundwater resources, and partly because of a feeling that well and borehole programmes have received too much attention in terms of rural development. With shallow, hand-dug wells in particular, the hope of providing a bacteriologically pure supply has proved to be very misleading, because the precautions necessary to protect a well from pollution have not

been fully observed or maintained. Sometimes, the construction of a concrete apron has been neglected, so surface water has been able to percolate down the shaft. In other cases where a pump has been installed and the top of the well has been sealed, all has been satisfactory until the occurrence of a pump breakdown. When this happens, people usually take the cover off the well and begin to draw water with a bucket or a rope, whereupon many of the advantages of the pure supply have been lost.

All these conditions were observed at hand-dug wells in Botswana, but these had been dug many years ago using traditional methods, e.g. wooden linings were made of roughly trimmed branches. More disturbing are the difficulties experienced in this respect by the Community Development Trust Fund, a Tanzanian charity which raises money within the country and overseas, including Britain. The Trust Fund has organised the construction of several hundred wells by Tanzanian villagers. The wells were intended to give good protection from pollution, but difficulties in construction and particularly in maintenance of the pumps have defeated this objective.

Another major problem has emerged in some of the major drought areas, where wells have dried up within a few months of the initial construction. Here expatriate charities engaged on drought relief have been deeply involved, and it is easy to attribute the failures to over-exploitation of the aquifer by numerous hand-dug wells, leading to a lowering of the water table. But the problem is more complex. As already mentioned, livestock-raising is widespread throughout the semi-arid areas of Africa, including the Sahelian zone. In drought conditions there is less grass available, and overgrazing problems become acutely serious quite quickly. When stripped of its grass cover, the ground loses much of the rain that falls on it as run-off, because in many places there is "capping" of the exposed soil, and the natural recharge of the

aquifer does not take place. Thus wells in the Sahelian zone which were dug as drought relief measures have failed often during the next season.

These kinds of experience make it seem necessary to concentrate less on wells and more on forms of water supply which make better use of rain and surface water, and which may ultimately fit into a soil and water conservation programme for the areas concerned. Thus the main emphasis of these chapters on water supply technology has been on the use of rain or surface water. Where wells can be usefully developed, it might often be advisable to plan them in conjunction with a groundwater recharge scheme such as that mentioned in Chapter 8, certainly there is need for a much greater consciousness of water conservation in future development.

10.2 Catchment Tanks

Of the four categories at the start of this chapter, it is the last one, small-scale rainwater catchment, which raises fewest conservation issues. This is the subject which is mainly discussed here. The subject may be considered as two parts: one, the collection of rain water from the roofs of houses and other buildings, and the other dealing with collection of water from the ground surface.

A "catchment tank" is an excavation or cistern which collects surface run-off water during storms before it has travelled far enough to reach a natural drainage channel, or to form a well-defined stream. Such a tank must be designed in relation to its catchment area, which may be a repared, largely impervious apron around the tank, or a larger area of ground in its natural state. Experiments have been done with catchments surfaced with stone, stabilised earth, polythene under a layer of gravel, glass fibre and bitumen, and aluminium foil, the last

being tried in a bauxite mining area of Jamaica (Stern, 1973a).

Collecting rain water from corrugated roofs is the extreme example of an artificially prepared catchment; at the other extreme of natural catchment areas, catchment tanks can be considered as small-scale versions of bunded dams and charcos (Chapter 8).

Catchment tanks have long been valued in arid and semi-arid areas. In places where springs and streams are non-existent in the dry season, where open storage of water is impractical because of high evaporation losses, and where groundwater resources are poor, they are the only feasible water supply method. Catchment systems can be said to have stood the test of time because of the way they supported a civilisation in the Negev desert for many centuries (Evenari et al. 1971); its agricultural and domestic supplies were based almost entirely on catchment systems, and some of the latter are still being used by the nomadic Bedouin tribesmen. The Negev catchment systems included covered catchment tanks for drinking water cut in the rock, and extensive water collecting arrangements on hillsides which made possible the flood irrigation of cultivated land.

For the size of catchment area, catchment tanks are a more efficient method of collecting surface water than impounding reservoirs, since they are located where run-off is proportionately higher. They also have the advantage that they can be constructed near the place where water is required. However, since relatively small quantities of water are collected, the main problem is to reduce leakage and evaporation losses to insignificant levels.

Since no satisfactory method has been devised for controlling evaporation from open reservoirs, the limit on the reduction of evaporation losses is imposed by the area of tank which can easily be covered with a roof, unless the tank is built completely underground.

Developments for small communities are necessarily limited in size and roofing is not usually difficult. Thus the problem is one of containing leakage.

Linings for Catchment Tanks

The linings to be considered range from traditional materials such as clay and mud mixtures; well established materials such as concrete blocks and various types of cement plaster; to new materials such as plastic and artificial rubber membranes.

Catchment tanks built in the Sudan and Kenya, and known as hafirs, are excavated from black tropical clay. If kept wet, this is practically impermeable. There might be good prospects for developing clay-lined catchment tanks in those parts of Swaziland where clay soils predominate, i.e. the eastern Lowveld.

Concrete block linings and concrete plasters have been used in many types of storage tank, but are generally considered too expensive for community self-help projects. However these materials are familiar, and require only conventional building experience, and these factors alone are sufficient for them to be a reasonable choice.

The newer materials have been tested under field conditions in Botswana by Gibberd (1969). The thicker membranes, such as PVC or butyl sheeting have the advantage of being easy to handle and of requiring very little labour. However PVC is attacked by termites and both are easily punctured by sharp stones or animals' hooves. Punctures can be repaired, once all the water has been lost, but a system which relies on a membrane, i.e. an impervious lining (as opposed to an impermeable one) can lead to a very rapid loss of water once damage has occurred.

Polythene sheeting is even more susceptible to puncturing and tearing, but because it is so cheap, several layers can be used.

If mud is interposed between layers of polythene sheeting then, in effect, an impermeable lining is created. This is intrinsically safer than a single membrane lining because the likelihood of all the layers being punctured at once is low, and in addition, the movement of mud particles into the tear would have a self-sealing effect.

The relative costs of some lining materials are given in Table 10.1. The mud polythene/cement sausage lining construction is described in more detail in later sections. From the table it can be seen that the cost of the concrete linings and the PVC membrane are comparable, and these are about twice the cost of the mud/polythene linings. The butyl linings are very much more expensive. They may be expected to have a longer life, but an inspection of a butyl lining at Serowe in June 1972 when it was four years old showed it to be in very poor condition. There were several large tears, caused mainly by goats, and the material itself seemed to have suffered from exposure to sunlight. PVC membrane is even more drastically affected by sunshine - all flexibility is lost, and the material cracks.

The other linings are also damaged by animals, but because the linings are composite materials they can be fairly easily repaired.

10.3 Catchment Tanks in Botswana and Swaziland

Two catchment tank programmes were introduced into southern Africa, one in Botswana (1967-68) and the other in Swaziland (1971-73). Isolated experiments with similar tanks have also been carried out in other places, e.g. in Rhodesia (Henson, 1972).

The Botswana programme initially included some experiments with butyl and PVC linings, but apart from these, almost all the tanks employ the mud-polythene construction in a way which allows the tanks to be built by voluntary labour on a self-help basis. In detail, the

Table 10.1

Cost of Linings per m² (Materials only)

	£	Notes
Concrete blocks*	N\$ 1.90	1972 prices in South-East Ghana
Cement plaster, with corrugated iron former. ("Hlekweni" tank construction) see Section 10.6).	R 1.05	1972 prices in Rhodesia
P.V.C. pre-shaped lining 0.012" thick	R 0.84	Also requires preparation of excavation to prevent stones puncturing sheet.
Butyl sheeting 0.030" thick	R 1.80	Imported from Britain. £1000 order.
Butyl pre-shaped lining 0.030" thick	R 4.30	S.African sheeting more expensive.
Mud-polythene layers with sand, and cement "sausages"	R 0.51	0.30
Mud lining plus one sheet of polythene and cement sausages	R 0.30	0.17

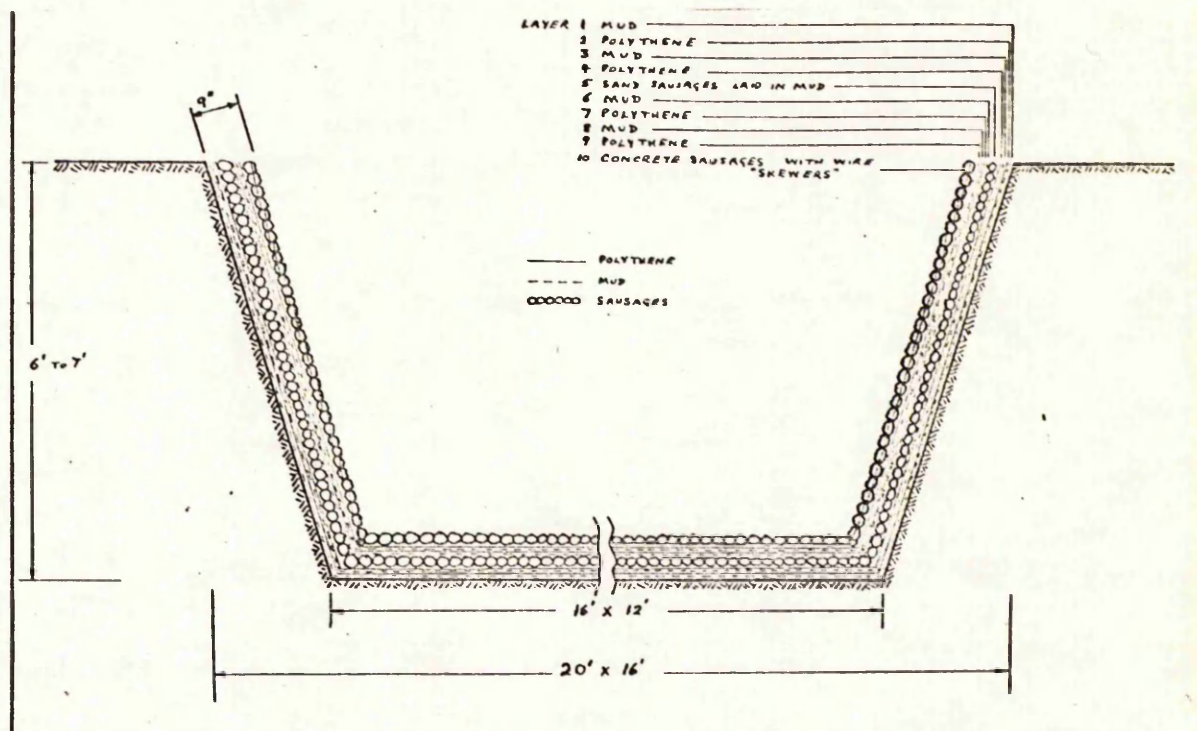
* Deduced from figures given by Parker (1973).
Theoretical price only, the reliability of such a lining was not tested by Parker.

method makes use of cement/polythene "sausages" as a protection to the polythene lining. These "sausages" are used in a way which can be compared to the sand-bag or concrete-filled sack method of construction. Two types of tank have been used, one with the water enclosed by a series of "beehive" shaped structures which are covered by sand, and the other a simple open tank. The way in which the concrete sausages were used in construction is illustrated in Figure 10.1. Further details have been published by ITDG (1969).

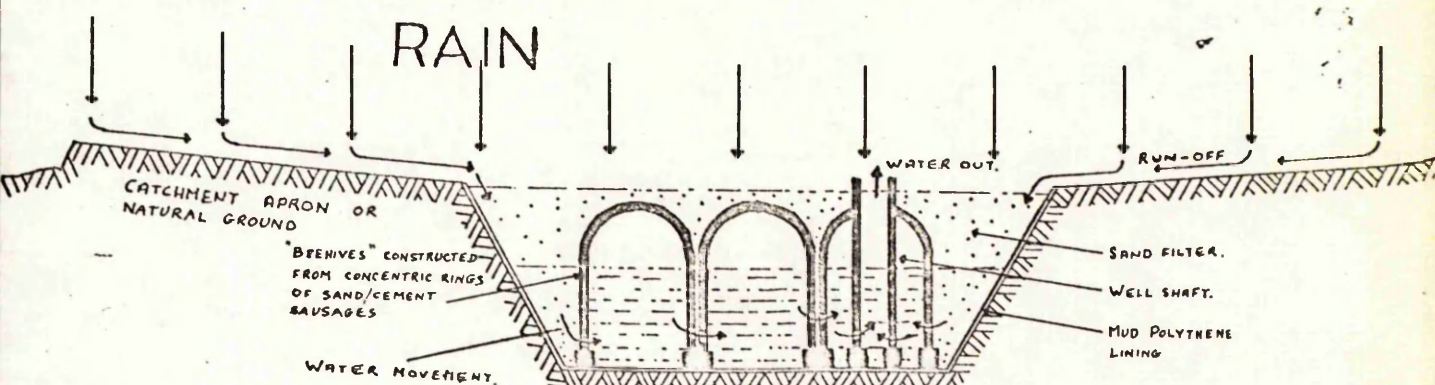
The open type of tank was used mainly in Botswana where tanks were built at schools to provide water for micro-irrigation of school gardens. Thus tomatoes and lettuces could be grown during the dry season, and these vegetables made a worthwhile contribution to the nutrition of school children.

The enclosed type of tank was used in two places in Botswana and on a much wider scale in Swaziland. The beehive structures are constructed without supporting framework, by adding ring after ring of sausages filled with wet weak cement-sand mix. The radii of the rings decrease as ground level is approached. Wire skewers link the sausages together (Figure 10.1). Above the completed domes, the excavation is back-filled with river sand to ground level. During storms, run-off flowing on to this sand from the catchment infiltrates and is stored in the dome cavities below, polythene sheeting laid over the top of the domes prior to the sand back-fill ensures that the water is filtered through at least 0.3 m of sand.

These tanks are intended to provide water for domestic purposes. The stored water is protected from evaporation and is relatively clean. In Botswana, such a tank provides a very satisfactory supply for a European family living near Serowe. Water is pumped by hand from the catchment tank into a cistern in the roof of the house,



(a) Cross-section of mud/polthene tank showing the various layers



(b) Cross-section of "beehive" tank illustrating the direction of water movement.

Figure 10.1 DETAILS OF LININGS AND "BEEHIVES" OF CATCHMENT TANKS
AS CONSTRUCTED IN BOTSWANA AND SWAZILAND
(from ITDG (1969))

from where it supplies all the outlets. Similar tanks in Swaziland have been built at schools to provide a drinking water supply for the preparation of school meals.

The capacity of the open tanks constructed in Botswana was generally 45,000 litres (10,000 gallons). The "beehive" tanks in Swaziland varied in capacity from 45,000 litres to 140,000 litres. There is theoretically no upper limit to the size, but 250,000 litres was the maximum considered practicable in this programme.

The size of the excavation required for a beehive tank of 140,000 litres is about 240 m^3 . Assuming that the domed beehives are 1.2 m in diameter, the volume occupied by concrete sausages and sand particles is about 100 m^3 . This leaves a space of 140 m^3 for water storage, but any water held in the top 0.3 m sand layer is likely to evaporate, and some water will be retained in the sand at lower depths, so the available water from a full tank is about 115 m^3 or 115,000 litres.

Assessment of the Catchment Tank Programmes

It must be stated without qualification that the open catchment tanks in Botswana have been a failure at almost every school where they were built. In most cases, the tanks were probably used as intended for watering school gardens during only one season. The author visited most of the schools concerned in June 1972, five years after the start of the project, and three years after the schools were known to have been using the water to grow vegetables. Only one tank then held water, out of the nine inspected; only two school gardens were being cultivated with any efficiency, and these were irrigated with water brought from other sources. Some tanks had been so completely destroyed that it was difficult to find the site where they had been.

The damage to, or destruction of the tanks was usually due to lack of maintenance of fencing around them, and consequent damage by

animals, mainly goats. The failure was therefore basically a human one, linked in several cases to the neglect of the school gardens which the tanks were meant to serve. At most of the schools, the tanks were the responsibility of a particular teacher, and when the teacher moved to another post, his successor rarely took much interest. Like so many self-help projects, this catchment tank programme was dependent too much on particular individuals. On the whole, school gardens were felt to be rather marginal activity by the teachers and perhaps also by the communities served by each school.

Being concerned with drinking water, the Swaziland tanks have the advantage of dealing with a problem of which most people in the community are conscious. Progress with construction has, however, been slow. In the two years prior to June 1973, 33 projects were initiated but only 12 tanks had been completed (Moody 1973). Of these 12, two were open tanks, which were used in the later stages of the programme so that completion would be speeded up. These latter tanks were given protection against evaporation by black polythene sheeting trapped between tensioned wires across the length and breadth of the tank. In these two cases, the tanks were designed to fill with rainwater collected from corrugated roofs.

Fuller reports on the catchment tanks in Botswana and Swaziland have been made to ITDG by the project officer. Here, the potential of these tanks for drinking water will be discussed.

The first tanks in Swaziland constructed in early 1971, have now been in use for three complete wet seasons. The indications are that completed tanks are lasting well with very little maintenance required. All the completed tanks filled in the season of 1972-73 which was one of below average rainfall. The construction methods have apparently been mastered by the builders and volunteer labour, since

there are no reports of large leakages through the linings (Moody 1973). And because only the well-shaft shows above ground the tanks are less vulnerable to damage by cattle and goats. Nevertheless some maintenance is desirable which is really a matter of tidying up. The sand filter at least should be protected by fencing so that cattle cannot pollute the stored water directly, nor damage the domes which are only just below the sand surface. All vegetation needs to be kept clear from this area since it is an unnecessary drain on the water stored, reduces infiltration rates, and roots could damage the linings.

If these points are attended to, and the characteristic of the catchment area do not change markedly, there is no real reason why the tanks should not continue to collect and retain water for many years. Any leaks which might have been present initially would tend to seal themselves as mud and sand is drawn into the fault. The only problem likely to be encountered is that the quality (taste, appearance and purity) of the water might deteriorate, either because of the effects of vegetation, or of any animals such as frogs which become trapped in the tanks. The catchment tank at Maphatinduku when visited in August 1973 was almost dry; the sample of water which was extracted contained dead insects, and a frog was living at the bottom of the well shaft. These sorts of "impurities" are likely to be of great concern to public health engineers, but generally of less consequence to the users of the catchment tank.

The sand layer on top of and between the domes filters the water as it enters the tank, and to a lesser extent as it is drawn off. The sand filter will retain suspended solids, but because the flow is not continuous, there is unlikely to be any bacteriological improvement comparable to that achieved with slow sand filtration. The greatest improvement in the bacteriological condition of the water is likely to

arise from the storage alone. The mechanism by which water is retained in a catchment tank is not dissimilar to the recharge of an unconfined shallow aquifer. These, as we have seen in Chapter 4, are vulnerable to pollution by contaminated surface water, and catchment tank water can be similarly affected. In Swaziland conditions, water from catchment tanks is like to be an improvement on reservoir water in terms of taste, appearance and bacteriological condition, but not as satisfactory as rainwater collected direct from roofs. Water from a similar type of catchment tank built in Botswana but with an artificial catchment area of black polythene was found to be free from all pathogenic organisms (Gibberd 1969).

The greatest drawbacks to the performance of the Swaziland catchment tanks were the hand pumps used for extracting water. Originally semi-rotary hand pumps were specified, mainly because they were relatively cheap - about £7 - and they could be supplied by a British manufacturer which is one of the conditions of the official British aid programme. This type of pump has proved most unsatisfactory, because it becomes inoperative when sand grains lodge in the valve seatings, and because it seizes very easily - the cast iron handle is often broken when trying to free the pump. The stripping down and repair of the hand pumps is not something which can be undertaken by most school teachers or community members.

A more satisfactory solution seems to be a diaphragm pump. Three diaphragm pumps were tested in Swaziland from early 1972 onwards. These were of British manufacture, intended mainly for the small boat market. The diaphragm action proved most satisfactory. The cheapest pump (£6) with an all-plastic body - withstood several months fairly intensive use before the body and handle fractured. The other two types - about £10 and £12 - were more robust and one is still in use.

The only problem was attaching the pipework to the pump; the semi-rigid P.V.C. piping split very easily, and new sections had to be inserted, but this was a task which could be carried out by the school teacher concerned.

The problem of cheap reliable hand pumps has bedevilled many small water supply schemes, and the development of one suitable for Asian conditions has been developed by Fannon & Frink (1967, 1970) following a \$58,000 research contract from the United States Agency for International Aid. Ricardo (1973) considers the "pump problem" to be the greatest technical problem for the extension of the self-help well programme in Tanzania. Hand pumps are the subject of the report on Africa Fieldwork and Technology given in Appendix 2 of this thesis.

10.4 Administrative and Human Problems in the Catchment Tank Programme

Neglecting the pumping problem for the moment, though that is not to discount its importance, catchment tanks would seem to offer a solution to the domestic water supply problem of many arid and semi-arid areas, and in particular the Swaziland Lowveld. The design and the construction methods involved satisfy all the criteria for "intermediate technology" solutions as outlined in Chapter 1, namely that the capital costs seem likely to be low, the design is simple, construction methods are labour-intensive, and maintenance requirements are small. Polythene is the main sealant, so the design embodies a product of modern technology adapted to traditional methods. Very great claims have been made for catchment tanks of this type (Ionides 1969):

" ... it is quite possible to see the solution to the drinking water problem realised, by a progressive process of direct investment of the surplus, seasonal under employed labour of the people themselves plus the local investment of a

current cash surplus to buy the materials which, inescapably, have to be bought from the outside. By such a mass attack the job can be done. No other way is in sight for a comparable solution. "

It would be inaccurate to say that a "mass attack" has occurred in Swaziland, but considerable resources have been devoted to the programme which include:

- a) the adoption of the programme by the Community Development Department of the Ministry of Local Administration
- b) the purchase of all the imported materials required by a British aid programme.

With these advantages in mind the question must be sincerely asked why more tanks have not been completed. Catchment tanks would seem to be an example of the suggestion made in Chapter 1 that even technology which appears to be "appropriate" often fails to establish itself.

The reason why catchment tanks have not been readily accepted in Swaziland are not easy to sort out, but perhaps two main ones can be identified, one connected with administration and government, the other with human factors in the rural community.

The catchment tank programme has undoubtedly suffered from the poor coordination between the government departments nominally responsible for rural water supply. Four other departments, apart from the Community Development Department have responsibilities. These are the Water Section of the Ministry of Power, Works and Communications, the Ministry of Health, the Ministry of Education (where schools are concerned) and the Ministry of Agriculture, which has overall control of rural development. This fragmentation of responsibility means that there is poor consultation, and barely a common policy. Each department works in isolation.

One problem has been that because catchment tanks do not require conventional engineering design, and appear to represent a lowering of standards when compared to usual water supply practice, the engineers of the Water Section (most of whom are expatriate) have considered the programme outside its province. Indeed there is a reluctance by these people to become involved in any rural water supply project, especially if volunteer labour is taking part. The general feeling is that a proper engineering job would be impossible. The main concern of the water section is thus urban water supply where conditions are familiar and standards have been established.

At the other extreme, the Community Development Department is staffed almost exclusively by Swazis, some of whom have had training in social and welfare work. The Department sees the solution to rural development mainly in human terms, for which projects the water supply improvements are desirable but not absolutely necessary. Its work has been concentrated on educational projects (e.g. school buildings, teachers quarters and literacy programmes) and on local administration projects - the Nkundla at Mpolonjeni is an example of the latter. Even though the engineering involved in water supply projects is relatively simple, it is still an unknown world to the Community Development Department. In the past, when it has sought assistance from the Water Section, it has been presented with schemes which have seemed quite inappropriate to people's needs and impossibly expensive. In 1972, there were only two technical people in the Community Development Department. One was the projects officer in charge of the catchment tank programme, the other was a Peace Corps volunteer who surveyed and designed small-scale piped water supplies.

In short, the Community Development Department considers the Water Section to be unaware of the real problems, and to have no understanding of the Swazi people. The collective view of the Water Section,

on the other hand, would probably be that the rural Swazis have little notion of the engineering involved, and are completely unrealistic about costs and standards.

This polarisation of opinion is only to be expected from two groups of people with such widely differing backgrounds and attitudes, but it is particularly unfortunate in a country like Swaziland where expertise in any field is scarce. The intermediate viewpoint to these extreme approaches is provided by the Ministry of Agriculture (staffed by expatriates and Swazis). But again, the author's impression is that major decisions about projects are made without full consultation with the rural population. The whole history of the Mpolonjeni Rural Development Area supports this contention, as does the uncertainty about who is responsible for the maintenance of dams. As far as water supplies are concerned, the Ministry of Agriculture has concentrated on facilities for cattle (stock watering dams and cattle dip tanks) and to a lesser extent, irrigation. Supplies for purely domestic purposes have only been provided as part of the longer term developments in the Rural Development Areas as, for example, the supplies at Ngcina and Mpolonjeni.

From this discussion of government organisation, it is clear that rural water supplies receive low priority. Catchment tanks, being initiated entirely within the Community Development Department (one of the smallest government departments) are even lower on the overall list of priorities. Some improvement can be expected in this situation from 1974 onwards, for a completely new rural water supplies section is being formed within the Ministry of Local Administration (Moody 1973), but involving all the other government departments which at present have some responsibilities in this field. It will be directed by a qualified engineer and will possess some earth moving machinery.

This move was inevitable once the importance of water supply in rural development had been accepted. It is significant that Kenya and Tanzania, two countries which have given high priority to rural water supplies, both have separate government departments which include engineers, economists and community development workers.

The main restraint on the catchment tank programme, according to Moody (1973), was inadequate transport facilities. He gives, as an example, one period in 1973 when only 6 vehicles out of the 27 allocated to the Ministry of Local Administration were serviceable. This small proportion was by no means exceptional, nor peculiar to that Ministry.

The transport difficulty is a symptom of a broader problem faced by many developing countries. Financial and manpower resources are too limited to provide for the day to day running of government departments. Obviously the tasks before them are often enormous, but they are aggravated by the tendency of aid donating countries to give capital grants for new projects and then to expect the recipients to take over maintenance and other recurrent costs.

The imported material costs for all community development projects in Swaziland are met by either British or United States aid. The problem is not the initiation of projects but the follow-up. For schools, this manifests itself in the difficulty of finding suitable teachers (and this is the main reason why British Aid in Swaziland now supports a more restricted school building programme); for water supply projects poor follow-up procedures show themselves by inadequate maintenance, eventually resulting in the failure of the project.

Turning to the human problem within the communities themselves, there are social and cultural reasons for the relative failure of the catchment tank programme. Some of these points have already been discussed (Chapters 2 and 6). The impression formed by the author

during his visits to catchment tank sites was that the basic concept had not been generally accepted by the people. This means that catchment tanks are unlikely to be initiated within a community. Instead, a more likely course of events is that a community committee will request the assistance of the Community Development Department with its water problem. The Department may then suggest a catchment tank as a solution, but not always wholeheartedly, as some of its staff do not seem to be convinced of the merits of these tanks.

The main doubt appeared to be that the quantity of water stored is too small for the needs of a community or a school. This is certainly true if people expect to draw all their water from a tank. The European family previously mentioned as deriving the whole of their supply from a catchment tank were using about 250 litres/day (Gibberd 1972) - a little less than the safe draught for a 90,000 litre tank in Botswana's climatic condition. Mpolonjeni people, using about 8 litres/head/day in their homes, could expect that a single tank would meet all the needs of only a small group of 20 to 30 people. However, the logical way of using a catchment tank is to restrict its use to high priority needs and to continue to use traditional water sources for purposes which do not require particularly clean water. This is a practice which is already carried out at a family level in the use of rainwater from corrugated roofs, but it is unlikely to be as successful on a community level where communal responsibility is needed. If the practice of rationing were developed on a community level, a tank could provide the basic drinking and cooking needs of perhaps 100 people.

But there may also be a psychological factor involved in areas where water is naturally scarce. There is bound to be some reassurance in the sight of a large expanse of water in a reservoir, but little can be seen of the water in a catchment tank. Perhaps if catchment

tank water can be shown to last through an extremely dry year the tanks may become more acceptable. Because the water in the tanks is invisible, apart from a small "circle" in the well shaft it is more difficult to estimate the quantity remaining, and therefore to budget the supply.

The main objection to catchment tanks, if not actually expressed, but evident from the slow progress on many of the sites, is the large amount of manual labour involved. Moody (1973) reports that communities consistently baulk at the labour required, especially the digging. This apparent reluctance may result from a lack of conviction about catchment tanks, or it may have its origins in the culture of the Swazi people. Water supply is mainly a woman's responsibility, and men may be unwilling to undertake an "extra" task. Most community projects are undertaken in the dry period after the harvest when labour is unemployed. This is regarded as a period of rest, or at least one when only house repairs are made. Catchment tank building might well fit into this category, but at present the lack of activity could also be related to the "economic" realities of existence in a semi-arid area. The weak physical condition of many Swazis during this period of scarce food may preclude labourous tasks. Thus the dislike of the labour involved can also be regarded as part of the "vicious circle" of life in a subsistence society referred to in Chapter 3. Given favourable conditions the Swazi people have proved to be good workers (Jones 1963).

In the present circumstances, it might be that the catchment tanks are too labour-intensive, especially in a society where communal action is still relatively rare. Evidence for this can be obtained by comparing the well-digging projects in Tanzania, which are carried on successfully in the context of similar voluntary labour conditions. A hand-dug well 12 metres deep, and a shaft diameter of $1\frac{1}{2}$ metres may serve

a village of 100-200 people, each drawing 10 litres per day. The volume of earth and rock to be removed is about 15 m^3 . A catchment tank which supplies less water to fewer people needs an excavation of 240 m^3 (see above).

Moody (1973) has recommended that a tractor and dam-scoop be used for the majority of the excavation at each site. Some concrete-block lined tanks have also been suggested. Given also, the present situation, whereby all imported materials for community development projects are paid for by external aid sources, it might be prudent to devise schemes which are fairly capital intensive. For instance, the Ngcina watersupply has a voluntary labour contribution not greatly dissimilar to that required for a 30,000 gallon catchment tank. The capital equipment is of course very much more elaborate, but people might consider it better value for their labour to build a piped supply which has a much greater capacity and which, with a small distribution system could supply a greater number of people.

10.5 A Suggestion for a Revised Catchment Tank Programme

Having discovered that the catchment tank programme just described has failed mainly for human, rather than technical reasons, it must be concluded that the technology used was not "socially appropriate". The catchment tank concept still seems promising; one of the tanks examined most closely by the author, that at Secusha School in Swaziland, has been extremely successful. The headmistress is very much in favour of catchment tanks, and she was very adept at getting her "boys" to do running repairs on the pump. It is probable that another tank will be built nearby to serve the community.

With this encouragement, it seems worth discussing some of the more important human factors affecting success or failure, and from this

it may be possible to adjust the technology employed so that it becomes more appropriate to its human context.

1. The tanks must be related to the needs of the people as they themselves perceive these needs. The irrigation of school gardens is perhaps very marginal by this criterion. The provision of a domestic supply, with a sufficient volume of water, is central to the perceived needs of at least the women in these communities.
2. The people must have confidence in the principle of the tank, which in the case of the beehive tank is really quite sophisticated. In Botswana, where wells, boreholes and sand rivers are common in some areas, people are likely to be more accustomed to the idea of storing water underground. In Swaziland, the strategy might be to build on successes like the Secusha School tank by developing projects in the immediate vicinity.
3. The labour required for the construction of a tank is large in relation to the amount of water provided. The construction of the tanks demands a larger labour force than the water from one tank can readily supply. The need then, is for tanks for a greater ratio of $\frac{\text{capacity}}{\text{labour requirement}}$.

These human problems have three technical aspects:

- (a) the choice of area in which to develop a programme
- (b) devices (e.g. a depth gauge) to make the principles of catchment tanks clear
- (c) the improvement of the capacity/labour ratio.

Of these the latter is perhaps the most important. The capacity/labour ratio can easily be improved by using a small tractor and scoop for making the initial excavation. But this move involves a straight

substitution of capital for labour, so that the money cost of the tanks would increase.

An alternative approach would be to redesign the beehive tank so that a larger proportion of the excavation was made available for water storage. Watt (1973) has already suggested that hexagonal chambers could be constructed from interlocking sausage lengths, or from a weak cement mix poured between linked shuttering of woven matting. It is also possible to envisage the hexagons being made from concrete blocks, since these could be easily made on site. In all these modifications the domes could be made as before by concentric cement sausage rings.

As Watt (1973) has noted, the introduction of interlocking beehives would entail a change in the route by which water would percolate through the sand into the tank. There would no longer be sand between the individual beehives, and thus the sides of the tank would have to be redesigned to increase the infiltration rate in these areas - probably by reducing the slope of the inflow side, so that water could enter the side of the chambers after filtration. An extension of this idea would be to have a two part excavation. One part would slope fairly gently, and be filled with river sand; this would be the infiltration chamber. The other part would be an open tank for storage, supplied with water from the infiltration chamber. The open section could have a corrugated roof, which would provide a supplementary catchment area.

Yet another possibility would be to build storage chambers from concrete rings precast (of sewer pipe sections). This would be an extension of "concrete ring technology". The idea is that a wide variety of useful structures can be made from precast concrete rings. In the Tanzanian well projects, the linings are made from these rings manufactured on site. Grain storage silos can also be constructed from them. For catchment tanks, the rings could be laid horizontally, or stacked vertically.

Most of these suggestions are aimed at increasing the capacity of the tanks, with incidental reductions in labour. One significant way in which the labour content of the "standard" cement-sausage tank could be reduced would be to dispense with the cement-sausage lining protection, or at least make it less substantial. This protection was necessary in the Botswana tanks to resist the force of inflowing water. The beehive tanks which are almost entirely below ground should need little protection for the basic mud-polythene lining.

All the ideas presented here have not been fully explored, but they are intended to show that there are many variants on the catchment tank principle, some of which use the volume of the excavation more efficiently and some which require less labour, or different skills. Very probably different types of construction will suit different communities, and it might prove to be a mistake to standardise on one single design. Table 10.2 summarises the approaches to further development outlined above.

10.6 The Collection and Storage of Rainwater from Roofs

An alternative form of rainwater catchment is the collection of water from corrugated iron (or similar material), tiled or even thatched roofs. Where a large roof, such as that of a school is used, the volume of water to be stored may be about the same as in the ground surface catchment tanks previously discussed. But with the roofs of ordinary houses, there is a different kind of possibility involving individuals rather than the community in the development of family scale supplies.

The main problems in the use of roof catchment systems in semi-arid regions are not so much with collection (except with thatched roofs) but with storage of relatively large volumes which have to be made to last a long dry season. The problems of storage, which will be discussed briefly later in this section, are similar to those of ground

Table 10.2

Approaches to the Further Development of Ground Surface
Catchment Tanks (particularly 'Beehive' Tanks) for
Drinking Water Supply

Objective	Approach	Method
1. Better water catchment	a) increase run-off b) collect from larger area	Artificial catchment surfaces. Use charco principle (Chapter 8)
2. Good water quality	a) Filtration b) Protection	Eliminate methods from sections 3 & 4 of this Table which do not include sand filter. Fence catchment area Seal well shafts in beehive tanks
3. Reduced labour needed in construction	a) revert to open tank b) Roof over tank c) use earth moving machines d) choose sloping site to minimise excavation, and a less elaborate lining e) See also (4)	Use block polythene cover (Moody, 1973) Use plastic floats Concrete block sides, corrugated roof. if lining is protected by sausages on the walls of tank.
4. Replace beehives with something that is easier to build	a) use modified beehives b) use concrete ring technology	linked hexagons built with sausages (Watt 1973) linked hexagons built with concrete blocks made with woven shuttering (Watt, 1973) horizontal pipes use rings to form beehives
5. Efficient extraction of water from tank	a) assume professional maintenance occasionally possible b) no professional maintenance	diaphragm pump use bucket on rope devise a pump for which all spare parts can be made in rural area

run-off tanks already discussed. But first the potential for rainwater collection from corrugated roofs in an area like Mpolonjeni will be considered.

Not all the rainfall will be collected. The roof will remain wet after the rain has stopped; the first spell of rain a long dry period may be allowed to clean the roof and gutters and then be discarded; and, depending on the pitch of the roof and the wind direction, the roof area may not be fully utilised. The magnitude of these factors will generally be small, and thus it has been assumed that 95 per cent of the rainfall is collected.

There will be further losses from the stored water. Even if the storage tank is completely covered, evaporation will still occur through an overflow pipe or vent - the losses will probably increase as the volume of water is reduced and the space above the surface increases. Evaporation rates will depend on whether the water is stored in an exposed iron tank, or whether the tank is shaded by thatch. It is not easy to calculate these losses precisely but their overall magnitude is probably around 10 per cent of the volume stored. Consequently, taking into consideration evaporation and the other losses mentioned above, the estimates of storage which follow assume that 85.5 per cent of the rainfall is usable.

The mean annual rainfall at Mpolonjeni has been estimated at 635 mm (Chapter 3). It has also been pointed out that although a dry season is usually identifiable, there are great variations in rainfall from month to month and year to year. In general, an occasional very wet year is offset by a number of moderately below average years. In the absence of any other statistical data on the rainfall at Mpolonjeni, a maximum consumption rate or "demand" of 85 per cent of the mean usable rainfall has been assumed. This figure of 85 per cent perhaps needs

more justification. In British water supply practice, 75 per cent is a more usual figure, but people in areas like Mpolonjeni cannot afford this degree of insurance against drought. They are also in a better position to adjust their consumption to meet periods of risk than water supply authorities in Britain, and thus a figure of 85 per cent mean inflow is a reasonable assumption.

With this information, the minimum storage required to satisfy this demand for the four consecutive years 1969-73 can be calculated. The method used, Thomas' sequent peak procedure is described by Fiering (1967), and Table 10.3 shows the stages involved. The monthly rainfall estimates for these years have been given in Chapter 3. Column (1) gives the inflow - 85.5 per cent of the monthly rainfall. Column (2) gives monthly outflow based on a demand of 85 per cent of the mean annual inflow. The accumulation (column 4) is a series of increasing "peaks" and "troughs" and the minimum storage required is represented by the greatest difference between a "peak" and its subsequent "trough", in this case, the beginning of May 1971 to the beginning of October 1971 - 149 mm of storage. With this storage volume, the quantities stored each month (column (5)) and any waste (column(7)) can be calculated.

This method has the advantage that the initial volume of water stored need not be known, but like all other methods based on monthly inflow and outflow, discrepancies can occur, because, whereas outflow is often a constant rate, the inflow depends on the vagaries of the climate. Thus, if the tank is full at the beginning of the month, all the month's rainfall may come within the next few days and be largely lost as overflow. The volume stored at the end of the month would be less in this case than when a constant rate of inflow had been assumed. Spasmodic, intense rainfall is more likely to occur in semi-arid areas, and for collection from roofs, there is practically no time lag between

Table 10.3

Sequent Peak Procedure for Determining Minimum
Storage at Mpolonjeni 1969-73

	Inflow Usable Rainfall (mm)	Outflow Consumption (mm)	Differ- ence (mm)	Accumu- lation	Storage (mm)	Waste (mm)	Stage of Storage
1969	85% mean inflow						
October	120	39	81	0			
November	87	38	49	81	81		
December	50	39	11	130	130		
1970							
January	11	39	-28	141 P ₁	141		
February	64	35	29	113 T ₁	113		
March	26	39	-13	142 P ₂	142		
April	21	38	-17	129	129		
May	28	39	-11	112	112		
June	17	38	-21	101	101		
July	2	39	-37	80	80		
August	21	39	-18	43	43		
September	15	38	-23	25	25		
October	76	39	37	2 T ₂	2		
November	31	38	-7	39	39		
December	73	39	34	32	32		
1971							
January	135	39	96	66	66	13	
February	29	35	-6	162 P ₃	149		Full
March	71	39	32	156 T ₃	143	26	
April	74	38	36	188	149		Full
May	31	39	-8	224 P ₄	149	36	
June	4	38	-34	216	141		

Table 10.3 (Contd)

	Inflow Usable Rainfall (mm)	Outflow Consumption (mm)	Differ- ence (mm)	Accumu- lation	Storage	Waste	Stage of Storage
July	0	39	-39	182	107		
August	0	39	-39	143	68		
September	9	38	-29	104	29		
October	69	39	30	75 T ₄	0		Empty
November	97	38	59	105	30		
December	105	39	66	164	89	6	
1972							
January	142	39	103	230	149	103	Full
February	142	35	107	333	149	107	Full
March	128	39	89	440	149	89	Full
April	3	38	-35	529 P ₅	149		Full
May	77	39	38	494 T ₅	114		
June	12	38	-26	532 P ₆	149		Full
July	13	39	-26	506	123		
August	3	39	-36	480	97		
September	4	38	-34	444	61		
October	16	39	-23	410	27		
November	62	38	24	387 T ₆	4		
December	41	39	2	411	28		
1973							
January	40	39	1	413	30		
February	162	35	147	414	31		
March	9	39	-30	561 P ₇	149		Full
April	26	38	-12	531	119		
May	51	39	12	519 T ₇	107		
June	4	38	-34	531 P ₈	119		
July	0	39	-39	497	85		
August	20	39	-19	458	46		
September	21	38	-17	439	27		
				422	10		

rainfall and storage, so clearly some extra storage volume has to be allowed.

In addition, some further storage would be required as 'insurance' against an unusually dry year or a delayed onset of the rainy season. The sequence of years chosen for the calculation of minimum storage above is customarily the three driest consecutive years on record. This cannot be done for Mpolonjeni; the four years considered include two with well below average rainfall, one of near average, and one exceptionally wet year. However, if a hypothetical dry sequence is considered, consisting of the years 1969-70, 1972-73 and 1969-70, then the storage required is 167 mm. This is probably a better indication of the minimum storage required.

With more data, and using more elaborate statistical techniques, a more reliable answer could be obtained. But the main purpose here is to estimate the approximate size of storage tank necessary, and decide whether one or more tanks are required; the sums of money involved are not large, and thus detailed analysis is not necessary.

Rainwater Collection at Mpolonjeni

At Mpolonjeni, within the last five years, the Nkundla, the women's association building, and the school extensions have been built. All have corrugated iron roofs, but none has any provision for collecting rainwater. Of the other buildings with corrugated iron roofs, the church, which also serves as school classrooms, has no guttering, but the three European style houses all make use of rainwater collected from the roof. Some of the traditional homesteads have less substantial structures covered with corrugated iron, from which small quantities of rainwater are collected.

At present, the minister's house has one length of guttering and the effective catchment area of the roof is 18.6 m^2 . The storage tank

capacity is about 6.6 m^3 . The tank was reported to be overflowing in the wet summer of 1972. With the same assumption of run-off and evaporation, and even allowing for a 40 per cent increase in the outflow during this period because of the wetter than average season, a mass storage calculation of the type carried out above indicates that the tank should have overflowed. This exercise therefore provides a useful check on the assumptions and estimates made.

The main buildings at Mpolonjeni and their roof areas are summarised in Table 10.4; the minimum storage volume required for 167 mm of rain is shown.

Storage Tanks

The most common type of storage tank in use in southern Africa is a galvanised corrugated cylindrical tank. The smallest size is 500 gallons (2.27 m^3) usually known as a "half tank" - 1000, 1500 and 2000 gallon sizes are also available, but are more difficult to transport. The cost of the two smaller tanks at a store in Big Bend in 1973 was as follows:

500 gallon tank	-	R33.75 (£18.20)
1000 gallon tank	-	R49.50 (26.29)

Transport to Mpolonjeni would add at least 10 per cent to these prices. The tanks stand on concrete aprons under the eaves of the building and the guttering leads water directly into them. Apart from the initial high cost, the tanks have a limited life - often no more than five years and sometimes as little as two years. The main problem is that the seams open up or corrode. Better installation could overcome this to some extent, but five years is accepted as a reasonable life by European farmers who have the knowledge and capital to improve the installation, and thus there appears to be some basic weakness in the design.

Table 10.4

Buildings at Mpolonjeni, Rainwater Collection and Storage

Buildings with Corrugated Roofs	Roof Area m^2	Gutter length m	Storage for 167 mm 'minimum' m^3	Water Available m^3 /year	Water Available 1/day	No. of 'Hlekweni Tanks' needed
<u>Nkundla</u>	190	36.6	31.75	87.6	240	5
<u>School</u>						
1) Main classrooms	200	44.3	33.40	92.2	252)	5
2) Office & classroom	101	12.2*	16.87	46.6	127)	3
3) Church	76.5	10.7	12.78	59.0	162)	2
<u>Women's Building</u>	67.5	7.7	11.28	31.1	85	2
<u>Minister's House</u>	45	9.3	7.51	20.8	57	1
<u>Square Thatched Hut</u>	15	15.2	1.27**	4.0	11	6 or 7 200-litre drums

* Single pitched roof

** Storage for 85 mm of water.

A much more satisfactory solution has been developed at the Friends' Rural Training Centre, Hlekweni (near Bulawayo, Rhodesia) (Henson 1972). They devised a similar sort of tank, but made from reinforced concrete built around a cylindrical former of corrugated curved sections. Full construction details are given in Appendix 3. A certain amount of building and plastering skill is necessary, but no complicated equipment is required so that the process is admirably suited to community development projects. The materials cost estimate in 1972 was around £10, a figure which is more appropriate for water supply improvements in areas like Mpolonjeni. The volume of the standard "Hlekweni tank" is 7.5 m^3 - a conservative estimate - but smaller and larger tanks could be built using the same techniques. The durability of these tanks has not been proven, because few have been in existence for more than three years, but even if leaks were found it would not be a difficult matter to re-seal the inside.

On the basis that the Hlekweni tank is 7.5 m^3 , the number required for each of the buildings at Mpolonjeni is shown in Table 10.4. Even the largest school building would require only five tanks, and this could be reduced to four by using slightly larger tanks. For all but the minister's house, there would be excess storage. For years of around the mean average rainfall, some overflow or waste is to be expected. When rainfall is greater than the average, as in 1971-72 (Table 10.3), most of the extra rainfall is waste.

In those circumstances, some temporary storage, (e.g. 200 litre oil drums) can be arranged, or extra permanent storage capacity employed (e.g. another Hlekweni tank) to retain the overflow. This could be used at other times of the years for non-regular commitments.

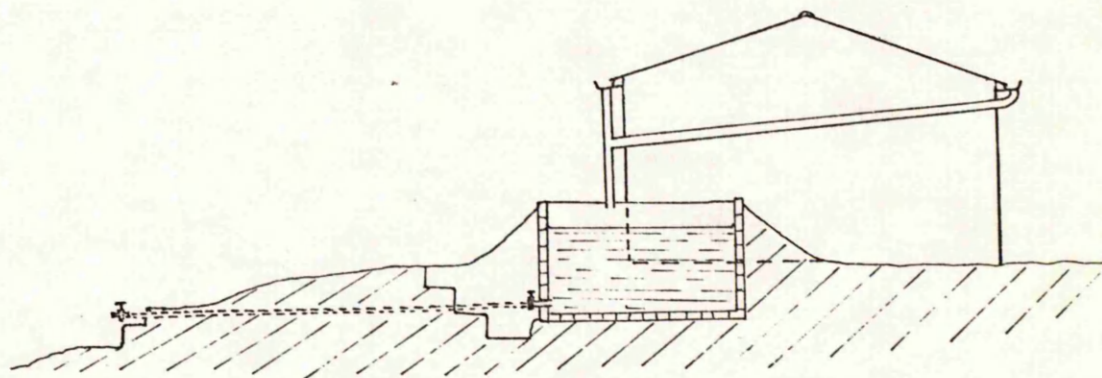
Other types of storage tank may be considered. Instead of having several smaller tanks, one larger tank could be built into the

structure of the building (Fry & Drew 1956), or a tank could be excavated in the ground near the end wall of the building (Moody, 1973). However, apart from the intrinsic advantages of having a number of smaller sources instead of one larger one, the first alternative - the built-in tank - requires careful design, and the second one - the excavated tank - sacrifices some of the advantages of rainwater collection from the roof, namely - protection from sources of pollution, and the avoidance of pumping. The last objection can be overcome by constructing the tank partially below ground and excavating a draw-off point, or by having a take-off pipe running underground to exit from the slope (Figure 10.2).

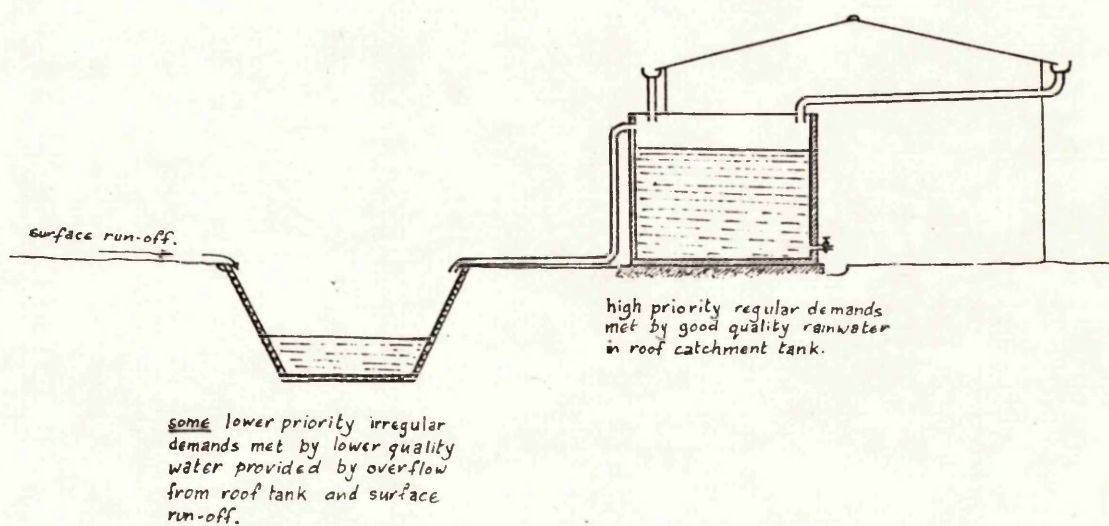
In semi-arid areas like Mpolonjeni, some thought has also to be given to the guttering to ensure that it is of sufficient cross-section to cope with intense rainfall. Some rainfall intensities for the Swaziland Lowveld are given in the O.D.A. Report on Water Resources Development Plan for the Imbuluzi River Basin (O.D.A/Government of Swaziland 1971). There is a 50 per cent probability that rainfall intensities of 72 and 58 mm/hr will be recorded for quarter-hour and half-hour storms respectively. A further indication of the rainfall intensities to be expected was obtained by examining the Wisselrode (near Big Bend) weather station records. For the period August 1973 to July 1973, a total of 449 mm of rain was recorded, of which 240 mm fell as "storms" defined as indicated below:

16 storms	rainfall intensity	5 mm/hr
8 "	" "	10 mm/hr
4 "	" "	20 mm/hr

Thus a significant proportion of the total rainfall - perhaps around a half - occurs in storms. If the assumptions made in estimating "usable rainfall" are still to be valid, then the collection system must be adequate to deal with these intensities.



(a) Two possible arrangements for a gravity supply from a partially excavated tank.



(b) Roof water and ground run-off water used in conjunction.

Figure 10.2 ARRANGEMENTS FOR ROOF TANKS

Collection of Rainfall from Thatched Roofs

Rainwater collection from corrugated iron roofs is a solution for only a small proportion of the people in Mpolonjeni. The great majority of the population live in traditional homesteads, which consist of a number of timber-framed thatched huts. The number of huts depends on the number in the family unit but, including food stores and kitchens, the ratio of huts to people is around 1 to 1. The floor area of each hut is approximately 15 m^2 . It is worth considering whether thatched roofs present any opportunity for collecting rainwater.

The most obvious deficiency, when compared with corrugated iron, is that thatch initially absorbs a lot of rain, much of which may never be collected in guttering. However, from the author's own experience, even poorly maintained thatch is remarkably impermeable, and thus once the thatch has become saturated, run-off should occur quite quickly. Some preliminary experiments carried out at Hlekweni, Rhodesia, suggest that 10-15 mm of rain is required to saturate the thatch, after which water runs off at rates comparable to corrugated iron roofs. Experiences of thatched roofs in Britain suggest that some run-off occur with less than 10 mm of rain. Thatched roofs would appear to behave more like the usual type of catchment where run-off is a lower proportion of the rainfall, and where inflow into streams and reservoirs continues long after the rain has ceased. Obviously, the proportion of run-off will depend on the type and quality of the thatching, but 50 per cent (including also evaporation losses) is probably a reasonable estimate in order to obtain an indication of likely storage and yield.

Applying the "sequent peak procedure" to the same four year period, the minimum storage for each 15 m^2 thatched roof for a yield of 85 per cent of the mean inflow is 1.28 m^3 (Table 10.4). This storage

capacity could be satisfied by five 200 litre oil drums, which can usually be acquired for about R1 each (approximately £0.6).

There are objections to using water collected from thatch - mainly that the quality of the water may be seriously affected by animals, birds and insects which live in the thatch. The author was able to observe that some poorly maintained thatches harboured lizards and mice or rats. The latter particularly are a potential source of infection. The thatch may also adversely affect the taste of the water collected. In addition, there are practical difficulties. Relatively long lengths of guttering are required which might be difficult to fix to unsubstantial structures; for round huts there are more problems in fixing guttering. For huts which are close together it might be possible to arrange a lower corrugated iron roof between the two huts and collect the water from both the thatched roofs.

Clearly, collection of rainwater from thatch is less satisfactory than collection from corrugated iron. If all the huts at Mpolonjeni were to be fitted with guttering and storage tanks, then the whole process could be very expensive, and the present demands of the population for water carried home could just about be met. There are valid objections against using water collected in this way, but where guttering can be easily fabricated, e.g. by bending flattened corrugated iron sheets, and oil drums are available, it is a source of water which should not be summarily dismissed.

The Use of Rainwater Collected from Roofs

By providing the minimum storage based initially on an average year's rainfall, this inevitably means that in some years large quantities of water are lost to overflow. On the scale of reservoir supplies extra storage can be provided downstream or, more economically, by

increasing the capacity of the original dam. Then by recording water levels and carefully controlling outflows, some of the water which would have formerly been lost could be put to good use. Obviously this strategy is not practicable for family supplies.

In order to devise a scheme at this scale, it is necessary to remember the two main characteristics of water use in a semi-arid area. These are:

- (1) "High priority water" is required for drinking and cooking (Chapter 8).
- (2) People are prepared to reserve their best quality sources so that they last through a long dry period.

This is usually possible where the source is under the control of one family or a small group of trusted people. Thus the water collected from the minister's house at Mpolonjeni was used by his family only for drinking and cooking. Washing of clothes and perhaps some bathing were done at a traditional source some distance away.

Rainwater from roofs, on all counts, is good quality water, and would therefore be used for high priority consumption. Any extra rainfall in wetter than average years could be used for low priority consumption (e.g. brickmaking, washing clothes, household repairs, or other irregular demands).

These differing demands could be met by the arrangement shown in Figure 10.3. If we consider the minister's house as an example, and use the figures of Table 10.3, then the minister and his family could draw-off a regular daily maximum quantity of 57 litres (just over six 2-gallon buckets) for their everyday domestic use, and still be confident that the supply would last through everything but the most extreme drought. The tank at ground level could supply some of their low priority and irregular demands. Since quality is of less importance

for this source water could be simply extracted by bucket. Such a ground level tank could also be supplemented by ground run-off.

Such a system would not be so practicable for those living in thatched houses, since roof areas are smaller and guttering is difficult to fix. In these circumstances it might be better to think of run-off from thatch being collected from catchment areas at ground level. Huts in a homestead grouping are usually close together and water from several roofs could be channelled to a common tank which incorporated some form of sand filter along the lines of the ground run-off catchment tanks described earlier. The tank could be divided into two parts; one which provided the high priority reliable supply, the other meeting the irregular demands.

A multiple-use water catchment system has in fact been developed by a Botswana family near Mochudi. One half of a double pitched corrugated roof (total area 90 m^2) fills a conventional corrugated roof tank of about 2,100 litres. The other half of the roof fills a concrete block lined tank which is partially underground. The capacity of this tank is about 18,500 litres, and the whole roof area would yield about 30,000 litres of water in a typical year. The overflow from these tanks, and run-off from the ground area surrounding the building, supply a 40,000 litre mud/polythene catchment tank.

This family has thus three different types of water source. The small roof tank can meet its culinary needs. The underground tank, requiring a bucket for extracting the water, provides a source for washing and bathing. The catchment tank, being the poorest quality, is used for maintaining a well kept garden.

10.7 Piped Water Supplies

Piped water systems are becoming more common in many semi-arid areas of Africa, notably Tanzania. Most are supplied by gravity flow,

but others are pumped supplies. If the source is a well or borehole, then pumping must be involved.

Piped supplies are usually only considered where there is a sufficient concentration of population to justify some form of distribution system. In Chapter 7, it was suggested that the population densities found in the Swaziland Lowveld are generally not high enough to warrant piped distribution, but in the Mpolonjeni study area, two village sites have now developed - Ngcina and Mpolonjeni, and as part of the Rural Development Area concept, piped supplies have been proposed for both these areas.

At first sight, this type of domestic supply would seem to be totally different from the catchment systems discussed previously, especially where pumped schemes are considered. The scale of the undertaking is much larger involving far more capital equipment and engineering expertise. However, like the catchment systems, the piped water schemes in the Mpolonjeni Rural Development Area were planned as self-help projects, depending for their construction on the voluntary labour of the potential beneficiaries. And although they seem more capital intensive, e.g. diesel driven pumps, the capital cost expressed in terms of the number of people served is much the same as for a beehive catchment tank (Figure 7.2, Chapter 7). The great difference is that a pumped system and piped supply is dependent on the outside help of a government department or other agency for technical assistance in construction and maintenance, whereas a catchment system could conceivably be initiated and completed wholly within a community.

Oxfam provided a grant for the Mpolonjeni and Ngcina schemes in 1968, a borehole was sunk at Ngcina at about this time, but little further has happened on the piped supplies until 1972-73, when the Ngcina scheme was completed and the Mpolonjeni scheme was started.

Progress on the latter has been slow for the reasons given in Chapter 6. Both schemes depend on diesel pumps which raise water from the Mbonga and Mkutshane Dams to supply Ngcina and Mpolonjeni respectively. In the completed system at Ngcina, the water is pumped into a 59 m^3 capacity storage tank on the ridge where the community is situated, and is reticulated from there to six public taps and drinking troughs for cattle. The only treatment is simple filtration through a 2,000 litre header tank containing graded gravels and sands; sedimentation in the storage tank is encouraged by dropping "alum blocks" into the tank each time it is filled. A local resident starts the engine and pump each time the tank empties, which happens about every two weeks.

Originally the borehole was meant to supply livestock and people, but the water was brackish and unpleasant to taste. The yield when originally tested was about 23,000 litres/hour (Geological Survey Department Records). Water was pumped by wind powered machinery, but it seems that this has been out of use for at least two years. The records of application for funds to Oxfam suggest that even before the borehole was sunk, the piped supply from Mbonga Dam had already been contemplated and costed (Progress Report September 1968 Oxfam). The fact that two supplies have been constructed which duplicate each other suggests that there has been insufficient consultation between government departments. The present plans for the borehole are that the pumping equipment should be repaired, and the water should either be an emergency supply or may be mixed with water from the dam to reduce the brackish taste (Tsabedze 1973).

With the quite separate piped supply at Mpolonjeni, the school and the Nkundla are the main places to be served. There will probably be taps on the delivery line between the school and Nkundla, but the present plans do not show any extension down the main road where large

numbers of homesteads are situated. If a community supply is envisaged, this would seem to be a logical development.

The cost estimates for the two schemes as prepared by the Ministry of Agriculture in February 1972 were as follows:-

1. Mbonga Dam to Ngcina Village

	Rand
Engine and Pump	850.00
Pump house & installation	250.00
Delivery line to village - 5000 ft. at 10c per ft.	500.00
Delivery line to bulcamp (already installed)	-
Delivery line to grazing camps 4500 ft. at 10c /ft.	450.00
Drinking troughs 1000 gallons/day	200.00
Extra storage at school 10,000 gallons	<u>400.00</u>
	2650.00
Contingencies 10%	<u>265.00</u>
	2915.00
	(= £1,495)

2. Mkutshane Dam to School and Nkundla Site

	Rand
Engine and pump	1200.00
Pump house and installation	250.00
Delivery line - Dam to school 11000 ft @ 30c/ft.	3300.00
Delivery line - School to Nkundla 3500 ft. @ 10c/ft.	350.00
Storage at school - 5000 gallons	200.00
Storage at Nkundla 10,000 gallons	<u>400.00</u>
	5,700.00
Contingencies of 10%	<u>570.00</u>
	6,270.00
	(= £3215.38)

Total head
m

Ngcina	52.5	5 hp. Lister diesel + piston pump
Mpolonjeni	44.2	5 hp. Lister diesel + centrifugal pump

These cost estimates, in the case of the Ngcina supply, have probably been followed quite closely. They refer only to materials. Other costs are the voluntary labour of the community, and the supervision and skilled labour provided by the Ministry of Agriculture, plus its overheads. The cost of estimates in terms of number of persons served have already been shown to be relatively high compared to other piped schemes in Africa (Chapter 7). Three further points may be noted:

- (1) The high cost of the engine and pump, amounting to between 20 and 30 per cent of the total estimate in each case, and especially the high cost of the centrifugal pump used for the Mpolonjeni scheme - since the engines are similar for both schemes.
- (2) The high cost of providing approximately 10,000 gallons (45.4 m^3) storage (actually 59 m^3 in the Ngcina scheme); these figures should be compared to costs of storage tanks made for roof catchments (Section 10.6) - 6 "Hlekweni" tanks equivalent to 10,000 gallons would cost about R110.
- (3) The cost of the dams, which is not included in these estimates, and perhaps should not be, since the dams serve other purposes as well. However, if the dams had been built specially to serve these projects, an extra £2,500 would be added to the cost of the Ngcina scheme (where the site is favourable for dam building) and another £5,000 would be needed for the Mpolonjeni supply.

The Ngcina Supply in Use.

When seen by the author in August 1973, the scheme had been in use for a few months and appeared to be working satisfactorily. The only shortcoming apart from the social considerations mentioned in Chapter 6, was that the head provided by the storage tank to the delivery

pipe was insufficient when the level was low. In fact, people were bending the standpipes towards the ground in order to obtain a satisfactory flow of water. All the taps were of the spring loaded type and there was no evidence of these being deliberately tampered with or "vandalised" as some authors have suggested (see for example, Holloway 1971).

The bacteriological quality and appearance of the water supplied by the system was an improvement on the water in Mbonga Dam (Chapter 5) and this degree of treatment would seem to be appropriate to the needs of the community. The water was used in the local clinic (possibly with sterilization), but there was no suggestion that people expected the water to be absolutely pure. In fact, the nurse in charge of the clinic still had her own domestic supply delivered in cans from the hospital in Siteki once a week. It is sometimes suggested (e.g. Jackson 1962) that people expect water from a tap to be absolutely pure and "safe" and this is then used as an argument for chlorination of all piped supplies. This may be the case in urban conditions, but is unlikely to be a prevalent view in rural areas of Swaziland.

Since the bacteriological improvement is largely the result of storage alone, the quality of the water is likely to be variable and will depend on the storage state of the tank. In order to achieve a consistent quality, the tank would need to be divided into two sections, one of which was refilled at regular intervals after being emptied into the other which supplied the distribution line. Such a system would require a management routine which could be operated by an ordinary villager.

In theory, the Ngcina supply is now the responsibility of the community. The chief had already bought some oil for servicing the engine. According to Mr. John Tsabedze, the officer from the Ministry

of Agriculture who supervised the project, the community members are only just becoming aware that they will have to pay to maintain the supply, and provide extensions. Of course, those community members who do not have a tap nearby are more reluctant to pay for maintenance. Mr. Tsabedze suggests that many of the community disliked the idea of having to rely on water being pumped, because of the cost and the risk of supply failures, and he is afraid that the scheme may not be used much unless the secondary school, for which the Chief has plans, becomes a reality.

Once a piped supply has been chosen, there is little scope for reducing capital costs, except in the storage tank facilities as pointed out above. However when pumping is required, a great deal can depend on the pump, and to an even greater extent the choice of driving engine. The traditional choice, which was followed in this case, is to use a slow-running diesel engine. Such engines have a good reputation for reliability and long life, and are economical to run. But they are very expensive, and when serious maintenance work is required, need a very skilled mechanic, or somebody with more training than the average motor mechanic.

The alternative, discounting natural sources and animal power, is to use a higher-revving lightweight engine running on petrol or petrol/paraffin. Engines of this type have recently become very popular - particularly Japanese models. Fuel costs would be higher, and the life of the engine would be shorter. Spark ignition engines also tend to be less reliable but they are a more familiar technology and could be attended to by a motor mechanic of average ability. Such engines could have beneficial educative effects, and help to break down the mystique of technology. More importantly, these engines are often one fifth to a quarter the cost of the diesel equivalent.

At Ngcina we have a situation where capital for development projects is scarce (though, in practice, since material costs are met by external aid agencies, this has distorted the situation). It has also been shown in previous chapters that the community is not completely dependent on a piped supply and 100 per cent reliability is not expected and thus, it would seem that better use could be made of scarce capital resources by choosing a cheaper engine, especially as the system has been devised so that the engine runs for only 10 hours every two weeks. Even if consumption increases dramatically when a village and a secondary school are established, it would still be a gross under-utilisation of capital resources.

This conflict between choice of engine is characteristic of the general one between "proper engineering" and "make-shift" solutions. The Community Development Department has supported a few pumped water supply schemes. It would be inconceivable that they would ever spend over £300 on an engine to supply relatively few people, when one of £60 - 100 would seem to be equal to the task.

10.8 The Choice of an Appropriate Domestic Water System

The three types of domestic water systems discussed in this chapter are so different that comparisons may seem irrelevant. Yet wells, catchment tanks and piped water systems have all been used in semi-arid areas of Africa, and there may be circumstances where limited investment funds have to be divided between projects of these different types. In some areas, of course, geological conditions exclude the possibility of wells; and in some districts the topography or the settlement pattern will make a piped water system difficult and costly to provide. But even so, a choice will very frequently have to be made.

Piped water systems offer a good combination of water fairly near the home, acceptable water quality, and an ample volume of supply.

Catchment tanks may score on the first two counts, but the volume of supply is limited. Wells cannot be so conveniently situated as public taps in a piped system. The volume of water is generally sufficient, but where the sources are used by many people the quality of the water is only good if precautions against pollution are taken. Thus it could be argued that a piped system is the only one capable of a reasonable supply, and that it represents a stage of development which is more advanced than either wells or catchment systems. Piped supplies might be seen as the ultimate replacement of an earlier phase of tank or well developments, and not as the alternative. In practice, however, because of scarce resources, satisfactory wells and tanks are unlikely to be replaced in the foreseeable future. In almost every instance, the problem is to introduce the most appropriate improvement in an area where the only earlier water development is a small dam or water hole. The choice of an appropriate improvement is partly a matter of what the potential beneficiaries want and can maintain, and partly a matter of unit costs, labour intensity, and other economic measures.

The obvious unit cost for a catchment tank is the cost per unit stored. But this only emphasises the "economy of scale" argument against small-scale systems. A more relevant unit cost, and one that enables comparisons with wells and piped supplies is the cost per person served by the supply. The number of people served is limited by capacity in the case of a tank, and by distance and ease of access in the case of wells and public taps. Taking 10 litres/head/day as a typical rate of consumption, a catchment tank with a capacity of 90,000 litres, and a daily draught of 250 litres can serve 25 people.

The best way of using a catchment tank is in conjunction with other water sources. In other words, it would serve high priority demands, and would have to be rationed during the dry season. In

these circumstances, water drawn from a tank might be cut by half, or twice as many people may be served. In order to estimate the unit per capita cost of a catchment tank, it would be necessary to estimate the cost of the water drawn from the alternative source, but this is rarely practicable.

Using this type of unit cost as a basis of comparison, it is possible to consider whether a catchment tank system could have been used at Ngcina as an alternative to the piped water supply. The material and semi-skilled labour costs of the 90,000 litre tank were R340 (about £200) (1971 prices, Swaziland, Ministry of Local Administration). Using a more detailed breakdown of costs given by ITDG (1969) for the mud-polythene tanks in Botswana, it is possible to deduce that the materials cost, including a pump at around £10, of this tank would be about £100. The possible types of water supply which might have been considered at Ngcina, given that the borehole was unsatisfactory, were as shown on Table 10.5.

The analysis shown in the table, although very approximate in some ways, suggests that all three systems are very much on a par as far as unit materials costs are concerned. Catchment tanks show up as the cheaper solutions, but it was observed above that there was scope for cutting costs in the piped supply by using a petrol engine or by economising on tank construction. At the same time it was argued that the excavations for beehive tanks might be made mechanically, or alternative forms of construction adopted, all of which would increase unit costs.

These money calculations all assume that labour is given free. The catchment tanks show up as very much more labour intensive solutions. If labour were paid for they would be very uneconomic. The total cost of the 90,000 litre tank, assuming all labour costed, would

Table 10.5

Alternative Water Supplies for Ngcina

	<u>Catchment Tanks</u>		Piped Supply
	Ground run-off Beehive type	Roof run-off (Parker 1973)	
	90,000 litre	71,000 litre	
<u>Labour Requirement</u>			
a) digging	160 m ³	80 m ³	300 m ³
b) building	(lining domes)	(tank walls roof)	(tank walls pump house)
c) total hours work	2 - 3,000 *	700	1,000
<u>Materials Requirement</u>			
	(polythene cement sand (transport) pump)	cement guttering roofing	pump engine pipes cement
Cost (1972 prices)	£100	£87	£1500
<u>People Served</u>			
at 10 litres/head/day (estimate)	25	20	300
<u>Unit Cost</u>			
	£4	£4.4	£5
<u>Hours work (per consumer)</u>			
	100	35	3.5
<u>Measure of Labour intensity</u>			
= $\frac{\text{Labour (hrs)}}{\text{Capital (£)}}$	20-30	8.2	0.7

* This estimate for total construction work has been based on figures provided by the Economic Planning Office, Swaziland (1971). The labour contribution to the cost of this size of catchment tank was estimated at R480. This includes skilled, semi-skilled and unskilled labour. Assuming average wage rates of R1 - 2 per day, the labour content has been estimated. This total estimate of labour content is generous.

be R820 (approximately £425, 1971 prices, Ministry of Local Administration). They are clearly only relevant where people have plenty of time available to devote to such tasks, thus substituting capital with labour.

Table 10.5 illustrates the situation in a semi-arid area. As mentioned in Chapter 7, the unit costs of piped supplies are generally lower in areas with moister climates, and may even be as low as £1 per person served. Hand-dug wells also generally show low construction costs. In a group of villages in Tanzania, seven hand-dug wells were built by voluntary labour at a cost of £81 each (1969 prices - probably increased to £90 in 1971), inclusive of the cost of a hand-pump (C.T.D.F. 1972). The average population per well was quoted as 400, though the number living near enough to be regularly served was perhaps a third of this. Unit costs were therefore £0.7 per head.

Thus, in contrast to the situation at Ngcina, the position in a moist climatic region with shallow groundwater might be as shown in Table 10.6; catchment tanks are now very much more expensive than the other possibilities. This confirms the point that catchments are only appropriate in rather extreme climatic conditions where other sources of water are few, and where populations are sparse.

Table 10.6
Water Supplies in Densely Populated, Moist
Climatic Zones

	Hand Dug Well	Beehive Catchment Tank	Piped Supply
Typical Unit Cost (£ per person served)	£0.7	£4	£1
Reference	CDTF 1972	Table 10.4	Chapter 7

In conclusion, it would seem that catchment tanks have rather restricted applications when these criteria are applied. High unit costs are sometimes acceptable where individual families can afford them, as evidenced by the extensive reliance on roof tanks by European families throughout southern Africa. Thus the Batswana family and their multiple-source catchment system referred to in Section 10.6 have probably spent about R175 (approximately £105) on their tanks. This figure includes some hired labour. The cost of the mud/polythene catchment tank, according to the owner, was around R100, and the concrete block lined tank about R40. The mud/polythene tank was considered a lot of trouble and tedious to build by comparison with the concrete lined tank. Assuming a family of six the unit per capita cost is about £17 which is much higher than the costs of other systems, but it should be remembered that the family has a complete supply, and is also able to maintain a garden.

One final hidden cost for roof catchment systems is the cost of the roof. Where a catchment area has to be specially constructed, the most systems would normally be too expensive. Where suitable catchment areas already exist, such as school roofs etc. it would seem sensible to take advantage of them, but for most ordinary families, the high money cost of roof catchment systems is a big disadvantage. There is clearly a need for an individualised roof tank system which can be constructed by householders using a greater do-it-yourself, money saving element.

CHAPTER II

CONCLUSIONS : CRITERIA FOR CHOICE IN WATER SUPPLY DEVELOPMENT

11.1 Criteria for Appropriate Technology

Water is an essential requirement for human life. The evidence presented in chapter 1 suggests that 1026 million people, or 88 per cent of the present world rural population, experience some hardship in meeting their daily requirements for water.

In societies which are often culturally and socially rich, but materially deficient by western standards, it may be difficult for an outsider from the developed world to judge the extent of hardship, or say what an "adequate" water supply might be. But there seems little doubt that the majority of these people desire better water supplies and that they either as individuals, communities, or represented by governments, want external assistance so that improvements can be made relatively quickly.

On the wider question of relationships between the rich and the poor, it seems that John Donne's line, "No man is an island" can also be applied to nations. The rich countries cannot abandon the poor countries to their fate, nor must they expect that the poor countries will be unable or unwilling to influence the affairs of the industrialized world.

In order to undertake this task of improvement it is necessary to ask three questions :

- (1) What is the present pattern of consumption and water used in the areas considered?
- (2) What are the likely consequences of improvements?
- (3) What are the best ways of carrying out improvements, and how great should the stages be?

Until recently, little was known by outsiders, and almost nothing had been published about water use in rural Africa communities. The quantities of water used; the qualities of water consumed; the distance people fetched water; their choice of various sources as it affected health and their preferences for taste, appearance, ease of lathering soap; the costs people paid for water; all these factors were largely unknown. What knowledge did exist was scattered amongst the records of former colonial administration.

Following the work done in East Africa by various Departments at the University of Dar-es-Salaam; by I.D. Carruthers and others; and most recently by White, Bradley and White the present pattern of water use in these areas has now been fairly well established. This thesis with less detailed surveys, has extended this work to some semi-arid regions of southern Africa, and has shown that the pattern of water use there is broadly similar.

One main difference is that people in the Mpolonjeni case study area, use less water at home than was recorded in East Africa by White et al. and Warner (1969 (a), 1969 (b)) - about 7 litres/head/day compared with 13 litres/head/day in Warner's studies and 15 litres/head/day in the studies of White, Bradley & White.

The Swaziland Lowveld also offers a much narrower range of dry season sources, but taste and appearance of the water are more important; the nearest source is frequently not chosen. One final major difference between East Africa and the Swaziland Lowveld is that in the latter region, water is often transported in bulk in 44 gallon (200 litres) drums on ox-drawn sledges or occasionally on donkey carts (Plate 4). The use of cattle and donkeys in transporting water necessarily involves the male members of the community, whereas in East Africa, domestic water supply is almost exclusively the preserve of the women.

It is unlikely that further work along the lines of White et al. for other sem-arid regions in southern and eastern Africa would reveal startling differences in say the amount of water used by people each day when it has to be carried home. In general, such work would only refine the basic points already made. However, further case studies of communities are necessary in order to establish what the priorities of local people are, and what opinions they hold about the adequacy and quality of existing local sources.

On the second question, about the consequences of water supply improvements, the position is much less clear. Again, the East African sources of information have provided a starting point in answering the question, and this thesis has suggested a way in which the problem can be tackled (Chapters 6 and 7). Many consequences have been identified and classified in to various types and orders, but the magnitude of the effects is still largely a matter of speculation.

The direct consequences of water supply improvement seem very small, but this is the case with other inputs to rural development, such as education and housing, when each is considered in isolation.

This is because the contributions of each input are difficult to identify in their entirety, and are inter-dependent.

Water supply is an essential ingredient of rural development; but the emphasis which should be given to it is still in doubt. The qualitative arguments in favour of a strong emphasis are good, and in the field of health consequences, White, Bradley & White have tried to make a quantitative assessment of the benefits. Their main conclusion was that the amount of water used, which in turn is influenced by its availability, has the greatest impact on the health of dispersed rural communities. Since the bacteriological purity of water contributes less to health benefits and has little effect on economic and environmental consequences, it seems clear that water purity is something of a luxury for the rural communities being discussed.

The health aspects are a particular class of consequences arising from water supply improvements. What is required is that the wide variety of economic consequences be similarly quantified. At the present only the most general effects are known; thus, per capita daily consumption can be used as an indicator of economic development in the same way that energy consumption is, but on the individual or community level the relationships between the quantity of water used and any economic activity above mere subsistence level is less well understood. Perhaps the only way of establishing these relationships is by carefully controlled case-studies.

It is doubtful whether social consequences can even be quantified in the same way; indeed, it may not even be desirable that they should be. Water supply improvements are bound to have social consequences, which may be more pronounced in areas where water is scarce, but the ultimate judgement on whether these are beneficial or detrimental, is

one that cannot be made by an outsider. One must be wary of over-analysing communities in order to determine social effects, since this may create the impression that the people in these communities are no longer in control of their own affairs.

Instead, the people should be presented with the possibilities for improving their water supply position, and they should be encouraged to make their own assessments and choices about the social change which may follow. Much academic research has been on the social effects of "development" in general (though rarely mentioning water supply). Much of this research has been rather sterile as far as practical results are concerned.

The answers to the two preceding questions about patterns of supply and consequences of improvement are obviously useful in formulating answers to the final question - what are the criteria which must be satisfied in implementing water supply developments? Previous developments have been undertaken largely on an intuitive, ad hoc basis rather than being based on considered assessments of the consequences. Water supply, like housing and health is an emotive topic, and it is likely that national and community decisions for developments will continue to be made on such grounds. In these circumstances the study of present conditions and the attempt to assess the consequences are thus really exercises designed to justify what might be considered "common sense" or "political" decisions.

In whatever way the decision is arrived at, water supply development should be appropriate in three ways :

- (1) technical.
- (2) economic.
- (3) social.

The technical efficiency of water supply developments in semi-arid areas, particularly the storage of water, has been dealt with in Chapters 2, 8, 9 and 10. Semi-arid regions are by definition areas where the supply of water, when evenly distributed is barely sufficient to support vegetation and animal life. These areas can only be managed successfully by concentrating the small and spasmodic rainfall for use where it is needed for crop cultivation, stock raising and for the human population. To do this, it is necessary to find methods which are "environmentally appropriate" in terms of water conservation. In general, these methods will be ones which collect and store water efficiently, so that the user does not have to contend with excessive and often unpredictable losses. This thesis has highlighted aspects of water supply technology where further research is needed, and these are listed later in the section on recommendations.

The economic appropriate-ness of a water supply project can be gauged by (a) cost levels dictated by environmental conditions and settlement patterns and (b) favourable ratios of benefits to costs.

The significance of the first point, is that if "rural development" and "redistribution of wealth" have any meaning the governments must expect to give greater capital assistance to those in semi-arid areas living in dispersed communities.

The significance of the second point is whether monetary yardsticks even in theory, can be used to express all the benefits and costs. If so, then a cost/benefit assessment is clearly the most satisfactory means of assessing rival schemes. If, on the other hand, it is believed that there are some items which can never be expressed in monetary terms, then a cost/benefit assessment is only one indication - possibly the most useful-of the likely value of a scheme. Money, like time, has different values to different people in different circumstances, and a water supply scheme can probably be satisfactorily assessed only by choosing the most favourable benefit/cost ratio which satisfies social pre-conditions.

The social appropriateness of an improved supply may be gauged by asking such questions as :

- (a) Does it meet the felt needs of the local people and their preferences as to water quality etc.?
- (b) Do the people feel that the supply belongs to them, is part of the fabric of their lives, because they have participated in its design and construction? Or do they regard it as an alien object provided by outsiders, so that they neither use it whole-heartedly, nor care for it properly?
- (c) Is there social control of maintenance and use?

In determining the success or failure of a project, social considerations are often the most important, since they ultimately override both technological and economic appropriateness. Thus appropriate social conditions are necessary and sufficient, whereas the other two are only necessary.

It is possible to think of schemes which are appropriate technically and economically (eg. perhaps catchment tanks) yet which have not been completely acceptable socially.

It is clearly not going to be easy to establish firm criteria for social appropriate-ness since by their nature these criteria are the unpredictable characteristics of humanity. However some criteria can be tentatively put forward. These are :

- (a) the physical scale of the project
- (b) the time scale for completion; the possibilities for the project being tackled in a series of small discrete stages, with the final possibility that the completed project leads to different methods of water supply.
- (c) the human resources of the people; apart from money contributions, labour and skills are needed. Experiences and abilities, such as that of being able to discriminate between the quality of different water sources, should form a basis for the choice of development. The traditional criteria for making choices, and the management skills in organising a project, are important considerations.
- (d) the social potential of the project in developing self-awareness, self-reliance and co-operative modes of working the community. Thus a simple water project may contribute to rural development.

In summarising the more technical conclusions of this thesis (Table 11.1) two of these criteria of social appropriate-ness have been emphasised. Although the time-scale problem and the social potential of a project are important, many of the issues discussed here can be understood in terms of a balance between physical scale and complexity on the one hand,

and human resources on the other.

Physical scale is relevant to the efficiency with which resources are used, and this is crucial in societies whose money resources are limited. Large-scale projects undoubtedly achieve "economies of scale" when looked at from a purely theoretical point of view, and many catchment tank projects seem relatively costly simply because they are intrinsically small in scale. But the "economies of scale" are often sufficient to hide the technical inefficiencies of large-scale projects and the managerial problems of dealing with a large and elaborate project. Often, especially in developing countries, the economies of scale may be quickly cancelled out if the people concerned cannot run it as intended. With scarce money resources, these are restraints on the size of project which can be considered. In these circumstances, it is more useful to consider how the technical and managerial efficiencies can be improved.

A recent book on technology in developing countries is entitled Small is Beautiful (Schumacher 1973). This book helps to underline the view that when social rather than economic criteria are considered, a small project is often more efficient than a larger one. The optimum depends on striking a balance between capital resources and human ones - both should be used to good effect.

The factors involved in striking this balance have been discussed in the previous chapters. Considering water sources separately from any distribution system, these points are summarised in Table 11.1. At the top of the table are the factors related to the scale of any new development of water sources and its technical efficiency, the criterion of scale being the quantity of water stored or available.

Table 11.1

Summary of Appropriateness for Various Types of Water Source

	Impounding Reservoirs	Wells (i) Boreholes (ii)	Bunded Dams	Ground run-off Catchment Tanks	Roof Catchment
<u>SCALE & EFFICIENCY</u>					
1. Quantity of water stored or available	++++	+++	+++	++	+
2. Quality of water					
a) taste	++	+	++	+++	++++
b) appearance	++	++++	+	+++	++++
c) bacteriological	+	++++	+	++	+++
3. Efficiency of collection *	+	-	++	+++	++++
4. Efficiency of storage					
a) seepage	+	+	+	+++	++++
b) evaporation	++	++++	+	+++	+++
5. Nearness to population	+	+++	++	+++	++++
6. Application limited by geography and geology	unsuitable in flat country	limited to certain areas	sloping land	bare ground	none
<u>RESOURCES EMPLOYED</u>					
1. Labour required per capita	++++	+	++++	+++	++
2. Technical skill	+++	++++ (ii) ++ (i)	++	+	++
3. Organising skill required	++++	++	++++	++	+
4. Degree of social control needed in operation	++	+++	++	+++	+
5. Capital resources	+++	+	++	+	+
a) total cost		+++ (i) +++ (ii)	++	+	+
b) unit cost	+	+	+	++++	++++

6. Future demands on resources

a) running costs	++	+++ (ii) ++ (i)	+	+	+
b) development need to provide supply near home	pipes, pump filters	pump (pipes)	not worth developing	pump	none

CONCLUSIONS

Appropriateness for:

a) high density of population	+++	++	++	+	++
b) dispersed settlement pattern	+	+++	++	+++	+++
c) semi-arid zones	+	+++	++	+++	+++
	High density nucleated	medium density	Low density nucleated	Low density dispersed	Low density dispersed
Money resources of community	High	High (ii) Low (i)	Low	Medium	Medium/High

* Run-off from large areas is very variable. Bunded dams usually receive greater proportion from large run-off areas. Catchment tanks deliberately sited in areas of high run-off. Roof catchment 95% run-off.

In lower part, the various types of resources employed in developing the water sources concerned are listed. These resources include the labour required (measurable in man-hours), and the skills needed by the people, e.g. in building, joining pipes or organising a labour force (as opposed to the skills of any outside engineer employed). The final parts of the table summarise the conclusions of previous chapters about the various types of water supply source.

11.2. Conclusions and Recommendations

At the beginning of this thesis it was suggested that "appropriate" technology ought to involve design at the systems level as well as the design of individual pieces of equipment which form only some of the component parts of the system considered.

This thesis has attempted to define the "system" with which the author is concerned, namely the pattern of water use among peoples in the semi-arid areas of southern Africa, and its social, economic and technological context. One test of how successfully this system has been treated is whether a full specification can now be put forward for an "appropriate" water supply technology for the communities concerned.

Another benefit from taking an extended view of this subject is that the major problems and bottlenecks are more identifiable, so that priorities for future technical development or scientific research can be more precisely defined.

The recommendations of this thesis fall into two groups. One specifies the characteristics of an appropriate water technology in the semi-arid areas discussed, and the other indicating the principal needs for further research and development in this field.

Added to these are some detailed recommendations applicable solely to the study at Mpolonjeni.

Recommendations: I Specification for an appropriate water technology.

An "appropriate technology" for an African community must be appropriate to that community's social objectives and perceived needs; it must use appropriate methods in planning, calculation and management; and it must use appropriate types of equipment and materials. A specification for an appropriate water technology which goes some way towards meeting these requirements would include the following points :

(1) Social and developmental factors.

- (a) An "appropriate" water supply improvement would be linked to other types of development which make use of the benefits the improvement may bring - e.g. education in hygiene, mother and child health services, family planning services, agricultural extension work, etc. (Chapter 6).
- (b) It would be based on the perceived needs and social objectives of the people as expressed through their participation in meetings connected with planning the project, and as shown by social surveys, and by their willingness to work on the construction of the project (Chapters 1, 6, 10).
- (c) It would lay particular stress on the management and maintenance of the completed works; and the extent to which the local community cared for the works on its own initiative would be regarded as a test of how truly appropriate the project had been (Chapters 1, 6, and 10).

2. Water use patterns

- (d) An "appropriate" water improvement would fit into the existing pattern of water use based on multiple sources with different functions for each, but it would offer the prospect of a stage-by-stage improvement in this existing system (Chapter 4).
- (e) It would, in many cases, add family-scale supplies to the existing system, such as house roof tanks, as well improving community water supplies (Chapter 10).

3. Economic factors.

- (f) An "appropriate" water improvement would be one which used low-cost technology, though recognising that costs are generally higher in semi-arid areas than elsewhere. For a project which provided water within, say, 100 metres of people's homes, typical cost levels might be £4 per person served (1970 prices (Chapter 7)).
- (g) It would employ voluntary labour as a means of saving capital, and as part of the community-participation aspect of appropriate technology; but labour requirements have to be matched to the community's capacity to provide them (Chapters 1 and 10).

4. Environmental factors.

- (h) An "appropriate" water supply improvement would employ techniques for water collection and storage adapted to environmental conditions in the area concerned - in semi-arid areas, short and variable rainy season, high evaporation and high sediment loads in streams and rivers (Chapters 2 and 8).

- (i) It would usually employ solutions whose applicability is summarised in Table 11.1, that is, for a community supply, wells where there is an assured supply of good-tasting water; elsewhere, roof tanks, ground surface catchment tanks, or simple piped supplies, gravity flow where possible, based on sand dams or open dams.

5. Water quality factors.

- (j) An "appropriate " water technology would not introduce any water treatment other than simple filtration and settlement in storage at the present stage, except where risks were exceptionally high, or where the people expressly placed a higher priority on low health risks than on the volume of water or the convenience of the supply. (Chapters 4 and 5).
- (k) It would use clean water sources wherever possible, e.g. rainwater, and would stress protection measures against pollution (Chapters 4 and 5).
- (i) It would aim to use water sources which conformed to people's preferences with regard to taste and appearance (Chapter 5).

Recommendations: II Needs for further research and development.

1. Open Dams and Sand Dams.

- (a) Work is needed to explore the potential of sand dams, and the possibility of extending their application outside areas where natural sand rivers occur. The selective process whereby sand is deposited while fines go over the weir could be applied to areas where rivers have a high sediment load (Chapter 9).

- (b) The study of the Mpolonjeni dams has raised questions on how soil mechanics, as applied to soils in temperate climates need modifying to deal with the extreme conditions of long dry seasons and intense rainfall (Ch. 8)
- (c) Further work is needed to assess the potential of charcos, perhaps used in conjunction with covered catchment tanks (Chapter 8).
- (d) The conditions under which small dams can be used for groundwater recharge, in conjunction with water supplies based on shallow wells needs further study. The application of this technique in parts of Botswana could be relevant (Chapter 8).

2. Tanks for water catchment from roofs and ground surfaces.

- (e) Work is needed to develop a cheaper roof tank for use at individual houses, perhaps using a kit for do-it-yourself construction so that labour can be substituted for capital. Attention is directed to efforts made in this direction at Hlekweni near Bulawayo (Chapter 10 and Appendix 3).
- (f) Work is needed on methods of collecting water from thatched roofs and on the amount of water that could be obtained. These collection methods would probably not use conventional guttering. (Chapter 10).
- (g) The covered type of catchment tank advocated by I.T.D.G. is worthy of a considerable development effort, aimed particularly at increasing the ratio of capacity to labour input without increasing costs (Chapter 10).
- (h) Further trials of diaphragm pumps in catchment tank projects would seem to be justified (Chapter 10 and Appendix 2).

3. The management of water supplies.

- (i) A management routine should be devised for operating those systems which depend on water purification by storage alone so a consistent quality water is supplied (Chapters 5 and 10).
- (j) Work is needed to devise simple methods of estimating a safe draught for small dams in rural areas where hydrological information is lacking; the object should be to produce a graph or other calculating device (Chapter 8).
- (k) Work is needed to devise water rationing or budgeting systems which ordinary people could use to make the limited supplies in catchment or roof tanks last throughout the year (Chapter 10).

4. Academic Research on Hydrology and Water Quality.

- (1) There is need for thorough hydrological studies of small catchments, possibly based on a chosen sequence of typical examples throughout the semi-arid areas, in order that run-off might be better understood. Run-off could be measured either by stream gauging or by monitoring dam water levels. Much of this work could be done by students at the University of Botswana, Lesotho and Swaziland (Chapter 8).
- (m) There is need of more thorough testing of water quality in low-cost water systems, e.g. shallow wells (where full protection against pollution is often lacking), beehive catchment tanks, piped water systems (Chapter 5).
- (n) Bacteriological conditions in dams and other water storage under extreme temperature conditions needs further study (Chapter 5).

- (o) The behaviour of clay suspensions in surface water as they affect bacteriological activity and aquatic life needs further investigation (Chapter 5).

5. Academic research on costs and benefits of water supplies.

- (p) There is need for more documented case studies which would show the consequences of water supply improvements in rural areas of Africa. The new water supply at Mpolonjeni would be suitable for such a study as the present author has at least partially established what conditions in this community were like before the improvement was put in hand. (Chapters 3 and 6).
- (q) There is need for a better understanding of the economic benefits arising from a water supply improvement (Chapter 6).
- (r) The mathematical model discussed in Chapter 6 could perhaps be developed to form a tool for analysing the costs and benefits of water supply improvements.

Recommendations: III Suggestions relevant to the case study area at Mpolonjeni.

- (s) A maintenance system for the dams should be instituted, with priorities, (i) to repair Hlangothi Old Dam; (ii) to repair spillways of all dams, and to deepen the Hlangothi spillway; (iii) to clear bushes on dam embankments; (iv) to check seepage to ensure that piping is not occurring (Chapter 8).
- (t) Dams should be fenced to prevent cattle from access to the places where people draw water (Chapter 4).
- (u) The completion of the Mpolonjeni piped water system should be secured, and the extension of a delivery line south of the Nkundla should be included so that as many people as possible may be served (Chapter 10).

- (v) Measures should be taken to secure the future of the piped water systems, which is by no means assured. These should include, (i) regular servicing of engines and pumps; (ii) efforts to gain the confidence and acceptance of the system by the people; (iii) a satisfactory arrangement for paying recurrent costs (Chapter 10).
- (w) The piped water systems should be managed so as to give optimum water quality, rather than a widely fluctuating water quality as at present; see recommendation (i) above.
- (x) Water from the larger dams should be used for small-scale irrigation. At Mkutshane and Mbonga Dams, the existing pumps and pipelines should be utilised for raising water to cultivated land on high ground with good natural drainage - much of the valley soil below the dams would be liable to waterlogging and salinity problems if irrigated for any length of time without installation of proper under-drainage. It would probably be better to use the water either for supplementary irrigation of existing crops, or for dry-season vegetable growing on a very small scale. This would minimise the possible complications resulting from unfamiliar techniques (Chapter 8).

Appendix 1 Water Consumption and Use at Mpolonjeni - 5th-13th June 1972

No formal survey of water use and consumption was made using a prepared questionnaire. Instead, the author, with the help of a co-worker and a Community Development Officer who acted as interpreter, conducted a small survey at a number of households in the district from conversations and observations. Table 1 gives the crude data and this has already been re-presented in Table 3.9 (Chapter 3) to indicate an average consumption figure 5.5 - 8.2 litres/head/day. The sample provided data for about 110 people, or about 14 per cent of the population of the Mpolonjeni study area based on the 1966 Census details (Jones 1968).

Thirteen homesteads gave information about the numbers living there; these give an average number per homestead of 8 to 9. According to the 1966 Census, the average size of homesteads in the Lowveld was 6.4 persons, and only 7 per cent of homes had more than 14 occupants. Clearly the homesteads of the survey were not wholly typical of Lowveld homes assuming that the 1966 Census data are still valid. Thus greater reliance should be placed on the smaller homesteads in the survey where the water consumption per head is greater (Table 2). The reasons for this are that there are likely to be economies in water use in the larger homestead. Water for cooking and washing utensils will be proportionately less. But also, most of the occupants of the larger homesteads are children, since the head of the household might have several wives.

As well as the variation in size there is the difference in the type of home. Three of the homes, numbers 9, 13, and 14, cannot be regarded as typical since they are European style houses, and the house-holders have regular incomes. In the case of the minister (13), and the storekeeper (14), there is some washing of clothes on the premises, and it is reasonable to expect that their water consumption will be greater than average (Table 2).

To obtain an indication of probable water consumption, a record of the Pacey-Farrar consumption was maintained during the visit. The consumption figure worked out at about 4.5 litres/head/day. Most of the food consumed during this period came from tins, so very little was used in cooking, and only boiled water was used for washing pots and utensils. When the Pacey-Farrar consumption (i.e. half a bucket each per day) was mentioned at a meeting of local men, this was considered very small. It should be remembered that the men do not fetch water on a daily basis, nor do they do the cooking so their knowledge of consumption figures may not

Table 1 Survey of Water Use at Mpolonjeni

Homestead and status of householder	No. of huts No. of people	Vessels for carrying water	Frequency of filling	Remarks & other equipment
1. Mr Gadele Gwebu Nduna & farmer	9 & kraal 8+	oildrum on sledge	--	ploughs, augers, yolks, chisels.
2. Mr Ephraim Zwane farmer, member Swazi Farmers' Association	- kraal 19	oildrums on truck, sledge or wagon	every 2 days	4 ploughs, 3 wagons, motor pick-up.
3. Mr Gorden bus driver & farmer	4 8	oildrum	every 3 days	maize mill, wagon, lamp, ploughs, disc harrow old car.
4.) women at 5.) Hlangothi Old Dam	- 5-8 } 5-8 }	4 gal bucket 3 gal bucket	usually } twice } daily }	
6. Mrs Sarah Nzimandze husband is farmer with other jobs	2 8	oildrum	every 3 days	corrugated roof ~ 5m ² giving about 1000 l/year. new cement block home being built.
7. No name given farmer	5 7	5 gal bucket	every day	
8. "Ten house" farmer	10 & kraal -	oildrum on sledge	-	sledge under construction
9. Mr Absolom Langwenya head teacher	school building 4	2 3-gal bucket (hired sledge and oildrum)	about 8 gal/day	sometimes water from Minister's roof tank (13)
10. Mr. Sipho Spring farmer, odd-job man	4 6	oildrum delivered (25 cents)	about every 3 days	chicken house, owner of beer hut

Table 1 contd.

Homestead and status of householder	No. of huts No. of people	Vessels for carrying water	Frequency of filling	Remarks & other equipment
11. Mrs Veronica Methula husband is a farmer (same husband as (6)?)	7 & kraal 17+	2 3-gal bucket	4-6 times a day	several ploughs, materials for new house with corrugated roof
12. <u>Nkundla</u> area builder	1 3	2 gal bucket	2 or 4 per day	radio
13. Minister's house farmer & minister	European style house and kraal 5?	roof tank 4,500 litres lasts 2-3 months in the dry season		
14. Mrs Masuku store keeper	cement block building 10	oildrum delivered (25 cents)	daily	washing on premises
15. Teacher at school also farmer	European style house -	all water from roof tank		
16. Mr Mahlikilili Dlamini herbalist & farmer	15 20	oildrum delivered	3 times a week	maize mills etc, some roof catchment defunct car.

Note: the lack of data are indicated by -.

Table 2 Comparison of Size and Type of Homestead with Per Capita Consumption

	litres/day	No. of people	Average consumption l/head/day	Persons per homestead
Larger homesteads no's 2,11,16	240-280	c.56	4.6	18.7
Smaller homesteads no's 3,6,7,10,12	180-227	32	6.4	6.4
Untypical homesteads no's 9,13,14	180-327	18-21	~13	~7

be very great.

From all the points considered above, it can be concluded that the average daily consumption per person was around 7 litres. This figure excludes washing, the majority of which is done at the side of the dam or water-hole. It also excludes most liquid refreshment. The water from the dams was so objectionable in taste and appearance that little was drunk by itself. Milk seemed unavailable, and although the store sold soft drinks, by far the most popular drink was locally brewed beer. About 4 or 5 homesteads, including the store, made beer regularly and sold it at the beer huts. Water for beer making was excluded from the survey. The average quantity drunk each day was between 2 and 4 pints per person (excluding children). School meals for the children would probably give them between 1 and 2 pints of soup each per day.

When these further points are considered, the overall per capita consumption of water from local sources for Mpolonjeni people is 12 - 17 litres per day.

Time spent carrying water

In his studies of water consumption in Tanzania, Warner (1969b) measured the average daily time spent by adults carrying water as described in Chapter 7. He assumed a walking speed of $2\frac{1}{2}$ m.p.h. and his data are plotted in Figure 7.1.

The Mpolonjeni data do not allow a comparable exercise, since the number of daily journeys for water is not known with certainty. However, using the estimates of distances to the source (Table 3.9) and a walking speed of $2\frac{1}{2}$ m.p.h., per capita time spent carrying water could be obtained and this was also plotted in Figure 7.1. Not surprisingly, the 'times' for Mpolonjeni appeared very much less since only one journey per household per day was assumed. Thus the data shown in Figure 7.1 are not comparable, but from the evidence given in Table 1 here it is clear that because water is transported in bulk and often only a few journeys are made each week, the differences between Tanzania and Mpolonjeni as shown by Figure 7.1 are likely to occur in practice.

AFRICA FIELDWORK & TECHNOLOGY

D M Farrar & AJ Pacey

Reports on: 1. Swaziland fieldwork
2. Technology
3. Methods and approaches

technology / report 1

HAND-PUMPS

Introduction

In rural water supply projects operated in Tanzania by the Community Development Trust, Dar-es-Salaam, and in Swaziland by the Government, with help from I.T.D.G., hand-pumps have had three types of application:

1. lifting water one or two metres from catchment tanks sunk in the ground.
2. pumping water from wells of less than 9m depth.
3. pumping water from deep wells and bore-holes, typically 20m, but sometimes up to 50m deep.

These three applications are typical of many cases where hand-pumps are needed for rural water supply purposes, so experience in Swaziland and Tanzania can provide some useful guidelines of general relevance.

Some pumps are suited only to very low heads, and so their relevance is limited to application (1) above; but in general, the first two kinds of application can be discussed together under the heading of low lift pumps, as opposed to the deep well pumps needed in (3).

The provision of a reliable pump at a low enough cost has proved to be a major problem with many small rural water projects in developing countries. For low lift pumps, many designs based on a do-it-yourself approach have been produced (V.I.T.A. 1970), and the traditional

technologies of some developing countries, mainly in Asia, have much to offer (Farrar, 1969). With both these approaches, the use of local materials and local skills helps to overcome cost and maintenance problems. With deep well pumps, however, there is usually little choice but to use factory-made equipment.

The Swaziland and Tanzania projects used factory-made pumps for both low lift and deep well applications, and it is solely with factory-made types that this report is concerned.

Low lift pumps

Several types of low lift pump have been considered, and semi-rotary pumps were used initially in the Swaziland and Tanzania projects. These have the advantage of being compact to transport and easy to instal. They have proved very unreliable, though, and have often ceased to function as a result of small amounts of sand being drawn up from a catchment tank or well. It is generally felt that semi-rotary pumps are extremely unsatisfactory for this type of project.

An alternative pump tried at the catchment tanks in Swaziland has been the diaphragm pump. This was selected for study by one of the authors because of its well-known ability to pass sand without damage. The main worry in this case was that the rubber diaphragm would wear or perish rather quickly, and no replacement would be available. Two diaphragm pumps were installed at catchment tank sites, and at the time of writing, it is known that the diaphragms have lasted for twelve months, and the pumps have worked well and without maintenance.

This is a better record than that of most semi-rotary pumps, but the trial has not been sufficiently extensive for firm conclusions to be drawn.

Many types of piston or plunger pump have been designed for use at shallow wells. One of the most outstanding, in terms of thoroughness of design, was developed by the Batelle Memorial Institute of Columbus, Ohio, for use in a number of Asian countries (Fannon and Frink, 1967, 1970).

Low lift needs for wells in Tanzania have been most successfully met by a pitcher-spout type of piston pump, (figure 1), which is now used in preference to the semi-rotary pump. Careful selection of the particular model of pitcher-spout pump proved to be important. Some models imported from England were insufficiently robust or unreasonably expensive.

Even when a satisfactory pump of this type was obtained, one weak point appeared after a period of use. Friction at the head of the plunger rod caused the bolt to wear out (figure 1). Fortunately it was possible to modify this part of the design to provide a better bearing and prevent lateral movement of the bolt.

Rural water supplies in developing countries need to be based on low-cost technologies. All these pumps come into this category, and examples of all of them with an output of around 30 litres/minute could be obtained for £10 or less in 1970. Pitcher-spout pumps were being bought in Tanzania for the equivalent of £8 in UK currency. Diaphragm pumps varied from £7 for one with a plastic body which was used in Swaziland to £12 for a larger model with a cast metal body.

These figures reflect only the cost of the pump itself. When transport, installation, and the necessary pipe work is added, a "low-cost" factory-made pump for low lift application could have cost up to £15 in 1970, or £20 in 1973.

Deep well pumps

In recent years it has become possible to consider hand-driven Mono pumps for deep wells and bore-holes, and these are fairly widely used in Malawi; they have the advantage of requiring very little maintenance.

Apart from the Mono pump, the only deep well pump suitable for manual operation is a piston-type pump with the pump cylinder near the bottom of the well and a rising main to bring water to the surface. The chief differences between the various available pumps of this type are related to:

1. the mechanism at ground level for driving the pump - fly-wheel or lever-type handle.
2. the possibility of extracting the pump from the well for repairs.
3. the type of valves used.

In wells of about 20m depth in Tanzania, a pump which has proved to be reliable, relatively cheap, and easy to maintain is the UNICEF Uganda pump (figure 2).

The characteristic feature of this design is the means of connecting the pump rod in the well to the wooden lever-type handle. The rising main is terminated at the top by a guide pipe (figure 3). The pump rod moves up and down inside the guide pipe, while a connecting pipe moves up and down outside it. A linkage joins the end of the pump handle to the bottom of the connecting pipe.

Various types of Uganda pump have been produced. The current (1973) model in Tanzania has a lighter structure than the ones illustrated, with some of the heavier wooden parts replaced by metal. In Malawi, the Department of Geological Surveys used to manufacture a small, all-metal version known as the "bush pump".

The Uganda pump is considered highly satisfactory for wells of about 20m depth or less. For deeper wells and bore-holes, a fly-wheel drive pump is more suitable. The fly-wheel (about 0.75m diameter) is turned by means of a crank-handle, and the required reciprocating motion is achieved by connecting rods and a crosshead. The mechanism is totally enclosed within a cast steel casing, and appears to be robust enough to work without maintenance for long periods. Such pumps have been used at rural bore-holes in Malawi.

Pumps of this kind can be fitted with double fly-wheels so that two people can operate them together. Two-man working allows 8 litres/minute to be pumped from 55m depth, while with one-man operation, the limiting depth is regarded as 40m. Geared versions with two-man operation can be used for depths as great as 110m.

The biggest maintenance problem with a deep well pump concerns valves and leathers in the pump cylinder, which may be 30m below ground. Some pumps have "extractable" cylinders, while others are designed, usually with ball valves, to minimise the danger of wear or blockage. Maintenance of fly-wheel drive pumps is made more difficult by the heavy construction of the head-gear. Uganda pumps suffer from wear at the top bearings, but are easier to maintain.

In considering cost levels, it is again necessary to include transport, installation, pipes and pump rods as well as the pump itself. A Uganda pump could be bought in Tanzania for £35 in 1970 (UK currency), but transport to a remote part of the country could add £5 to this, and the final cost of the installation was sometimes £80 to £90.

The other deep well pumps mentioned have not been used in the Tanzania or Swaziland projects being considered, but comparative costs after installation on site would appear to be about £150 for an ungeared fly-wheel drive pump built for one-man operation; and about £225 for a Mono pump. In Malawi, the extra capital outlay needed for a Mono pump is often regarded as acceptable because of the lower maintenance requirement.

With costs as high as this, a small engine-powered unit is often nearly as economical as a hand-pump, provided that fuel and maintenance facilities are accessible. So it is not surprising that in parts of Botswana, small engines are used at bore-holes very frequently. With the possible exception of the Uganda pump, there seems to be no real low-cost technology for a deep well hand-pump.

Manufacturers and Suppliers of Pumps

PITCHER-SPOUT PUMPS:

J. S. Davis & Co. Ltd.,
Machinery and Hardware Importers,
P.O. Box 9020, Dar-es-Salaam, Tanzania.

DIAPHRAGM PUMPS (cast metal body)

Munster Simms Engineering Ltd.,
Belfast, Northern Ireland.

DIAPHRAGM PUMPS (plastic body)

Henderson Pumps and Equipment Ltd.,
38 Medina Road,
Cowes, Isle of Wight, U.K.

UGANDA PUMPS

Craelius East Africa Drilling Co. Ltd.,
Norwich Union House,
P.O. Box 90, Nairobi, Kenya.

FLY-WHEEL DRIVE PUMPS

Thomas & Son (Worcester) Ltd.,
Climax Works,
P.O. Box 36, Worcester, Great Britain.

also:

H. J. Godwin Ltd.,
Quenington, Gloucestershire, Great Britain.

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(Volunteers for International Technical Assistance,
College Campus, Schenectady, U.S.A.)

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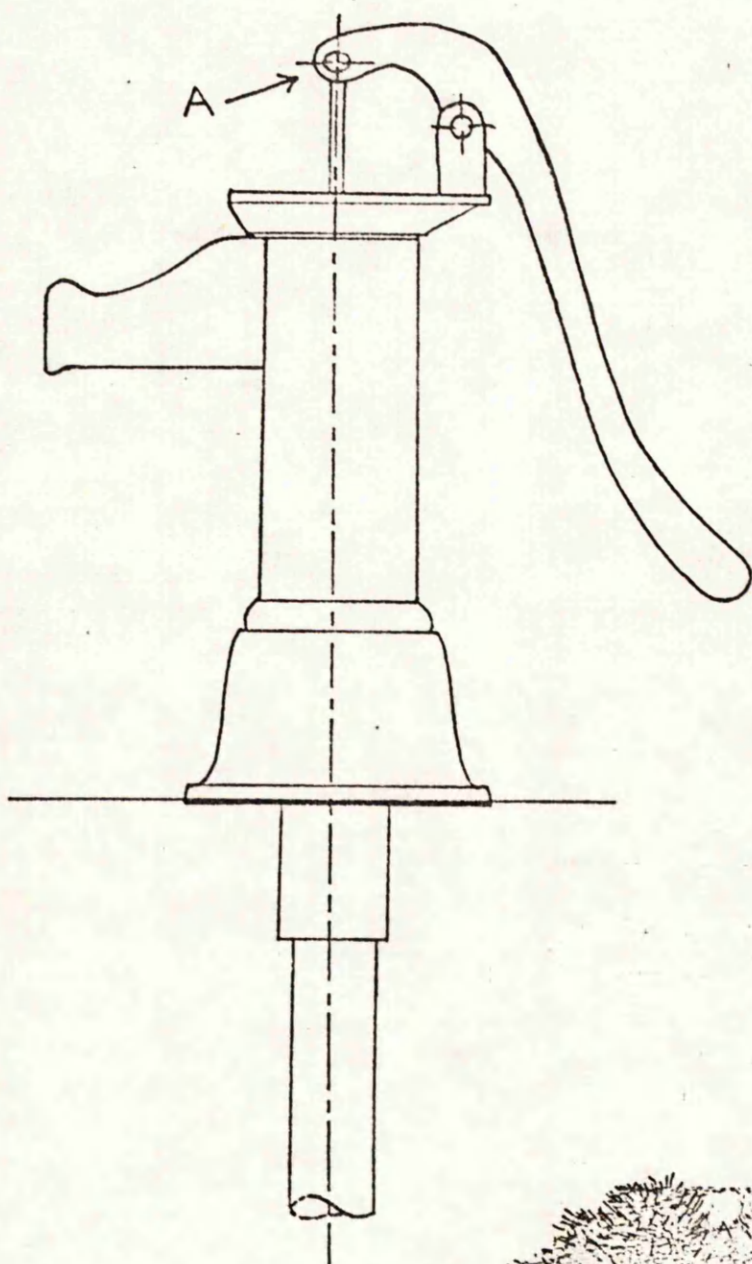
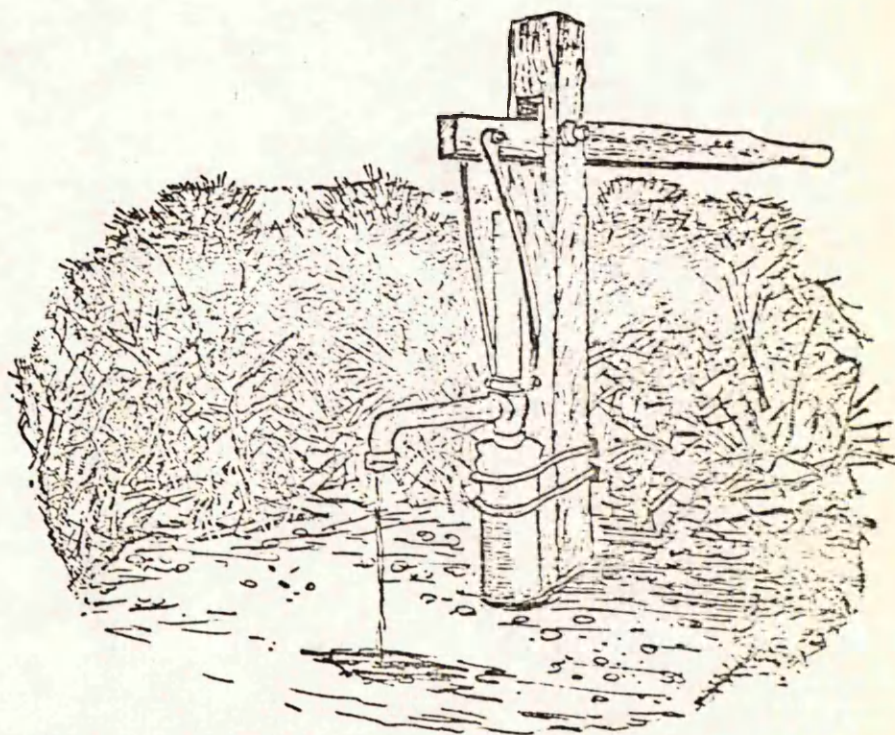


Figure 1.

A typical pitcher-spout pump. The bolt 'A' was subject to wear and friction problems in Tanzania.

Figure 2.

General view of a Uganda pump at a rural bore-hole.



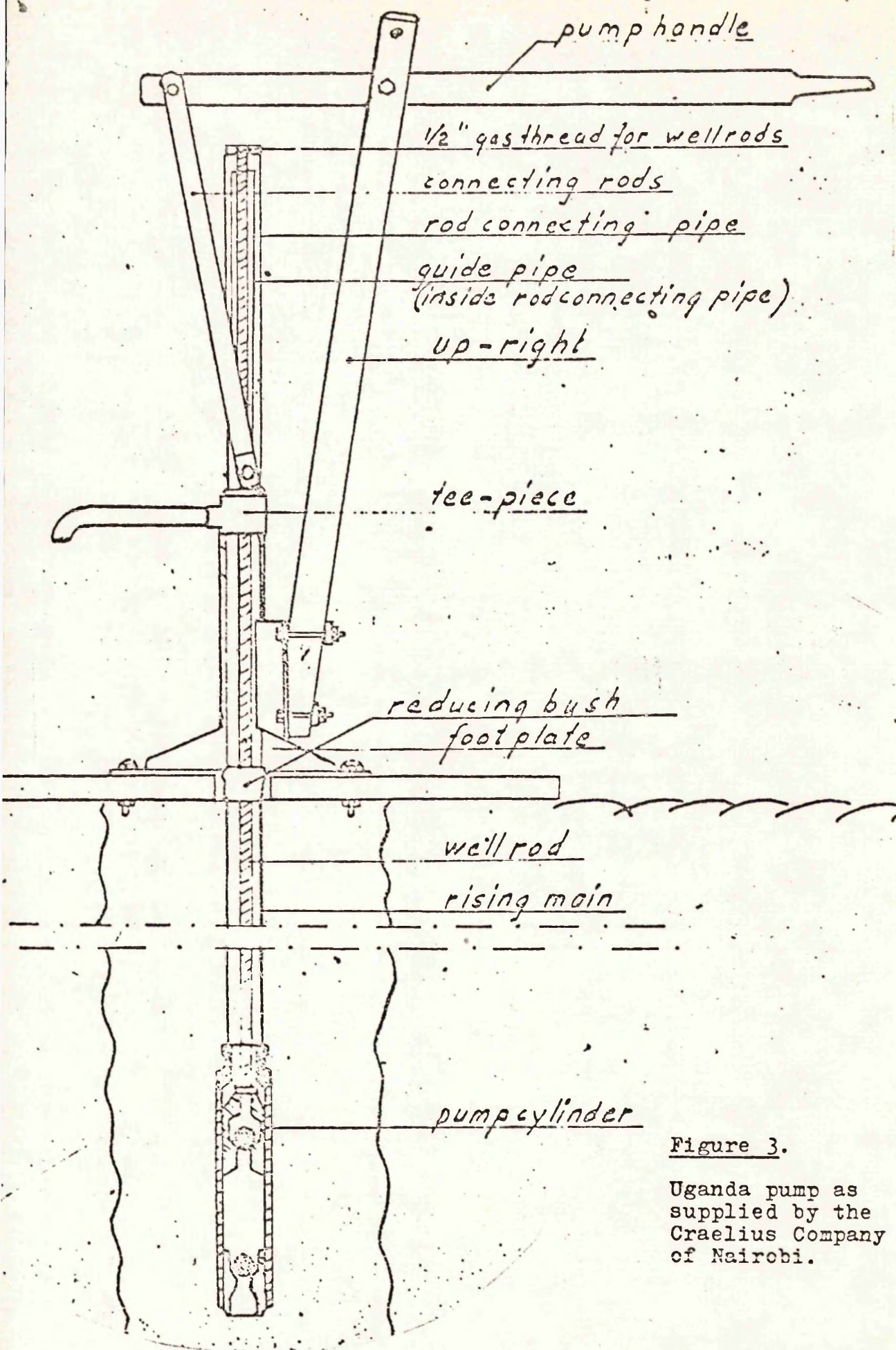


Figure 3.

Uganda pump as
 supplied by the
 Craelius Company
 of Nairobi.

RAINWATER TANKS

The tanks are made from reinforced sand/cement having a diameter of 2,5m and a height of 2,0m giving a capacity of 7,5 cubic metres. Such a tank can be filled from 200mm rain falling on a roof area of 47,5 square metres. (One millimetre of rain on an area of one square metre produces one litre of water).

The Form : is circular and made up of 16 sheets of 1,8m corrugated iron 0,6mm thick and curved with a radius of 1,25m. There are four sections and each section has angle iron riveted to the vertical edges, one side allowing a small overlap. The angle irons are then bolted together with spacers.

METHOD OF CONSTRUCTION

1. A circular foundation 2,8m in diameter is dug at the end of the building and a concrete floor 80mm thick is laid using a mixture of 1 cement, 2 river sand, 5 aggregate.
2. A 20mm bore pipe is concreted into the floor. This should be 0,7m long with a bond on the inside which projects 80mm above the floor of the tank. A tap is fitted to the outside end.
3. On this floor the form is erected and covered with wire netting 50mm mesh (1,00mm wire). Lengths of 2,50mm plain wire are pulled around the corrugations as follows :-
 - 2 wires in each corrugation for the first four.
 - 1 wire in each corrugation for the next eight.
 - 1 wire every 2nd corrugation to the top.
 - 2 wires on last corrugation.
 (200m of 2,50mm wire will be required; about 8kg mass)
4. The outside is then plastered with a thin layer of 1 cement, 1 pit sand and 3 clean sharp river sand.
5. Two hours later a second layer of plaster is applied to the outside to just cover the corrugations. This is finished off with a wooden float.
6. 36 - 48 hours after the 2nd plastering the form is unbolted and removed and a 100mm length of 80mm down pipe let in the top for the overflow. A 50mm layer of 1 cement, 1 river sand and 2 aggregate is poured on the floor.

-2-

7. The inside walls are plastered with a mixture of 1 cement, 1 pit sand, 3 river sand.
8. A second coat is applied with a mixture of 1 cement, 1 pit sand and 2 river sand.
9. The floor is plastered with a mixture of 1 cement, 4 river sand.
10. The inside walls and floor are finished off with a paste of cement and water to render the tank water proof.
11. Water to a depth of 50mm is poured on the floor and the walls kept wet for 4 days.

COVERING : The tank is covered with sheets of 0,50mm flat iron supported by two lengths of angle iron.

NOTE : These tanks can also be used for grain storage, such a tank holds 6 000kg maize.

THE COST : The form will cost about \$50,00 but this will build many tanks. Forms are available in Matabeleland and in Mashonaland. In time every Council may have a form.

The materials to build one tank will cost about \$18,00.

MATERIALS REQUIRED

12 pockets cement.
Wire netting 8m by 2m.
Plain wire 200m by 2,50mm.
Water pipe 0,7m by 20mm.
Tap.
Overflow pipe.
Flat iron and angle iron for roof.
Pit sand, river sand and aggregate.

A new galvanised corrugated iron tank of this size will cost \$100,00 plus transport and has a life of about five years.

The credit for this idea and the information rests with Mr. Roy Henson of Hlekweni, P.O. Box 708, Bulawayo.

Appendix 3

Construction details for rainwater roof tanks devised by the Friends' Rural Training Centre, Hlekweni, Bulawayo, Rhodesia, and taken up for use by schools by the Education Office of Mashonoland North Province, P.O. Box 8198, Causeway, Rhodesia. Document dated 18th April 1972.

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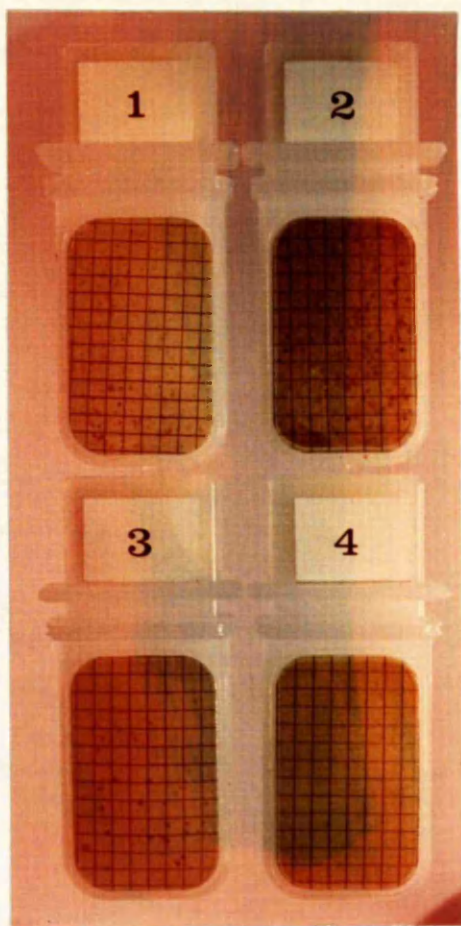
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1. COLI-COUNTS AFTER INCUBATION
The actual size of the filter area is 40 mm x 25 mm. The colours of the photograph are not strictly accurate, but coliform colonies grown on the surface of the filter will be in the blue, blue-green or green range illustrated on the left.

The Coli-counts shown here are for samples from:

1. Catchment Tank, Secusha School (no.15)
2. Hlangothi Old Dam (no.9)
3. River Usutu (no. 24)
4. Bore-hole, Malindza (no.19)



2. THE SMALL-BUNDED DAM, MPOLONJENI

This source, the nearest to the Nkundla, is used by about 250 people. During the winter months June - October it is usually dry. The photograph shows the social function of washing and bathing, when the women and children of several families gather together.



3. HLANGOTHI OLD DAM

The most popular time for collecting water is early morning. Sometimes supplementary journeys are made in the late afternoon. The cattle are watered in the late morning. On the morning this photograph was taken 30 women and girls came to collect water in the period 6.15 to 9.30 am. One man collected a 44-gallon drum. The water is too shallow to fill the bucket directly; instead the woman wades out and ladles water into the bucket with a small bowl. The bucket is always washed out before fresh water is collected. A branch of leaves floated on the water surface reduces splashing when the woman is walking with the bucket on her head.



4. MKUTSHANE DAM, MPOLONJENI

Water is often carried back to the homestead in bulk. Here 4 200-litre drums are being transported by donkey-drawn cart. This comes within the man's sphere of activity. Wheeled transport in the traditional rural sector is relatively rare; a more common method is ox-drawn sledge (plate 5).

In the background, on the near shoreline, the pump-house for the Mpolonjeni water supply is under construction. Along the skyline are the Lubombo Hills.



5. HOMESTEAD AND SLEDGE, MPOLONJENI

In the foreground is a partially complete sledge made from a specially selected bough of a tree. Behind, near the hut, is a sledge complete with a 200-litre drum. At the homestead, water is extracted from the drum by a hosepipe syphon.



6. MAGGENYA'S DAM, MPOLONJENI

The embankment is in the background. In the foreground are typical cattle, and the dark clay soils of the K-set.



7. SEEPAGE WATER, MAGGENYA'S DAM

The photograph shows the downstream embankment of Maggenya's Dam. The water in the foreground is seepage water. The photograph was taken in August 1973 when there had been virtually no rain for two months. Note the lush surrounding vegetation and the growth of trees on the embankment.



8. SOIL EROSION, MPOLONJENI

This area, to the north-west of the Hlangothi Old Dam catchment, is typical of many in Swaziland known as "dongas". The original cause of the erosion seems to be gully erosion hastened by stock routes and overgrazing. Similar, but less extensive areas in the catchment of Hlangothi Old Dam, produce rapid and high percentage run-off.



9. THE SHASHE RIVER, BOTSWANA

The Shashe river is one of Botswana's major "rivers", but it only flows during the rainy season. When all the standing water has evaporated, the Batswana dig holes in the sand bed. As the dry season progresses, the water table falls and more substantial, lined well points have to be made. In the background is the bridge carrying the main Francistown - Palapye road. The river is about 350m wide at this point.



10. WELLS AT TAMASANA, BOTSWANA

This is one of several wells in an area of about 3ha near Tamasana. The water table is 10 to 15m below ground. Many hundreds of cattle and goats are watered here each day, and the whole area, apart from the trees, is completely bare of vegetation. Note the drinking trough is a hollowed log.