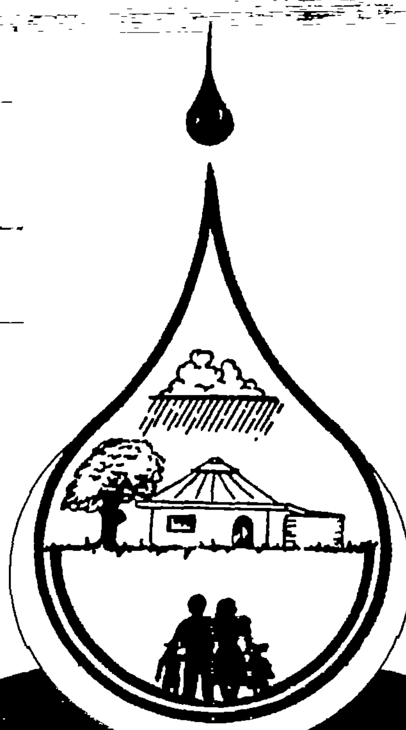

PROCEEDINGS OF THE SIXTH INTERNATIONAL CONFERENCE ON RAINWATER CATCHMENT SYSTEMS

PARTICIPATION IN RAINWATER COLLECTION FOR LOW INCOME COMMUNITIES AND SUSTAINABLE DEVELOPMENT

NAIROBI, KENYA, 1-6 AUGUST 1993

EDITED BY:
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UNCHS (Habitat)

SIDA

PARTICIPATION IN RAINWATER COLLECTION FOR LOW INCOME COMMUNITIES AND SUSTAINABLE DEVELOPMENT

Proceedings of the Sixth International Conference on Rainwater Catchment Systems, Nairobi, 1-6 August, 1993.

Edited by:
G.K. Bambrah
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JANUARY 1994

Copies of these proceedings may be ordered from:
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P.O. Box 38638, Nairobi, Kenya.
Tel: (2542) 445905 Fax: (2542) 445796

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ISBN 9966-9891-1-0

Produced by Engineering Design Consultants Ltd, P.O. Box 38638, Nairobi, Kenya.
Copy edited by J. R. Leeland, Illustrations by B. S. Bansal, Typed by R. W. Muriithi.

CONTENTS

TECHNOLOGY

WATER QUALITY

HYDROLOGY

AGRICULTURE

EXCURSIONS

IRCSA ACTIVITIES

FOREWORD

Rainwater has been collected and stored for domestic and agricultural uses for thousands of years. This ancient art is still practised in many parts of the world. In other regions, however, development and widespread application of ground water drilling technologies and large-scale water resources exploitation have tended to shift the emphasis away from rainwater harvesting systems. Thus while rainwater catchment has long been embraced as a water supply technology appropriate to local needs in parts of the Caribbean, Middle East, Asia and Australia, only recently has its enormous potential been demonstrated elsewhere. In Thailand, for example, more than twelve million 2000/litre ferrocement roof catchment jars have been constructed since 1985. Rainwater catchment systems are increasingly being recognized as affordable, low-cost and environmentally sound and a simple alternative to water supply in many urban and rural settings.

The seed for the establishment of an association for rainwater catchment systems was sown when the first International Rainwater Cistern Systems Conference was convened in Hawaii, in June 1982 by Professor Yu-Si-Fok. Subsequent international conferences were held in the US Virgin Islands (1984), Thailand (1987), Philippines (1989) and Taiwan (1991). At the 4th International Conference held in Philippines, it was agreed that an international association for rainwater catchment systems should be established. The International Rainwater Catchment Systems Association (IRCSA) was officially launched at the 5th International Conference on Rainwater Cistern Systems held in Taiwan in 1991.

The 6th International Conference on Rainwater Catchment Systems was held in Nairobi in August 1993. The theme of this conference was "Participation in rainwater collection for low income communities and sustainable development". More than 60 technical papers presented at this conference by delegates from some 30 countries around the world are contained in these proceedings.

We take this opportunity to acknowledge the contributions made by United Nations Centre for Human Settlements (Habitat), the Swedish International Development Authority (SIDA), United Nations Children Fund (UNICEF), the World Bank/UNDP Regional Water and Sanitation Group, the German Volunteer Service and the Royal Netherlands Embassy, among others, who helped to finance the 6th International Conference on Rainwater Catchment Systems. We also wish to extend our gratitude to the University of Nairobi, the hosts, and the Ministry of Water Development for supporting this conference.

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OPENING ADDRESSES

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Chairman of the Local Organizing Committee

Mr Chairman; The Honourable Minister of Land Reclamation, Regional and Water Development; UNEP Headquarters; The Vice-Chancellor, University of Nairobi; Your Excellencies; Distinguished Participants; Ladies and Gentlemen,

Mr Chairman allow me to welcome all the local and foreign participants to the 6th International Conference on Rainwater Catchment Systems.

The theme of our conference is "Participation in rainwater collection for low-income communities and sustainable development". And, Mr Chairman, the conference objectives are:

1. To explore the potential for rainwater use in rural and urban areas.
2. To identify problems and constraints - technical, social, cultural, or economic - that restrict participation in the development and use of rainwater catchment systems on a sustainable basis.
3. To exchange lessons learnt and experiences gained in the development and use of technologies in rainwater catchment systems.
4. To study the role of women and community participation in the development of rainwater harvesting systems.

Mr Chairman, it is my hope that the participants will find the conference suitable and enabling in order to achieve the objectives proposed here.

Lastly, Mr Chairman, may I wish everybody a fruitful conference. For those of you visiting Kenya for the first time, we are sure it will not be your last and we hope you will all have an enjoyable stay.

Thank you.

WELCOMING ADDRESS

By Professor Francis J. Gichaga
Vice-Chancellor, University of Nairobi

The Honourable Minister for Land Reclamation, Regional and Water Development; Director Habitat; Director, UNICEF; Representatives of SIDA and the Netherlands; Directors of Government Departments; Professor Yu-Si Fok, President of the International Rainwater Catchment Systems Association; Mr John Mbugua, Chairman of this Conference; Distinguished Guests; Ladies and Gentlemen,

It gives me great pleasure to welcome you all on this important occasion. Many of you have travelled long distances to attend this Conference, some from as far as Hawaii and Japan. You are all most welcome and we wish that your stay in Kenya will be both rewarding and enjoyable. If we can do anything to assist you to make the most of your time in Kenya, please let us know.

When the conference organizing committee requested the University of Nairobi to host this conference we were pleased to accept. As an institution of higher learning we have been involved in training, research and development activities to support the efforts of the Kenya Government to meet the needs of our expanding population for improved water supplies. The goal which was set in the sixties of "water for all by the year 2000" was very ambitious, and though much progress has been made, it is clear that a lot remains to be done.

Kenya suffers from low and unreliable rainfall over about 80% of the country which is semi-arid, arid or very arid. In these areas people tend to be widely scattered and the provision of a piped water supply is difficult. Even in the 20% of the country which has more humid conditions water is often in short supply.

It is becoming clear that much more could and should be done to harvest rain where it falls. Having water close to home can not only relieve the burden of carrying it for long distances but can make a major contribution to improved health. Harvesting rainwater is not a panacea - sometimes there is little or no rain, as we have experienced recently. However, whereas rainwater often goes to waste, it could be used to augment other supplies for domestic purposes, and to some extent for livestock and crops. There are many ways in which this can be done and we hope to gain much from those of you who will share experiences of rainwater harvesting in different parts of the world, during this conference.

The University of Nairobi hosted the 2nd National Conference on Rainwater Catchment Systems, in Nairobi in August last year and we were pleased that Kenya was chosen as the venue for the 6th International Conference on this important theme.

The conference organizing committee represents a wide range of organizations including government bodies, parastatals, non-government organizations, donor agencies and consulting firms. They have been busy making preparations for this conference and I must thank them for the hard work that they have done. The cooperation between many different organizations in this way is to be commended.

I would also like to take this opportunity to thank those organizations who have provided financial and other assistance, without which it would have been impossible to mount this conference.

First, I would like to thank Habitat for providing the conference venue, with such excellent facilities, and for financial support. I would also like to thank UNICEF and SIDA for major contributions. Additional support has come from the Netherlands Development Cooperation Office, from the World Bank and from the German Volunteer Service. We are most grateful for all this assistance.

Finally I must thank you for coming and in particular the Minister of Land Reclamation, Regional and Water Development who is represented by the Assistant Minister.

Thank you.

OPENING SPEECH

By The Honourable Darius M. Mbela, ECH, MP

Minister for Land Reclamation, Regional and Water Development,

Mr. Chairman, Representatives of Foreign Missions, Heads and Representatives of UN Bodies and Donor Agencies, the Vice-Chancellor of the University of Nairobi, Distinguished Guests, Participants, Ladies and Gentlemen,

I am pleased to welcome you all to the 6th International Conference on Rainwater Catchment Systems.

I sincerely hope that those of you visiting Kenya will find us sufficiently hospitable to enable you to participate in this conference with efficacy.

Mr Chairman, I am informed that participants at this important conference are drawn from more than 40 countries and that it is the first time that the conference has been held in Africa. I see this as a great honour for our country and our continent.

Ladies and Gentlemen, you are all aware that 1981 - 1990 was designated the International Drinking Water Supply and Sanitation Decade by the United Nations, whose objectives were to provide potable water and adequate sanitation for all.

Towards that end increased governmental and donor community investments have been made. However, despite those endeavours the objectives remain unconsummated. Rainwater harvesting becomes important in that, other than meeting the objectives of the drinking water supply and sanitation decade, it is an activity that can be implemented from household to institution level with equal degrees of satisfaction. Research has established that the quality of rainwater, depending on geographical zones, is quite acceptable both for domestic and industrial needs. Moreover, rainwater relative to other sources of water, is an option which is available free and could be harnessed for the benefit of everybody at a nominal cost. In light of the foregoing, I find the conference and its theme appropriate.

Mr Chairman, the relevance of the conference to Kenya cannot be over-emphasized. Kenya has about 27 districts which are categorized as arid or semi-arid. These are the districts that suffer the most from drought conditions, yet are the same ones devastated by floods during the short spells when they are blessed with rainfall. It is a shame that this very vital resource should go to waste in areas where it is most needed.

Our arid districts constitute about 87% of the Kenyan land, are inhabited by approximately 21% of the total Kenyan population and support over 50% of the livestock herds in the country. This scenario implies that 80% of Kenya's population is concentrated in the less than 20% of high-potential areas, which have reached saturation levels.

We find ourselves with no alternative, therefore, other than to make our arid and semi-arid lands habitable and productive, and the only way is to provide water in sufficient quantities and of acceptable quality to those areas. Rainwater harvesting becomes part of our wider strategy to halt the rural-urban population drift, as well as a vehicle for higher economic productivity.

We have to boost the agricultural and industrial potential of these areas so as to relieve the immense population pressure currently witnessed in our minuscule fertile lands.

Mr Chairman, the Government of Kenya has a variety of measures in place to try and reclaim arid and semi-arid lands. These measures are manifest in the creation of my Ministry, with the purpose of raising the socio-economic potential of those lands through the provision of water resources. To reclaim these arid and semi-arid lands my Ministry regards rainwater harvesting as the *sine qua non.* It is in that light that I find this conference very appropriate.

Ladies and Gentlemen, what I have already said should not delude anyone into thinking that rainwater harvesting should be restricted to arid and semi-arid areas only. Rainwater harvesting is useful in every area, including those with sufficient water and rainfall.

While ensuring that rainwater does not go to waste, its harvesting also ensures that it does not become a nuisance or a hazard. In urban areas surface runoff has unleashed havoc on the urban infrastructure and been the ruination of property and human life.

This conference has brought together experts, practitioners and researchers in the fields of engineering, hydrology, architecture, building, agriculture and economics, all with the aim of sharing knowledge and experience in the field of rainwater catchment systems technology. I am optimistic that from your deliberations some useful ideas, realistic strategies and implementable recommendations will emerge.

The conference should be wary of the "conference bandwagon" effect, where it is all talk and nothing tactile emerges from it. I request, therefore, that you do at least three things:

1. Ensure that recommendations from this conference are practicable, palatable and catalytic to policy.
2. That the recommendations are environmentally sustainable.
3. That the recommendations of the conference should first and foremost take account of the needs of those least privileged in our society.

Mr Chairman, my remaining remarks are reserved for all those who have in one way or another contributed to make this conference a reality. In that regard, my first thanks go to the pioneers of this conference. Also, I wish to thank the 6th Conference Organizing Committee, the University of Nairobi for their splendid efforts in organizing this conference and for hosting it. I wish to thank the Royal Netherlands Embassy, Habitat, UNICEF, the World Bank and others for funding this conference.

With these remarks, and with great honour and pleasure, I now declare the 6th International Conference on Rainwater Catchment Systems officially opened.

Thank you.

KEYNOTE ADDRESS

By Ms Elizabeth Dowdeswell

Under-Secretary-General, UNCHS (Habitat)

Mr Chairman, Distinguished Members of the International Rainwater Catchment Systems Association, Ladies and Gentlemen,

I should like first of all, to welcome you to the United Nations facilities in Nairobi, and to thank the International Rainwater Catchment Systems Association for the opportunity that it is providing us to review the current state on the promotion of rainwater catchment systems to meet the increasing demands for sustainable freshwater supplies, both in rural and urban areas.

The contents and expected outcome of the conference are of special relevance to the present efforts of the United Nations Centre for Human Settlements (Habitat) to provide support to member countries in improving the provision, operation and maintenance of environmental services in general and of freshwater supply systems in particular.

The challenges faced in this regard are daunting. In the first place, I would like to mention the increasing demand for freshwater resources as a result of growing population and productive activities. It is estimated that by the middle of the next century the global population, now almost 6 billion, will have reached 10 billion. Within this general trend, urban areas, in many countries the focus of over 50% of national economic and productive activities, will be growing at a faster pace, concentrating the greatest part of future population growth. The projections show that by the year 2015, approximately half of the population in the developing countries will be located in urban areas, and that in some regions such as Latin America, over three quarters of the people will live in cities.

To attend the needs of growing human activities water withdrawals have been increasing about 4 - 8% per year in recent decades, with most of the increase occurring in developing countries. Industrial and domestic demand for water is expected to increases more rapidly than agricultural demand in the coming years, but the latter will nevertheless increase in absolute terms. Currently, nearly 69% of global freshwater withdrawals are used for agriculture, 23% for industry and only 8% for domestic uses. However, regions experiencing rapid population growth such as Asia and Africa, will sharply increase industrial and domestic use by the end of the 1990s. Confronted with these prospects, many developing countries already struggling to attend to existing demands, are simply not prepared to face the emerging challenges.

Despite water being the most abundant resource on earth, only a minimal amount can currently be used as a viable source of freshwater. The primary source of freshwater is precipitation. However, of the total global precipitation 20% falls on land and only 9% stays on the land surface - in rivers, lakes, wetlands and reservoirs - or flows into the ground where it is stored in ground water aquifers. These factors, combined with considerable variations in the distribution of rainfall, contribute to create conditions of acute water scarcity in several regions of the world. Thus, while rainfall in countries like Canada and New Zealand results in a daily run-off of about 300 m^3 per person, countries like Kenya and South Africa have only

1.8 m^3 and 4.0 m^3 per person per day, respectively, to satisfy their domestic, industrial and agricultural needs.

In this regard, the demand for domestic drinking water and sanitation is of special relevance. It should be remembered that despite national and international efforts during the United Nations International Drinking Water and Sanitation Decade (1981 - 1990), the coverage of water supply and sanitation services in most countries have merely kept pace or fallen behind population growth. Given the ample evidence existing on the negative health and economic effects of poor drinking water supply systems in developing countries, it is clear that improving supplies, in addition to improving the quality of life, is a sound social and economic investment. However, the equitable attention to unsatisfied demands of water for domestic use, will further increase the stress on limited freshwater resources, forcing countries to adopt clear policies for demand management and for the allocation of resources among various users.

The relevance of the above issues to attain sustainable water resources management and settlements development was fully recognized at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992, and included in the therein adopted Agenda 21. Chapter 18 of Agenda 21 on the "Protection of the quality and supply of freshwater resources" acknowledges that freshwater is a finite resource, not only indispensable for the sustenance of man on earth but also of vital importance to all social-economic sectors. Agenda 21 also indicates that the widespread scarcity, gradual destruction and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand truly integrated water resources planning and management.

From our human settlements perspective, there are several essential elements to be taken into account in implementing an integrated approach to the planning and management of water resources, including rainwater, and we hope that some of them can be discussed during the present conference in order to arrive at concrete proposals for improvement actions in this area. In the first place, we consider that an integrated approach should treat water resources management as an integral component of human settlements management. Therefore, it links water supply issues to other sectoral and overall strategies to achieve sustainable settlements and national socio-economic developments.

Secondly, an integrated approach needs to work at the whole water cycle, including the distribution of rainfall, the conservation of sources, the systems of water supply and wastewater treatment and disposal, and the interaction with land use and the environment. It also includes an ecological approach and the interaction with other natural resources.

In the third place, we believe that the mechanisms applied to the planning and management of freshwater resources and human settlements should integrate the main groups of society related to such activities. Thus, central and local government institutions, service agencies, the private sector, non-governmental organizations and organized community groups, should be able to express their particular interests in relation to water resources management, and engage in a process of negotiation leading to the design of actions that represent an equitable answer to their various demands.

It is precisely in the area of promoting an integrated human settlements approach to the planning and management of water resources that UNCHS (Habitat) has focused its research and capacity building activities. The experience gained in the execution of water supply and sanitation activities has shown us that the processes intervening in the implementation of traditional projects and programmes in this area face a series of constraints that preclude the application of an integrated approach, and limit their coverage to levels well below the magnitude of the needs.

The experience has also shown us that the most important processes intervening in the integrated management of water resources and human settlements are those related to financial, institutional, human, social, environmental and technological aspects. We have observed the repeated failure of many water supply projects and programmes due to the lack of a clear understanding of the above management processes, and of the constraints faced for their efficient development. In this regard, certain features are worth noting in the present management of freshwater supplies that justify their particular attention and the need to integrate them with overall settlement goals.

On the financial side we can see that the prevalence of formal financial mechanisms in the operation of sectoral institutions and the scarcity of conventional financial resources limit the coverage of the programmes executed by these institutions, and preclude the mobilization of non-conventional financial resources available at household and community level. Formal institutions have failed to develop sustainable financial and cost recovery instruments that take into account the irregular income pattern of the largest part of the demand for water supply services: the poor. Formal institutions have also failed to apply the pricing policies necessary to sustain the provision of water supply services and increase their coverage and standards. In their attempt to increase the delivery of services to the lower income sectors of the population, public sector institutions have often failed to make a clear separation between the distributive role (subsidies and transfers) of the public sector and the sound financial management of service provision. As a result, most service agencies do not have an adequate financial base to invest in service expansion or even to provide satisfactory operation and maintenance to existing facilities. Inadequate pricing policies have also contributed to promote an irrational use of water resource, and an inequitable allocation of resource among different users.

If we look at the traditional institutional features of water supply planning and management it is also possible to identify a series of constraints of effective service delivery. The institutional arrangements normally applied to the management of domestic water supply services often do not have provisions to integrate the requirements and plans for urban development, industrial activities and the agricultural sector. In addition, many public sector institutions lack the technical and administrative capabilities to run the complex set of operations necessary to provide and maintain services under non-conventional conditions such as those present in peri-urban areas and resource-scarce rural areas. In many cases, such institutions have a limited capacity for innovation and change to suit local conditions since they are governed by general regulations applying to the public sector and by political, economic or administrative relations of dependency from other authorities. In this regard, it is necessary to bring to your attention the negative effects of conventional public sector institutional structures and practices that inhibit the participation in water supply management of other agents from the private sector or the organized community.

The need for human resources development as a requisite for improved management is regularly mentioned by national governments and international support agencies, however, a sustained approach in this regard has been difficult to find. This situation can be partly attributed to the failure to understand that well-trained personnel represent a human capital that should be accumulated and constantly reproduced. Labour and human resources management practices are normally governed by public sector regulations, and are therefore not rigorous in the application of competitiveness and productivity criteria. Also, and as I have mentioned before, the provision and maintenance of water supply services under non-conventional conditions require a variety of professional and technical skills for which public sector institutions do not normally have incremental and sustained programmes of capacity building.

I believe that the social aspects of water supply embody perhaps the most relevant issues in relation to the subject of the present conference since the nature of present technological options for rainwater catchment systems require to a larger extent the active participation of users and community groups. However, many public and private institutions working in the sector regard the participation of the community on water supply management as task specific rather than as a permanent mechanism of community development, thus leading to the duplication of other processes and structures of community organization and often contributing to their fragmentation. Also, on many occasions the formal planning, programming and administrative practices of public and private sectors institutions fail to adjust to the peculiar patterns of project execution imposed by irregular processes of community participation.

Despite their almost generalized acceptance of community participation principles most national and local authorities have failed to put in place formal mechanisms of negotiation with community groups and other stakeholders in the management of water supplies. In this regard, the experience has shown us that the establishment of partnership between the public sector, NGOs and community organizations is a requisite to make an efficient use of all the capacities available at the local level. It can also not be ignored that women play a key role in the demand and use of water for domestic purposes and that, if projects are to be successful, they have to take into account gender issues and prevailing forms of gender division of labour. In conclusion, given present conditions, the implementation of community participation principles is one of the areas where a great deal of work still has to be done in translating general declarations of principles into effective and sustainable management processes.

The finite nature of freshwater resources requires that water supply projects give particular attention to their environmental sustainability. Additional water resources to satisfy domestic demands are becoming increasingly scarce and exploitation costs are rising accordingly. However, the assessments of the utilization of freshwater resources for human settlements normally do not take into account the feasibility of their recycling and reuse, the protection of water sources or the application of water saving devices and practices. In this respect, we believe that water supply projects, including rainwater catchment systems, should consider the application of saving and recycling principles and the extension of sanitation coverage as an integral part of overall water resources management.

Finally, I would like to say a few words in relation to the process of technology selection in the sector. We can see that at present there is knowledge on an ample array of appropriate low-cost technologies for the supply of water for domestic use, however, their application is often hindered by official norms and standards or by the administrative practices of national and international funding agencies. Typically, the applied norms and standards tend to emphasize the properties of the products rather than the functions and performance they should deliver, thus inhibiting the search for technological innovation and development, as well as the application of technologies that allow the incremental improvements of service standards. Another aspect worth mentioning in relation to technology selection is the tendency to optimize costs and use of resources on the construction of facilities, without giving due regard to the inputs required for their subsequent operation and maintenance.

This general overview of the main features of current water supply projects indicates that many of the policies applied in the past for service improvement have in fact unwillingly contributed to deplete the scarce resources available for the extension and management of water supply services. Examples abound of sectoral investment programmes with negative financial returns; of contradictory programmes of institutional strengthening and reform; on the isolated application of capacity building programmes that encourage the drainage of human resources from service agencies; on the implementation of non-sustainable community participation programmes that tend to fragment the social organizations; on the irrational exploitation, use and pollution of freshwater resources; or on the uncritical application of so-called appropriate technologies.

The main lessons we have gained from assessing present conditions are that the planning and management of freshwater supplies have to give more attention to the identification of those constraints that systematically frustrate efforts to implement appropriate policies; programmes and projects; and that well-targeted actions to overcome them should be designed taking into account the main processes that intervene in the demand and delivery of freshwater resources.

Before concluding, let me briefly mention to you the work that the United Nations Centre for Human Settlements (Habitat) has been doing in the area of water resources management, keeping in mind our main focus of responsibility, that is, to provide technical and policy assistance to national and local authorities in the management and development of human settlements. UNCHS (Habitat) had the privilege to participate in the preparatory processes for the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. As such, I am proud to say that the Centre made substantive contributions to various preparatory activities to UNCED, such as the "International Conference on Water and the Environment", held in Dublin in January 1992, and also played an active role in the actual Preparatory Committee for UNCED that led to the formulation and adoption of Agenda 21.

In this respect, the implementation of Agenda 21 recommendations related to environmental infrastructure, and urban water resources management has been identified as one of the priority areas for action by UNCHS (Habitat). Chapter 7 of Agenda 21 calls for the promotion of an integrated approach to the planning, development, maintenance and management of environmental infrastructure - water, sanitation, drainage and solid waste management - focusing on the needs of the poor. For this purpose, UNCHS (Habitat) has launched the Settlements Infrastructure and Environmental Programme (SIEP).

SIEP's current activities in the area of water resources include the execution of field research and capacity building aspects in partnership with local authorities of several developed countries. Those activities aim at the formulation and application of instruments for policy formulation and management of water resources and infrastructure services in urban areas. SIEP also participates in a programme for the assessment of water resources management in eight Asian megacities in collaboration with the Asian Development Bank, as well as the organization of training activities on methods and instruments for investment planning on infrastructure programmes. Additionally, an action programme is being formulated by the Centre which will serve as a guidance for the formulation and implementation of future support activities in the area of urban water resources.

At the global level, the Centre endeavours to coordinate its activities with other international support agencies in order to maximize the impact of our programmes and keep abreast of emerging issues in the area. As such, we are active members of the Water Supply and Sanitation collaboration council and provide substantive support to its Working Group on Urbanization. The results of the work of this group will be presented at the next meeting of the Council to be held in Rabat, Morocco, in September of this year. The Centre also participates in the activities of the United Nations Steering Committee for Water Supply and Sanitation, and in the Sub-committee on Water Resources of the United Nations Administrative Committee on Coordination. It is important to mention that in the context of the activities of the Sub-committee on Water Resources, the Centre has been entrusted with the formulation of a strategy for collaboration among agencies of the United Nations System in the implementation of Agenda 21 recommendations on urban water resources management. Finally, let me mention that our efforts to bring collaboration closer to the daily activities of the Centre and the United Nations Environment Programme have resulted in the identification of water resources and waste management as priority areas for the establishment of joint activities between both agencies.

Let me conclude by expressing my optimism that the deliberations of the present conference will contribute to the formulation to overcome some of the constraints that I have mentioned before, especially in relation to the implementation of rainwater catchment systems, and thus provide additional tools to support the efforts of the United Nations Centre for Human Settlements (Habitat) and other international and national institutions committed to improve the management of freshwater supplies. This is of particular relevance to the Centre since we are now embarked in the preparatory activities for the second United Nations Conference on Human Settlements (Habitat II) to be held in 1996. I sincerely hope that the results of this conference could be instrumental in providing support to the preparatory process for Habitat II through the revision of experiences, identification of issues and formulation of proposals for the improvement of water resources management in a context of human settlements development.

KEYNOTE ADDRESS

By C.B. Lostelius

Swedish International Development Authority

The Honourable Assistant Minister, Mr Chairman, Conference Officials and Participants, Ladies and Gentlemen,

It is an honour for me and it is with much pleasure that I address this conference with its national and international delegates.

My colleagues and I are very pleased to participate in this event. This is particularly so because of the importance Sweden and SIDA pay to the use of appropriate technologies aimed at achieving sustainable projects with minimum strain on the environment.

In the water sector we recognize rainwater harvesting as one such technology. In our opinion its potential as a water extraction method as a means for better water resources management has not been fully explored.

We are therefore happy to be one of the major supporters of this conference in which rainwater harvesting and its related subjects will be discussed.

Ever since the Swedish International Development Authority, SIDA, was created almost 30 years ago, water development has been on its agenda and many lessons have been learnt.

The need for continuous assessment and re-assessment of approaches has been apparent, as well as for innovative technology and methodology developments.

As was recognized by the recent global environment conference, UNCED, in Rio and its preceding conferences, water is a natural resource with limited availability.

Water is, however a precondition for the survival of life. Vast areas of the globe are already reporting water scarcity and acute water stress. Coupled with the population increase and degradation of the environment the problem is likely to worsen. In this context a fair remark may be that until now this precious product, water, has been handled carelessly, the consumers believing that it will always be there in abundance and that it will readily swallow any waste poured into it.

Ladies and Gentlemen, despite our own favourable water situation in Sweden, we have also experienced problems. It became a concern some years ago that trees died in our forests and fish were dying in the lakes, and that water developed a foul smell.

It was found that the cause was acid rain which originated partly from the exhausts of our own industries, and partly from industrial outlets outside Sweden, bringing the issue into the international arena.

The solution was to discuss the issue at the international and national level and particularly to mobilize the community and bring the subject into all levels of the education system.

If industry and agriculture are allowed to pollute water sources there is not much point in trying to protect water in the drinking water sector, though using rainwater would be helpful in areas with less polluted air.

Catching the water before it touches the ground would provide one solution as regards drinking water.

Controlling runoff could provide improvement in the agricultural sector.

Even rainwater harvesting needs protection. Pollution must be a concern at local, national as well as international levels.

Recycling of water and waste has been introduced in many countries but much remains to be done in promoting water-saving methodologies.

To pollute or spoil water in other ways should be regarded as a serious crime as it represents an assault on the very base of our existence.

The recognition that water is increasingly becoming a scarce resource raises the demand for our efficient use of it.

The management of water resources at all levels is therefore of growing importance; there is also a need for coordination, control, advice and education.

The drinking water sector represents only a small portion of total water use; the large users are agriculture, hydro-power, and industry.

There is the situation of too much rain received over a short period, requiring runoff and flood control.

It is, therefore, important that water is seen in a holistic integrated perspective in planning and coordination.

There is also the need for coordination of water development activities, not least the donor supported programmes, to make sure they are sustainable, a subject which I hope will be discussed at this conference.

It is seen by SIDA as most important that at the same time as issues are discussed in international fora such as this conference, or at the national level, that management of the resources, with appropriate advisory services, are decentralized to the consumers or to the lowest appropriate level.

Ladies and Gentlemen, governments can't do everything; especially in the poor countries where their capacities are limited. Typical government roles would be national policy formulations and legislation, monitoring of water extraction, enforcing laws and facilitating decentralized water resources and information management.

More decentralized operations are required for the implementation of community, agriculture and household water supply; implementation at this level should be largely a task for the users themselves. Experience shows that if facilities are brought within the control of individual families or concerned user groups, care and up-keep improves.

It is therefore important that suitable environmentally sound technologies are developed or refined and that participatory approaches are encouraged and that training and information services are made available.

Rainwater harvesting will come into focus both in the context of drinking water supply and agricultural water supply as a complement to conventional water supplies, particularly in the towns, as well as in soil and water conservation.

I am confident that this conference with delegates representing different professions and from areas of our globe with different conditions and experiences will constructively and operationally discuss most of the issues I have raised, as well as many others.

Having said so, it only remains for me to wish this conference every success in its deliberations.

SIDA will await with great interest the outcome of the conference with its challenges and proposals for practical solutions on improving utilization of the vulnerable water sources so necessary for life.

KEYNOTE ADDRESS

By C. Hubert

Water and Sanitation Section, UNICEF Kenya Country Office

Mr Chairman, Distinguished Guests, Ladies and Gentlemen,

In 1990, the World Community formulated goals which could be achieved by the end of the decade, that is by the year 2000, for the wellbeing of the child.

Among the goals relevant to the water and sanitation sector, three were clear. That there should be:

1. Widespread access to safe drinking water;
2. Widespread access to sanitary means of excreta disposal;
3. Total elimination of guinea-worm disease.

On the face of it these are very ambitious goals. They will require properly coordinated strategies if they are to be achieved. Of course the strategies will depend much on country to country situations.

Let us briefly look at the Kenyan situation. Today, the infant mortality rate (IMR) is about 74/1000. The under five mortality rate (U5MR) is estimated at 105/1000. These death rates are caused by many underlying factors amongst which is the limited access to safe drinking water. In fact, only 45% of the rural population have easy access to safe drinking water. According to the National Water Master Plan, more than US $4 billion is required to achieve 100% coverage by the year 2010. Clearly such an amount of money far exceeds the budgetary capacity of the Government and even the donor community.

This is why the Kenya Government, with support from UNICEF, has reviewed the situation and come up with National Plan of Action to realistically formulate what is achievable within the resource constraint.

Now let us have a look at some of the strategies within the National Plan of Action.

Involvement of communities

Involving communities in their water supplies has the effect of reducing not only the capital cost, but also the recurrent cost.

Community friendly technologies

This will create greater interest among the communities to manage their water supplies; in fact many communities will own these facilities without depending too much on external support even from the Government.

Low cost technologies

Communities should be able to afford and sustain any technologies which are going to give them water in the long run. Unless technologies are affordable and sustainable, experience shows that such systems fall into disuse rapidly; and one wonders why they were installed in the first place!

Dissemination of information

It is believed that a lot of relevant information exists and yet this information is not easily accessible to those in dire need. Therefore, as a strategy dissemination of information is paramount.

A forum like this is one way of disseminating information with the hope that many more people will benefit. This information is even more important at local level where implementation takes place.

The effect of such dissemination of information is two-fold: firstly, it facilitates replication of projects; i.e. similar projects could be implemented in similar situations elsewhere. Secondly, dissemination of information facilitates monitoring which has great impact on improving facilities and technologies.

UNICEF is supporting the Government and the communities in developing systems along the strategies already mentioned.

In the recent past, UNICEF has contributed toward the development of over 500 roof catchment systems and pans in various parts of the country. This has been possible through collaboration with other agencies. Communities have played an even greater role, providing the necessary expertise and materials. *Fundis* (artisans) have been trained amongst the communities. These *fundis* are, and will continue, constructing structures for rainwater catchment. We now hope that the number of such units will increase considerably in future.

In many regions of Kenya, there is high rainfall (above 500 mm/year). This creates large amounts of runoff which could be conserved not only for domestic use, but also for agricultural activities.

Looked into in another way, water conservation will improve the potential for ground water which is lacking in many parts of the country.

Through afforestation measures Kenya has gone a long way to reduce soil erosion. However, much more remains to be done. Combining water harvesting with soil conservation measures is an effective method of increasing agricultural output.

I know that many of these points will be taken up during the conference.

In summary, UNICEF attaches great importance to any strategy that reduces deaths that otherwise are easily preventable through provision of safe drinking water and adequate sanitation.

Rainwater catchment is an effective intervention. The other cost effective interventions include spring development, gravity systems, shallow wells and hand-pumps. These are some of the components of programmes which UNICEF will continue to support.

In conclusion, Mr Chairman, Distinguished Guests, Ladies and Gentlemen, thank you very much for your attention.

POLICY

POLICY ISSUES - CASE AND COUNTRY STUDIES

L. Kallren

UNDP - World Bank Regional, Water and Sanitation Group

The technique of collection of rainwater seems to be undergoing a renaissance. The idea of "harvesting" the rains for storage during the dry seasons stems back thousands of years. Why then do we need to arrange a conference on promoting rainwater harvesting in 1993? Maybe because RWH is a skill and tradition that to some extent needs to be rediscovered. A number of papers herein present examples of old house construction methods and architectures where rainwater collection was an incorporated component, in the form of roof and courtyard design. The influence and standard-setting of the "modern" western design of housing supplied with piped water could, in some parts of the world be one reason for this heritage being somewhat forgotten. Population growth and thus increasing demand for a scarce resource, costly operation and maintenance of conventional water supply systems etc, have forced a recognition of alternative and more affordable and easily maintained systems. The latter constitute another basis for holding this conference.

Rainwater harvesting, one of the more affordable water supply alternatives, has, as opposed to the conventional systems, some striking advantages: it is a renewable resource and its environmental impact is small; it generally does not require any treatment; no external energy is required for its extraction or transportation and most of the labour, material and spare parts are locally available. It is because of these advantages that rainwater harvesting is receiving increasing recognition today in developing countries where budget constraints require decision makers to be more creative and open to alternative technologies and financial/institutional options.

The constraints facing rainwater harvesting and its promotion are of a varied nature, although not necessarily always specific for this particular technology. The first problem is the effort that is needed to elevate its status among water engineers and technicians, who today are mainly trained in design of complicated and expensive water supply systems. Rainwater harvesting often does not seem "glamorous" enough; some sensitization work is required. Policy makers, too, should be a target of this awareness raising campaign. On the implementation side of it, there is still in many cases a financial constraint. The size of the storage facility implies a relatively high investment cost. Consequently most rainwater harvesting projects today focus on communal solutions, whereby institutions like schools and clinics are being targeted. Communal solutions, however, involve an aspect which can be referred to as social constraints. When the organizational skills and management capacity of the community are overlooked, a community based approach is bound to fail. Furthermore rainwater is sometimes also subject to different cultural and traditional beliefs, which can limit the feasibility of rainwater harvesting development, e.g. the taste of water, with its relatively low mineral content, is in some cultures a factor that has to be taken into account. Flowing water is sometimes considered more pure than stored water etc.

Of paramount importance and related to the above considerations is the choice of technology. The need for matching the technology to the hydrological conditions is obvious. But the aims should also be to match the technology with the appropriate financial resources and the appropriate institutional environment. This is true at the community level as well as the overall national environment. Poor design and/or inappropriately chosen technology, furthermore, negatively affects the credibility of rainwater harvesting as a serious water supply option. Leaking storage tanks, sub-quality taps, lack of screening against insects etc., move the promotion work in the wrong direction. Related to this is the need for further development of different techniques and designs. This must be done in a structured and well-coördinated manner, where new ideas are field-tested and monitored closely prior to embarking on large-scale implementation. Enthusiasm and precious community resources must not be misused by introducing poor quality or sub-standard designs.

The development and testing of handpumps during the International Drinking Water and Sanitation Decade could, in some aspects, serve as a model for the research needs in the field of rainwater harvesting. This handpump development was largely a multi-agency collaboration between governments, UN agencies, bilateral organizations and NGOs. The effort included, and is still going on, design and materials development, laboratory and field testing, support to local manufacturers and technical assistance in the area of quality control and assurance. There is no reason for settling with anything less than such an approach for rainwater harvesting technology. A prerequisite for such a development to take place is, as stated above, the creation of awareness and commitment by both governments and external support agencies to a level comparable to that of handpumps today.

As regards the role of central and local governments in the national development of rainwater harvesting, the first step (assuming a certain level of recognition of the potentials of rainwater harvesting), is to, in a serious manner, incorporate RWH in national water policies and water master plans. This implies a systematic and comprehensive assessment of these potentials in each region of the country. The assessment will have to take into account all the above-mentioned constraints as well as opportunities. A natural part of this policy preparation is to clearly define the government's own, as well as other institutions roles and responsibilities and also the required national support structure to facilitate the development of rainwater harvesting in the country.

The importance and the benefits of a national strategy on rainwater harvesting systems is proved by the case of Thailand, possibly the most successful country in the world in promoting and implementing rainwater harvesting. The government, in cooperation with other appropriate institutions, can have a role in the following areas:

- General delineation of responsibilities as regards the various stakeholders, including the communities;
- Facilitating the creation of water users associations and a range of options on By-Laws;
- Financial assistance in starting up revolving funds and other alternative credit facilities for low-income groups;
- Assistance in supplying simple tools and storage tank forms etc.;
- Setting of standards on water quality, incorporating the potential in an urban context as well, and structural engineering standards;
- Manuals preparations;
- Training support both to communities and private small-scale construction initiatives; and

- Monitoring and evaluation of the national rainwater harvesting programme.

Obviously there are many lessons to be learned from the Thailand case, but it is up to each country to conduct its own assessment and based on this, define its own objectives, policies and support strategy. If Thailand has come a long way in this respect, it seems in some countries the development of rainwater harvesting is still dependent on a few individuals. In other words, many countries still have most of the awareness creation and sensitization work to do. It also seems that at the present time this is where emerging national branches of the International Rainwater Catchment Systems Association (IRCSA) have their main role to play. The following are some of the suggested tasks for a national IRCSA branch:

- Act as a national information and reference centre for rainwater harvesting;
- Preparation of simple manuals for implementing rainwater harvesting projects, e.g. technology, finance/management options, and participatory training schools;
- Act as a resource institution and counterpart to central and local government in setting standards for water quality and structural engineering;
- Monitor, document and disseminate information on successful rainwater harvesting projects in the country; and
- As a reference centre, ensure a lively exchange of information and lessons learned from rainwater harvesting development in other countries.

A national/local institution like this, in collaboration with the government body responsible for water affairs, is furthermore most certainly a factor contributing to the interest and commitment from external support agencies.

Following below are a number of examples of the dissemination of experiences and lessons from around the world: Kenya, Namibia, Tanzania, Thailand, China etc.

IMPORTANCE OF NATIONAL POLICY FOR RAINWATER CATCHMENT SYSTEMS DEVELOPMENT

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ABSTRACT

The importance of national policy for rainwater catchment systems (RWCS) is presented in this paper. The best process for policy making is to have inputs from cultural, social, environmental and economical considerations. Ideally, these considerations should come from grass-root communities - the water users. Alternatives for water supply should be presented for their selection, along with the advantages and disadvantages. With limited financial support from central, provincial and local government, and foreign aid, water users should be informed and motivated to commit their own share of the cost and labour for the construction and operation of their rainwater catchment system. In most developing countries, women are in charge of household maintenance, and water supply for them is an important chore; their inputs and involvement in the national policy for RWCS development are most necessary. Using appropriate technology in RWCS development is a sustainable water supply policy that should also be included.

The Thailand National Water-jar RWCS Policy is referred to as a successful example of national policy for RWCS development.

INTRODUCTION

The use of rainwater catchment systems (RWCS) for rural and urban domestic and other water supply has been reported and promoted in previous proceedings of the international conference on rainwater cisterns systems. The impacts of RWCS on institutional policy have been reported by Fok (1982, 1984) and Walker (1984). However, the importance of national policy for RWCS development is still worth further exploration. This paper suggests that the best process for formulating national policy for RWCS may be the consideration of cultural, social, environmental and economic aspects gathered from grass-root communities - the users; alternatives for water supply should be presented for their selection, along with the advantages and disadvantages, and the long-term government plan for the community's comprehensive development.

With limited financial support from central, provincial and local government, and foreign aid, water users should be motivated to contribute their own share of the cost and labour for the development and operation of their rainwater catchment system. In most developing countries women are generally in charge of household maintenance, water supply for them is an important chore; their involvement in formulating policy for RWCS development are most necessary.

The Thailand National Rural RWCS Policy is one of the successful examples (Wirojanagud and Chindaprasirt, 1987; Sethaputra, 1986; Fok, 1989). It is again briefly presented in this paper to show the importance of national policy for RWCS development.

CONCEPTS FOR NATIONAL POLICY DEVELOPMENT

In a democratic country the national policy can be initiated from either its citizens and/or government, following the processes defined in the law. A national policy is developed for the benefit of the citizens; therefore, their participation in the national policy-making process is most necessary. A viable national policy requires a partnership between government and the citizens who have the right to make selections from alternative policies. Once the selection has been made, government has the power to execute the policy. Furthermore, citizens have a duty to honour their selected policy by committing their own resources to ensure the success of the national policy.

THE BEST PROCESS FOR FORMULATING NATIONAL POLICY FOR RWCS DEVELOPMENT

According to the concepts stated, the best process for formulating national policy for RWCS development is to consider cultural, environmental and economical aspects of the communities - the users. Parallel to a RWCS, alternative water supply systems should also be prepared by government and presented, together with the advantages and disadvantages of each alternative as related to long-term plans for community development, for users selection. Once the decision to establish a national policy for RWCS development has been made, cultural, social, environmental and economic practices of the users should be considered.

Cultural aspects

The cultural aspects are firmly related to traditional water sources and uses. Each nation or tribe has its own cultural traditions relating back to its history. Cultural traditions should be preserved, and any remedial measures must be introduced with the utmost care. Catching rainwater for water supply is a method that may or may not be acceptable according to the traditions of a nation or a tribe. For example, villagers in Gunung, Kidul, Indonesia, have long been accustomed to using surface water. After the RWCS was built, some tank owners dumped buckets of mud into their tanks of clean rainwater to restore the taste that they were accustomed to have with surface rainwater (Airstani, 1986). If RWCS national policy decision-makers had carried out an advance survey of users' cultural preferences, some remedial measures could have been provided via public education programmes.

Social aspects

Social aspects can sometimes be an obstacle to the successful operation and maintenance of the RWCS. In general, the systems are privately owned by individual houses. This tradition was established before centralized public water supply systems were introduced.

In some Polynesian social systems, communal ownership of property is practised. As a result the private ownership of RWCS in individual houses becomes impractical, because during water shortage periods, neighbours would ask RWCS owners to share their water, and their requests could not be denied according to social tradition. RWCS national policy decision-makers should pay serious consideration to social traditions during their policy-making process.

Environmental aspects

Environmental aspects may be considered in two phases: present and future. For the present, the practicability of a RWCS for its user should be incorporated in the environmental consideration. Users should be reminded that a RWCS is part of their residence, therefore, storage facilities should be an intergrated functional addition which should be in harmony with other buildings in shape and style. If a RWCS environmental impact assessment was conducted at present, one would find that most developments could be classified as positive.

For the future, the environmental impact of RWCS may be assessed as having some negative aspects. RWCS may have a short economic life. If national *per capita* income was improved, then replacement of RWCS with other water supply systems might be feasible. In this case, the retired RWCS would present a disposal problem. Ideally, replacement and disposal considerations should be included in the RWCS national policy-making process.

Economic aspects

Economic feasibility is the major consideration in national policy development. Since most RWCS are privately owned, users are expected to pay all of the cost and provide their own labour in RWCS construction; their participation, therefore, is very important in the selection of their water supply system. Alternatives for water supply such as shallow wells and surface water catchment systems should also be presented, along with their advantages, disadvantages and the cost of each system. Where there is a possibility of financial aid from the government or a foreign donor, the method of payment and/or repayment should also be presented.

In most developing countries women are in charge of household maintenance, and water supply for them is an important chore; therefore their input and participation in the RWCS national policy development are most necessary. Using appropriate technology in RWCS development can assure a sustainable water supply; clearly, it should be part of the RWCS national policy.

A SUCCESSFUL EXAMPLE:

The Thailand National Water-jar RWCS policy has been reported by Sethaputra (1986), and Wirojanagud and Chindaprasirt (1987):

1. Villagers (users) should be involved in project formulation, development, construction, management and operation. They are given alternatives to the Thailand Jar Project including advantages and disadvantages of each, so that the users can decide whether or not to join the project.
2. The project should be financed with a revolving fund and should begin with a group of villagers who are capable of repaying their loan to buy construction materials, on a monthly basis. This is done at each participating village so that the revolving fund can be quickly established and its initial participants can serve as models for others to follow.
3. The government is responsible for supplying tools, jar forms, training for jar construction and maintenance, and training for managing the revolving fund.

To implement the project, the government should conduct the following preparation and training.

Preparation of the community
Public health seminars should be conducted to teach villagers the importance of safe drinking water supply and sanitary disposal of human and animal waste; to inform them of the details of the jar project as a cooperative project among themselves; and to demonstrate the working of a revolving fund. The community preparation project itself is a cooperative effort between local district administrators, the sub-district working committee and the village working committee.

Training
Each Province is responsible for coordinating the work of related technical agencies, such as the Department of Accelerated Rural Development and the Provincial Office of the Department of Health, which train village technicians in jar construction. Subsequently, the village technicians train other villagers. A simple manual for jar construction which includes many step-by-step illustrations was published. This manual illustrates the need for the teamwork of at least two men for one day to build a jar. This training promotes villagers working together, sharing and communicating with each other, to realize the fruits of their hard work. They will appreciate the leadership of government officials who provided financial and technical assistance to the project. The positive effects of the Thai jar project are the development of healthier water supplies and better organized rural communities with the experience of working together in community projects to upgrade their living conditions. The whole country benefits from the spirit of self-reliance and team-work generated by this project.

The revolving fund
The government is responsible for providing initial funding for villagers to purchase jar construction materials and for administering repayment of this fund to create a revolving fund. The supervision and management of the revolving fund is later through cooperation between participants, village committee members and sub-district council members.
It was found through experience that poor rural villagers were able to repay their loans at about $4 per month; thus this amount was set as the repayment rate.

Project cost load on the government

According to Wirojanagud and Chindaprasirt (1987), the up-front cost of the project to the government was about US$ 20.4 milion. Of this, the revolving fund is about $13 million; training and providing the jar forms amounts to $7.4 million. The Government of Thailand has developed an outstanding policy for providing drinking water to rural villagers at a cost of US $7.4 million of government money to build 9 million $2m^3$ jars in 4 years. As reported, during 1986 alone, 1.7 million jars had been built; by the end of 1987 a total of 3 million jars had been constructed, and by 1990 the goal of 9 million jars had been surpassed. A total of 18 million rural people now enjoy their new source of drinking water supply.

Assessment of the Thailand jar project

The Thailand Jar Project meets all nine factors favouring the selection of a RWCS: traditional method; community participation in selection; low cost; private ownership; relatively good water quality; easy to construct; low operation and maintenance costs; convenience and flexibility. The jar is large enough to permit a person to get in for regular cleaning and repair yet light in weight (450kg) and round in shape so as to be readily moved around a house. The jar is tall and smooth enough to prevent young children from climbing in. Although the service life of the $2m^3$ reinforced cement jar has not been tested, it is expected to last for 30 years or more. In summary, Thailand may be the only developing country to have provided a safe drinking water supply for every rural household by the year 1990.

CONCLUSIONS

The importance of national policy for RWCS development has been presented in this paper. The best national policy should have inputs from cultural, social, environmental and economic consideration, which should, ideally, come from the users. Alternatives for water supply should be presented for users' selection, with the advantages and disadvantages of each system provided. In most developing countries women are in charge of household maintenance, and water supply is an important chore. Therefore, their input and involvement in the national policy for RWCS development are most necessary. Using appropriate technology in RWCS development is also a policy that should be included, so that users can operate and maintain RWCS effectively. The successful Thailand RWCS policy is a good example.

ACKNOWLEDGEMENT

The author wishes to acknowledge the partial financial support of this study provided by the US Geological Survey via a grant to the Water Resources Centre, University of Hawaii at Manoa.

REFERENCES

Aristani, C. (1986). Dian Desa's Rainwater Catchment Program - Its Implementation and Development, p. 132. Manuscript Rep. IRRC-Mr 127e, International Development Research Centre, Ottawa, Canada.

Fok, Y.-S. (1982). Rain Water Cisterns Systems Impact on Institutional Policy. *Proc 1st Int Conf. on Rain Water Cistern Systems*, p.387. University of Hawaii, Honolulu, USA.

Fok, Y.-S. (1984). Assessment of Rain Water Cistern Systems Impacts on Institutional Policy. *Proc. 2nd Int. Conf. on Rain Water Cistern Systems*, P. G1-1 University of the Virgin Islands.

Fok, Y.-S. (1989). International Drinking Water Supply and Sanitation Decade and the Progresses of Rainwater Cistern Systems. *Proc. 4th. Int. conf. on Rain Water Cistern Systems*, p. A1-1. Manilla, Philippines.

Sethaputra, S. (1986). Lessons from the Thailand Jar Program. *Proc. 3rd Int Conf. on Rain Water Cistern Systems*, p.5. Khon Khaen University, Thailand.

Walker, W.R. (1984). Rainwater Cisterns: Legal, Institutional and Policy Considerations. *Proc. 2nd Int. Conf. on Rain Water Cistern Systems*, p.G2-1. University of the Virgin Islands.

Wirojanagud, P. and Chindaprasirt, P. (1987). Strategies to Provide Drinking Water in Rural Areas of Thailand, *Proc. 3rd. Int. Conf. on Rain Water Cistern Systems*, p. B5-1. Khon Kaen University, Thailand.

A REVIEW OF THE DEVELOPMENT, CURRENT STATUS AND FUTURE POTENTIAL OF RAINWATER CATCHMENT SYSTEMS FOR HOUSEHOLD SUPPLY IN AFRICA

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ABSTRACT

Rainwater catchment systems for domestic water supply have been used in Africa for at least 2000 years. In this paper an overview is given which firstly traces the historical development of the technology in Africa and secondly seeks to establish the current state of the art on the continent.

The significance of the present role of rainwater catchment systems technology for the provision of household water supply is assessed, based on evidence from East and Southern Africa.

The relevance of rainwater catchment systems (RWCS) technology in supporting the dual goals of sustainable development and self- reliance in Africa are discussed.

Finally, the potential future role of rainwater catchment systems in contributing to water supplies in both rural and urban Africa in the 21st century is considered. The most promising designs and implementation strategies currently being adopted are examined with reference to case studies and their more widespread dissemination proposed.

INTRODUCTION

In the late 1970s the launching of the International Drinking Water Supply and Sanitation Decade (1981-90) led to high hopes that before the end of the century the problems of poor water supply and sanitation would be virtually eradicated. By the end of the Decade, however, it was clear that the world in general, and Africa in particular, had failed even to come close to achieving its main goals, such as providing clean water for all within 400m of every household.

The Decade did, nevertheless, coincide with the improvement and rapid dissemination worldwide of one water supply technology, namely rainwater catchment systems (RWCS). The unprecedented expansion in the use of this ancient technology was, however, very uneven. Some regions (e.g. South-east Asia) benefited greatly whereas others (e.g. West Africa), despite having both a great need and potential, witnessed only a few scattered projects.

In Africa, new RWCS spread fastest in Kenya where scores of different projects developed in the late 1970s and 1980s. These used various low-cost rainwater tank and rock catchment designs, and many involved implementation strategies based around the concept of community participation. Despite the success of many individual projects, however, the coverage of improved rural water supply remains low in Kenya. In fact this is true of much of

Africa, where the need and the potential for further developments are enormous. Apart from Kenya, the development of various types of rainwater catchment systems has taken place in Botswana (Gould, 1985; Gould and McPherson 1987), Togo (Lee and Visscher, 1990; O'Brien, 1990) and Ethiopia, Mali, Sudan and Zimbabwe (Pacey and Cullis, 1986).

Elsewhere in Africa the technology is continuing to spread with many new projects currently on-going in Malawi, South Africa, Mozambique, Sierra Leone and Tanzania (Fig. 1). The hosting of the 6th IRWCS Conference in Nairobi and recent workshops in Togo (1987), Kenya (1987, 1991 and 1992), Botswana (1993) and Namibia (1993) are also indicative of an increasing interest in rainwater catchment technologies in Africa.

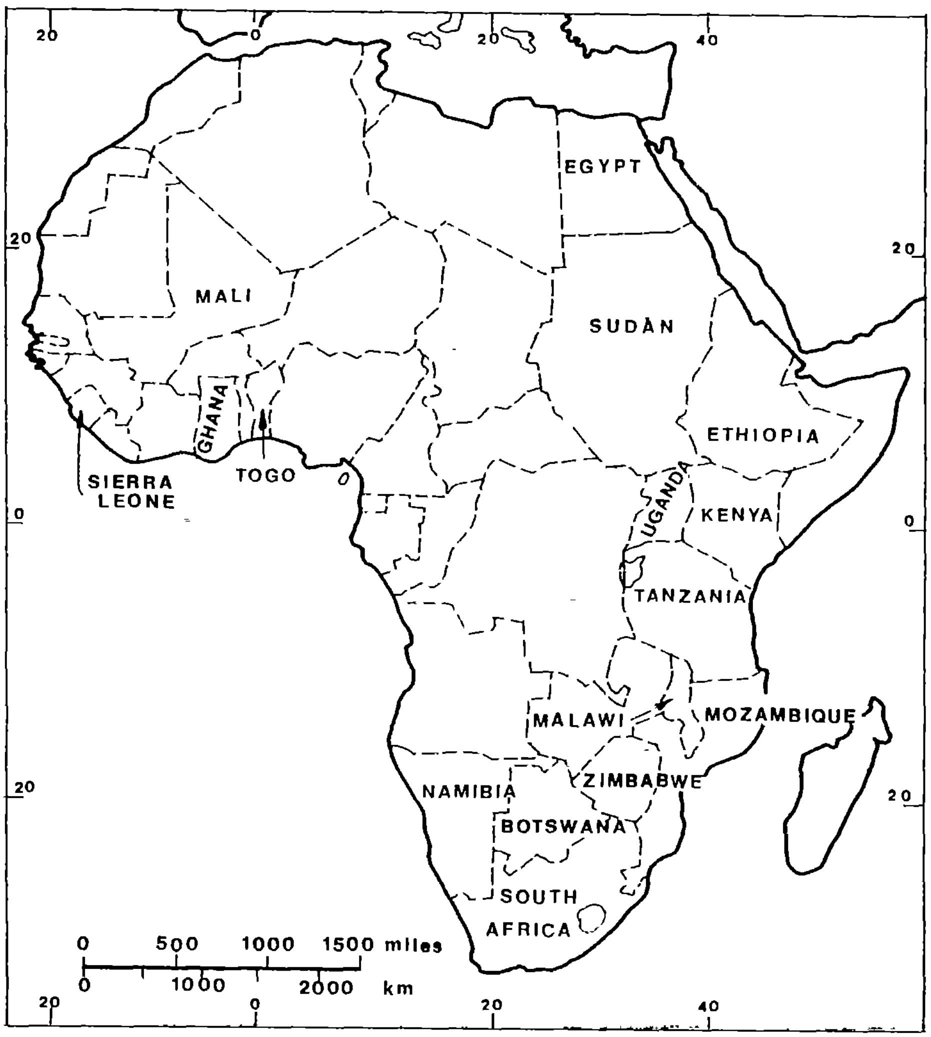

Figure 1. Map of Africa showing the countries cited.

HISTORY OF RAINWATER CATCHMENT SYSTEMS IN AFRICA

Rainwater collection has been practised in Africa for at least 2000 years. The earliest documented evidence relates to cisterns in the Western Mediterranean Coastal Desert in Egypt which date back to Roman times. At present there are 2000-3000 cisterns in the region and many are still operational with sizes ranging from 200 to 2000m^3, (Shata, 1982). Traditionally, people have collected and stored rainwater running off the eaves of thatched roofs in earthenware pots, or runoff from their compounds in hand-dug pits.

Along the east coast of Africa, rainwater collection systems known locally as *Djabias* have been constructed for several centuries and are still used today, e.g. on Manda, Pate and Wasini Islands, Coast Province, Kenya. These consist of rectangular tanks made of coral blocks and were traditionally plastered with local cement made from burning and crushing coral. These systems often had a small purpose-built catchment area to complement roof runoff. In the Sudan large ground catchment systems involving the excavation of sub-surface tanks have existed for centuries. These are known as *haffirs* and are still constructed, although now-a-days often with the aid of machinery.

In the first half of this century, rainwater catchment systems were often built at missions, churches and schools, especially in localities suffering periodic water shortages. In South-east Ghana, for example, Parker (1973), referred to a system built in 1910 which was still operating. In Botswana roof tanks at the old mining barracks (now a primary school) in Nata date back to the early 1940s. In Kenya there are many examples of systems built earlier this century, including several rock catchment systems built in north Kitui in the 1950s. Some large *djabias* were also constructed in the 1950s and 1960s and serve whole communities e.g. Wasini and Mkwori on Wasini Island (McPherson *et al*, 1984).

THE PRESENT STATE OF THE ART

Although in some parts of Africa rapid expansion of rainwater catchment systems has occurred in recent years, progress has been slower than that achieved in parts of South-east Asia. e.g. Thailand. This is due in part to the lower rainfall and its seasonal nature, the smaller number and size of impervious roofs (thatch still being common in most rural areas) and the higher costs of constructing catchment systems in relation to incomes than in South-east Asia. The unavailability of cement and clean graded river sand in some parts of Africa and even a lack of sufficient water for construction in others, all add to transport costs and hence overall costs, significantly.

Nevertheless, rainwater collection is becoming more widespread in Africa, and Kenya, in particular, is leading the way; numerous projects have sprung up all over the country, mainly on the initiative of NGOs implementing a variety of RWCS technologies including roof, ground and rock catchments, as well as micro-irrigation and micro-catchments for agriculture. There are certainly tens of thousands, if not hundreds of thousands, of roof catchment systems alone in Kenya at present. The country contains considerable expertise and experience relating to the implementation of the technology from which other African nations could potentially benefit.

Already some of the designs and implementation strategies developed in Kenya are starting to spread to other parts of Africa. Organizations with interests in various parts of the continent such as church groups, bilateral and multi-lateral agencies (e.g. SIDA and UNICEF) and even private companies (e.g. ASAL Consultants) have played a pivotal role in this respect.

New projects have recently sprung up in Namibia and Tanzania and interest in replicating some of the developments in Kenya has been expressed by agencies in Botswana and Zimbabwe.

The significance of rainwater collection systems in the context of both sustainable development and self-reliance

Rainwater collection systems have a number of advantages over most conventional water sources both for water supply in the context of development, and of sustainable systems, these include:

- Rainwater is a renewable resource.
- Rainwater is generally pure and requires no treatment (except in a few polluted industrial areas where the atmosphere is contaminated).
- Once constructed, RWCS require no fuel or external energy source to extract or transport the water.
- The environmental impact of a RWCS is generally very small and may in some cases actually be perceived as beneficial, e.g. through reducing runoff-related erosion and by assisting ground-water recharge.
- Labour, materials and spare parts required for the construction of the systems are frequently available locally, ensuring the technology itself is sustainable.

RWCS also offer the potential for individuals and small communities to achieve another traditional goal of African rural development, namely that of self-reliance. Whilst the costs of installing simple roof catchment systems at some of the tens of millions of households where women still walk long distances to collect water is still beyond the means of the poorest, as development proceeds it is becoming a possibility for many others.

The steady transition from thatched to corrugated iron roofs, the development of new cost-effective ferrocement and other tank designs, and the setting up of community-based revolving funds and credit facilities, have all encouraged this process.

IMPLEMENTATION STRATEGIES

During the 1970s and much of the 1980s the emphasis of most RWCS implementation programmes was on the "hardware" aspects of projects, i.e. the physical design and construction techniques. Project objectives were frequently short-term and involved the implementation of a given number or capacity of systems within a given time. Recently there has been a growing recognition that a more gradual long-term approach involving the development of a capacity within the community to design, construct and maintain systems offers a much more promising route to ensuring the replication and sustainability of the technology within a given community (Lee and Visscher, 1990).

For any rainwater supply project to succeed an essential pre-requisite is the existence of a real felt need for improved water within the community, and a willingness to pay and make other contributions in kind towards any improvements. Apart from being technically feasible, rainwater catchment systems also need to be economically appropriate and socially acceptable to the community.

Economic considerations

Although the capital cost of rainwater catchment systems is high when compared with many other alternatives, this is to some extent off-set by their negligible recurrent costs. The construction of rainwater tanks is, however, seldom justified where plentiful good quality ground-water sources are readily available at shallow depths. The cost of the systems increase in arid areas where rainfall is more seasonal in nature and where larger catchment surfaces are required. Although economies of scale may be achieved using larger tanks where runoff suffices, the affordability of the systems always needs to be considered.

In most cases, particularly amongst rural communities in Africa, the cost of a rainwater catchment system will be far beyond the means of most households. Developing mechanisms for financing rainwater catchment tank projects therefore poses a major challenge to those trying to initiate projects in these circumstances. Most programmes rely on the contribution of "free" labour and local materials by the community and despite this, significant subsidies from funding agencies or government are still generally needed.

Socio-economic and cultural considerations

No implementation project is likely to succeed unless it is economically feasible. Among methods used to help finance RWCS projects in the past have been revolving funds, income-generating activities (integrated with the project) and grant subsidies. The success of any rainwater catchment system programme ultimately depends on the interest, enthusiasm and active support of the community for the technology. However technically appropriate a rainwater catchment supply may be for a given area, if it is socially inappropriate or unacceptable in any way, it is unlikely to be successful. Local customs, perceptions and preferences must be given a high priority when considering the feasibility of the technology and possible implementation strategies. It is always vital to be sensitive to local perceptions regarding the quality and suitability of rainwater.

CASE STUDIES

Kenya:

Diocese of Machakos rainwater tank programme

One of the largest and most successful roof catchment tank projects in Kenya is that of the Diocese of Machakos, which was initiated in 1983 and is being coordinated by the local Catholic Diocese Development Office. The project covers the whole district and is assisting groups of ten households to set up revolving funds for financing concrete ring tanks built to a locally developed design. A third of the cost of the tanks was initially covered by the local Development Office, supported by a foreign donor. The rest had to be met by the group members using the revolving fund.

The recipients of tanks provide materials and unskilled labour to help to reduce costs. The project has now become completely self-financing and by 1990 around 3000 tanks between $4.5m^3$ and $15m^3$ had been constructed. The success of the project is due, in part, to the effectiveness of setting up revolving fund groups for financing the development and motivating other groups to do likewise (de Vrees, 1983).

Projects in Kitui District

A number of the early designs attempted in Kitui failed or were deemed inappropriate and have since either been abandoned or improved. Among these designs were the highly publicized Ghala tanks which used a basket-work frame as both a mould, and as "reinforcement", onto which mortar was plastered. Although this was initially heralded as a low cost solution to tank construction and thousands were constructed, the basket-work frame was susceptible to decay

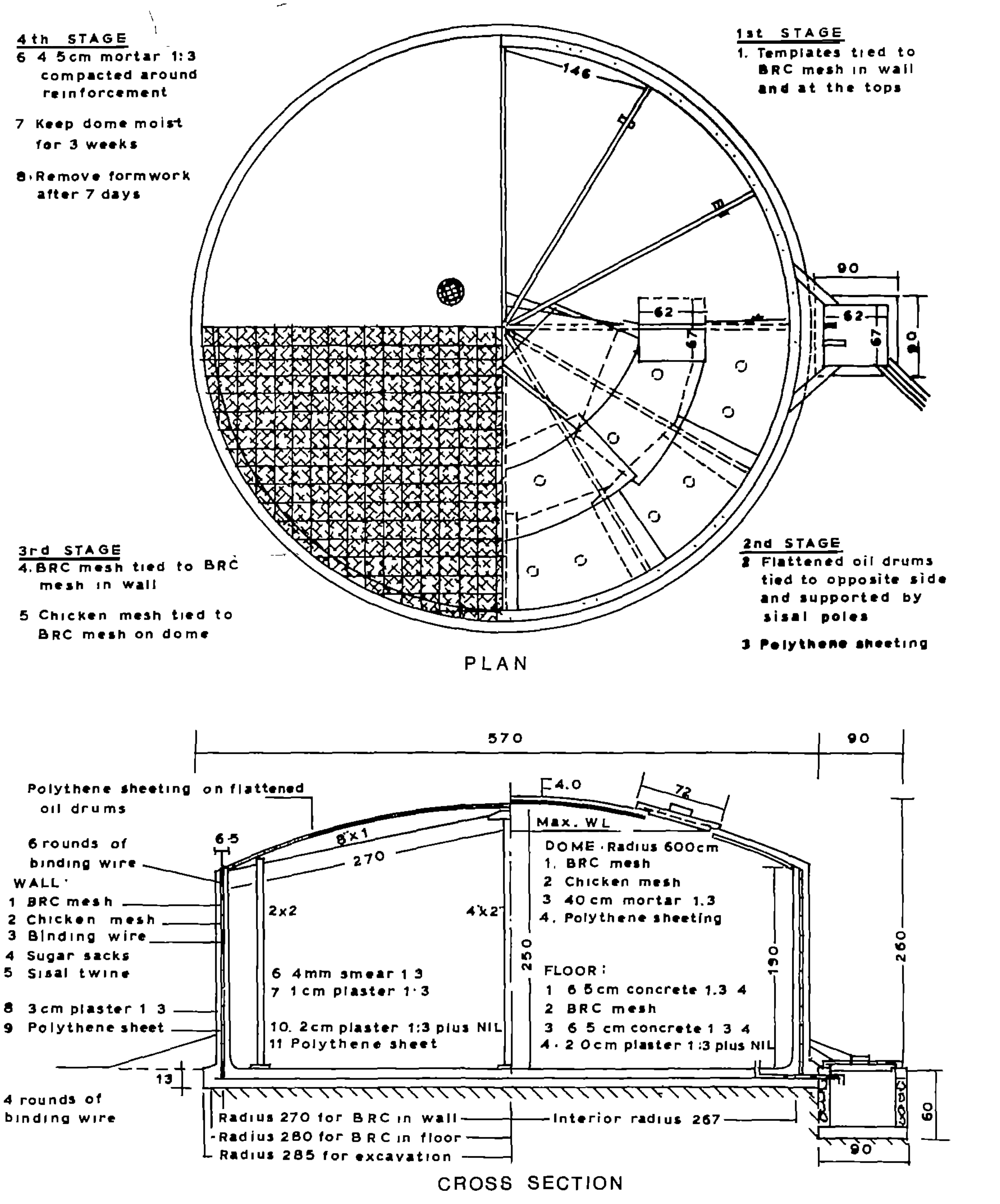

Figure 2. 46m^3 ferrocement tank design (after Nissen-Petersen, 1990).

and termite attack and after a few years most tanks cracked. The design was also too small and lacked a cover to protect the stored rainwater from contamination. Recent trials with sisal fibre reinforced cement tanks by the Catholic Diocese of Kitui have also been unsuccessful. The use of organic reinforcement both in Kenya and elsewhere (e.g. South-east Asia where bamboo reinforced tanks failed) is now being abandoned and is not to be recommended. Unfortunately, these designs are still promoted in several books and reports written in the mid-1980s and still in wide circulation.

Where cheap, abundant locally available building materials (such as quarry blocks) and appropriate construction skills and experience are absent, ferrocement designs have emerged as a durable, cost-effective method for both surface and sub-surface catchment tanks. The widely publicized construction method outlined by Watt (1978) involved the use of a re-usable cylindrical corrugated iron mould. This design has now been generally replaced on most projects by construction methods involving the erection of a chicken wire/BRC weldmesh reinforcement bar frame. This new design developed at the Mutomo Soil and Water Project, Kitui in 1985 by Erik Nissen-Petersen and his colleagues has been widely publicized in Kenya by UNICEF (1985) and several projects have adopted or modified this basic design applicable for tanks up to $50m^3$. A high standard of workmanship, use of good cement, careful selection and mixing of clean well-graded sand and thorough curing at every stage are essential for a good result. Dirt and other contaminants should be kept out of the water and mortar at every stage.

A similar design and construction method is also being used for $46m^3$ tanks currently being built by the Kitui Integrated Development Project at several hundred primary schools in the District (Fig. 2). The design is basically the same although an additional internal layer of mortar is included giving the tank a total wall thickness of 6.5cm. This is extremely well illustrated step-by-step, in a photo-manual produced by ASAL consultants/DANIDA (Nissen-Petersen, 1990). The design also includes a movable down-pipe to allow the first rains to wash the roof and gutters and run to waste.

Another innovation employed by this project is the use of splash guards to ensure that no water is lost from the very long gutters, sometimes exceeding 50m on larger school buildings. V-shaped sheet metal gutters made on site and wire hangers help reduce costs, while their use in conjunction with splash guards allows a 1% slope to be maintained without much water loss even if the gutter hangs 50cm below the eaves.

Botswana

The ALDEP Rainwater catchment tank project.

In semi-arid Botswana a project involving the construction of several hundred $10\text{-}20m^3$ ferrocement ground catchment tanks for the collection of rainwater from traditional threshing floors has been in progress for almost a decade. Recently the design has been modified to include a purpose-built $40m^2$ roof catchment and $7m^3$ imported polyethylene tanks (on cost grounds), to improve the quality of the water. Although the original design was intended for the provision of water for livestock the tanks were invariably used as a drinking water source. Excrement from small children and animals on ground catchment surfaces result in water in the system often being of very poor quality and tests have revealed serious bacteriological contamination. Table 1 shows clearly the contrast in water quality between rain collected from ground and roof surfaces.

Table 1. Results of bacteriological analysis of stored rainwater in ground catchment and ferrocement roof tanks in Botswana

Type of tank	*Total coliforms*	*Faecal coliforms*	*Faecal streptococci*
ALDEP ground catchment	TNTC	330	121
Covered roof catchment	0	0	38
- Max. recommended concentration (WHO)	<10	<1	<1
- Local guidelines (rural supplies)	<100	<10	<10

* Mean from eight samples; per 100ml calculated from 5ml and 50ml samples.
TNTC = too numerous to count.
Source: Gould and McPherson (1987).

DISCUSSION AND CONCLUSIONS

During the last decade many new and exciting developments have taken place in the field of rainwater catchment systems technology. Although there have been a few serious failures these are overshadowed by several very successful projects. Most important, significant lessons have been learnt, including:

- The danger of using organic "reinforcement";
- The importance of covering tanks with a durable cover;
- The poor quality of rainwater from ground catchments;
- The necessity of field testing any new design thoroughly over a prolonged period before publicizing it widely or attempting to replicate it elsewhere.

The success of RWCS projects both in Africa (especially Kenya) and around the world during the last decade is clear evidence that this is a technology appropriate to Africa's present development requirements. From the point of view of self-reliance, use of local materials and skills, and affordability, it has several advantages over a number of conventional water supply technologies. Since rainfall is a renewable resource, once constructed a RWCS can provide a sustained clean, convenient water supply over long periods with negligible running costs or energy requirements and very low environmental impact.

At present RWCS are greatly under-utilized in Africa, yet as the population increases and the number of possible catchments (e.g. iron roofs etc.) increase so will the potential for its application. RWCS offer the means of enabling Africa to achieve the IDWSS Decade targets (albeit somewhat belatedly) for rural water supply provision, as they have done in Thailand, where more than 12 million tanks have been built in the last decade. There are several regions in Africa which have the potential to meet these targets early in the 21st century if given the necessary support by governments and donor agencies. While external assistance is important in some places, for many areas most of the capital costs could be met by the local communities themselves through the use of revolving funds and income generating activities. Several projects in Kenya, including the Machakos Rainwater Tank Programme outlined in this paper have already demonstrated this potential.

In urban Africa rainwater catchment systems could provide a vital, supplementary (back-up) water supply in many African cities where mains supplies are notoriously unreliable. The wider use of rainwater collection in water-short rural areas could help to improve water supply provision both for domestic use and micro-irrigation. In this way the technology may help to alleviate problems of rural poverty, the burden carried by rural women and rural-urban migration.

REFERENCES

de Vrees, L. (1987). *Machakos Diocese Rainwater Tank Programme.* Development Office, Diocese of Machakos, P.O.Box 640, Kenya.

Gould, J.E. (1985). An Assessment of Rainwater Catchment Systems in Botswana. Unpublished M. Sc. thesis, University of Alberta, Edmonton, Canada.

Gould, J.E. and McPherson, H.J. (1987). Bacteriological Quality of Rainwater in Roof and Ground Catchment Systems in Botswana. *Water International*, **12**, 135-138.

Gould, J.E. (1987). An Assessment of Roof and Ground Catchment Systems in Botswana. *Proc. 3rd Int. Conf on Rain Water Cistern Systems.* Khon Kaen, Thailand.

Latham, B. and Gould, J.E.(1986). Lessons from Field Experience with Rainwater Collection Systems in Africa and Asia. *Aqua*, **4**,183-189.

Lee, M.D. and **Nissen-Petersen, E.** (1989). The Use of Low-cost, Self-help Rain Water Harvesting Systems for Community Water Supply in S.Kenya. *Proc 4th Int Conf on Rainwater Cistern Systems*, Manila, Philippines.

Lee, M.D. and **Visscher, J.T.** (1990). *Water Harvesting in Five African Countries* Occasional Paper, 14. IRC, The Hague, The Netherlands.

McPherson, H., McGarry, M., Gould, J. and **Latham, B.** (1984), *Low Cost Appropriate Water and Sanitation Technologies for Kenya.* GTZ report to the Ministry of Water Development, Nairobi.

Nissen-Petersen, E. (1990). *How To Build A Cylindrical Water Tank With Dome. A Photo-Manual.* KIDP/DANIDA, Nairobi.

O'Brien, L. (1990). Report on Rainwater Harvesting Project in Togo. Raindrop Rainwater Harvesting Bulletin, 3. Virginia, U.S.A.

Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas.* IT Publications, London.

Parker, R.N. (1973). *The Introduction of Catchment Systems for Rural Water Supplies - A Benefit/Cost Study in a S.E. Ghana Village.* University of Reading, UK.

Schiller, E. and **Latham, B.** (1982). *Rainwater Roof Catchment Systems· Information and Training for Low-Cost Water Supply and Sanitation*, Ed by D. Trattles. World Bank.

Shata, A.A. (1982). Present, Past and Future Development of Catchment Areas in the Mediterranean Coastal Desert of Egypt. *Proc. Int. Conf. on Rain Water Cistern Systems.*

DISCUSSIONS

Dr Schmoll asked whether rainwater collection from grass thatched houses was possible. The author responded that some collection of rainwater runoff from thatched roofs does take place. In Kenya plastic sheeting is sometimes stretched over thatched roofs to aid rainwater collection. This plastic is, however, susceptible to ultra violet degradation from sunlight. Many people from rural Africa do not like to drink water from thatch as it is discoloured and sometimes smells bad.

Mary Kasaija noted that some projects in Botswana are constructing roofs for rainwater harvesting and this is an underutilization since roofs could be constructed on houses. The authors responded that the point was well taken and that the same observation was made during the National Rainwater Catchment Systems Workshop in Botswana in March 1993. While having a follow-up, the Ministry of Agriculture, University of Botswana and Botswana College of Agriculture are looking into the idea of producing a manual to encourage villagers to add walls to their roof catchments to provide a dwelling.

Mr A. Swamy asked how feasible rainwater catchment systems were in areas where 80 - 90% of annual precipitation occurred within a very short duration of 60 - 90 days, followed by long dry spells leading to high incidence of drought and drinking water scarcity. The author responded that in such semi-arid climates large storage tanks were required increasing the cost of rainwater catchment systems. Nevertheless, in such areas water was often scarce and if good ground or surface water sources were not available rainwater tended to be the best option especially for small and scattered settlements as was the case in many parts of rural Botswana.

Amin Ahmed commented that where rainfall patterns were not uniform throughout the year, big storage facilities were required to meet the demand of the period when there was no rainfall. The construction of such storage facilities was very expensive and not affordable. In Bangladesh where there is little rainfall from December to March large storage is required. There being no other alternative source of water, people use surface ponds as reservoirs for rainwater collection and use these ponds throughout the year. Most of the ponds are grossly polluted and at the moment pond sand filters are being used for treatment of this water. A handpump is used to draw water from the pond, which then passes through a filter constructed on the bank of the pond. The villagers pump water and take filtered water from the tank at the bottom of the filter bed (190 x 97 inches). What alternative and cheap technologies could the author recommend for Bangladesh?

The author responded that perhaps the $6m^3$ ferrocement tanks being built in the Philippines subsidized by donor communities might be a good solution in these circumstances.

A SYSTEMATIC ANALYSIS OF THE POTENTIAL USE OF RAINWATER HARVESTING IN KENYA

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ABSTRACT

Given the limited availability and maldistribution of water resources in Kenya, a comprehensive approach to national water use planning is required. Rainwater constitutes an important part of water resources but its potential as a water supply option for Kenya still needs to be realized and evaluated.

This paper contains a systematic, integrated and comprehensive analysis of the potential use of rainwater harvesting in Kenya. A multi-level matrix method is used for this analysis which encompasses a spatial, temporal and technological framework of considerations.

The paper concludes with a discussion and recommendations relating to propagation of rainwater harvesting in Kenya.

COUNTRY BACKGROUND

Kenya has a total area of 592,000km^2 of which about 11,230km^2 are occupied by water surfaces which include a number of small lakes, most of Lake Turkana and some 3,831km^2 of Lake Victoria (see Figure 1). The country has tremendous topographical diversity ranging from unhabitable volcanic desert to forests, fertile valleys and rich farmland. Arid and semi-arid areas occupy 490,000km^2 of the land area. Only 89,000km^2 of the land area can be used profitably (TAMS, 1980).

Kenya's economy centres on agricultural production, an activity that is critically dependent on land and water resources. Well balanced physical and economic development of Kenya calls for comprehensive, integrated and efficient water resources planning. Given the limited availability and maldistribution of Kenya's water resources, this is no easy task (JICA, 1992).

Administratively, the country is divided into eight provinces which are further subdivided into 44 districts. The drainage in Kenya is primarily determined by the Rift Valley which roughly bisects the country from north to south. West of the Rift Valley, rivers drain into Lake Victoria while to the east the rivers follow a south-easterly course into the Indian Ocean. Within the Rift Valley drainage is into a chain of lakes which have no surface outlet. Based on these drainage characteristics, Kenya is divided into five major drainage areas as shown in Figure 1 and detailed in Table 1, (TAMS, 1980; JICA, 1992).

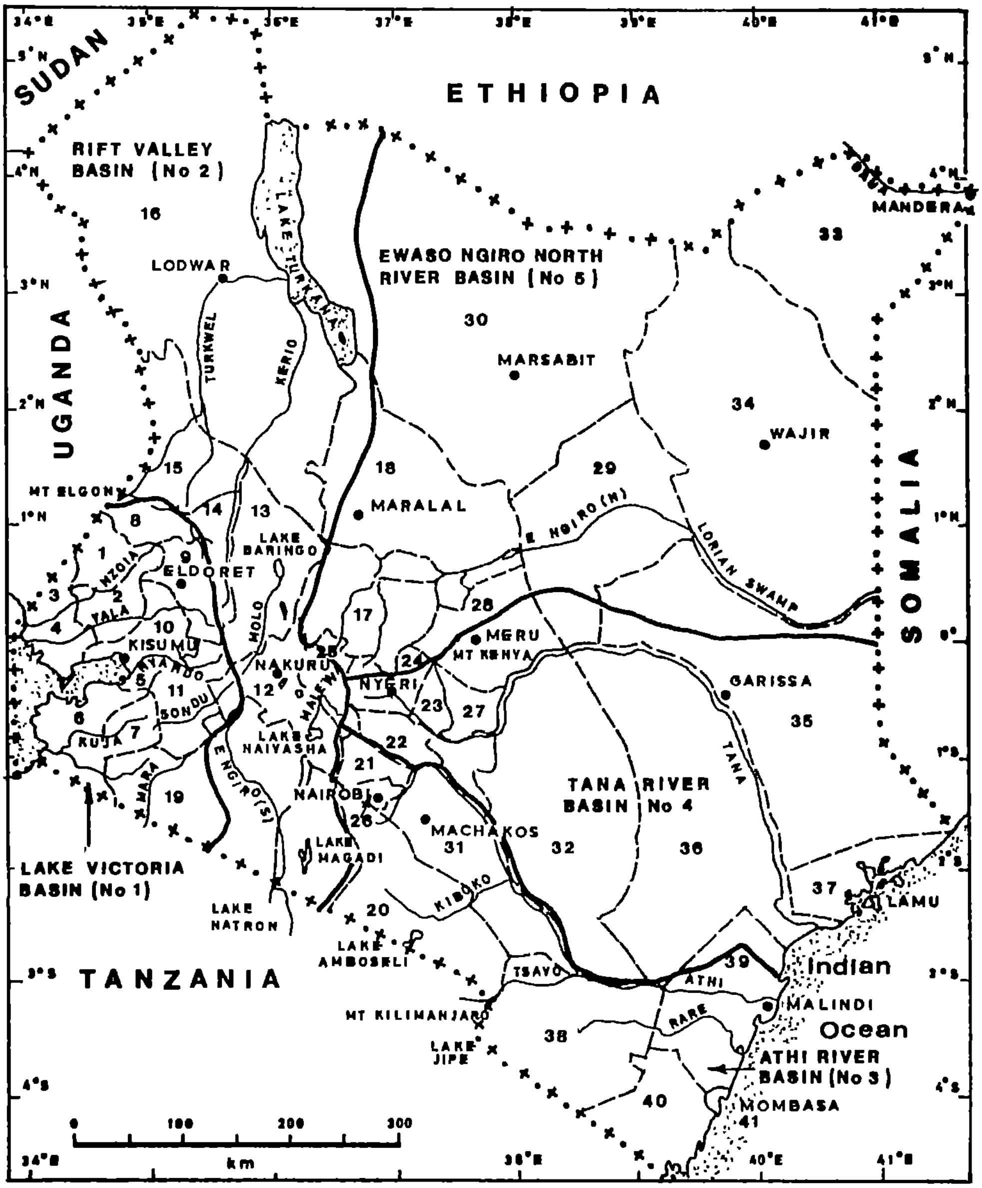

Figure 1. Administrative map of Kenya (source: The Study on the National Water Master Plan. Jan, 1992, JICA).

Legend of Fig. 1

No.	District	No.	District	No.	District	No.	District
1.	Bungoma	11.	Kericho	21.	Kiambu	31.	Machakos
2.	Kakamega	12.	Nakuru	22.	Murang'a	32.	Kitui
3.	Busia	13.	Baringo	23.	Kirinyaga	33.	Mandera
4.	Siaya	14.	Elgeyo Marakwet	24.	Nyeri	34.	Wajir
5.	Kisumu	15.	West Pokot	25.	Nyandarua	35.	Garissa
6.	South Nyanza	16.	Turkana	26.	Nairobi	36.	Tana River
7.	Kisii	17.	Laikipia	27.	Embu	37.	Lamu
8.	Trans Nzoia	18.	Samburu	28.	Meru	38.	Taita Taveta
9.	Uasin Gishu	19.	Narok	29.	Isiolo	39.	Kilifi
10.	Nandi	20.	Kajiado	30.	Marsabit	40.	Kwale
						41.	Mombasa

Table 1. Details of drainage areas

Drainage area	*Annual rainfall (mm)*	*Aquifer capacity (m^3/hr/m)*	*Ground-water abstraction (m^3/yr x 1,000,000)*
1. Lake Victoria Basin	1368	0.19	9.93
2. Rift Valley	562	0 29	11.67
3. Athi River and Coast	739	0.20	27.76
4. Tana River Basin	697	0.17	4.79
5. Ewaso Ngiro and North	411	0.13	3.65

Source: The Draft Study on the National Water Master Plan, January 1992

Potential water resources as identified in the study on the National Water Master Plan (JICA, 1992) and demand in the year 2010 are shown in Table 2. Significantly, rainwater harvesting is not regarded as a direct source of water within this framework.

This paper contains a review of the draft of the latest water source development plan for Kenya. Incorporating spatial, temporal and technological considerations, the analysis uses a multi-level matrix method and established drainage-area boundaries as its basis. This analytical approach has been developed by the author during previous research (Bambrah, 1989). The objective is to establish the potential for use of rainwater harvesting in Kenya.

THE SYSTEMATIC APPROACH

Method

The analytical framework for the present analysis of potential use of rainwater harvesting (RWH) in Kenya involves the systems approach which incorporates:

- Stating the goal of the analysis, establishing an appropriate measure of effectiveness and developing an objective function;

- Determining limits and constraint conditions for the analysis;
- Determining a solution to achieve the stated goalwhilesatisfying all relevant limits and constraint conditions.

Table 2. Summary of water resources and demand in 2010

Resources (m^3/d x 1000)		*Demand (m^3/d x 1000)*	
1 Perennial surface water	19,540	1. Domestic and industrial	3562
2. Ground water		2. Livestock	621
Boreholes	193	3. Irrigation	4524
Shallow wells	426	4. Wildlife and fisheries	46
TOTAL	20,209		8483

Source The Study on the National Water Master Plan, January 1992 (JICA, 1992).

Table 3. System definition

Goal	*Objective function*	*Effectiveness measure*
Establish potential for use of rainwater harvesting in Kenya	Spatial: where can RWH be used?	Rainfall Land use
	Temporal: when can RWH be used?	Rainfall and climate Runoff
	Technological: How is RWH done?	Catchment methods Storage devices Transportation methods Quality Costs

Table 4. Limits and constraints

Objective function	*Effectiveness measure*	*Limit/Constraint*
Spatial	Rainfall	Distribution
	Land use	Ecology, human activity, land adjudication, topography
	Water sources	Abundance or scarcity
	Administration	Drainage basin/local authority boundaries
Temporal	Rainfall	Amount and patterns
	Runoff	Amount and rates
	Consumption	Daily requirements and use patterns
Technological	Catchment	Purpose, types
	Storage	Types
	Transportation	Source to catchment, catchment to storage, methods and techniques
	Quality	Assessment, control and management
	Cost	Sustainability, affordability, management

The analytical framework

Using the multi-level matrix method, the framework for this analysis may be represented by the matrix shown in Table 5.

Table 5. Total system matrix

Objective function and effectiveness (i)	*Drainage area (j)*				
	1	2	3	4	5
	Lake Victoria Basin	Rift Valley Basin	Athi River & Coast	Tana River Basin	Ewaso Ngiro & North
1. Spatial	1.1	1.2	1.3	1.4	1.5
2 Temporal	2.1	2.2	2.3	2.4	2.5
3. Technological	3.1	3.2	3.3	3.4	3.5

Table 6. Data available

Effectiveness measure	*Lake Victoria Basin*	*Rift Valley Basin*	*Athi River Basin*	*Tana River Basin*	*Ewaso Ngiro & North*
1. Spatial					
Rainfall distribution	See Fig 2 (country level information)				
Land use					
(i) urban (ii) rural (iii) livestock (iv) industry	See Table 2 (information available at country level)				
(v) irrigation potential (ha x 10^6)					
Upland crops	2.57	1.77	2 05	3.86	2.99
Lowland crops	0.74	1.68	1.46	3.25	3 64
(vi) Wildlife watering	Information available at country level (see Table 2)				
(vii) Fishery	Information available at country level (see Table 2)				
Water sources					
(i) surface water	See Figure 3 and Table 1 (national, and drainage area)		Note difference in administrative and drainage boundaries (Fig.1)		
(ii) ground water	See Figure 4 and Table 1 (national, and drainage area)				
(iii) administration	See Figure 1 (national, provincial & district levels)				
2. Temporal					
Mean annual rainfall (mm)	1368	562	739	697	621
Runoff	See Figure 6 national level				
Consumption	See Table 2 (country level information only) water supply coverage difficult but over 50% of women still dependent in unprotected water sources (JICA, 1992).				
3. Technological	No systematic database available on the type of rainwater technologies being used in different regions of Kenya. Case studies in individual projects are available (Ndege, 1992).				

Source: JICA, 1992 or TAMS, 1980 unless stated otherwise.

THE ANALYSIS

The analysis should be carried out for each cell of the total system matrix. Data collected and availability of information is central to this analysis. The information available for the analysis is contained in Tables 1, 2 and 6 and Figures 1 to 6. As can be seen from Table 6, most of the information is available at the national (country) level only. Thus it is not possible to carry out a detailed analysis for each of the five drainage areas. This analysis shows that:

1. The information available was highly inadequate for a detailed analysis.
2. It is not possible to assess what proportion of the Kenyan population has access to safe water supplies. The study on the National Water Master Plan (JICA, 1992) mentions that more than half of the women in Kenya still depend on unprotected water sources. Existing water supplies are highly inadequate.
3. Most of Kenya falls under the arid and semi-arid climate zones based on the Thornthwaite system (JICA, 1992) and experiences less than 600mm of mean annual rainfall. This rainfall is spread out over two distinct rainy periods.
4. Water resources (surface and ground water combined) in Kenya far exceed the likely water demands expected up to the year 2010 (see Table 2).
5. In spite of this, a water balance analysis between projected demands and available water resources in the country shows that 63 out of 164 sub-drainage areas will suffer from a water deficit in the year 2010 (JICA, 1992) (see Fig. 5).
6. The total cost of implementation of water resources development to meet potential demands up to the year 2010 is estimated at US$ 15.65 billion according to the draft report on The Study on the National Water Master Plan (JICA, 1992). This plan, however, is concerned with large-scale exploitation of surface waters, ground-water abstractions and piped water supplies; little attention is given to rainwater catchment systems.

The development strategy for Kenya is contained in sessional paper No. 1 of 1986 on Economic Management for Renewed Growth (GOK, 1986) and is summarized below.

- According to the present development strategy for Kenya, renewed economic growth is crucial to the major national goals of creating greater employment, providing basic needs, food security and improved rural-urban balance.
- Since 1970, about 25% of the gross national product of Kenya has been invested on average. However gross national saving has fallen and is now a matter of concern.
- Kenya is striving to increase its national saving in order to reduce foreign indebtedness and its dependence on foreign aid and investment by further reducing resources available for development and provision of basic services.
- The implication of this background for water resources development is that clean water, being a basic need whose provisions will depend on a rapidly growing economy to provide the necessary resources, will necessarily suffer under the present trend of slow growth.

It is therefore unlikely that the resources required to implement the proposed water resources development (JICA, 1992) will be available under the present conditions of limited resources and slow economic growth. Of necessity therefore, rainwater collected and stored for domestic and agricultural uses, is increasingly being recognized as an affordable, environmentally sound, and simple alternative to large-scale water resources exploitation.

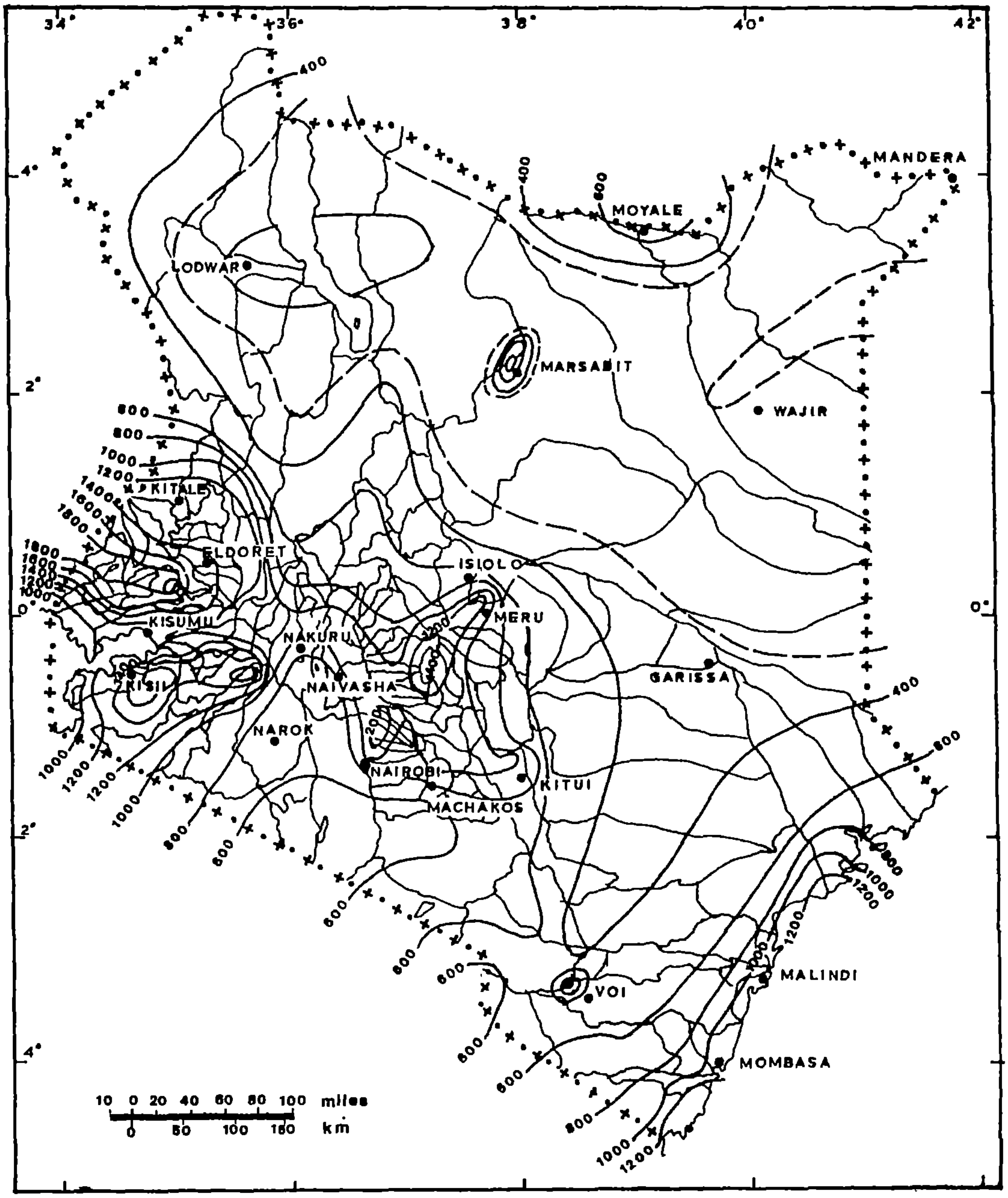

Figure 2 Isohyetal map of annual rainfall (mm) (source: The Study on the National Water Master Plan, Jan. 1992, JICA).

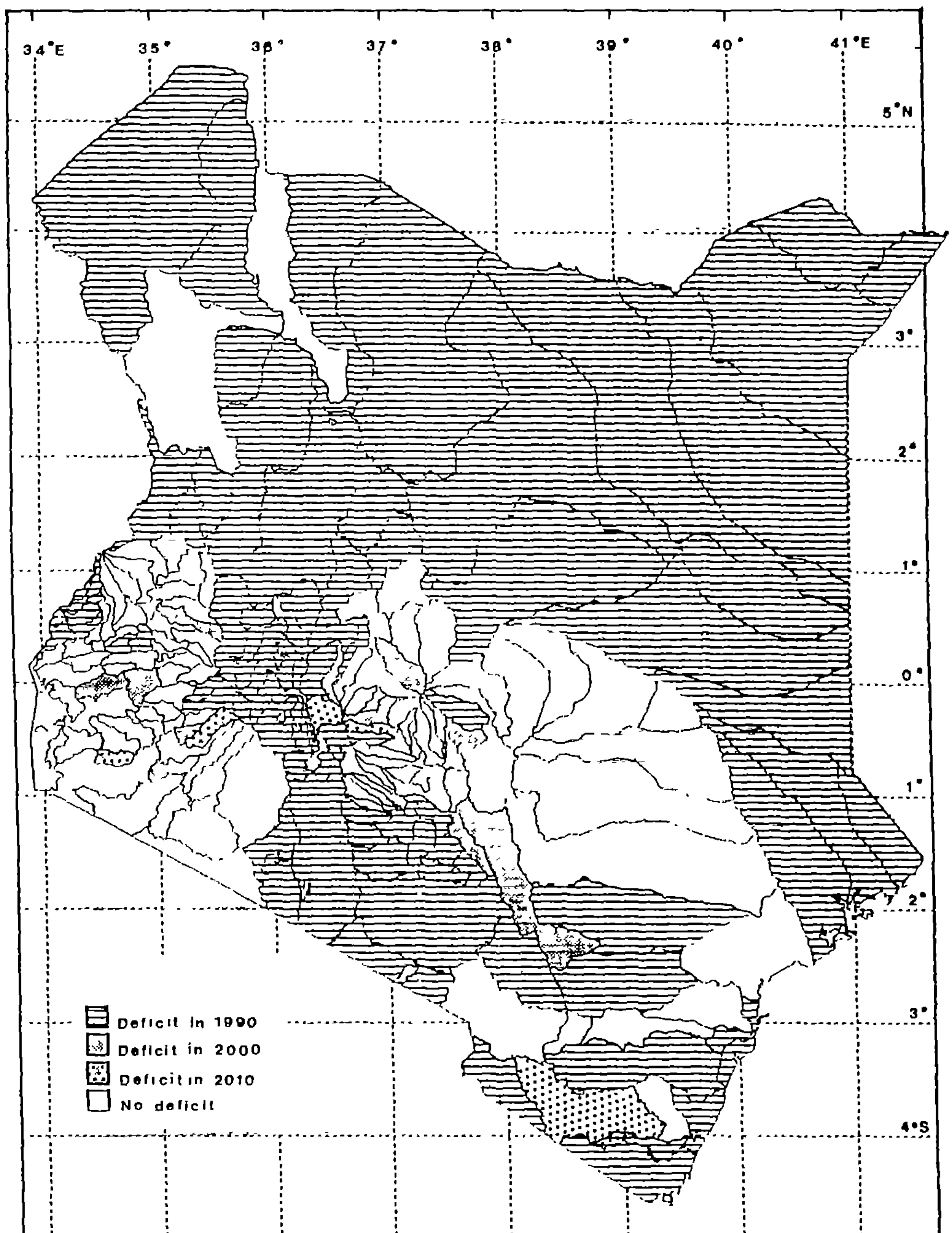

Figure 3. Balance between demand and available surface water (source: The study on the National water Master Plan. Jan 1992, JICA).

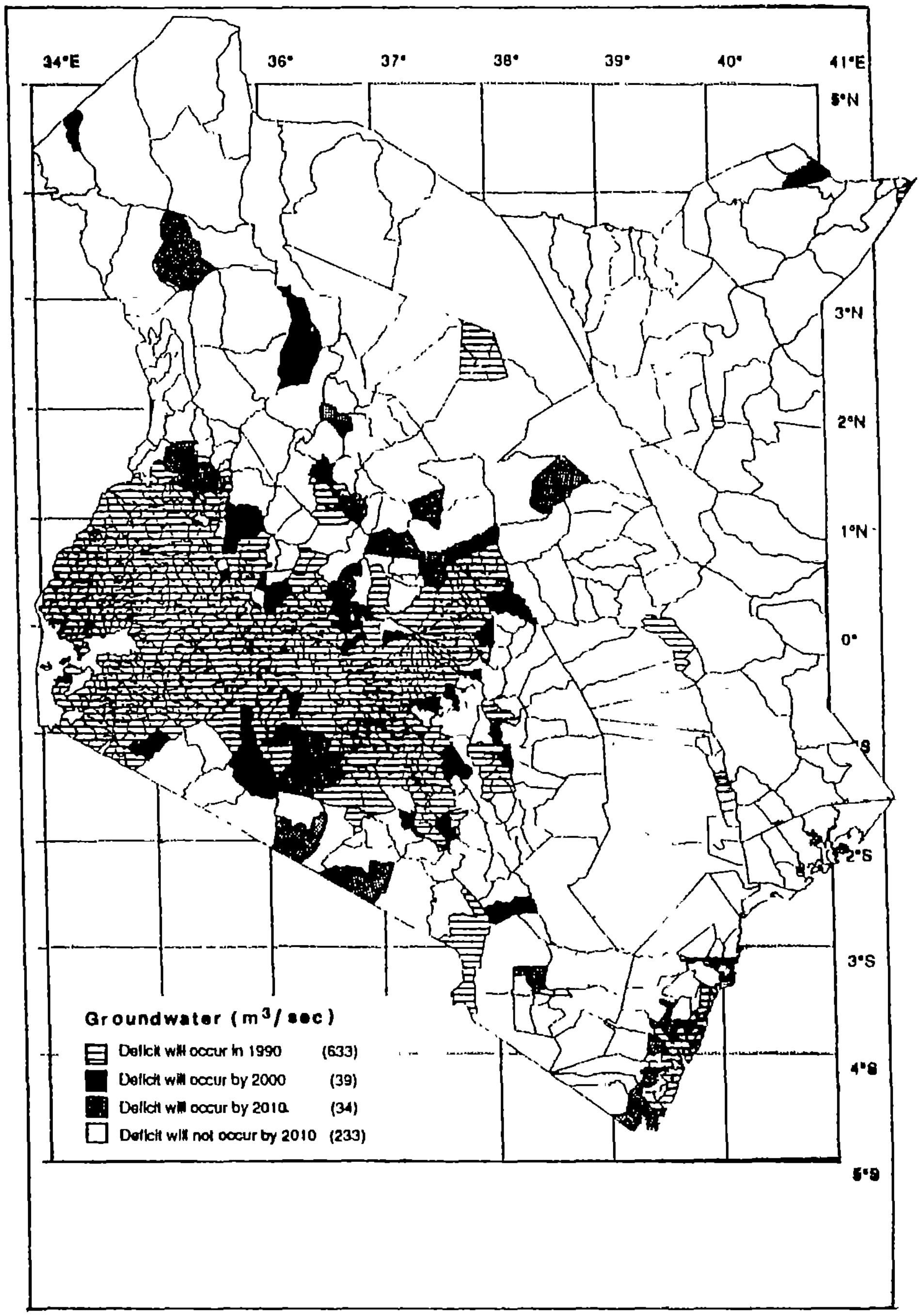

Figure 4 Balance between demand and available ground water (source: The study on the National Water Master Plan. Jan 1992, JICA).

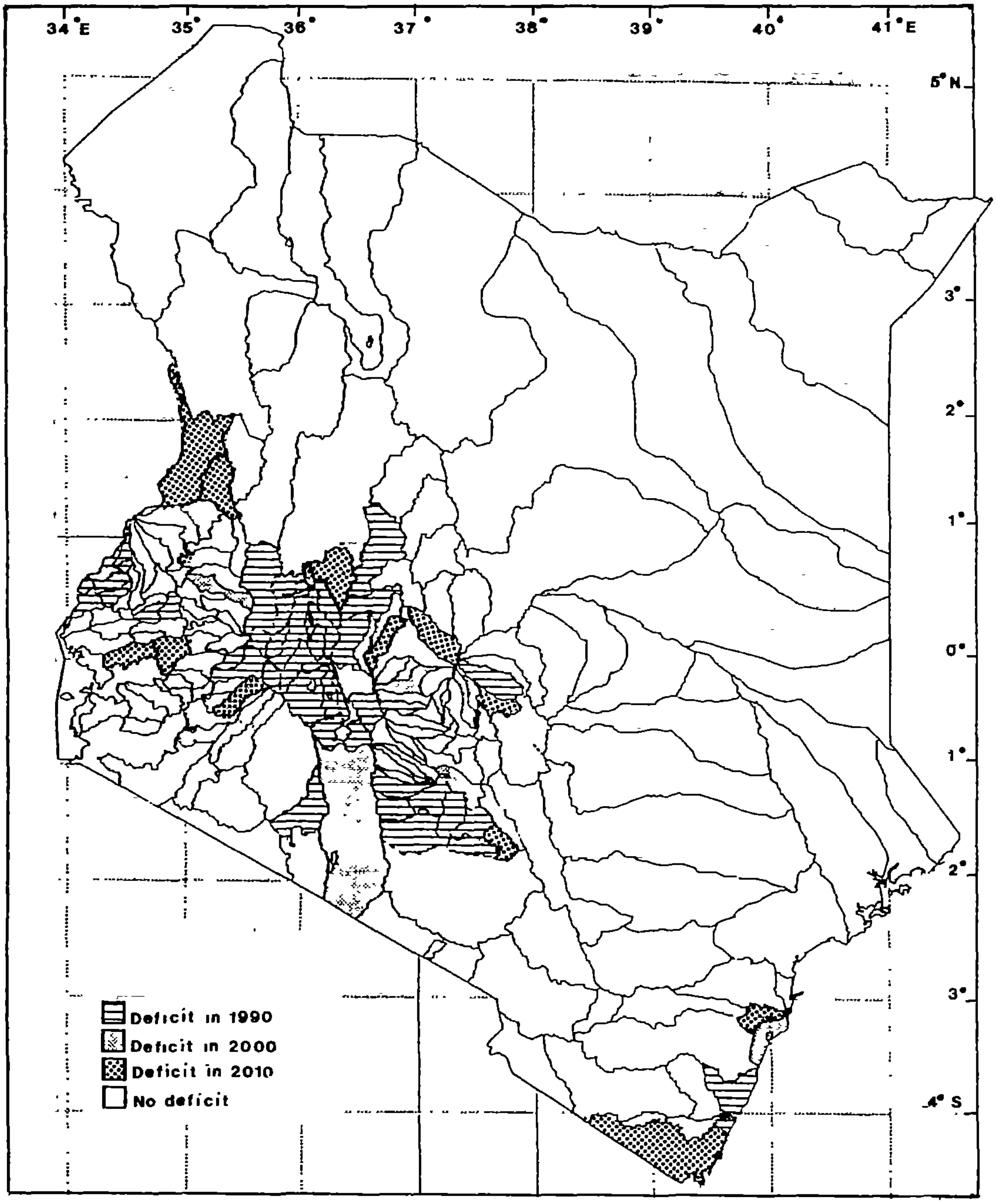

Figure 5. Balance between demand and available water: surface water + ground water (source: The study on the National Water Master Plan. Jan 1992, JICA).

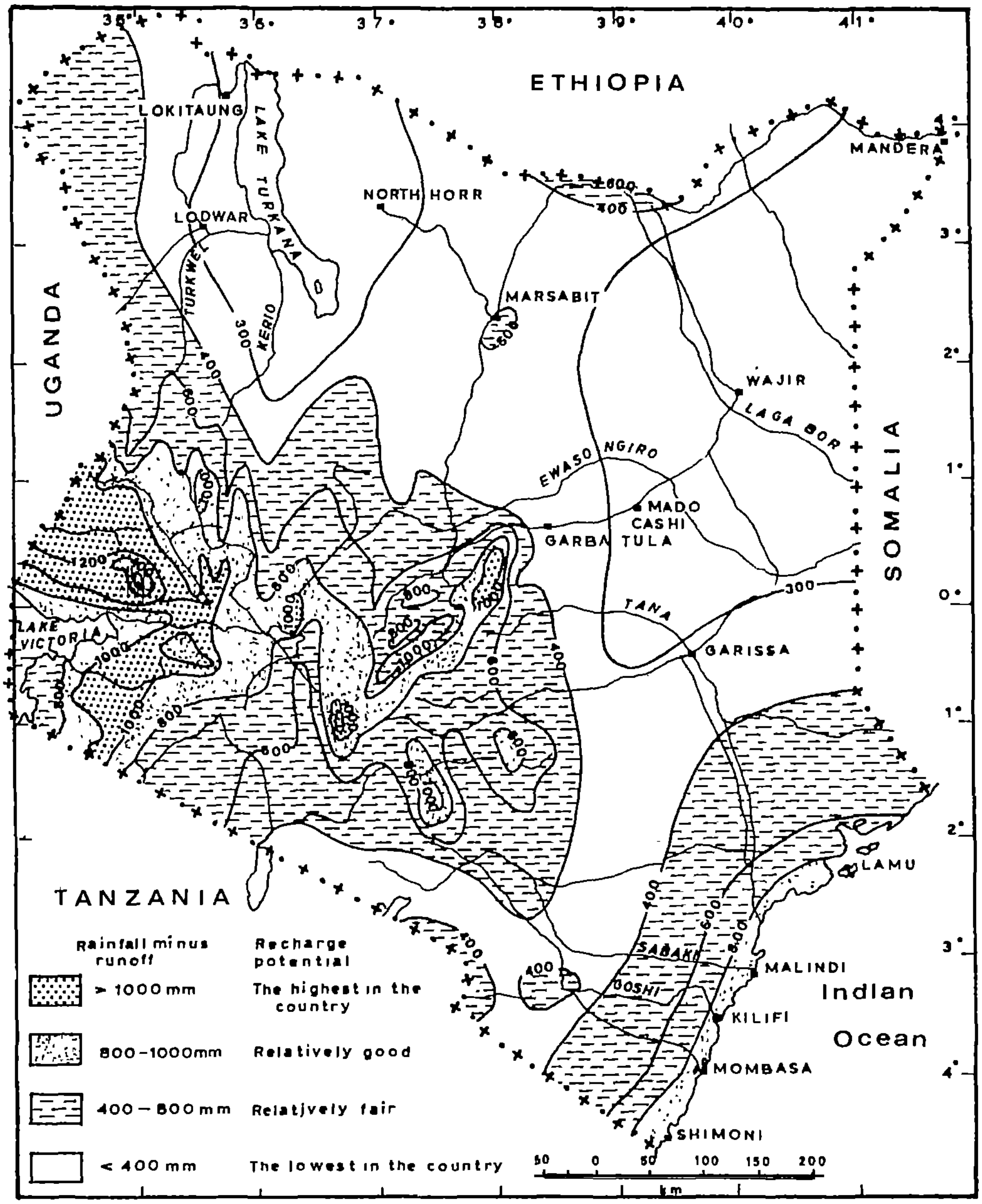

Figure 6. The difference between average annual rainfall and runoff (source. National Water Master Plan, Stage 1. 1980, TAMS).

CONCLUSIONS AND RECOMMENDATIONS

Rainwater harvesting systems, being simple, low-cost options for water supply, are highly appropriate to the current Kenyan situation of limited resources. Although in much of Kenya low rainfall levels means that this option cannot be used as the only source of water supply, it can be concluded that:

- Because of the adverse current economic climate in Kenya, in the short term rainwater harvesting must be promoted in much of this country to supplement the adequate and poor existing water supplies, particularly for agricultural and livestock needs.
- In the long term, rainwater harvesting will need to be promoted in the interests of water conservation in the water-deficient areas.
- Under these circumstances, rainwater harvesting is a necessity and not an option for efficient management of water resources and requirements in Kenya.

REFERENCES

TAMS (1980). *National Mater Water Plan*, (stage 1), Vol. II, Part 1, National Resources and Potential Projects. Tippets-Abbett-McCarthy-Stratton.

JICA (1992). *The Study on the National Water Master Plan* (main report), Vol. 1: Water Resources Development and Use Plan Towards 2010 (draft). Japan International Cooperation Agency.

Bambrah, G.K. (1989). A Systematic Approach to Appraisal/evaluation of Civil Engineering Projects, with Special Emphasis on Technology. PhD Thesis, Loughborough University of Technology.

Ndege, M.M. (1992). Rainwater Harvesting in Kenya: The State of the Art. *Proc 2nd Nat. Conf. on Rainwater Catchment Systems*. Nairobi.

Government of Kenya (1986). *Economic Management for Renewed Growth*. Sessional Paper No. 1.

AN OVERVIEW OF RAINWATER CATCHMENT SYSTEMS IN NAMIBIA

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ABSTRACT

The mean annual rainfall of Namibia varies between 600mm in the north and 150mm in the south; it is, therefore, one of the driest countries in the sub-continent. Rainwater catchment systems have, over the years, been introduced to facilitate the provision of potable water, particularly to schools and clinics which are situated in rural areas with saline ground-water resources. This paper reviews past and present experiences with rainwater catchment systems in Namibia. Consideration is given to the future potential of the rainwater harvesting programme and the possible expansion of this to all regions of the country.

INTRODUCTION

Namibian rainfall is erratic and is mainly concentrated in a rainy season lasting from October to April. The south has particularly hot summers, low rainfall and high evaporation during the rainy season. The wettest central and northern areas have less marked monthly variation in evaporation compared to the rest of the country.

Perennial rivers such as the Cunene and Kavango, the Zambezi and the Orange are situated at the borders of Namibia with Angola, Zambia and South Africa respectively. The daily water requirements for major towns is supplied from a network of dammed units. Good dam sites are available particularly within the Cuvelai flood and drainage system. However, the excavation of earth dams in this and other areas has been limited, due to a lack of forward planning by the various administrations and a lack of sufficient development funds.

A proportion of the inhabitants of rural areas obtain their water from the piped networks of the Department of Water Affairs. The capacity of these networks is often inadequate to provide for additional connections to increase water distribution coverage. Additional extensions of the networks would also proportionately increase the operational and other costs, especially since water is provided free of charge to the inhabitants of the rural areas. There is no system of cost recovery in operation in Namibia when it comes to the provision of water to rural communities.

Good quality ground-water resources are available in some regions of the country. However, the depth at which water is struck makes drilling a very expensive operation. The cost of drilling and equipping a borehole is approximately R100,000 (US $30,000) at 1993 prices. Some 4000 boreholes have been sunk countrywide to date. The government provides diesel and other services to the tune of some R5m (US $1.6m) per annum to keep the boreholes in operational condition. These costs are likely to increase as the demand for more water increases. It seems desirable in the present economic climate, therefore, that an alternative water source be found to complement current water supply efforts, especially in areas with saline ground-water reserves. Rainwater harvesting techniques are one of the viable options open to the developers of the rural water supply sector.

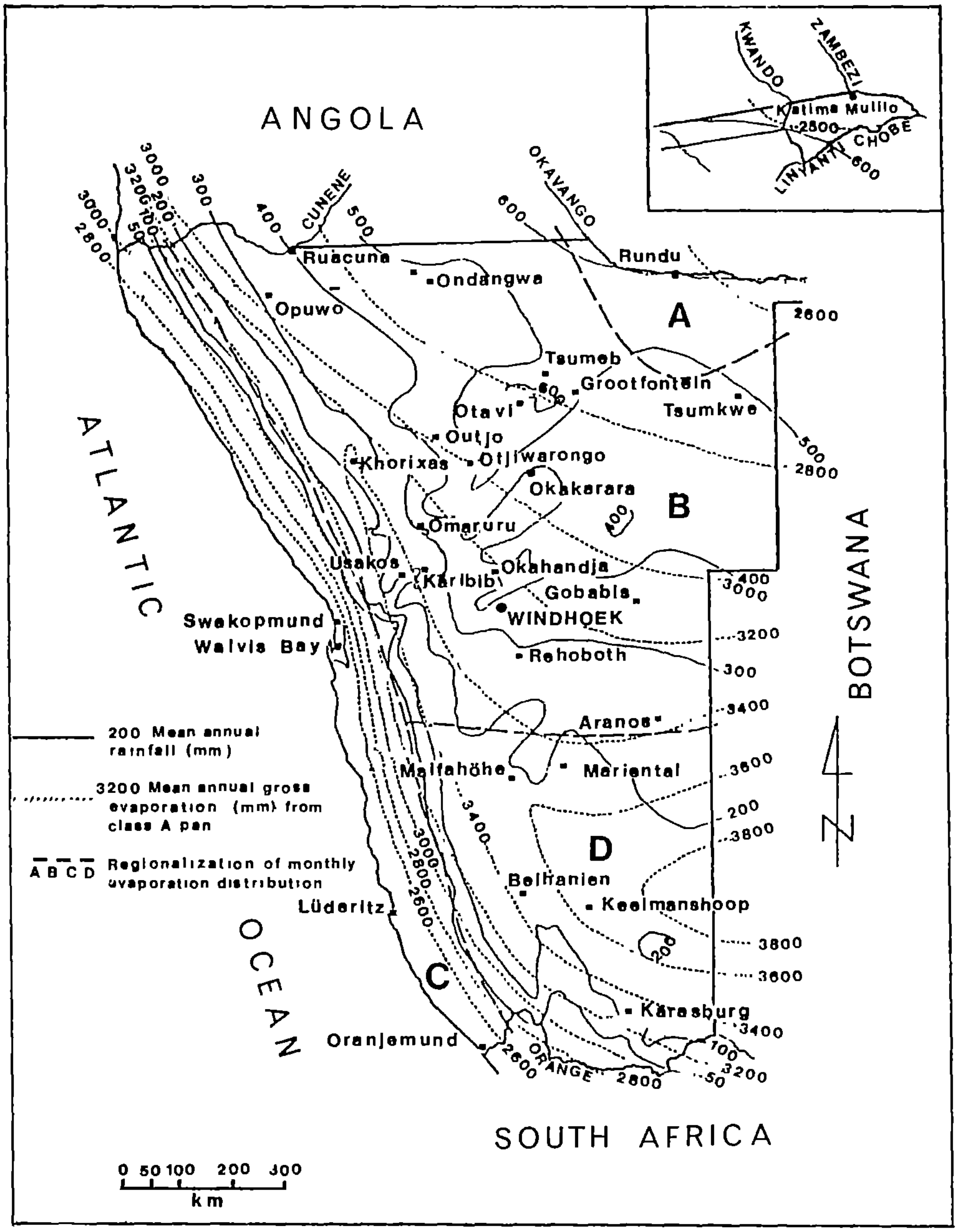

Figure 1. Annual rainfall and evaporation

The technical committee for the Namibia Household Rainwater Catchment Programme was formed shortly after independence in 1990. The task of this committee was to assess technical options which would be suitable for improving a household's access to clean drinking water through the promotion of affordable rainwater catchment systems.

HISTORY OF RAINWATER CATCHMENT SYSTEMS IN NAMIBIA

Traditionally, communities have collected rainwater running off ground surfaces and threshing floors into specially excavated pits for many centuries. This is still practised to-day in many areas. Since these are open systems, large amounts of water are lost through evaporation and bacteriological contamination is very high.

Small to medium sized earth dam systems started to form part of the rural water supply scheme in the 1930s. Around 400 earth dams with capacities ranging from $7000m^3$ to $200,000m^3$ were constructed throughout the former homelands. These systems are mainly designed for stock watering, although water for household use is also obtained from these units. Earth dams are normally not fenced off and the quality of water, therefore, is bad as a result of animal droppings and urine.

Roof rainwater catchment systems were introduced in Namibia around the 1880s. However, little has been done to improve such systems or to develop and test new ones. Asbestos cement tanks with capacities of $5m^3$ were included in the design of some school buildings in the 1970s.

Some of the asbestos cement tanks are not in working condition as a result of vandalism and destruction during the war. Table 1 shows some statistics of tanks installed at schools in the northern regions.

Table 1. Details of tank installations in schools in the north

No. of tanks	*Construction firm*	*Condition*	*Capacity (litres)*
2	Government	Working	800
40	Bavaria	Vandalized, damaged, not working	2000
4	Unknown	3 working, 1 with hole	10,000
15	Unknown	Not working, holes at the bottom	600
5	Hochland Construction	Partially destroyed during the war	650
15	Water supply and sanitation project UNICEF	Working	5,000
25	ELCIN	Working	10,000

CURRENT STATE OF ART

Roof rainwater catchment systems with above ground tanks

The Namibia Household Rainwater Catchment Programme, under the auspices of UNICEF, is responsible for the construction of ferrocement rainwater tanks in schools. Around forty, 5m^3 water tanks were constructed at schools in the northern areas in 1992 and 1993 alone. To ensure that the new tanks are properly maintained, the school authorities are required to participate in the construction process. This storage method ensures that the quality of collected water remains reasonable. The risk of contamination is reduced through limited accessibility to the storage tank.

Plastic sheet ground catchment system

This system was designed at the Integrated Area-based Project (IABP) in Uukwaluudhi to collect rainwater from the ground surface overlaid by a 5m x 5m plastic sheet. The collected water is stored in an approximately 6m^3 underground tank. This pilot demonstration unit came into operation in February 1992.

The plastic lining has so far served its purpose well. However, its resistance to sunlight and other conditions and its durability is still to be fully assessed. Very fine soil particles blown onto the plastic catchment area are washed into the underground storage tank when it rains. The sedimentation of this material at the bottom of the storage tank affects the physical quality of the water. Bacteriological analysis of the stored water is still to be done.

The construction of earth dams

The earth dam construction programme is continuing albeit on a reduced scale. Sixteen new units were constructed in 1992/3 and twenty existing dams were de-silted or rehabilitated. The activities for 1993/94 are expected to concentrate mainly on the rehabilitation of existing earth dam structures.

POTENTIAL FUTURE DEVELOPMENT

The rainwater catchment programme has just been instituted in Namibia. Although the ferrocement tanks currently under construction have the capacities of only 5m^3, it is expected that they will be increased to make the programme cost effective.

In addition, Namibia has a potential for rock catchment systems, which needs to be explored. The SADCC training course on rainwater harvesting to be held in Namibia in 1994 is likely to give impetus to developments in harvesting water for agricultural and domestic use.

DISCUSSION AND CONCLUSIONS

The roof rainwater catchment systems are viable options for expansion at schools, clinics and at household level. The systems are being promoted in areas with bad quality or deep ground water, especially where roof catchment areas are adequate.

Namibia generally receives high intensity storms of short duration. For the rainwater catchment systems to make an impact, therefore, the capacity of storage tanks needs to be increased to 10m^3.

Activities pertaining to the construction of earth dams is to continue, with more emphasis placed on community involvement to ensure long-term sustainability.

REFERENCES

Critchley, W. and **Siegert, K.** (1991). *Water Harvesting.* FAO.
Government of Namibia (1988). *Evaporation Maps for South West Africa/Namibia.* Report No. 11/1/8/1/H1. Department of Water Affairs, Namibia.
Government of Namibia (1990). *Master Water Plan for the Owambo Region.* Department of Water Affairs, Namibia.
(1991) *Assessment of Technical Options for Namibia Household Rainwater Catchment Programme.*

RAINWATER USE AND RECENT DEVELOPMENT IN CHINA

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ABSTRACT

China is one of the areas of the world most deficient in water resources. But China lags behind in the direct use of rainfall at present; mainly because of management and political factors. With economic and political reform, private ownership and management will encourage the direct use of rainwater.

The characteristics of China's water resources distribution are compared with those in other countries to determine the potential benefits of rainfall use. The region between the eastern plain and western plateau is the most suitable area for the direct use of rainfall.

Techniques of rainfall use in various parts of China are presented, i.e. the *kaerz* in arid areas, the jar in semi-arid areas, the large mouth well in semi-humid areas, and ponds in humid areas.

In suburban districts not served by the city water supply and in rural areas, it is not economical to supply pumped and treated water. Single jars cannot meet a family's water requirement for one year. People have developed the courtyard system for rainwater collection after the design of the traditional farmer's courtyard; this is a good method of rainfall catchment, suitable for many parts of the world.

INTRODUCTION

Rainwater is the most economical and convenient water source for direct use. It was the main water source in China for thousands of years, and the Chinese people, despite the varied nature and the unbalanced economic development in different regions, are very experienced in combating drought. To provide sufficient water for domestic use and for animals, roofs, courtyards, the grounds, roads and tanks are all used for rainfall harvesting.

China is an agricultural nation. Although irrigation provides a reliable water supply for stable and high yields, rainwater is very important in China's agricultural production. Over the years, the Chinese have developed various techniques for using rainfall for agriculture, as well as for household purposes. However, utilization of rainwater for domestic supply has not reached the level necessary to solve the water shortage problems in some areas. The purpose of this paper is to examine the potential areas and benefits of harvesting rainwater in China, and to analyse the current problems and the reasons for them so as to provide a basis for decision-making for future systems development. A summary of rainwater use in different parts of China is given, and a promising rainwater catchment system, the courtyard method, is also presented.

THE PROBLEMS OF DIRECT USE OF RAINWATER IN CHINA

China is situated on the western side of the Pacific Ocean and on the slant of Eurasia which slopes towards the southeast. Due to the monsoon climate and the terrain, rainfall decreases progressively from south to north and from east to west, with prevailing wet summers and dry winters. The average annual rainfall for the entire country is 600-700mm. The average annual runoff is the sixth greatest in the world. The distribution of rainwater resources in China is very uneven - the north and northwest (45% of the whole country) are arid or semi-arid areas suffering from frequent water shortages (annual rainfall is less than 450mm). Because of drought caused by uneven rainfall distribution, and water shortage caused by water pollution, the water problem is becoming more and more serious. There is a definite need to develop rainwater resources in China.

In China, especially in rainfall-rich areas, and except in a few remote regions, rainwater use for household water supply is not widespread and is not on the scale it should be for the following reasons.

Firstly the close relationship between water and people's health: recent research shows that drinking water which does not meet health standards can result in more than 50 different diseases. People who drink pond or canal water have an incidence of liver cancer ten times as high as those who drink well water. Most people think that untreated ground water is unhealthy and unsuitable for drinking. This discourages people from using rainwater unless there is no other water source available.

Secondly, the Chinese Government pays much attention to water safety, believing that solving the drinking water problem is beneficial both for people's health and their economic status. Government often allocates huge sums for water supply and water quality improvement for rural areas. In 1985, 50% of 800 million peasants had their drinking water quality improved to meet health standards. About 150,000 rural waterworks and 15 million water wells were constructed for this purpose. These efforts have had a great social impact, making peasants more dependent on the government and less enthusiastic about using rainwater.

Since the agricultural reform of China, production methods have changed to independent management and individual ownership by the peasants. At present, funds are collected from many channels to construct rainwater catchment systems, which are then run by the local people and subsidized by the state. This method not only mitigates the state's difficulty in investing huge funds, but also the operation, management and maintenance of the water supply system by the peasants is beneficial for sustainability.

THE CHARACTERISTICS OF WATER RESOURCES TIME AND SPACE DISTRIBUTION

Taking the least agricultural rainfall demand as being for dryland wheat at 250mm, China can be divided into five different rainfall regions.

1. West of the 250mm rainfall isopleth is the arid region. Rain-fed agriculture is not possible; without irrigation there is no agriculture.
2. The area between the 250mm and 400mm rainfall isopleths is the semi-arid region. They are prairies and pastoral areas and unstable areas of rain-fed agriculture.
3. East of the 400mm rainfall isopleth is the main agricultural region that includes the middle and lower reaches of the Yellow river and the north China plain; this is the semi-humid area used for dryland crops which need irrigation for a guaranteed yield.

4. Between the 800mm and 1000mm rainfall isopleths is a transition region from semi-humid region to humid region. The uneven annual distribution of rainfall can often cause drought or flood
5. South of the 1000mm rainfall isopleth is the humid region where wetland rice is the main crop.

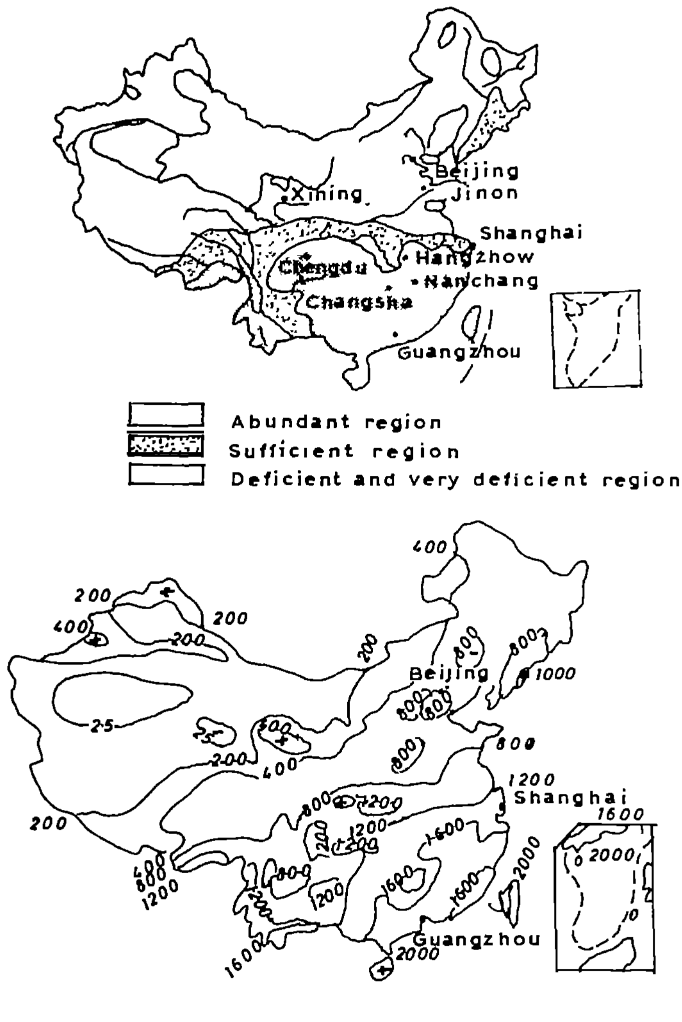

Figure 1. The rainfall distribution of China.

The rainfall should be both reliable in amount and distributed evenly throughout the four seasons to meet crops' growth demand. China has a monsoon climate and is humid and hot; this is advantageous for agricultural production. However, rainfall is distributed unevenly during the four seasons as shown in Table 1.

Table 1. The seasonal proportions of total rainfall in northern and southern China

Region	*Winter (12-2)*	*Spring (3-5)*	*Summer (6-8)*	*Autumn (9-11)*
North China	5-10%	10-15%	60-75%	15-20%
South China	10-15%	40-50%	40-50%	15-20%

Therefore, much of China needs to store rainwater to satisfy the seasonal agricultural water demand and to avoid drought and flood.

In the mountainous region of middle China, annual rainfall is less than 400mm. Almost all of the rainfall is absorbed and evaporates. The vertical exchange is very strong, and there is almost no runoff. As rainfall increases from 400mm to 800mm, ground runoff increases gradually. When rainfall exceeds 800mm, both ground and underground runoff are active and horizontal water movement is predominant. Therefore in the region west of the 400mm rainfall isopleth, it would be necesary to construct special catchment surfaces to collect and utilize rainfall due to the absoption and high evaporation. For regions between the 400mm and 800mm rainfall isopleth, construction of catchment surfaces will increase the rate of runoff, making them suitable for rainwater harvesting. These regions suffer from water shortage, which makes rainwater catchment very economical. Heavy and frequent rainfall with rich ground runoff in the humid regions of China makes them suitable for centralized water supply development.

The region between the 400mm and 800mm rainfall isopleths is mainly loess plateau and north China plain which occupy 40% of the total country area. The loess plateau is drier, with rainfall between 250mm and 600mm, and covers over 15,000km^2. There are 40,000mu of cultivated land. The population is more than 14 million, of which the rural population is 12 million. The *per capita* water supply in this area is only 36% of the country as a whole. The terrain has broken terraces, deep river valleys, low water flow and the land is steep. The inhabitants have difficulty in getting drinking water, so this is a potential area for the development of rainwater catchment systems for household water supply.

SEVERAL METHODS OF RAINWATER USE IN CHINA

It is difficult to count the number of different rainwater systems in China. This paper only gives a brief summary of some of them from the arid to the humid zones.

Arid region - *Kaerz*

Kaerz is a system of irrigation wells connected by underground channels in the arid desert of west China to utilize rainwater. Ice and snow melt from mountains and plentiful rainfall seeps into the rock to form underground streams which drain down to the arid region. The system supplies a large amount of water regularly, and there is little evaporation loss. Water is used for irrigation and household supply. The wells are simple and easy to dig and construct. It is a very practical water conservancy project. There are *kaerzs* in Xinjiang and Gansu Provinces.

For example, there are over 1300 *kaerzs* which irrigate 350,000mu of farmland and supply 80% of the local water consumption in Tulufan Basin, Xinjiang Autonomous Region.

Semi-arid region - water cellar

In the loess plateau of China, which includes Shanxi, Sanxi and Gamsu provinces, the land surface is broken and there is little rainfall. Water both for agricultural production and domestic use is difficult to obtain. There is a lot of clay in some loess. People dig underground water cellars and line them with clay or rammed earth to store rainwater. This has been an important water supply source for local inhabitants since ancient times. In recent decades, because of the government's water improvement and supply work, the water shortage has been ameliorated, but the method is still used in many remote areas.

Semi-humid region - shallow well

This is a common method of using rainwater and underground water in the semi-humid regions of east China such as Shandong Province. In some areas the soil is quite sandy and rainwater drains underground very fast; the water table is high. The riverbeds are wide and dry on the surface, but the potential from runoff seeping underground is very rich. Shallow wells - either round or square- are dug to tap and store the rainwater and groundwater for agricultural irrigation and water supply of small villages. The wells are easy to dig and can provide large amounts of water. It is quite acceptable to use both rainwater and underground water in this region. There are a hundred thousand shallow wells in just one county - Wendeng, Shandong Province.

Humid region - ponds

A pond is a common natural or man-made depression to store rainwater in the humid region of China. They can be seasonal or perennial, of various sizes and are countless in number. These ponds collect rainwater and are mainly used for aquatic breeding (mulberry fish being the most common) and animal feeding, but seldom for drinking water.

DEVELOPMENT OF RAINWATER HARVESTING FOR HOUSEHOLD WATER SUPPLY - THE COURTYARD METHOD

Most courtyards are found in the rural areas. There are about 180 million peasant households in China. If suburban courtyards, are included, over 80% of Chinese people live around courtyards. If each courtyard covers 0.3mu of land, there are at least 60 million mu of courtyards in China, this amounts to 4% of the total cultivated land, and 64% of the total cultivated land in Japan. If this large area were to be developed for rainwater collection, the prospects would be very bright.

The peasant's courtyard as a whole is composed of the dwelling house, storehouse, yard, livestock shed and water facility. The courtyards are of two types: northern and southern. Northern courtyards are often grouped into a village, yet each courtyard is independent of the others. Southern courtyards are scattered on the hillslopes or plains; they look similar to the northern ones but with fewer enclosures (Fig. 2). In west China, because of broken ground, courtyards are also dispersed.

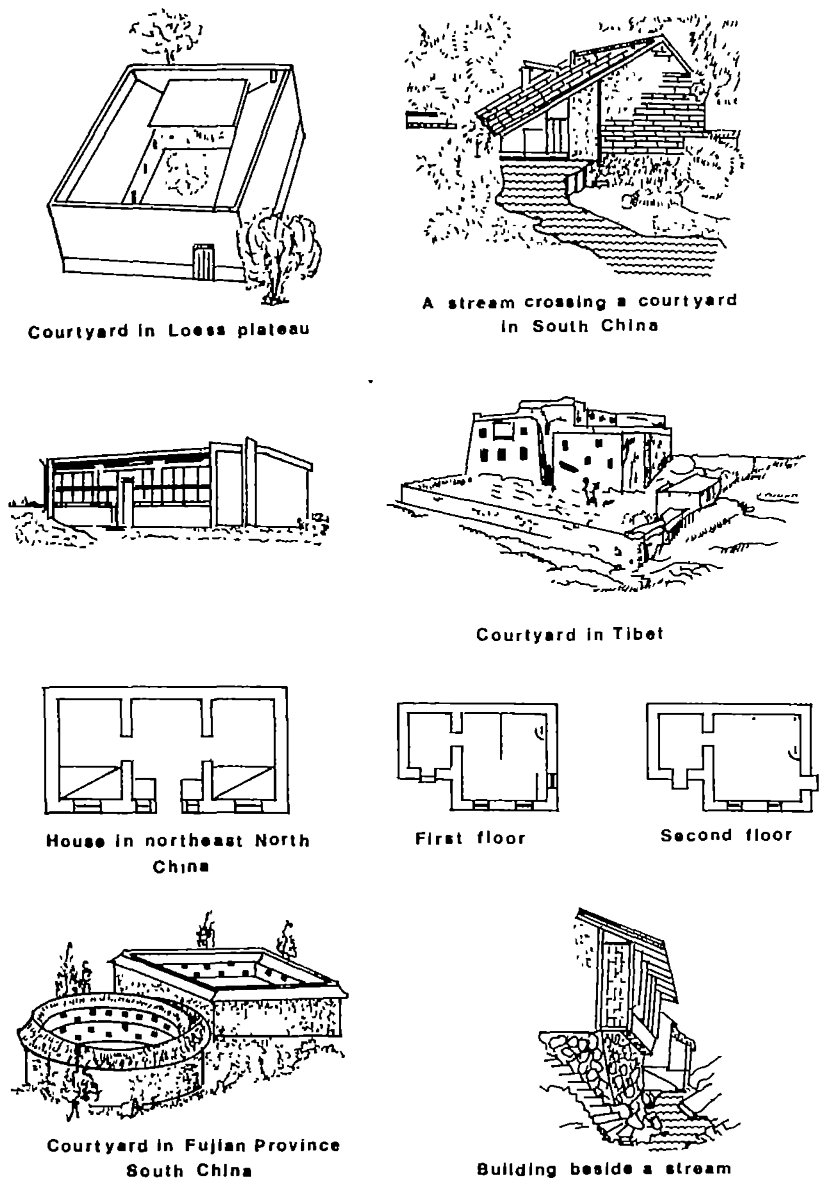

Figure 2. Different courtyards of China.

Rainfall amounts influence the structure of the courtyard in each region. There is an obvious relationship between roof structure and rainfall. From south to north, a clear change in roof structure can be seen (Fig. 3).

In the northeast where there is a lot of snow in winter, the roof has the shape of an inverted vee. In the north where rainfall is little, the roof is flat. In the south where there is a lot of rainfall the roof is also pitched. The characteristics of rainfall or snow are taken into consideration in the design of the roof. In the dry region of northwest China, water discharge and rainwater catchment are considered in the design of rural courtyards to provide drinking water for people, and domestic fowl.

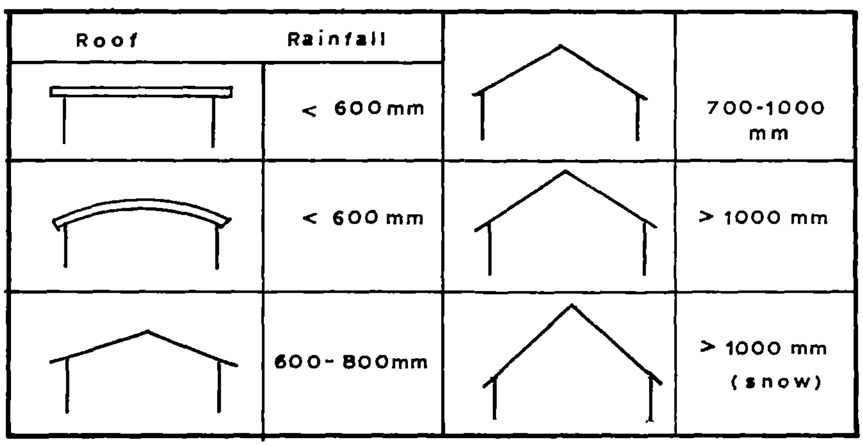

Figure 3. Relationship between rainfall and roof shape.

The courtyard system is composed of:

1. Main house, side house, simple shed, enclosure, gate, open space;
2. Concrete water cellar (25-30m^3);
3. Concrete yard (depth 5cm) 65m^2, slope 1:50;
4. Roof with 2-3 cm cement tile surface (area: 53m^2, projecting area: 20m^2).

The courtyard rainwater catchment system occupies 115m^2; materials cost is US$15/person. It can provide sufficient water for five people and domestic fowls around the year. This system only occupies 50% of the total yard area and the area left can be used as a barn, a vegetable plot or an orchard.

Table 2. Cost of courtyard rainwater catchment systems in different rainfall regions.

Annual rainfall	*Runoff per m^2*	*Runoff per $40m^2$*	*Concrete yard (m^2)*	*Cost (RMB)*	*Cost (RMB/m^3)*
400	0.24	9 6	35	240	13 3
300	0.18	7 2	80	322	17 9
200	0.12	4 8	110	487	27.0

The operation of this system is simple and low cost. Therefore it is suitable for a family to build. It is also convenient for users to fetch water. The concrete yard is easy to keep clean. Because the system is built and run by each family and managed well, it will be useful for a long time.

The courtyard rainwater catchment system is applicable to many regions, but is limited by rainfall availability. With little rainfall, the cost of construction increasing less gradually; it is not suitable in areas where rainfall is less than 150mm.

REFERENCES

Changming Liu *et al* (1992). Rainwater Catchment System in a Rural Area of North China *Regional Conf of IRCSA.* Tokyo Japan. 1992.

Jiansheng Huang (1987). Practice of Rural Drinking Water Management. *Proc. Int Symp on Environmental Management of Water in China.* National Environmental Protection Agency of China, Shanghai.

NEPAC (1992). *Eco-agriculture of China.* National Environmental Protection Agency of China, Shanghai.

Tongjie Lian (1987). *Guildines for Assessment of Natural Resources.* Chinese Peoples University, Beijing.

Water Conservancy Agency, Gansu Province, (1990). Experiments in Rainwater Use. *Jl of Water Conservancy and Electric Technique of Gansu Province.*

Xiquan Yang *et al.* (1992). Courtyard Rainwater Catchment in Arid Areas. Lanzhou University.

Zhengming Yun *et al.* (1989). *Outline of China's Courtyard Ecosystem.* House of Sciences, Hebel Province.

RAINWATER FOR DOMESTIC USE IN CHINA

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ABSTRACT

In China, rainwater cistern systems have been used mainly for domestic water supply in rural areas where ground-water is unfit to drink or costly to develop. For example, in the loess plateau of northwest China, the annual rainfall is quite low - 316mm - 64% of which is concentrated from July to September every year. The ground-water is either too bitter to drink or too deep to exploit, while there is little surface water the distances are too great to fetch it. Consequently, more than 0.2 million pits were built during the 1980s to solve the drinking water supply problem of more than 0.6 milion residents at a capital cost of US$ 7 per person. Similarly, in the southeast coastal area and on remote islands, abundant rainwater is traditionally considered the only source of drinking water due to the high chloride concentrations in the ground-water. About 20 000 water tanks were constructed to serve 0.2 million people during 1980s, at a capital cost of US$ 10 per person.

It has been established that with proper design, construction, operation and maintenance, rainwater harvesting systems can provide palatable and cheap water for drinking.

INTRODUCTION

China is a vast territory extending from north to south across temperate and tropical climate zones; it has varied topography, different land forms and hydrogeological conditions, giving rise to a wide range of water source types: river, stream, reservoir, lake, pool, pit, water-logged dam, shallow well, deep well, hand-pumped well, motor-pumped well, spring, karst cave, etc.

Direct utilization of rainwater was the first water source for human life and this practice has continued over the years in China. In some areas, micro-catchment systems such as pools, ponds, pits, water tanks and water-logged dams are practised. An estimated 5.49% of the whole population is supplied with domestic water from 1 million pools and 2 million pits and water tanks. Table 1 indicates the distribution and population percentage using rainwater cistern systems in each province.

One or more pools or ponds are used to collect direct surface runoff in each village in the south of China where the average annual precipitation is more than 2000mm. A covered pit is used to harvest rainfall from paved surfaces and natural ground by each family in the northwest of China where rainfall is low and concentrated between July and September. Evaporation there is so high that surface storage of rainwater is impossible.

Table 1. Percentage of the population supplied with rainwater cisterns systems in China

Main Type	*Province*	*Population (%)*
Pool and pond	Hubei	19 06
	Anhui	14 48
	Hunan	11.79
	Jianxi	11 26
	Yunnan	10.74
	Jiangsu	9.41
	Guangxi	5.25
	Sichuan	4.42
	Fujian	4 04
	Liaoning	2.95
	Henan	2.11
	Guizhou	1.47
	Shandong	0.32
	Tianjing	0 08
Pit	Gansu	11 76
	Ningxia	9.56
	Shanxi	4 96
	Shaanxi	4.73
	Qinghai	0 89
	Hebei	0 89
	Inner Mongolia	0.71
Water tank	Zhejiang	4.47
Water-logging dam	Xinjiang	21.84
	Tibet	4.32

Covered water tanks used to collect rainfall from the roofs of buildings for every one or two families in the southeast coastal area and some 5000 islands, where the abundant rainfall is the only source of drinking water due to high chloride concentrations in the ground-water (1000-1500 mg/l). A water-logged dam in each village is used to intercept rainfall and melted snow in low-lying lands in northwest China.

DESIGN

A rainwater cistern system, in general, consists of catchment, transportation, purification and storage. These components are described below:

Catchment	-	ground, roof, roads, yards;
Transportation	-	ditch, gutter and downpipe;
Purification	-	plain sedimentation, coagulation sedimentation, filtration and disinfection;
Storage	-	pit, cellar, water tank.

Catchments

Rainwater harvesting is given most consideration in those areas where rainfall occurs as heavy storms of considerable intensity, and intervals during which there is practically no rainfall. Adequate catchments for harvesting the water are required and depending on the circumstances either ground or roof catchments can be used to collect the runoff.

Ground catchments

Ground catchments are most used for collecting rainwater runoff in the northwest of China. The main advantage of using natural ground, roads and yards as catchment surfaces is that water can be harvested from quite a large area. For example, at least a $460m^2$ area is needed for a $20m^3$ storage volume in the loess plateau. The amount of rainwater that can be collected from ground catchments is dependent on whether the catchment is flat or sloping, and the permeability of the top layer. The ideal surface is compacted and sloping to ensure a sufficiently rapid flow of water to the collection point to reduce evaporation and infiltration losses. The portion of rainfall that can be harvested is about 30% in the loess plateau where the average annual precipitation is 316mm. For a ground catchment area of $460m^2$, the amount of rainwater that can be collected on a year-round basis may be estimated as:

$$460 \times 0.316 \times 0.3 = 44m^3/year$$

$$= 120 \text{ l/day on average.}$$

Considering an average dry season of 4 months the storage volume required would be:

$$4 \times 30 \times 120 = 15m^3.$$

Roof catchments

Roof catchments are commonly adopted for harvesting rainfall in the southeast of China. Corrugated tiles have been found to make good roof catchment surfaces. The size of the roof depends on the size of the house, and the quantity of rainwater that can be collected by roof catchment is largely determined by the effective area of the roof and the local annual rainfall. A yield of about 0.8 litres will be generated by 1mm of rainfall on $1m^2$ of roof, allowing for evaporation and other losses. For a roof measuring 5m x 9m (in plan) and assuming an average annual rainfall of 750mm, the amount of rainwater collected in a year may be estimated as:

5 x 9 x 750 x 0.8 = 27,000 l/year

= 75 l/day on average.

Considering 3 months without rainfall in an extremely dry year, the storage volume required would be:

3 x 30 x 75 = 7m^3.

Transportation

Collecting drain

Ditches along contours are dug on slope of 0.3% for delivering the water collected from ground, roads or yards to storage tanks.

Gutter and downpipes

When the roof is used as a catchment area, gutters made of sheet metal are installed on the roofs with a 0.2% slope, which allows the collected water to flow towards the water tank. Downpipes, which are mostly made of plastic hosepipe, are used to channel the water collected in the gutters to the water tank.

Purification

To safeguard the quality of the collected rainwater, a purification process is often installed. In the loess plateau of northwest China, silt traps, plain sedimentation tanks and screens are built to remove dust, leaves, bird droppings and silt. In the remote islands and the coastal area of southeast China, treatment includes not only coagulation, flocculation, sedimentation and filtration tanks for disinfection but also mineralization units for improving the water quality. For instance, such a rainwater collection and purification system was built up recently on Yongxin Island of Xisha Archipelago for domestic purposes at a capital cost of US$ 4 million. In the coastal area of Zhejiang, integrated purifiers, in which coagulation, flocculation, sedimentation and filtration are combined are commonly used to purify the collected rainwater. The purifier is characterized by small size, high removal efficiency, low cost of construction, operation and maintenance, easy installation and shipment.

Storage

These facilities are generally of two types: pits and water tanks.

Pits

Its capacity is optimized so that the maximum water volume can be stored with the minimum input of material, labour and construction cost. The pit can be made of cement or directly in the ground by simply compacting the earth. There is much less leakage in the former due to higher allowable stress. Such below-ground storage facilities have the general advantage of being cool and dark which prevents algal and bacterial growth and the breeding of mosquito larvae, as well as preventing loss of water by evaporation in those arid areas where surface wells are not viable.

Water tanks

Tanks are rectangular or circular, above ground and located just outside the house; they are designed with capacities between 2m^3 and 10m^3. Construction consists of making a frame out of steel reinforcing bars and wire mesh, or interlocking cement bricks as formwork which is wrapped with steel reinforcing bars. In Zhejiang Province, about 20,000 water tanks of this type were built and 0.2 million people have benefited during the 1980's at a cost of US$ 10 per person, excluding labour.

CONSTRUCTION

Pits

The construction procedure basically involves digging, shaping and ramming a pit of appropriate dimensions in the ground. Afterwards, the pit is trawled with hemp-fibre and lime plaster 1cm in thickness. A framework of steel reinforcing bars of 6mm diameter is then riveted, at intervals of 25cm, into the walls. Then a 1.2cm thick layer of cement mortar is applied to the sides followed by cement paste as a surface layer, to obtain a smooth finish. Finally, the pit is cured for 8-9 days and the shuttering removed before use. A 20m^3 pit requires about 330kg of cement, 33kg of steel bars and 7 man days of skilled labour.

Water tanks

The main stages of construction include making a frame with steel reinforcing bars held in position by wire, attaching wire mesh to the frame, placing the frame onto the reinforced concrete base and plastering twice both inside and outside, as well as painting the outside of the tank. The materials required for a 7m^3 tank include 750kg of cement, 300m of 9mm diameter steel reinforcing bars, 20m x 0.9m of 12mm welded wire mesh and 3m^3 sand.

COST BENEFIT ANALYSIS

The cost benefit analysis of the pit system, is presented as an example. A 20m^3 pit can provide a family of five with water for domestic use for 4 months. In Shaanxi Province, around 0.2 million pits of this type were constructed during the 1980s to serve 0.6 million people, at a cost of only US$ 35 per 20m^3, excluding labour. They are easy to operate and maintain, the running cost is negligible and no energy is needed. The total cost was estimated at US$ 0.25/m^3/year, assuming a life of 8 years for each pit.

As a result, these rainwater cistern systems have not only solved the problem of drinking water supply in the area but also saved 50-60 man days per year which was spent in fetching water from far away. Consequently, rainwater cistern systems are acceptable to local residents, especially to the women. Most girls are willing to marry those who have rainwater harvesting facilities at home.

CONCLUSION

Although rainwater can be collected almost anywhere with simple construction, low running costs, ease of maintenance and low impact on the environment, it is only in certain circumstances that it provides the best available source. In areas where surface and groundwater supplies are not readily accessible, are unreliable or are contaminated, rainwater collection may provide a viable alternative or important supplementary supply.

REFERENCES

Gould, J.E. (1989). Rainwater Harvesting Systems for Drinking Water Supply. *Proc. 4th Int. Conf. Rainwater Catchment Systems*, pp. 42-67. Manilla, Philippines.
Huisman, L. (1981). *Small Community Water Supplies*, pp. 59-75. International Reference Centre for Community Water Supply and Sanitation, The Hague, The Netherlands.
Li, J.R. (1989). *Nation-wide Survey on Drinking Water Quality and Waterborne Diseases*, The National Patriotic Health Campaign Committee of China, Beijing, China.
Mao, M. and **Xue, Y.Z.** (1987). *Roof Catchment and Storage.* Shaanxi Provincial Association for Water Conservancy, China.

LESSONS FOR SUSTAINABILITY OF WATER ASSOCIATIONS

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ABSTRACT

The delivery of basic services to rural communities needs appropriate technology in both engineering and management disciplines. It has been observed that water system maintenance in rural communities is directly related to people's capability for managing the project - be they users' associations, local government, or any other group.

A local government took a second look at its water delivery system and compared one approach with the other. Both approaches used people's organizations. In the first initiative, the government organized water associations, constructed the water systems and handed them over for independent management and care by the associations.

In the second approach, the government channelled the water fund to a non-government organization. A water association was organized by the NGO to construct the water system, operate and manage, with monitoring by a local government.

Cases from these two approaches involving 24 water associations were studied. The following lessons were drawn from the study:

- Promote continued congruence of purpose of individuals and groups in associations.
- Create positive inter-personal relationships among group members by continued communication, paving the way for the eventual emergence of democratic leaders.
- Instill the reality of life-long capability building process in problem solving.
- Allow clear internal structures and systems to be established by associations themselves.
- Advocate for support groups, structures and policies to assist the association.

INTRODUCTION

The delivery of basic services to rural communities needs appropriate technology in both engineering and management disciplines. Experience shows that such appropriateness has an impact on sustainable development. It has always been a challenge to implementors of development projects to make perceptible gains last beyond the project life.

The Iloilo Provincial Government, located in the central part of the Philippine Islands, took a closer look at its efforts to deliver water to rural communities. Efforts were made to anchor a rainwater collection system on an association for self-help and for maintaining the benefits from the water system technology.

It has been observed that water system maintenance is directly related to an association's capability. A breakdown in the group systems results in a dysfunction of the former. The condition, therefore, requires two types of investment; one for building the capability of the association and the other for the construction of the water system.

The traditional approach was for government to deliver the water system to its constituents and maintain the system through a local government unit. Again, the success of the water system depended upon the efficiency and effectiveness of the local government machinery.

The Philippine social climate has significantly changed since the EDSA revolution and since NGOs have emerged to participate in areas which traditionally belonged to government, thus influencing the thoughts and ways of doing things. NGOs for example are now involved in the delivery of basic services because of bureaucratic problems in the government, inefficiency, centralization, and graft and corruption. This trend was further institutionalized by the passage of the Local Government Code in 1991. NGOs today hold 25% of the seats on local development councils and they participate in local legislative bodies through representatives from various sectoral groupings. The new Code also provides a structure for the creation of people's organizations. Organized groups participate through the mechanisms of initiative and recall.

In this climate of increasing democratic space, the local government of Iloilo Province reviewed its experience in delivering water to rural areas.

One-third of the area of the entire province is considered flat (0-3% slope), one-quarter of the total area has an 8.1-15% slope, and about half is mountainous with more than 35.1% slope, This topography accounts for more than a hundred rivers, streams and creeks traversing the province from the mountainous areas to the coast line. The province has identified 31,366 sources of water; about 26% are dug wells, 22% are public wells, 13% are private deep wells, and 38% are rain catchments, springs, rivers and creeks. Level 1 water systems which are a communal shallow well or deep well, serve 54.82% of the population; level II, which includes a communal tap, serves 7%; and level III, where water is piped in houses, serves 38%. About 45% of the population do not have a safe source of drinking water.

Water projects for the rural areas were initiated way back in 1980 under the Barangay Water Program. The status in 1993 shows a total of 1102 households served and a total project cost of P10.8 million or US$0.4 million (at an exchange rate of P27 to US$1).

Another initiative was undertaken in the Municipality of Bingawan where 10,000 litre capacity rainwater catchments with hand pumps were constructed. A total of 849 households have benefited from the facilities at a total cost of P500,000 or US$18,500.

Both initiatives used people's organizations as the anchor for the project. Deviating from the traditional method of water delivery, these two pilot projects considered empowerment of people as an objective for development intervention. People empowerment refers to the recognition of the potential of persons and groups to address their concerns and successfully resolve them. In the first initiative, the government organized water associations, constructed the water system, and handed over the system for independent management and care by the association. The cost of construction was considered to be a loan by the association to the government. The objective was to use the repayment for putting up another water system in another village.

In the second initiative, the government channelled the funds to an NGO. A water organization was formed to construct the water system and to manage it, with monitoring by the local government. Since the amount involved was small, the water association was not obliged to pay back the amount but was held responsible for the maintenance of the system.

From these two experiences, four case studies were conducted, two from each. Of the two cases taken from each group, one is considered successful and the other is considered a weak group.

THE GUIMBAL WATERWORKS AND SANITATION ASSOCIATION CASE

The water system is rated level III, with piped water to every household. The cost was P7,451,068.50, or US$276,000, and was operated by the association in 1987. At the present time, the organization and the system is operational with 574 member users, an increase from the 460 members in 1987. The present membership comprises 80% of the total households in the town. The members continue to pay their fees, which support a management staff of five. Water supply is available 24 hours daily. During the earlier part of project implementation, water came only in a trickle during the dry months, especially in elevated areas. This prompted the association to undertake the drilling of two additional wells; four wells are now in operation.

The association management implements strictly agreed policies and procedures which include a monthly schedule for meter reading; distribution of water bills; collection of fees, and the imposition of fines.

It was also ascertained that the association has a simple but complete accounting system, as well as records and a filing system.

The association is managed by a board of directors whose members receive an honorarium for attending meetings. The board meets every month, in addition to emergency and special meetings which are called when needed. An annual general assembly of members is held and the average attendance rates 90-95% of the total membership.

The association keeps its money in time deposits; there are no plans to invest in other projects since management is afraid to take the risk. The loan is not being repaid because, according to the association officers, the provincial government does not collect from them.

THE SINUGBAHAN WATERWORKS AND SANITATION ASSOCIATION CASE

The water system for the village of Sinugbahan was constructed as a level III facility with a P338,000 loan (US$12,500) and 67 members. This project started in 1985. In 1993 the association is no longer functional. Daily water flow lasts only for, at most, an hour and a half. According to the provincial technical officer, the project was not feasible from the beginning because of the limited water source, but it was pushed through since it was a priority need of the people.

However, the members state that the feasibility study showed a sufficient water source. On learning this, a representative from the provincial government told them to form an association so they could obtain a loan from USAID to develop the water facility. A membership of 100 households and a bank deposit of P4,500 were all that were required.

Operational problems were not attended to by the members of the board. In eight years (1982-1989) the board of directors met only three times. From 1989 to 1991 the water system did not function. In late 1991, because of the dire need for a water supply, the Barangay Council took over the project, withdrew the P4,500 bank deposit and used it to repair the facilities. The Barangay captain (village head) then appointed an operator/collector who was paid P500/month.

It was also reported that nobody from the provincial project office visited the area after the inauguration of the project. No financial recording and reporting system was installed. Records and files were not complete. When asked whether they were aware of the loan obligation, the members answered that they were willing to pay for the loan provided the service is adequate.

THE MALITBOG ILAYA WATER ASSOCIATION CASE

Forty-three households joined the water association in 1989. Some were served by a 10,000 litre rainwater catchment and the others by water pumps. The association was formed after a community assembly, consultation between the village and the Department of Health, a seminar on health and water potability, and another seminar on the technical aspects of water catchment. All village residents were invited to the seminar. As soon as the association was formed, responsibilities were discussed and officers and committee members participated in the project planning stage.

Upon completion of the water facilities, a maintenance agreement was signed between the association, the village council, and the mayor or the executive officer of the local government unit. The Department of Health tested the potability of the water.

In 1993 the organization is still functional but members whose houses are located at a distance from the communal rainwater catchment did not continue their membership. The association was able to access funds for a soap-making project, using local materials. Some of the original members who were not interested in the livelihood project, also discontinued their membership of the organization. The soap-making project maintained the interest of association members for a while but when they met with technical problems, the group decided to switch to a swine-fattening project.

The Department of Health, a government agency, continues to involve the water association in community activities such as training in vitamin A deficiency control and nutrition education. A new project on bio-intensive gardening is planned by the association, more households are getting interested again and expressing an interest in rejoining the association. A local government representative continues to monitor the activities of the water association every month.

THE CAIROHAN WATER ASSOCIATION CASE

Barangay Cairohan covers an area of 164 hectares and has a population of 600 people or 80 households. There were a total of 60 dug wells, open and shallow, in the village. There is no school in the village and most residents are farmers and sugar-cane labourers. The water association participated in the planning and construction of the rainwater tank and water pump. The Barangay village head donated a piece of land where the water facilities were constructed. The roof of the Barangay chapel was used as the catchment area for the tank.

The association meets regularly throughout the year and was able to secure a loan for its members for cattle fattening. The loan was repaid and the members were planning to renew the loan for another project.

In 1993 the rainwater catchment although it was properly constructed, is serviceable, has water all the time, and is properly maintained, is not being used by households. According to the association members, the catchment is only used by children. The members said that they prefer to use the pump water and most of them have access to the pump. They said they agreed to form a water association and to continue participating in it because they wanted to cooperate with the municipal officials, and that the association was a means of access to livelihood projects which are their priority need.

LESSONS LEARNED

In deciding priorities for investment in infrastructure, local government may have to review the cost involved in a particular level of technology appropriate for rural areas. The cost of level III is US$363 per household while the level II technology costs only US$22. The cost of the first alternative, though, would have decreased if the fund had revolved and been reused by other organizations.

RAINWATER HARVESTING IN NAIROBI: POSSIBILITIES AND CHALLENGES

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INTRODUCTION

Nairobi is the capital city of Kenya, it has also become the centre for regional and international organizations. The city has grown considerably since it was founded in 1899 as a railway depot. By 1963 the area of the city was increased to approximately 680km^2 from an area of 77km^2 in 1927. The city was initially zoned and services provided on a racial basis. Most of the annexed areas have no basic services.

The population of the city is now estimated to have risen above 1.2 million from a figure of 0.6 million in 1976 (Table 1). The projected water demands by the Water and Sewerage Department of NCC from the year 1978 up to the year 2000 (Table 2) indicate that the increase in the number of people served by the NCC water supply system is higher than the growth rate of Nairobi's population by approximately 7% per annum (Humphrey, 1980). The reality is quite the opposite; water shortages in all neighbourhoods, irrespective of economic status, are very common. Reasons for not meeting expectations include mechanical breakdown of plant and supply lines, drought etc.

The demand for water continues to grow; more people want more water in Nairobi each and every year. Should there be a limit to this growth? Will economic realities force us to reconsider our current water sources and use?

Table 1. Population growth in Nairobi since 1906

Year	*Total Population*
1906	11,512
1926	29,864
1931	47,919
1949	118,579
1962	266,795
1969	509,286
1979	887,775
2000	2,800,000 - 4,200,000

Table 2. Nairobi's past and projected water demand.

Year	*000s of litres of gallons*
1978	24,953
1980	141,619
1982	160,508
1984	181,916
1986	207,715
1988	238,946
1990	274,874
1992	316,207
1994	363,750
1996	418,448
1998	481,366
2000	553,713

The study looked into rainwater harvesting as a complementary system to the existing irregular municipal water supply in Nairobi and argues that a household/community-based water supply is much more efficient than a centrally controlled and unreliable one, especially for the low income sector.

Results of a sample survey of households by the Water and Sewerage Department of NCC indicated that within any given income group *per capita* level of water consumption varied inversely with household size (Humphrey H., 1980). The average size of households in Nairobi increases as one moves from the high to the low income group, hence the relative increase in water demand for the low income group would be expected to be much higher. Observations indicate that with increased occupancy levels and an increase in *per capita* income, total household consumption would increase proportionally, while increased occupancy through reduced *per capita* income would cause a fall in water consumption.

In the very low income housing and unauthorized shanty areas like Kibera and Mathare Valley, people are almost entirely dependant on licensed kiosks for their daily water requirements. The kiosks sell water at rates which are four to six time greater than the normal tariffs levied by the Water and Sewerage Department (Ladu, 1990); this contributes to the generally low levels of *per capita* consumption. The low income group, therefore, is vulnerable; unless alternative affordable and sustainable water supply sources are identified and introduced immediately, they will be forced to resort to unhygienic sources.

The study objectives include:

- To explore, through a review of the literature and observation, the various factors affecting sustainable rainwater harvesting systems development in low-income neighbourhoods of Nairobi.

- To find out how the technology has developed with time, and how it fits into the urban environment and contributes to the aesthetic quality of buildings.
- To investigate how people, and especially architects and planners, have responded to and integrated the technology into their work, if at all.

RAINWATER HARVESTING TECHNOLOGY, AESTHETICS AND INTEGRATION

Modern technologies for obtaining and using water are concerned chiefly with the exploitation of river systems and the accessing of ground water by means of wells and boreholes.

In earlier phases of human development, major rivers were exploited but there was also a complementary and more extensive pattern of settlement in areas where rivers were few and where the direct collection of rainfall was one of the few methods available for securing a water supply. Rainfall was collected from house roofs which were designed to maximize yield, and runoff was sometimes directed into cisterns from paved courtyards.

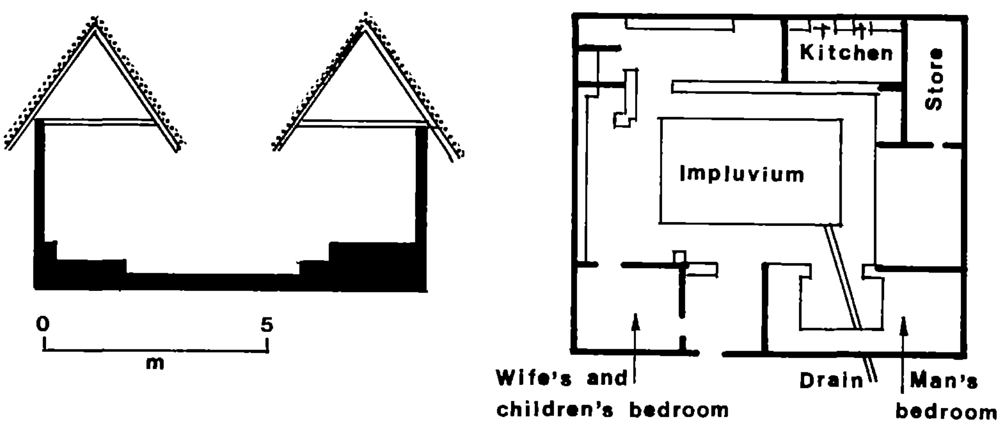

Figure 1. Plan and cross-section of an Ibo house, Nigeria, ca. 1920 (Denyer, 1978).

Observations in Nairobi show that rainwater harvesting structures are not integrated into the building but are added as an afterthought.

The interception of rainwater from roofs and other impervious surfaces is common in rural areas and is partly developed in the high-income neighbourhoods of Nairobi. Technology for harvesting rainwater directly is well researched and established, but this abundant knowledge has not been applied to its full potential, especially in low-income neighbourhoods. There is tremendous scope for increasing rainwater harvesting if public awareness was raised by the authorities and professional bodies involved.

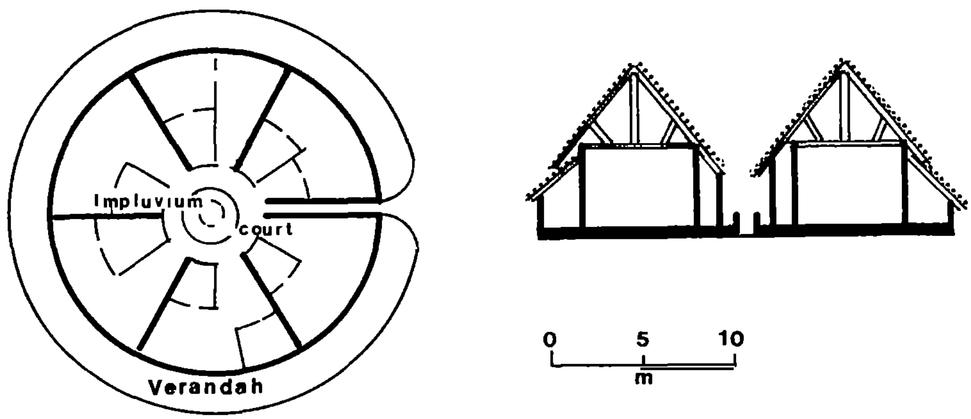

Figure 2. Plan and cross-section of a Diola house, Senegal, ca. 1940 (Denyer, 1978)

WATER SUPPLY AND CONSUMPTION LEVELS IN NAIROBI

Water is a basic requirement for human as well as animal and plant life. People need water for drinking, preparing food and for sanitary purposes.

In spite of the fact that the past 30 years have seen great efforts in the area of water resources development, with the construction of large water projects, there is still under-provision of water for domestic use in Nairobi.

Currently Nairobi is supplied from Kikuyu Springs, Ruiru and Sasumua Reservoirs and Chania via Ngethu (Table 3) which together supply an average of 237,800m^3/day when all are operational. In addition, some areas of the city are still supplied with water from boreholes, either as their only source of supply or to supplement the main system.

Sadly, in spite of the vast amounts of money channelled into such schemes, the projected benefits have not been realized because of a plague of broken and badly functioning facilities, rapid population increase and the development of new housing schemes, putting a strain on the existing systems. Poor plant maintenance has been a continual problem in water provision in Nairobi and a major cause of unsustainability. The problems of irregular water supply have now reached a critical state, and taking into account population growth, it is clear that there is a great need for complementary water supply sources which are environmentally sound and sustainable.

Providing a water supply to a community involves tapping all sources of water available, ensuring that it is fit for human consumption and supplying it regularly and in adequate quantities. The *per capita* quantity of water used daily by a family varies with physical and

Table 3. Supplies available to Nairobi (at 100% efficiency) 1980.

Source	*Supply rate (m^3/d)*	*Peak capacity (m^3/d)*
Kikuyu Springs	3,600	4,500
Ruiru Reservoir	21,400	23,100
Sasumua Reservoir	45,800	63,700
Chania via Ngethu	134,800	178,800
Total	205,600	270,000

socio-economic conditions and consequently, varies widely between and within a neighbourhood, as mentioned earlier. The level of service provided has also been found to have a marked influence on water usage. Where water has to be carried over long distances, or when waiting times at water kiosks are lengthy, consumption may be as low as 10 litres per family member daily. Examination of the billing records for the water kiosks serving the Kibera and Mathare Valley shanty areas suggests that water consumption is of the order of only 10-14 litres per head per day. The quantity may be five or more times this when a supply in the house or courtyard is provided.

Water is supplied at the following service levels in Nairobi:

I - Water kiosks, burst pipes, streams etc.;

II - Public standpipes;

III - Yard connections;

IV - House connection - multi-tap house connection.

RAINWATER HARVESTING, WATER QUALITY AND HEALTH

In low-income neighbourhoods of Nairobi, it has been noticed that owners of houses with metal roofs are reluctant to install gutters although women and children spend hours at water kiosks. People appreciate the value of rainwater and place containers under their eaves when it rains, so their lack of interest in gutters and permanent storage containers is not due to any ignorance of the value of rainwater.

It was also noticed that in the high income neighbourhoods, water collection is not limited to rainwater harvesting; some families have built underground tanks to collect Nairobi City Council water which flows at very irregular intervals.

A major advantage of rainwater collected from roofs is that it is usually much cleaner than water from streams, burst pipes etc., and this offers a considerable advantage when used for drinking and cooking. However, it should not be assumed that water from roofs is totally free from contamination. Birds, small animals, rotting roofing materials and wind-blown dirt.

may all contribute some pollution. Moreover, rainwater is usually lacking in mineral salts whose presence in other water supplies is regarded as beneficial in appropriate proportions.

When rain falls after a long dry period, water collected from a roof may carry noticeable amounts of debris arising from dust and leaves which have accumulated on the roofs and in gutters. It is therefore recommended that water running off the roof during the first 5-10 minutes of a storm should be discarded. The simplest method is to have flexible joints in the pipes conveying water from gutters to tanks. If this is not done the tank need to be cleaned out more often and there is every chance that organic debris in the tank will promote the growth of bacteria and other organisms.

There should also be some form of coarse screen between guttering and the delivery pipe, and a finer screen or filter at the point where water enters the tank. The greatest danger arises when tanks and clogged gutters become mosquito breeding sites, and gutters should be free from depressions in which water is left standing. All openings to the tank, such as overflow pipes should be fitted with fine gauze. Maintenance of the system is very important.

If a programme is directed to low-income groups, the bad state of their housing, including roofs, should receive attention. Technical support for roof repair or replacement might become part of the programme.

REPLICATION AND INNOVATION

The essence of appropriate technology is that equipment and techniques should be relevant to local resources and needs, feasible to organize and suitable for the local environment. In all technical and social assessments, and in most inventories of materials and skills, considerable attention must necessarily be devoted to housing conditions.

Experience in Nairobi of low-income housing shows that where houses are being actively improved it is relatively easy to arouse people's interest in rainwater tanks; they are perceived as desirable improvements to the house.

The role of women in supplying the household with water is not limited to the rural areas. The inaccessibility of water on the premises means that women have to spend lengthy periods at water kiosks or public stand-pipes. In some cases the time spent stretches to hours.

Clearly, women have more to gain from an improved water supply and are more motivated to ensure its provision because the time they spend fetching water could be spent in some income-generating activity. Advantage should be taken of this; women's groups and co-operatives have been found to be very useful in improving the living conditions of their families and should be utilized to ensure a continuous improved water supply (Ladu, 1990). It should also be made more appealing to the men folk to install gutters and water tanks as part of the house construction.

If housing is seriously overcrowded or poorly constructed and people cannot afford any improvement, they will not be able to afford rainwater tanks either.

For health promotion rainwater harvesting technologies should be introduced as a bye-law in the NCC Building Guidelines and any new development should be encouraged to explore and apply the rainwater harvesting technologies, to the extent that the site and conditions allow.

Being household/community-based, the introduction and application of rainwater harvesting technology would be easy to implement for the following reasons:

- It is easily understood with relatively little technical knowledge required, and can be carried out by the local population.

- It presents a clear improvement over the existing systems, especially in operation and performance, but does not demand radical changes.
- It creates jobs through labour-intensive methods.
- It revives locally available ideas and resources, and uses them extensively.
- It is economically feasible.
- It is socially acceptable.
- It is ecologically/aesthetically sensible.

The great goals, which include the International Water Decade (1981-1990), the International Year for Housing and the Homeless (1987) and the WHO Health for All by the Year 2000 will not be achieved without commitment from professionals both locally and internationally.

In Nairobi, as already mentioned, people cannot be expected to improve their current living conditions alone. In most cases the water problem facing households is just one of the problems of urban survival. It is also a fact that some people do not realize that the situation, they are in can be improved. The international goals put forward at conferences are completely unknown to them and they continue live in poverty. We cannot be indifferent to the situations; it is up to us, at all levels in society, to do something in our respective fields.

REFERENCES

Denyer, S. (1978). *African Traditional Architecture*. London.

Humphrey, H. Kenya Ltd (1980). Chania-Thika Study. *Economics*, **2**. 1980.

Ladu, B (1990). Low-income Housing in Nairobi: An Alternative Approach. Research Paper No. 178, Centre for Urban and Community Studies, University of Toronto.

Mukerji, K (1986). Angepasste Technologies Feur Entwicklungslaender. *Bayerische Architektenkammer*.

Pacey, A. and **Cullis, A** (1986). *Rainwater Harvesting · The Collection of Rainfall and Runoff in Rural Areas*. IT Publications, London.

CONSTRAINTS LIMITING THE SUCCESSFUL APPLICATION OF RAINWATER CATCHMENT SYSTEMS IN DEVELOPING COUNTRIES

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ABSTRACT

The potentiality of rainwater harvesting systems as a significant contribution to water supply has, lately, been made evident in different parts of the world. One would imagine, therefore, that many countries facing water scarcity problems, particularly the developing ones, would quickly adopt this relatively cheap technology. This is not the case though, and this state of affairs cannot be without reason.

This paper identifies and discusses the constraints and problems that limit the efforts of various developing countries to adopt, and restrict their participation in the development and use of rainwater harvesting systems on a sustainable basis. These problems have been shown to be different in nature. While most of them are due to economic considerations others are a result of mechanical, social, cultural and other limitations. Possible measures to be taken in order to overcome some of these problems have been suggested.

INTRODUCTION

Interest in the use of rainwater as an alternative or supplemental source of water for domestic, agricultural, livestock and other uses has, lately, been stepped up. This has been more so in developing countries where, due to a number of problems, availability of adequate and potable water within easy reach is not always assured. Also, the cost of supplying water to the people through pumped, gravity or other schemes is higher than can be afforded. Rainwater catchment systems (RWCS) are one of the answers to the global water use problem, especially where water is limited (Fok, 1992). They have been implemented in different parts of the world, particularly South East Asia, where in some countries, rainwater is a very significant part of total water supply.

It would be expected that due to the significant degree of success of RWCS in countries like Thailand, the efforts made there would be readily and quickly replicated in other developing countries. This is not the case, though. Awareness of the potentiality of RWCS in solving water supply problems has spread in many countries but adaption of the technology on a larger scale has not materialized, because of economic, technical, technological and social constraints.

ECONOMIC CONSTRAINTS

The rural areas of developing countries, where a large percentage of the population lives, stand to benefit most from rainwater catchment. Unfortunately the financial base in these areas is generally weak so that rooftop harvesting systems for individual households are not easily affordable. Many houses have thatched roofs which need to be changed to more suitable roofing materials like corrugated iron sheets. Sometimes a rainwater catchment roof has to be constructed next to a thatched residential house.

Capital investment is relatively high for other RWCS too and not many individuals or communities can afford them easily. For an average Nepalese family, for example the cost of a rainwater system is prohibitive (Dixit and Upadhayaya, 1991). Large storage facilities are necessary if rainwater is to have an impact on the overall water supply of a household, community or village. The cost of constructing a water storage tank or water jars is relatively high. For instance the cost of a $20m^3$ ferrocement standing tank for rooftop catchment in Tanzania is US$925 (Lee and Visscher, 1990). This is far above the average annual *per capita* income of the country. Hence construction of such tanks has to be heavily subsidized.

Construction of surface catchment systems like earth dams and excavated reservoirs relies either on intensive use of labour or heavy earth-moving machinery. The latter are very expensive to buy and maintain. Sub-surface tanks are usually fitted with handpumps whose operation and maintenance is not easily afforded by the users.

TECHNICAL/TECHNOLOGICAL CONSTRAINTS

Designs of RWCS need to incorporate materials, skills and construction methods that are compatible with local conditions so that they are replicable and sustainable (Lee and Visscher, 1990). Some rainwater catchment systems have been introduced without having been tested and found to be suitable for the beneficiaries. In some places the materials needed for construction of the system are not readily available.

Sustainability is also undermined by lack of proper operation and maintenance of the RWCS. This comes about due to either insufficient maintenance skills of the users of the systems or lack of regular maintenance. In Bangladesh a traditional method of rainwater collection is by the construction of ponds, but maintenance of those ponds is not carried out regularly as expected. Thus a large number of such ponds are finally abandoned for lack of management (Biswas, 1992). Sub-surface rainwater storage tanks are usually fitted with handpumps, whose operation and maintenance is not always as good as it should be.

One problem which is faced by both developing and developed countries is availability of rainfall. In the arid and semi-arid areas where rainwater harvesting would be most beneficial, the rainfall amounts are very low and the dry seasons very long, requiring large costly catchment surfaces and storage facilities. In places where the level of hygiene is not satisfactory the quality of stored rainwater can deteriorate.

All these constraints, then, counter the efforts to convince potential users to adopt RWCS.

SOCIAL CONSTRAINTS

In different parts of the developing world some ethnic or tribal groups have reservations or even negative attitudes about rainwater. These are either psychological beliefs or may be deep-rooted in the traditions and culture. In Nepal, for instance, collection of rainwater and its storage for drinking purpose was not practised because stored water was regarded as impure and flowing water as pure (Campbell, 1973).

Social conflicts sometimes arise over ownership of water harvesting systems that are communally used. This happens especially among non-cohesive social groups, because the stored rainwater is sometimes not sufficient to last the dry season. However, under-utilization of the water source due to severe rationing may leave the user dissatisfied with the level of service provided (Lee and Visscher, 1992). This state of affairs brings about in equitable water abstraction from the storage, which becomes the source of conflicts.

Failure to involve the community in the planning, design, siting and construction of the RWCS is commonly a cause of failure of the system. Willingness to pay is yet another big constraint where the RWCS is for communal use. Where an agreement is sought from families in a village to contribute to the cost of constructing a common system, there are very often some families not willing to spend their money on this important investment.

ADMINISTRATIVE CONSTRAINTS

The success of any programme or project is very much dependent on good and effective administration. Often the planning and administration of rainwater catchment system programmes in developing countries leaves a lot to be desired. Discussing the factors that contributed to the success of the much acclaimed Jar Programme in Thailand, Gould (1992) points out that effective adminstration of the programme was one of the key reasons.

OTHER CONSTRAINTS

One constraint that hinders the adequate dissemination of information on rainwater harvesting in developing countries is insufficient documentation. There is very little literature available on rainwater harvesting experiences in Tanzania (Rutashobya, 1992). Such a situation is common in many other developing countries.

In Sri Lanka the reason for RWCS technology not being adopted as widely as it might be is lack of awareness of the system (Ariyabandu, 1992). The importance and benefits of using rainwater for domestic use is rarely understood by the beneficiaries.

In the majority of developing countries rainwater harvesting systems are not yet a mainstream technical option and hence have little or no institutional support. Individuals interested in the technology therefore find it difficult to secure financial support. It is only recently that national governments and donor agencies have begun to pay serious attention to RWCS technology and planners and policy makers are slowly changing their attitudes towards it.

Another constraint is that women are rarely involved in external intervention projects, despite their traditional role in water management (Lee and Visscher, 1990); this is a serious situation because decisions made get imposed upon them.

MEASURES TO BE TAKEN

The first important step towards achieving successful and sustainable rainwater catchment systems is to create awareness of the technology among its potential users. This could be achieved through mass media, seminars, workshops and even grass-roots formal and informal meetings. Because, as Ariyabandu (1992) put it, if "we can convince 50% of the policy makers we can expect some success in our endeavour."

In order to lessen the constraints of economic and financial weakness it would help to use cheap, locally available materials in the construction and implementation of rainwater catchment cistern systems. Also governments must be willing to set aside funds to establish revolving funds and subsidies (Gould, 1992) as was done successfully in Thailand.

It is important to conduct research relating to the technical development of designs and construction materials and methods in order that RWCS are readily accepted and sustainable. New designs must first be sufficiently field-tested before they are first introduced into any developing country.

It is also very important to focus on women as prime agents for RWCS development. They should be involved in the planning, design, construction, maintenance as well as technical and financial aspects of rainwater projects. Indeed the community as a whole should participate in the projects in order to realize meaningful, acceptable and sustainable rainwater catchment systems.

REFERENCES

Ariyabandu, R.S. (1992). Rainwater Cisterns: A Challenge for the Future, *Proc. Regional Conf. of the Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Biswas, M.R. (1992). Rainwater Conservation for Farm Use in Dry Seasons, *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Campbell, L.B. (1973). *Two Water Case Studies: Research cum Action.* Project Paper No. 5. Department of Local Development/UNICEF, Kathmandu.

Dixit, A. and **Upadhyaya, S.** (1991). Rainwater Cisterns in Nepal - Problems, Prospects and Promotion. *Proc. 5th Int. Conf. on Rainwater Cistern Systems.* Keelung, Taiwan.

Fok, Y.S. (1992). Rooftops: The Under-utilized Resource. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems* Assoc. Kyoto, Japan.

Gould, J.E. (1992). Development in Roof Catchment Systems in Rural S.E. Asia. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Lee, M.D. and **Visscher, J.T.** (1990). *Water Harvesting in Five African Countries.* Occasional Paper 14. IRC, The Hague, The Netherlands.

Lee, M.D. and **Visscher, J.T.** (1992). *Water Harvesting; A Guide for Planners and Project Managers.* Technical Paper Series No. 30. IRC, The Hague, The Netherlands.

Rutashobya, D.G. (1992). Rainwater Harvesting as a Potential Solution to Water Supply Problems: A case of Tanzania. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc* Kyoto, Japan.

DISCUSSIONS

Observing that rainwater harvesting was a solution to the immediate burden of water provision that faced many women, **Ms Muthoni Ngotho** asked the author of this paper to identify elements of policy that would encourage women to develop sustainable rainwater catchment systems.

Dr Rutashobya suggested that a good policy on the involvement of women in rainwater catchment systems should; first ensure that women take part in planning, construction and maintenance of the systems. Second, water committees should be formed to manage the rainwater catchment systems and half of the members should be women. Also women should be involved in the siting of communal rainwater harvesting systems.

In response to a question on formulation of a clear policy for rainwater harvesting, **Dr Rutashobya** observed that, while the constraints involved in such an action would not be easy to overcome, every government should nevertheless attempt to formulate a clear policy on rainwater catchment systems.

Dr Jessica Salas observed that one of the constraints limiting successful development of rainwater catchment systems was the stereotyped role assigned to women, combined with socio-cultural and traditional values. She suggested that men should be involved in water gathering and child-care activities to overcome this stereotypic image and to transform socio-cultural values. The author agreed with this suggestion.

PROSPECTS FOR RAINWATER CATCHMENT IN BANGLADESH AND ITS UTILIZATION

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INTRODUCTION

Bangladesh emerged as a sovereign country in 1971. It straddles the Tropic of Cancer extending between 20°34′ and 26°38′ north, and between 88°01′ and 92°41′ east. It is almost surrounded by India, except for a short south-eastern frontier with Burma and the southern deltaic coast, fronting the Bay of Bengal. It has an area of 143,998 km^2, and a population of over 110 million of which 85% live in the rural areas. Bangladesh is one of the most densely populated countries in South East Asia.

CLIMATE

The climate of Bangladesh is dominated by seasonally reversing monsoons. The winter is relatively dry, extending from November to February; the average minimum and maximum temperatures, respectively, are 11°C and 29°C. The "summer" is remarkably equable; the average monthly temperature is 29°C from May right through to September. There are pre monsoon rains in April and May, but it is the southwest monsoon that brings heavy rains. The average monthly rainfall is shown in Figure 1.

Bangladesh has a typical humid tropical monsoon climate, but it is subject to violence from time to time; for example when a tropical cyclone, charged with energy and water vapour is swept in by high winds, it devastates low lying areas in the coastal part of the delta. Such extreme natural events tend to bring high seas and salt water flooding, so that there is damage to the soil as well as terrible loss of life and property.

PHYSIOGRAPHY

Bangladesh is almost entirely an alluvial plain with hills on the northeast, east and southeast margins. The alluvial plain slopes northwest to southeast from an elevation of 90m in Tetulia to less than 3m in the Southeast. Within the plain there are some elevated tracts like the Lalmai hills of Comilla, the Modhupur tract and the Barind in the northern part of the country. The elevated tracts range in height from 15m to 40m above mean sea level. The highest areas of Bangladesh are the hill tract regions of anticlinal ridges and synclinal folds, the elevation of the ridges being 70-100m. There are also some hillocks in Sylhet region with elevations ranging from 20m to 60m. Three major rivers, the Ganges, the Jamuna and the Meghna, along with their various tributaries and distributaries drain the country.

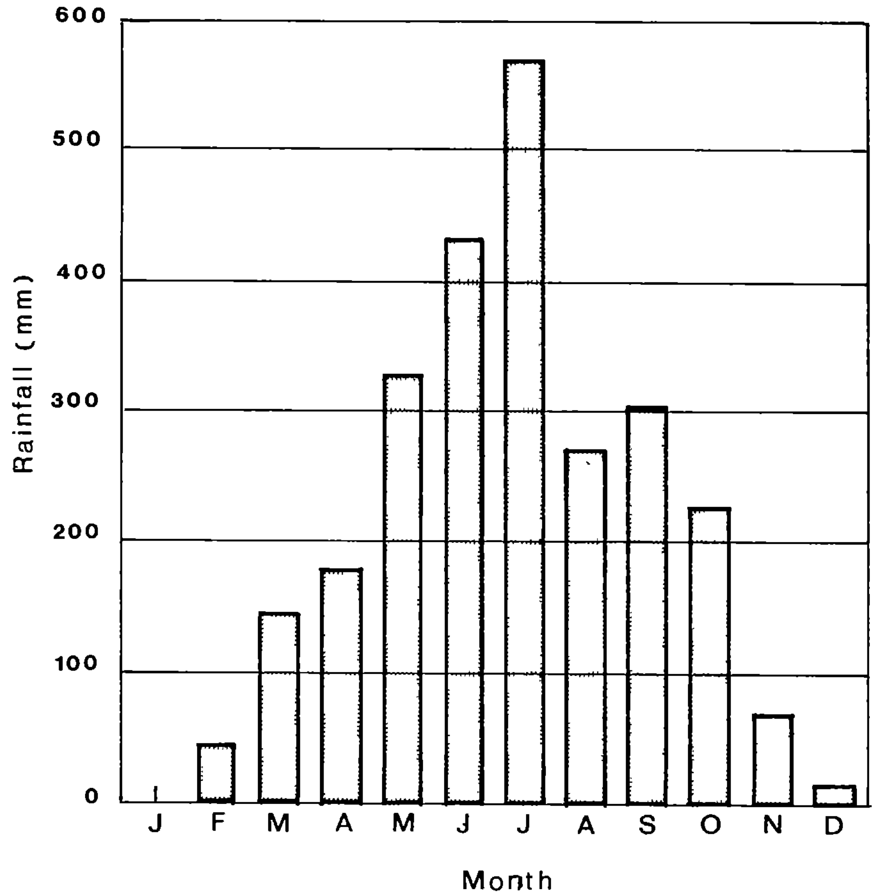

Figure 1. Mean monthly rainfall Bangladesh (1990).

GEOLOGY

Geologically Bangladesh is a part of the Bengal Basin which encompasses the political areas of Bangladesh and part of West Bengal in India. The basin originated about 200-230 million years ago as a result of rifting of the Indian block within the Condwana land, thereby creating a new oceanic basin for sediment deposits. The depositional history of the Bengal Basin since crustal separation in the cretaceous period includes widespread marine transgressions and regressions. The regression process and the Ganges-Jamuna-Meghnar delta formation toward the Bay of Bengal are continuing at the present time.

The Bengal Basin filled up from the north, east and west by antecedent river courses contains both marine and terrestrial sediments, the latter being more suitable as water-bearing formations. Terrestrial sediments are progressively finer towards the south making aquifer conditions relatively better in the north than in the southern coastal belt. Of course stratigraphically the geologic pattern is more diverse in the active delta towards the south.

SOCIO-ECONOMIC AND HEALTH INDICATORS

The present rate of population growth is 2.6% per annum. *Per capita* GNP (1990) is US $ 210. About 47% of the population live below the absolute poverty line. The adult literacy rate is 25%. The rate of infant mortality is 105 per 1000. Life expectancy at birth is about 52 years. About 300,000 children under 5 die every year because of diarrhoeal diseases.

WATER AVAILABILITY

Surface Water

Apart from the available flow in the rivers and streams in a certain region, the in-stream storage potential and static water bodies contribute to surface water availability. For the whole of Bangladesh the in-stream storage is estimated at approximately 500 million m^3 and the static water bodies at approximately 500 million m^3.

Ground Water

Bangladesh is almost entirely underlain by water-bearing layers, with ground water present at depths varying from 0m to 12m below the surface, except in the Chittagong hill tracts, Rajshahi High Barind, the Madhupur tract and the hilly areas around the edge of the Sylhet basin. Apart from these areas, ground-water levels are at or near ground level during the period August to October, and are lowest in the April and May. Ground-water levels rise in response to recharge during May and generally reach their highest level in late July.

There are several areas of Bangladesh, however, where ground- water withdrawals are causing a large decline in ground-water levels during the dry season. Temporary overdraft conditions are evident particularly in Rajshahi district during drier than normal years. Usable recharge to ground water is estimated at 43 million m^3 per year or 19% of the annual rainfall. Due to the lowering of ground water tables a large number of hand tubewells go out of operation during the dry season.

QUALITY ASPECTS OF POTENTIAL WATER SOURCES

The chemical properties of surface water in Bangladesh, in general, do not restrict its use as a source of domestic water supply; but in the coastal belt where it is brackish to saline it cannot be used for this purpose. Dissolved iron concentrations are high almost all over the country; in most places the level is more than 2ppm, and some places are as high as 10ppm or more.

WATER SUPPLY PATTERN IN BANGLADESH

In Bangladesh the principal source of water supply is ground-water both in urban and rural areas. In urban areas ground water is extracted through large diameter (150mm) production wells and transmitted through a network of underground pipes to the consumers. In a few urban centres surface water is also extracted on a limited scale.

In the rural areas ground-water is extracted through small diameter (38mm) hand-operated tubewells installed in households.

According to the hydrogeological conditions of various areas in Bangladesh, the rural water supply system is classified into three major types as follows:

1. Shallow water table area - shallow tubewell;
2. Low water table area - deepset/tara tubewell;
3. Coastal belt - deep tubewell.

Service levels vary quite considerably throughout the country because of the need for different technologies to meet the needs of different areas. Some technologies are inexpensive and easy to install and others are more expensive and far more difficult to handle.

Shallow tubewells

This is the simplest and cheapest type of technology for extracting ground water when the water table is no more than 7m below the surface. It is also known as a No. 6 hand pump.

About 59 million rural people are dependent on shallow tubewells. The total number of government shallow tubewells in the country is now 773,272; the number of people per tubewell is about 76.

Deepset or Tara tubewells

A Tara tubewell can draw ground water from greater depths than the shallow tubewell. They are being fielded in Bangladesh in areas where ground water tables are more than 7m below the surface. About 23 million people are now dependent on Tara tubewells. The number of Tara tubewells operating by June 1993 was 72,457, and the number of people using a well is around 316.

Deep tubewells

These are wells with shafts more than 77m deep, but they use the No. 6 suction handpump. They are usually installed in the coastal belt of the country where wells have to go deep to find fresh-water aquifers. About 10 million people now depend on deep tubewells. At present there are 49,142 government owned deep tubewells, and the number of people using each well is about 242.

Other technologies for rural water supply in specific areas include shallow shrouded tubewells, very shallow shrouded tubewells, pond sand filters (mostly for coastal areas), and small iron removal plants.

Bangladesh has achieved remarkable success in rural water supply. Already 85% of the population has access to tubewell water within 150m of the household; the average population per hand tubewell is about 92.

THE COASTAL BELT OF BANGLADESH - THE PROBLEM AREA

Bangladesh has a very long coastline and covers 20,000km^2 area forming the coastal belt - this is considered the problem area in respect of the availability of potable water. Ground water in the coastal belt is uncertain; either a suitable aquifer is not available or the water is extremely saline. In some particular areas deep tubewells are successful at depths of 300-400m but over 10 million people living in the belt have one kind of problem or another obtaining usable water and run the risk of epidemic diseases due to consumption of contaminated water.

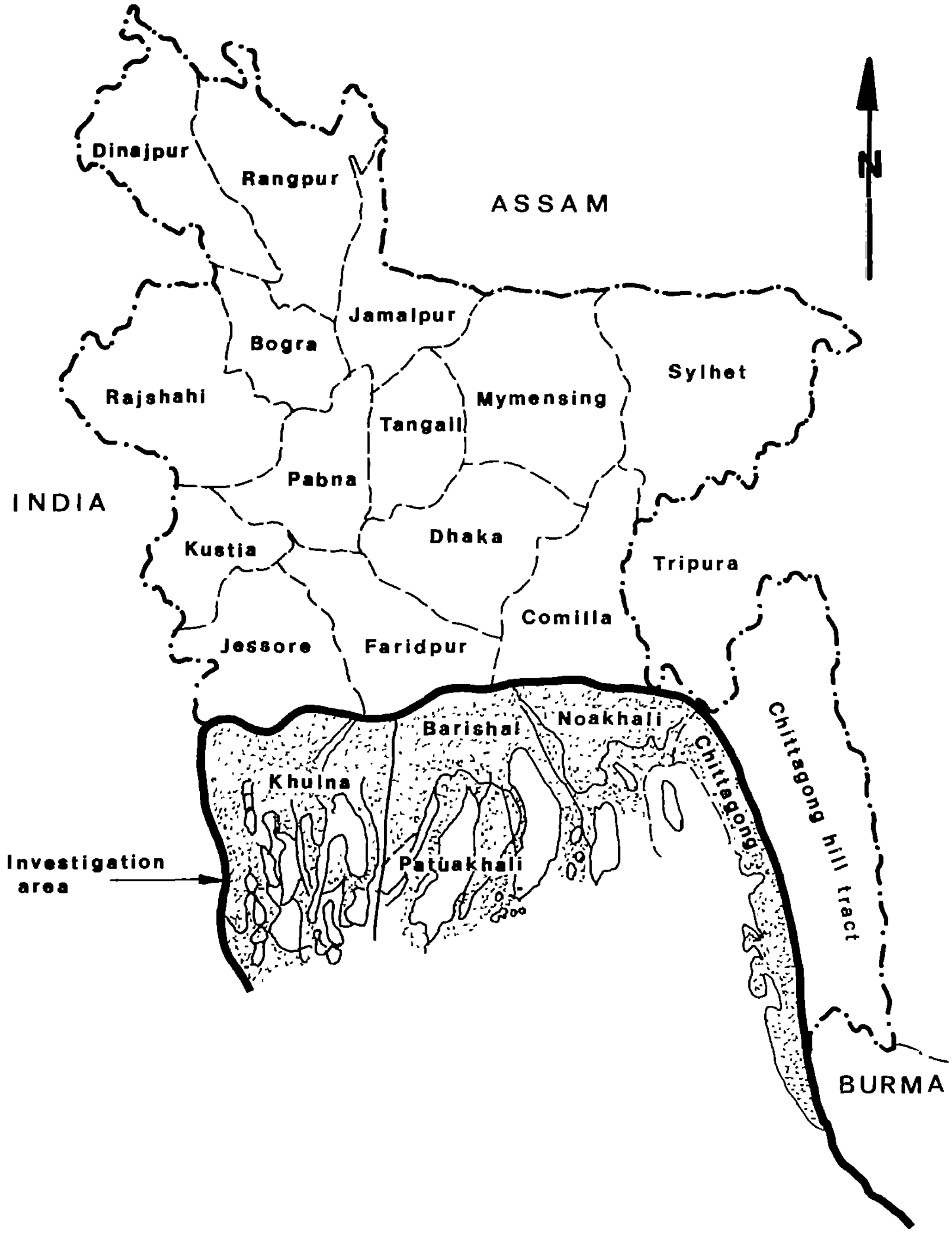

Figure 2. Bangladesh, showing the coastal belt.

UNICEF and DPHE have been at work during the last few years to provide safe water in the "underserved" areas of the coastal belt. The problem areas of the coastal belt are shown in Figure 2. The technologies used for rural water supply in the coastal areas include shallow tubewells, deep tubewells, shallow shrouded tubewells, very shallow shrouded tubewells and pond sand filters.

In those parts of the coastal belt where deep or shallow tubewells are successful the problem is not felt much, but a severe problem is experienced in the rest of the area, particulary in the dry season. Having no potable water source in the vicinity of the house the people, including the womenfolk, walk considerable distances to fetch water from a surface water pond or a hand tubewell. In these areas the research and development division of DPHE has recently been trying to locate non-saline potable water. In some places the attempt has been successful and others not, but investigation and exploration are continuing.

Prospects for rainwater catchment in the problem areas of the coastal belt

Bangladesh is a tropical country and receives heavy rainfall due to north-easterly winds during the rainy season between June and October. A 10-year rainfall pattern based on the country mean rainfall intensity from 28 stations for the period between 1981 and 1990 is shown in Figure 3. In 1990 the maximum monthly rainfall occurred in July and the minimum rainfall was recorded in January/February and November/December. Rainfall in Bangladesh is not uniform over the year, but catchment of rainfall in one season and storing it for use in the dry season is normally both inconvenient and unnecessary, particularly where tubewells are normally successful.

However in the coastal belt there is a predominance of clay and clayey formations at ground level (Fig. 4). As a result surface tanks serve as rainwater catchment reservoirs which the people use round the year both for drinking and other domestic purposes, with or without any treatment. Normally alum $[AL_2(SO_4)_3 \cdot 18H_2O]$ is used for treatment and the decanted water is then suitable for drinking purposes.

In recent years pond sand filters (PSF) have been devised (Fig. 5) which pump in raw water from the pond and produce bacteriologically safe drinking water for consumers in the problem areas.

Following a series of exploratory borings it has been confirmed that in some parts of the coastal belt the availability of potable ground water is either nil or the prospects are bleak. The only solution here is rainwater catchment in surface ponds. These ponds have natural clay linings and serve as rainwater reservoirs. A pond sand filter should be on the bank of each pond to provide a supply of potable water. Rainwater harvesting is at present practised on a very limited scale, mainly on offshore islands. Owing to the unequal distribution of rainfall throughout the year a system completely dependent on rainwater would require large reservoirs, but the potential of rainwater as a supplementary water source is very good. Since the rainy season covers a period of about 6 months water collection is not possible throughout the year, however there is ample scope to explore the possibilities for large-scale storage of rainwater during the rainy season for use in the dry season; low cost technology for collection and storage has yet to be developed.

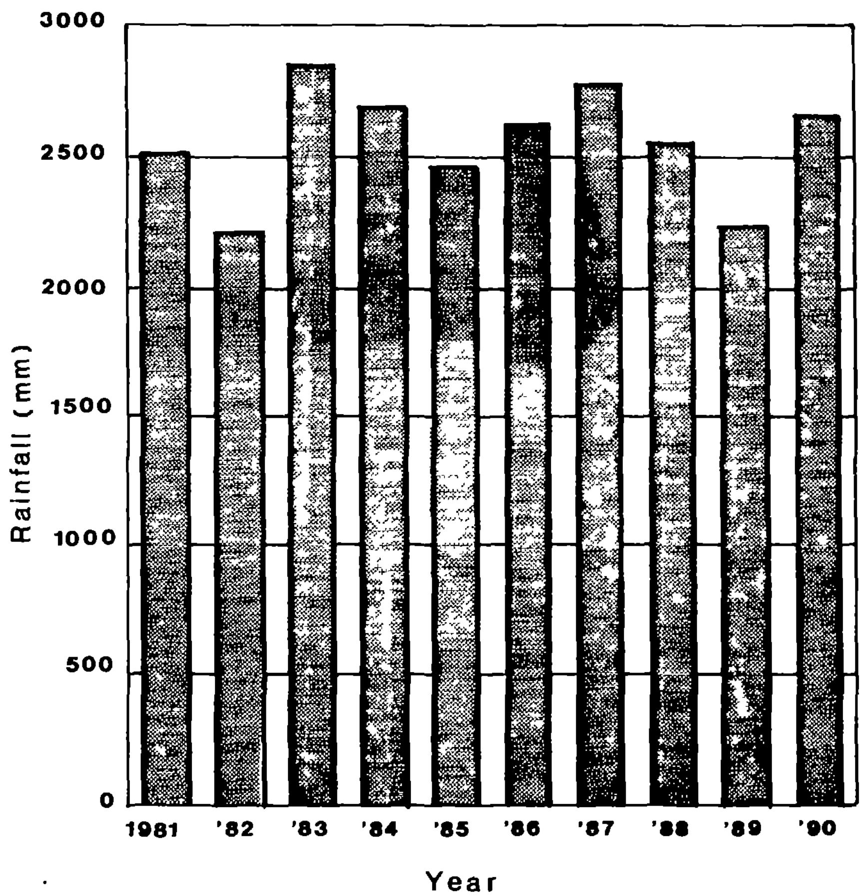

Figure 3. Mean annual rainfall Bangladesh.

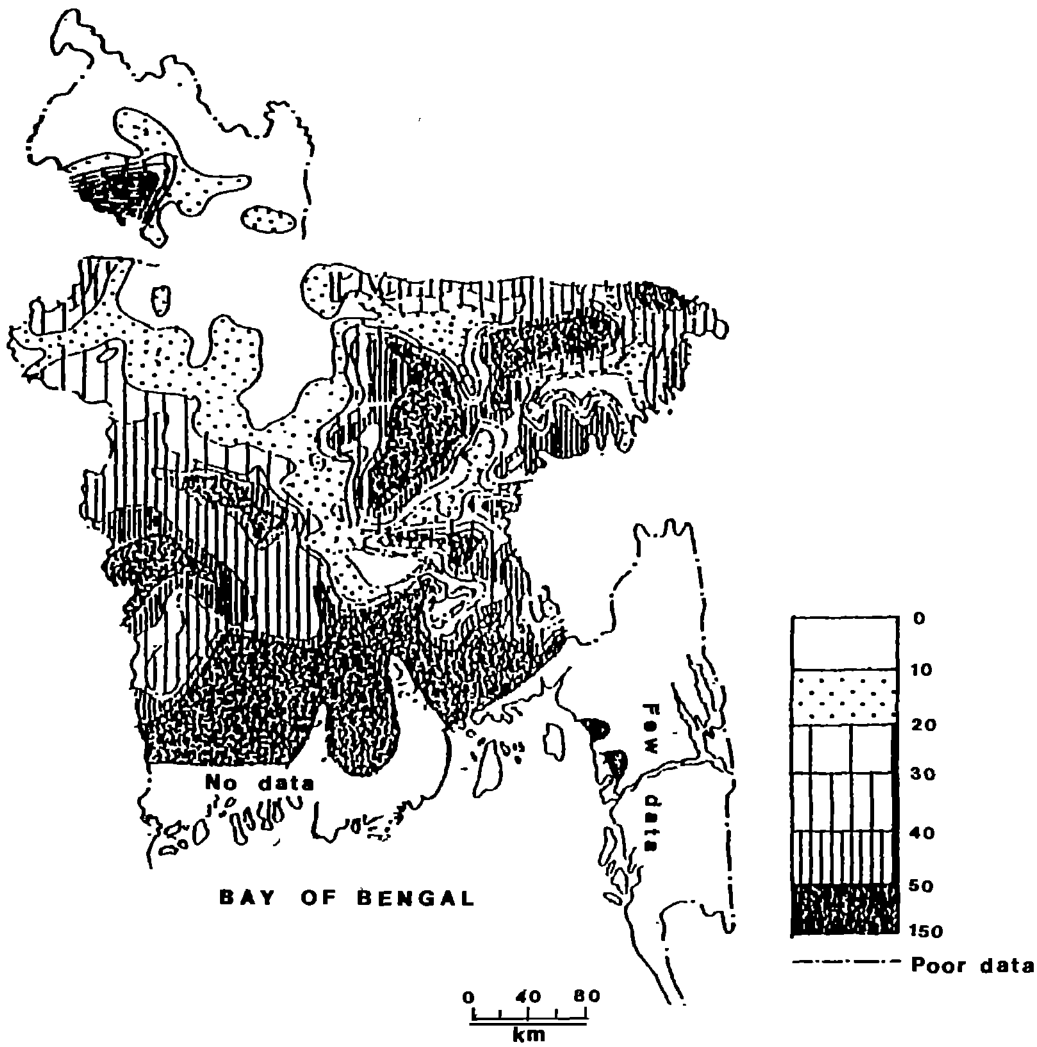

Figure 4. Bangladesh showing the maximum thickness of silty clay (source: MPO).

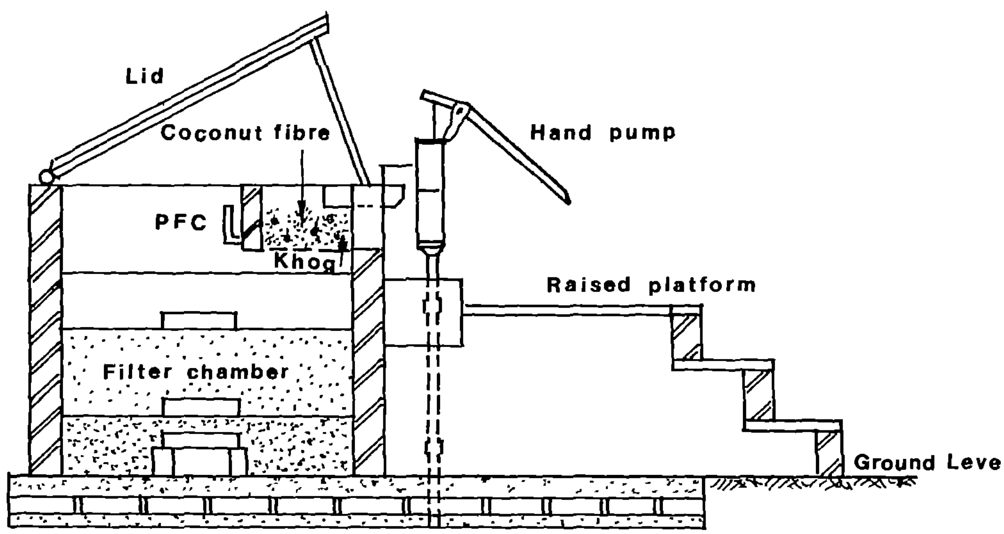

Figure 5 Sectional view of a small pond sand filter.

CONCLUSION

In Bangladesh, a lack of fresh ground water is not so acute, except in the saline coastal belt where various water supply systems have been developed. One of these is the pond sand filter which is dependent on rainwater storage in surface water ponds. In rural areas, homesteads are widely scattered. Wherever there are surface water ponds they can be used to collect rainwater and developed to augment potable water by constructing pond sand filters. More surface water ponds need to be excavated for catchment of rainwater, but this would, of course, involve a huge monetary investment.

TOWARDS AN ACTIVE INVOLVEMENT OF THE PRIVATE SECTOR FOR HIGHER EFFICIENCY IN THE PROVISION OF WATER IN TOWNS: OPTIONS FOR KENYA

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ABSTRACT

As more people move to towns, a major problem for the coastal authorities is emerging in the provision of water with regards to both the quantity and the quality.

The management of water supply systems are far from reaching their desired targets, since responsibility is mainly shouldered by local authorities, which are constrained by numerous problems. The net result is that few urban residents have access to clean water.

This paper puts forward a case for a more active role for the private sector in the provision of water in our fast growing towns.

INTRODUCTION

Urban centres are characterized by very high population densities (e.g. Nairobi has an average population density of 3040 residents per km), intensive land use and very fast settlement dynamics. Consequently the water demand is very high for each of the various urban requirements, i.e. domestic, commercial, industrial and institutional, the quantity and quality being specific to the use.

Water provision in the growing towns is the responsibility of local authorities - which range from urban councils to city councils - who have been unable to meet the water supply needs as the population continues to grow. Their constraints include financial, technical, institutional incapabilities, political and social problems and result in a large deficit in water supply. This has health implications, especially in the low-income areas.

URBANIZATION

The most striking social change in Africa in general, and East Africa in particular, in recent years has been the relatively rapid growth of both existing and newly established population centres, ranging from trading centres to small towns, and the rate of growth is accelerating. The current rate of urbanization is estimated to be about 6% per annum, while the level of urban settlement is about 25% of the total population (Fig.1).

Table 1. Rate of urban population growth.

Year	1950	1960	1970	1980	1990	2000	2010	2020	2025
Urban population (%)	5.6	7.6	10.1	16.4	23.0	29.6	36.6	43.8	47.8

This shows an increasingly bigger population is living in towns.

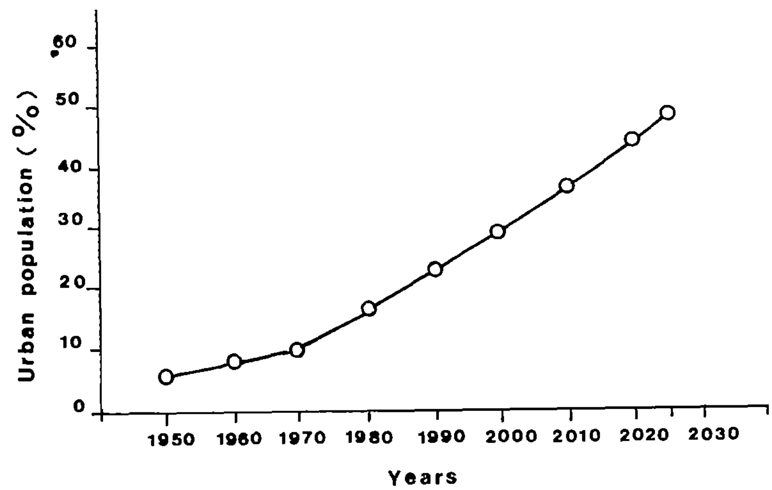

Figure 1. Actual and projected percentages of total urban population in Kenya, (UN, 1992).

CURRENT WATER PROVISION BY LOCAL AUTHORITIES AND ASSOCIATED CONSTRAINTS

Water provision by the various small local authorities is undertaken by sections of departments such as engineering and planning. It is only in big towns where there are specific departments (such as the Water and Sewerage Department in Nairobi) catering for water use.

Responsibilities in water supply can be represented systematically, as illustrated below:

Water catchment (surface water)

↓

Water treatment

↓

Piping

↓

Supply point management (by use of a water meter)

↓

Waste water disposal.

At the catchment point, engineers use gravitational and topographical advantages for water intake and subsequent flow.

Water treatment is normally done by the settling method and by using purifying chemicals to achieve the permissible consumption quality, before transportation to consumers by pipes; delivery is controlled by a water meter at the outlet. After the water has been used it is normally disposed off through the sewer system.

Consumers apply for a water meter from the relevant local authority, which installs it and charges for the water used, at specified rates, after a monthly meter reading.

The whole water supply system is maintained by the relevant local authorities. But there is not involvement by them in rainwater harvesting and the associated ground-water sources in urban areas as alternatives or supplements to surface water sources. The initiative for this is left to individuals, who may have limited resources and little technical know-how on their exploitation and the associated water quality risks. Individual efforts at tapping rainwater and ground aquifers is evident only in the high income areas where roof catchment and borehole drilling are practised, but this is on a very limited scale. The enormous potential of rainwater harvesting and ground aquifers lies untapped while thousands of urban residents go without water. Roofs, tarmac roads, pavements and other concrete areas which predominate in urban areas, offer possible choices for rainwater harvesting; the frequent urban flooding (which is rainwater going to waste) can attest to this. These alternative water sources need to be incorporated in urban water supply policy if any meaningful development in water provision is to be attained and more research and political goodwill should be geared in this direction. The major towns in Kenya lie in the high rainfall zones of the Kenya highlands and the associated Rift Valley, the Lake Victoria basin and the coastal strip (Fig. 2). Other towns in the arid and semi-arid zones could also benefit from rainwater harvesting and ground aquifer exploitation, as they are adequately endowed with both.

The problems which have been identified in the water supply process by the local authorities include:

1. Financial problems;
2. Technical problems;
3. Manpower problems and poorly motivated staff;
4. Ethical problems, e.g. corruption;
5. Institutional incapabilities;
6. Poor collection methods of water charges;
7. Long delays in water meter installation and subsequent monitoring, leading to water wastage and free supply;
8. Low research priorities in alternative sources of water;

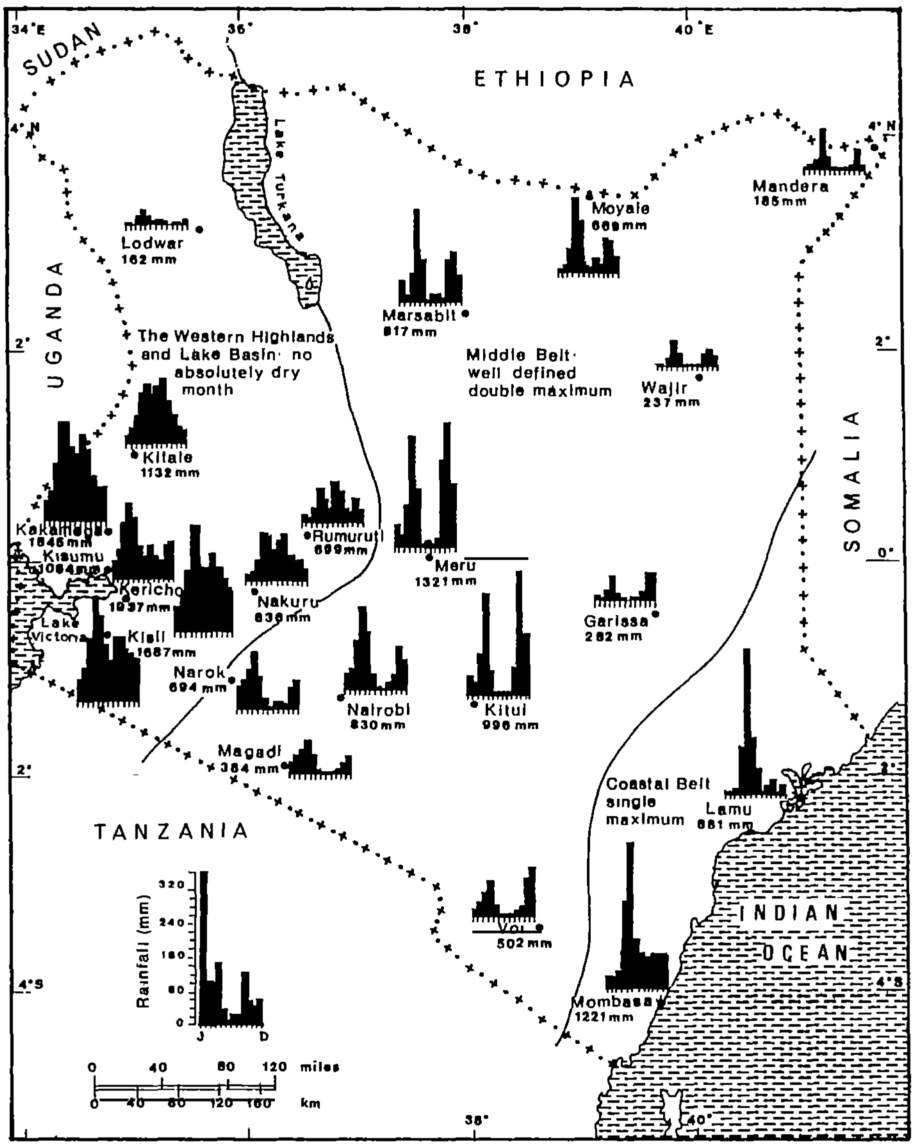

Figure 2 Annual rainfall in selected towns

9. Political interference and bottlenecks in the management of local authorities.

As a result many urban residents are making do with scanty water, low-quality water, or no water at all in some cases.

THE PROPOSED ROLE FOR THE PRIVATE SECTOR IN URBAN WATER SUPPLY, AND THE WORKING MODALITIES

The private sector is traditionally more efficient as it works for profit maximization. With relatively more favourable terms they manage to attract highly motivated better-qualified manpower, leading to better management skills. They strive to provide the best service in a competitive environment. They can also be sued if a project is not completed to specification, unlike local authorities which, being extensions of government, are immune from legal redress.

Local authorities, which are part of the large amorphous public sector, have proved incapable of providing most urban services efficiently, hence the need for the involvement of private enterprise in the following proposed areas:

1. Water catchment, treatment and piping;
2. Installation of water meters and collection of water charges on a commission basis to increase revenue;
3. Exploration ofthe use of sub-surface tanks for runoff catchment should be intensified, and carried out on a cost-recovery basis. Research into alternative water sources such as rainwater, ground-water aquifers, and waste-water recycling.
4. Incorporation of rainwater catchment technology at the project design stage, e.g. architects and engineers should include basement storage tanks for roof and runoff catchment in their designs.
5. Construction of water tanks for roof catchment: underground tanks in basements and in newly built estates and public places (e.g. parks).

If there is no means of purifying harvested water to make it fit for human consumption, it can be used for toilet flushing, general washing and fire extinguishing, among other uses.

The operations of private companies should be in high income residential areas, industrial areas, commercial areas and institutions, where the beneficiaries can definitely afford to pay. If need be, government or the relevant local authority can be involved in pricing of the commodity to avoid exploitation.

By partial privatization of water services in specified areas, the local authorities, would be expected to provide adequate water in the low-income areas as their overall burden would be lessened. There should also be more NGO, Aid Agency (e.g. UNICEF), volunteer (e.g. churches) and community-based water supply projects (e.g. boreholes) using appropriate technology (e.g. hand pumps) in low-income areas.

CONCLUSIONS

The above proposals would enhance water supply as the private sector is more efficient if the right incentives are available. This would increase the revenues collected, which are necessary for the support of other aspects such as research, water quality monitoring and maintenance. The burden on local authorities would be reduced without them losing control with the benefit of revenues generated from urban services. The better qualified and motivated private sector manpower, and better managed research capabilities would be available for urban water supply programmes.

REFERENCES

Otieno, F.O. (1992). Quality of Urban Runoff in Nairobi. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems in Kenya.* Nairobi.
Ojany, F.F. and **Ogendo, R.B.** (1988). Kenya: A study in Physical and Human Geography, Longman, Kenya.
UNCHS (1991). *Urbanization and Sustainable Development in the Third World: An Unrecognized Global Issue.*
UNCHS (1991). *The Conservation of Drinking-water Supplies: Techniques for Low-income Settlements.*
UN (1992). Department of Economic and Social Development, Population Division.

TECHNOLOGY

RAINWATER CATCHMENT SYSTEMS AND TECHNOLOGIES - AN OVERVIEW

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Rainwater has been collected and stored for domestic and agricultural uses for thousands of years. Modern techniques involving exploitation of river systems and ground water resources using large piped water supplies and deep wells have over the last five decades tended to divert attention from development of rainwater harvesting technologies.

Even though the developed countries in the world take most of their water from large river basins, it is now clear that modern technologies involving huge water resource development projects are not necessarily viable in all situations. Even where these technologies are considered viable the relationship between large-scale water resources development and the destruction of eco-systems gives cause for concern. Nor has this type of water resource development shown much success in developing countries, which faced with enormous food security pressures, rapid population growth and economic hardship, can ill-afford to make the large investments required for these modern systems.

Furthermore, the human population in water-deficient regions is steadily increasing, heightening the need for a generally applicable and sustainable water technology. The development, promotion and utilization of rainwater catchment systems may well be the answer to this need.

Rainwater harvesting is an ancient art which is still practised in many parts of the world. Rainwater harvesting techniques such as rock catchments, the collection of runoff through construction of furrows and channels, floodwater spreading and storage of run-off in dams, tanks and cisterns, are used by many people in rural and urban settings. These technologies are increasingly being recognized as affordable, environmentally sound and simple alternatives for water supply systems.

In urban areas rainwater harvesting can help alleviate critical water supply problems and supplement floodwater control activities and this aspect of rainwater harvesting systems needs to be promoted much more seriously. A useful background to innovative rainwater harvesting in urban and peri-urban areas is presented in several papers in the technology section, as well as on the alternative uses of storm water and runoff for non-potable requirements.

Rainwater harvesting in remote and rural areas of developing countries represents another critical area of concern. A number of papers concerned with viability of using rainwater harvesting as a source of rural water supply, for augmenting village water supplies, as a supply scheme for remote areas, and modelling, are also included. Rainwater harvesting technologies and techniques for rural and remote areas need to be developed and propagated on a much larger scale than at present. However, combining local skills with good design and building methods in these areas is a major challenge at present.

Engineering aspects including design, implementation, construction and operation form the cornerstones of success for any technology. Material and technique developments lead to improved and appropriate construction practices, and proper operation ensures optimal use. A number of papers covering these technical aspects are included in this section. These relate to strategies for implementing rainwater catchment systems; the design of rainwater catchment technologies, particularly ponds, rock catchments, storage devices (including rainwater jars, cisterns and reserviors), instrumentation and disinfection systems. Water quality, design of storage devices, sustainability, cost and performance of rainwater catchment systems are major areas of concern for future development, based on these papers.

The final section on rainwater technologies relates to cloudwater harvesting and includes the use of cloudwater for mountain agriculture, and high elevation fog as a water source. This technology has a very regional emphasis at present and needs to be promoted more widely.

Rainwater harvesting is a technology which can contribute much towards the challenge of providing drinking water to all lacking this vital life sustaining commodity. It is hoped that the papers contained in this section of the conference will contribute significantly to increasing current knowledge about rainwater harvesting technologies.

RAINWATER CATCHMENT: POSSIBILITIES IN URBAN AND PERI-URBAN BOTSWANA

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ABSTRACT

There are enormous possibilities for rainwater catchment in urban and peri-urban Botswana which have not been exploited. A considerable amount of housing stock, for instance, still relies on stand pipes as the main source of domestic supply, and large Government developments rely on water bowsers for landscaping needs which are both wasteful and extremely costly. Existing roof catchment systems are frequently poorly designed and consequently operate far below their full potential.

This paper considers the use of rainwater as a supplementary water source and the possible savings which this can provide. The problems of water quality and computer-aided design for sizing are also discussed. By using estimates of housing stock and Government buildings in the capital city, Gaborone, a case is made for rigorous implementation of a rainwater catchment programme.

The water management system for the proposed new Botswana Technology Centre headquarters, an extension of the extensive inter-linked rainwater catchment system already in place, is also considered.

INTRODUCTION

Botswana has a semi-arid climate with mean annual rainfall varying from less than 250mm in the extreme southwest of the country to more than 650mm in the extreme north (Fig. 1). The rainfall is erratic and mainly concentrated in a rainy season lasting from October until April. Evaporation, on the contrary, is predictable and rates exceed 2000mm per annum in most areas. Due to Botswana's flat topography and sandy pervious soils, surface water sources are limited. Although a few ephemeral rivers have been dammed to create reservoirs for serving major settlements and industry, the lack of suitable rivers and dam-sites means that surface water supplies are not generally appropriate for providing rural water supplies.

Good quality ground water is available in many areas of Botswana and over 15,000 boreholes have been sunk throughout the country to access this supply. In some areas, however, the ground water is either too deep, too unreliable or too saline to provide an acceptable supply for domestic purposes.

In urban areas water supplies are good for the wealthier sections of the population, who generally receive a reliable supply of high quality potable piped water at a very reasonable price considering the scarcity of the resource. The poorer sectors living in make-shift or self-help housing agency accommodation often have to make do with water supplies from shared standposts at some distance from their homes.

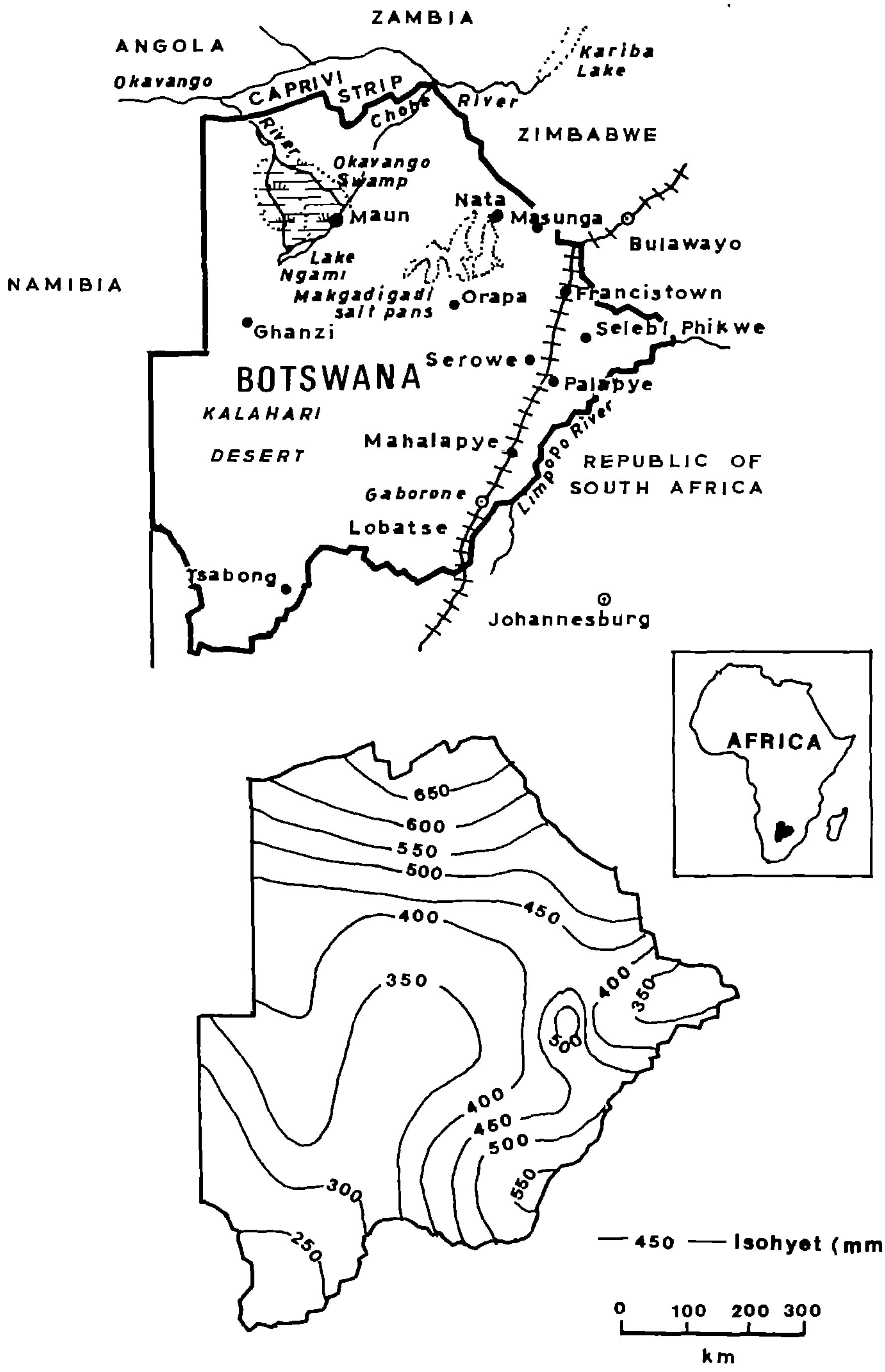

Figure 1. Map of Botswana and mean annual isohyets.

HISTORY OF RAINWATER CATCHMENT SYSTEMS IN URBAN BOTSWANA

Although the evidence is limited, traditionally people in Botswana have collected rainwater running off ground surfaces in excavated pits, and from the eaves of thatched roofs. While major villages such as Serowe and Kanye with populations exceeding 10,000 have existed for centuries (although Francistown, an old gold mining railway town, dates back to the 1860s), most urban settlements in Botswana are less than 30 years old. The largest, the newly planned capital of Gaborone has grown from a cattle-post of a few hundred people to a city approaching 150,000 in less than three decades.

The use of formalized rainwater catchment systems, such as roof catchment tanks, probably dates back to the turn of the century. At that time the first corrugated-iron roofed railway buildings and small trading stores served by the rail service provided the opportunity to develop effective roof catchment systems.

Many older buildings in Botswana had rainwater tanks included in their original design. In Nata, for instance, an old miners' staging post (now part of the primary school) still uses tanks built in the 1940s, and even in Gaborone many of the Botswana Housing Corporation (BHC) high cost houses built in the 1960s had corrugated iron tanks. Today, only a small minority of mainly older houses still have tanks.

In the 1980s the Botswana Technology Centre encouraged the implementation of ferrocement rainwater tanks using the design advocated by Watt (1978) involving the use of corrugated iron moulds. Around 150 tanks of this type were constructed ranging in volume from 10 to $30m^3$. However, as a result of poor workmanship and inadequate training and supervision (Gurusamy-Naidu, 1991), there was a variety of problems with these tanks and only a minority have stood the test of time.

FINDINGS FROM A SURVEY OF GABORONE

Aerial photograph analysis

In this survey a 1:20,000 aerial photograph taken over Gaborone in December 1989 was enlarged to 1:7500 and then, using a Planovariometer, the image was further enlarged to 1:2000. From this image measurements were taken of 100 residential houses selected at random. Although the method worked well for larger houses it was difficult to measure smaller roof areas accurately. The method was therefore complemented by direct measurements from the 1:7500 enlargement assisted by a magnifying glass. Using these two approaches it was found that roof areas ranged from $48m^2$ to $315m^2$ with the mean area being $109m^2$.

Survey of buildings in the government enclave

A survey of the buildings within the government enclave in Gaborone was conducted using a 1:1000 map (updated in April 1991), in conjunction with an enlarged 1:20000 aerial photograph image over the area. The objective of the survey was to examine the technical and economic feasibility of constructing tanks for supplying water for the lawns and flower beds next to buildings and for washing cars. The findings are summarized in Table 1.

Table 1. Summary of government enclave survey

No. of large buildings (>400m²)	**32**
Total roof area	**32,782m²**
Maximum potential rainwater supply	**13,112m³**
Tank capacity required	**6,556m³**

Possible project scenarios

1. In order to maximize the volume of the rainwater supply from the 32 main buildings within the enclave, the construction of 143 46m^3 tanks would be required. This would provide an estimated mean supply of 13,112 m^3 per annum.

2. A second more practical scenario might involve focusing on the 12 main government buildings (ministries etc.) in the enclave and endeavouring to build four 46m^3 tanks at each one.

3. The third and most favoured scenario would involve the construction of one 46m^3 tank at each of the 12 government institutions within the enclave. Although this would involve the construction of only 25% of the storage capacity of that proposed in Scenario 2, due to the very large roof area supplying each tank, the supply is estimated to be almost 50%.

Using data from Bhalotra (1985) it was noted that Gaborone has an average of 13 rainstorms per year exceeding 15mm of rainfall. The high roof area to tank volume ratio in this scenario means that considerable losses will occur due to tank overflow. Nevertheless, if we assume that a volume of water at least equivalent to the runoff produced by the 13 largest storms each year could be collected, the total runoff from the 12 buildings would be 2010m^3 per annum. This would yield 40,198m3 over the 20-year life expectancy of the tanks at a cost of P72,000 (12 x P6,000) equivalent to P1.79/m^3.

Table 2. Potential rainwater supplies and costs of each scenario

	Supply (m³)	*Total cost*	*Cost per m³*
Scenario 1	13,112	P858,000	P3.27
Scenario 2	4,428	P288,000	P3.25
Scenario 3	2,010	P72,000	P1.79

Notes:
Scenario 1: 143 large (46m³) ferrocement tanks.
Scenario 2: 48 large (46m³) F/C tanks at 12 buildings.
Scenario 3: 12 large (46m³) F/C tanks at 12 buildings.

The costs associated with these three scenarios, namely, P3.27/m^3, P3.25/m^3 and P1.79/m^3, compare favourably with the long run marginal cost for water in Gaborone estimated at P3.98/m^3 (Water Master Plan, 1990). The cost in scenario 3 is even competitive with the current Water Utilities Corporation tariff of P2.37/m^3. The prices quoted refer only to the cost of building the required storage tanks and not the cost of making modifications to gutters and down pipes or to the cost of site survey etc.

Scenario 3 makes economic sense even when additional costs are added into the calculations. The construction of large ferrocement rainwater tanks at every ministry building would also afford the government an opportunity to demonstrate a serious approach towards promoting water conservation throughout Botswana. The tanks might also be used as billboards with slogans promoting water conservation.

Survey of residential housing stock

The total developed housing stock in Gaborone in March 1991 was 16,034 units. Using the fact that the average roof areas of BHC (Botswana Housing Corporation) high, medium and low cost housing are 136m^2, 112m^2 and 64m^2 respectively, and that the number of units in each respective category were 884 units, 1778 units and 4478 units, it was possible to calculate the mean and total roof areas for all BHC housing. The total roof area for all BHC houses came to 605,952m^2, an average of 85m^2 per unit. Based on information obtained from Self Help Housing Agency (SHHA) it was estimated that the mean roof area of SHHA houses is 80m^2. The remaining housing stock not covered by either SHHA or BHC is comprised of privately owned units accounting for just 7% of the total stock.

In order to obtain an approximate estimate of the total roof area of all developed residences in Gaborone, the figures for the SHHA and BHC housing were added to a figure for private housing. This gave a grand total of 1,483,932m^2 or an average of 93m^2 per unit (slightly less than the 109m^2 obtained from the aerial survey method). To compensate for the inclusion of flats a reduction of 5m^2 per unit was made giving a mean average figure of 88m^2 per unit.

Potential residential roof runoff supply in Gaborone

Based on the figures above it is easy to calculate that the mean annual (collectable) roof runoff for residential properties in Gaborone is 88m^2 x 0.535m x 0.8 = 37.7m^3. To maximize the amount which could on average be collected and would provide a steady supply a 15m^3 tank would be required. This could provide an even supply of 30m^3 per year with a 95% reliability of supply. If all residences had this ratio of rainwater storage volume to roof area 481,035m^3 could be collected annually having a value equivalent to P1,140,000 at current Water Utilities rates.

In an urban environment such as Gaborone where all BHC and private units have house connections, and where SHHA houses have, at the very least, convenient access to a standpost, the aim of a rainwater catchment system is not necessarily to provide the maximum possible supply, but rather to provide a back-up supply and encourage water conservation in the most economical way possible. A least cost solution to collecting as much rain as possible while keeping expenses to an absolute minimum is thus desirable.

Using the same analysis that was applied to the 12 buildings in the government enclave (Scenario 3) in which the minimum water yield from the 13 wettest storms each year (which on average in Gaborone exceed 15mm) was calculated. One finds that in relation to the total residential housing stock, a yield of 220,115m^3 per annum or almost 14m^3 per household could be achieved using only a very limited storage capacity of just $2m^3$ provided water was used up when available and not stored for prolonged periods. In this instance the value of the water when priced at Water Utilities rates would be around P521,672 per annum.

Thus over 20 years (the assumed life expectancy of the tanks) water worth over P10 million could be collected from the roofs (existing as of March 1991). This works out at P625 worth of potential water savings per household based on a scenario involving the comprehensive installation of 2 m^3 roof tanks and the maximum use of available rainwater (Table 3).

Although the quantities of water are small in comparison with the total annual demand and the scale of supply offered by major projects such as the Bokaa Dam and North-South Carrier, they are nevertheless significant, particularly if developed in conjunction with large roof tank construction on institutional buildings and on commercial and industrial buildings. The largest industrial and commercial buildings in Gaborone have roof areas of several thousand square metres and dwarf even the government ministry buildings. Widespread collection of roof runoff, collection and use of storm water runoff and greater emphasis on industrial water recycling and domestic conservation measures such as use of grey water and low flush toilets could go a long way to reducing Gaborone's rapidly increasing water demand, or at least defer the time before the next major water supply project needs to be undertaken.

Table 3. Summary of Gaborone residential roof supply survey

Available roof area:	
Total housing stock (March 1991)	16,034 units
Estimated total roof area	$1,483,932m^2$
Estimated total roof runoff	$481,035m^3$
Potential Rainwater Supply:	
Using limited storage ($2m^3$ per household)	220,115 m^3
Annual value of water saved	P521,672
Total potential saving over 20 years tank life	P10,433,440
Total saving per household over 20 years	P625

APPLICATION OF COMPUTER MODEL FOR TANK SIZING IN BOTSWANA

Computerized methods of tank size determination

A number of computer modelling techniques based on the principle of mass curve analysis have been developed by Schiller and Latham (1982) and others. These models use past rainfall data to predict the future performance of a rainwater catchment system given certain parameters such as catchment area, tank volume and demand. An accurate and lengthy rainfall record is essential for this method. Additional calculations for the reliability of different levels of supply can also be included and the results plotted in a graphical form.

Using a computer model developed by Latham (1983) as a design tool, Gould (1985, 1987) calculated the potential rainwater supply given as a fraction of the total catchment runoff (the supply fraction) for different storage capacities, using actual monthly rainfall data for a 30 year period from 10 stations in Botswana. In the case of Gaborone a storage equivalent to 0.4 (40%) of the volume of useful runoff was found to provide a yield equal to 0.8 (80%) of the runoff volume, with 95% reliability. In other words, a $40m^3$ tank being supplied with $100m^3$ of runoff per annum would yield a steady supply equal to $80m^3$ per annum, with 95% reliability. This means if the life time of the tank is 20 years one would expect it to be empty for a total of only 5% of that time, 1 year or 12 months in total. This would occur only during the severest drought periods and in reality the application of rationing could in theory greatly reduce the period the tank might be dry. In the case of Botswana as a whole Gould (1985) found that constructing tanks with volumes larger than 0.4 (40%) of the useful runoff soon becomes uneconomic on the grounds of diminishing returns.

The limitations of existing computer modelling techniques

While computer models can be useful when trying to design a system for meeting a certain demand or for calculating the maximum annual supply from a given system and for a given reliability (probability) level, short-comings arise when trying to model actual behaviour of the systems. The reason for this is that while it is easy to develop a model showing the behaviour of a system when a fixed demand is assumed, in reality users dependent on rainwater as their primary supply are likely to ration water in periods of drought or water shortage, but use water liberally at times when the tank is full and rainfall frequent. Modelling the complex response of the users demands to the fluctuating availability of the rainwater supply and a variety of other external factors, e.g. time of the year, dry or rainy season etc. is much more difficult.

For many urban situations the use of rainwater catchment systems is frequently as a supplementary or back-up supply; in such cases rainwater may only be used for certain purposes and at times when the main supply is temporarily suspended. Again modelling this sort of system is much more difficult because the performance of the system is difficult to predict as it depends on unpredictable parameters, e.g. the time and length of a breakdown of the main supply.

A rainwater catchment system modelling program called RAINSIZE has recently been developed by Latham (personal communication, 1992) for use on PC's using Lotus 1-2-3 software. This is currently being tested using rainfall data for Botswana and results should be available shortly.

EXAMPLES OF POOR DESIGN

While the careful optimization of catchment areas with tank capacities is a desirable long-term goal, at present so many basic design errors, requiring no more than careful observation to identify and often little expense to rectify, are still prevalent, that efforts to address these would prove equally worthwhile. Obviously, for new projects where standard designs are being developed, computer-aided design techniques can help to increase system efficiency and cost effectiveness. The following example, on the other hand, clearly illustrates the enormous inefficiency and waste of resources which can result from poor design.

A recent attempt to include roof catchment tanks in a major government housing scheme in Masunga in northeast Botswana involving the construction of 70 units, provided a classical example of how not to design a roof catchment system. Five major design flaws were obvious even to the casual observer; they are illustrated in Figure 2 and include the following problems:

1.	Gutters not sloping	(50% of collection capacity lost)
2.	Only half roof area used	(50% of collection capacity lost)
3.	Overflow pipe too low	(25% of potential storage capacity lost)
4.	Tap too high	(25% of potential storage capacity lost)

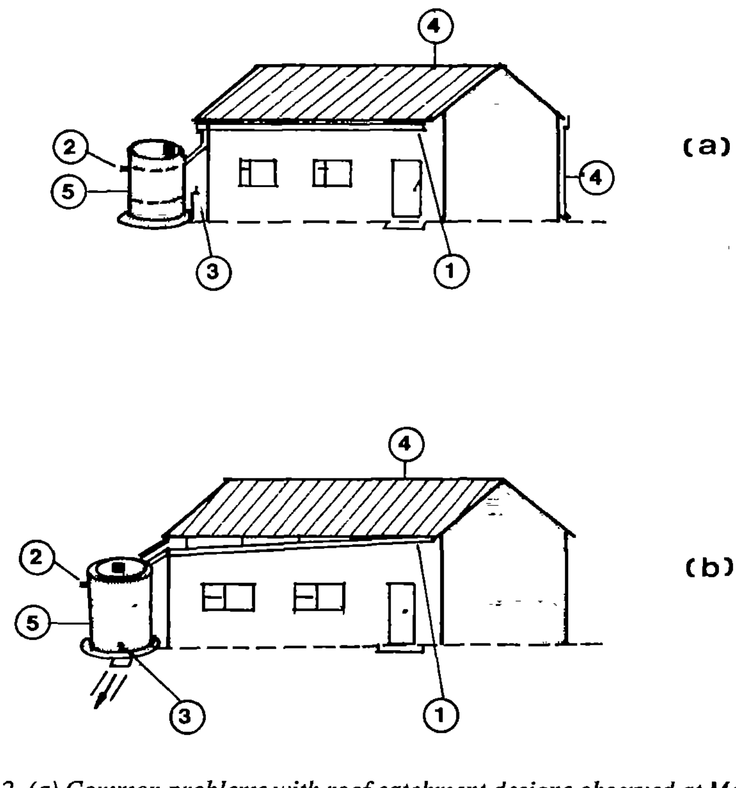

Figure 2. (a) Common problems with roof catchment designs observed at Masunga, Botswana and (b) an example of a good system. Important points: 1, gutter slope; 2, height of overflow; 3 height of tap; 4, catchment efficiency; 5, storage efficiency.

The result of these design inadequacies was that the overall efficiency of the roof catchment systems was reduced to an estimated 10-20% and many householders complained that their tanks were not getting filled. Considering that the total cost of all the tanks constructed was at least P350,000 the cost in wasted potential will amount to between P280,000 and P315,000 for this project alone if these flaws are not rectified. This case illustrates the problems of not integrating rainwater catchment systems into the original designs but including them as after- thoughts, and of using contractors who are not sufficiently aware of the purpose and design requirements for constructing an effective system.

RAINWATER CATCHMENT SYSTEMS AT THE BTC HEADQUARTERS

Existing facility and future development

In 1983 the Botswana Technology Centre (BTC), keeping with the need for more accommodation for its growing staff, commissioned the building of a new headquarters in Gaborone. This was in the midst of a drought when the government had decreed that no building would be allowed as part of a water conservation strategy. Permission to go ahead was finally obtained by incorporating a comprehensive rainwater catchment system into the plan, which provided the possibility of the centre being completely self-sufficient in its water needs. The BTC headquarters was built during 1984 to an award-winning design which incorporated not only the water catchment features mentioned above but also passive solar design features and an innovative choice of building materials. A plan of the building and the water tanks is shown in Figure 3. A total storage capacity of 240m^3 is provided by four underground and one above ground ferrocement tanks (Gurusamy-Naidu and Gould, 1992). A computer model was used in order to design the system to maximize water supply within realistic costs. The rainwater runoff from the roof as well as the car parking areas is collected. To aid with water self-sufficiency, low flush toilets and water conserving faucets were used, cutting down water usage significantly. The whole system was connected to a back-up mains water supply.

In keeping with the further expansion of the BTC a new headquarters is being commissioned on the existing site (Chishimba, Davis and Gurusamy-Naidu, 1993). The building will have a plan roof catchment area of approximately 900m^2 with a courtyard catchment contribution of 180m^2. The rainwater collected will be primarily used for low flush toilets, and for evaporative cooling. A total of four Cool Towers have been incorporated in the design which will provide an inexpensive and natural means of cooling the internal working environment at BTC. Rainwater will also be used to replenish one exterior and one interior fountain. The movement of water and subsequent evaporation will add to the overall cooling strategy for the building. The total storage volume will be 85m^3 using twelve extra 5m^3 above ground water tanks and one, 25m^3 underground water tanks in the central courtyard.

The water for the landscape will be drawn from the existing underground water tanks. As a demonstration of the technology a purification filter will be incorporated in one line leading to the fountain, for drinking water.

The water catchment facility of the existing BTC headquarters will be integrated with the new design envisaged and once completed will be an impressive example of the unlimited use of rainwater in an urban setting.

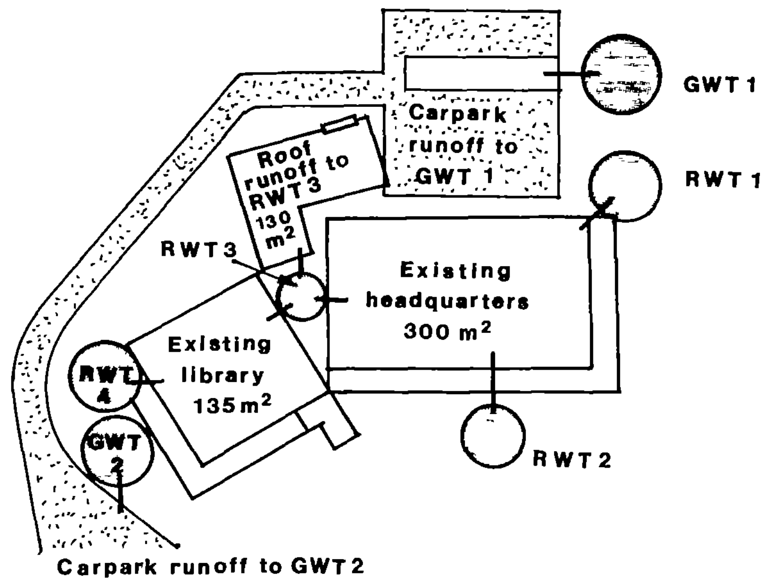

Figure 3. Plan showing the existing rainwater catchment tanks at Botswana Technology Centre. Total car park area = 220m^2; total roof catchment area 565m^2; total rainwater tank (RWT) volume = 140 m^3; total groundwater tank (GWT) volume = 100 m^3.

Water quality

Tests on the water collected at the BTC headquarters confirms that the sub-surface tanks collecting ground runoff have a much higher coliform count as compared to roof catchment tanks. However in all cases the WHO standards for water quality have not been met. In one case cleaning of a roof catchment tank improved the quality of water substantially, reducing the total coliforms from 930 to 13 MPN/100ml while the faecal coliforms were reduced from 4 to 2 MPN/100ml.

POTENTIAL FUTURE DEVELOPMENTS IN URBAN BOTSWANA

There are a number of areas where new development could be encouraged, these include:

- the inclusion of 2m^3 roof tanks in the designs of all future low cost BHC and SHAA housing projects;
- the construction of roof catchment tanks at all peripheral urban houses not currently supplied with piped water;
- the introduction of rainwater catchment systems at large institutional buildings in urban centres to encourage water conservation;

- the construction of large ferrocement roof catchment tanks with volumes up to $50m^3$, at all large government buildings in urban areas (similar to those currently being constructed in Kenya).

CONCLUSIONS

Rainwater catchment systems are currently under-utilized in urban Botswana and considerable potential exists for extending their use. For example, the provision of 12 large ferrocement tanks ($46m^3$) to collect rainwater runoff from the ministry buildings in the government enclave in Gaborone could provide a supplementary water supply for landscaping at a cost well below the current Water Utilities Corporation tariff.

If a $2m^3$ roof tank can be provided for all dwellings in Gaborone (existing as of March 1991) water worth more than P10 million could be collected from the roofs over a period of 20 years giving a potential saving per household of P625.

Widespread collection of roof runoff, collection and use of stormwater runoff and greater emphasis on industrial water recycling and domestic conservation measures (such as use of grey water and low flush toilets) could go a long way to reducing Gaborone's rapidly increasing water demand, or at least defer the time until the next major water supply project needs to be undertaken.

REFERENCES

Bhalotra, Y.P.R. (1985). *Rainfall Maps of Botswana.* Dept of Meteorological Services, Gaborone.

Chishimba, S. Davis, G. and **Gurusamy-Naidu, K.** (1993). Rainwater Catchment: The Botswana Technology Centre Experience, March 1993. *Rainwater Catchment Systems Application and Technology Workshop, Gaborone, Botswana.*

Farrar, D.M. and **Pacey, A.** (1974) *Catchment Tanks in Southern Botswana: A Review.* Africa Fieldwork and Technology, Myson House, Railway Terrace, Rugby CV21 3HT, UK.

Gould, J.E. (1985). An Assessment of Rainwater Catchment Systems in Botswana. Unpublished M.Sc. thesis, University of Alberta, Edmonton, Canada.

Gould, J.E. (1987). An Assessment of Roof and Ground Catchment Systems in Botswana. *Proc. 3rd Int. Conf. on Rain Water Cistern Systems.* Khon Kaen University, Thailand.

Gurusamy-Naidu, K. (1991). Developments in Ferrocement Construction in Botswana. *Proc. 4th Int. Conf. on Ferrocement, Oct. 1991.* Havana, Cuba.

Gurusamy-Naidu, K. and **Gould, J. E.** (1992). Developments in Rainwater Catchment in Botswana. *International Rainwater Catchment Systems Association Regional Conference, Oct. 1992.* Kyoto, Japan.

Latham, B. (1983). Rainwater Collection Systems: The Design of Single Purpose Reservoirs. M.A.Sc. thesis, Dept of Civil Engineering, University of Ottawa, Canada.

Nissen-Petersen, E. (1990). *How to Build a Cylindrical Water Tank with Dome ($46m^3$). A photo manual* KIDP/DANIDA, Nairobi.

Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting : The Collection of Rainfall and Runoff in Rural Areas.* IT Publications, London.

Schiller, E. and **Latham, B.** (1982). Rainwater Roof Catchment Systems. *Information and Training for Low-Cost Water Supply and Sanitation,* edited by D. Trattles. World Bank.

DISCUSSION

In response to a question by **Mr Dan Campbell** regarding the percentage of a family's water needs that may be provided by rainwater tanks, **Mr Gould** stated that total household needs can never be met by rainwater harvesting. In Botswana rainwater is used for drinking, he further stated.

Mr Alfred Wafua, wanted to know how well tanks sized using the computer-aided design methods described in this paper were performing, what percentage of the time these tanks remained empty and how much water was lost through spillage. **Mr Gould** responded that according to the model, the tank will remain empty 5% of the time, but in reality this may be more. He further stated that while spillage had not been measured, it might be considerable during heavy downpours at the end of the rainy season. In response to a question about what percentage of the storage survived into the next "filling period", **Mr Gould** stated that generally none of the storage survived into the next "filling period".

Asked to comment on whether the sizing of the tanks was based on (i) annual rainfall, (ii) demand or, (iii) cost of construction, operation and maintenance, **Mr Gould** responded that the sizing of the tanks, while taking rainfall and catchment area into consideration, is heavily weighted towards maximizing water supply while minimizing the cost.

In response to a question by **Mr Julius Wanyonyi** on whether the failure of gutters, as shown in one of the slides, was due to negligent design and construction or poor operation and maintenance, **Mr Gould** replied that the design problems amounted to negligence on the part of the architect and supervising engineer.

Asked to comment on maximum design capacities and the basis for these capacities for ferrocement tanks, **Mr Gould** stated that ferrocement tanks can be built upto $100m^3$ or more, provided their height does not exceed 2m.

THE UTILIZATION OF RAINFALL IN AIRPORTS FOR NON-POTABLE USES

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ABSTRACT

Rainwater catchment systems have wide applications, from simple roofwater collection to abstraction schemes involving very large catchment areas and associated hydraulic structures like dams, spillways, canals etc. One category of catchment which can be fruitfully tapped is an airport, which has large turfed areas and paved runways. In a case study involving the local international airport, which has a utilizable catchment area of 530 ha, the existing stormwater collection and discharge system includes an extensive network of surface drains and three storage reservoirs. One such reservoir having a capacity of 320,000m^3 has been successfully utilized as a storage reservoir for the last 7 years. The collected surface runoff is pumped at a uniform rate of 128m^3/h to a small pre-treatment plant and the treated water stored in a tank having a capacity of 3332m^3. The water quality, though not of drinking water standard, is being used for toilet-flushing and fire-fighting purposes. The required drinking water is supplied from the town so this airport, in effect, has a dual mode of supply. Whenever the water level falls in the treated water storage tank, drinking water is drawn in. Using an up-graded version of a rainwater catchment model (NTURWCS.MK4) for discretized time intervals of 1 hour, it is established that storage requirements amount to 80,000 m^3. If this is maintained there is no need to replenish the treated water storage tank with drinking water. The annual savings due to the present use of rainwater for non-potable uses amounts to approximately S$390,000.

INTRODUCTION

The roofs of buildings have been used as catchment areas for collecting rainwater since ancient times (Ried, 1982; Gordillo, Gonzales and Ganoa, 1982). Such systems have been revived in the last decade, particularly in developing countries. The utilization of catchments ranging from a few square metres to much larger catchments, have been found to be quite successful. A large catchment area that is extensively paved and also has large well-turfed areas is found at airports. The main objectives of this paper are:

1. To describe the existing rainwater catchment system at the international airport in Singapore;
2. To utilize a developed version of an input/output model using hourly data to appraise the relationship between design parameters like the rainfall input and the variable demand (output) and to determine the optimum storage reservoir volume;
3. To discuss the existing system and computer runs and draw conclusions on the utilization of such rainwater collection systems.

UTILIZATION OF RAINWATER FOR NON-POTABLE USES

A study was carried out in the United Kingdom (Fewkes and Ferris, 1982) in which roofwater from individual dwellings was collected and combined with wastewater and used for flushing of water closets. The results were quite encouraging in terms of implementation and economics. Stored roofwater with minimal treatment was combined with the existing water supply in Japan and used quite successfully for flushing toilets (Ikebuchi and Furukawa, 1982). One of the few studies conducted on storm runoff quality at airports was carried out in Honolulu (Gordon, Elizabeth and Lau, 1984). The runoff, which was subjected to minor treatment, was used for non-potable purposes and had a projected cost which was less than half that of using treated water for the same purpose. In Singapore a study of rainwater tapped from a bus-park cum interchange established that surface runoff could be used for washing buses and then recycled (Appan, Alsagoff and Tab, 1988).

DEVELOPMENT OF AN INPUT/OUTPUT MODEL USING HOURLY DATA

Input/output models

The concept of equating daily inputs and outputs in a simple rainwater catchment system (Appan, 1982) will give the following relationship:

$$Q_i = Ar_i - [(E_i + b_i) + D]$$

where

Q_i is the quantity of water at the end of day i
A is the catchment area
r_i is the rainfall during day i
E_i is the evaporation rate per day
D is the daily drawoff, and
b_i is the absorption rate per day.

This equation has been utilized extensively in the study of abstracting water from the roofs of high-rise buildings (Appan, Lim and Loh, 1987) and an aquaculture farm (Appan and Tay, 1989) in which input (rainfall) and output (demand) data are utilized on a daily basis. In a subsequent study (Appan, 1992), a model was developed (NTURWCS.MK3) in which the input could be varied from 1 second to 1 day and the design parameters compared. This study established that the most conservative operational values were obtained when rainfall data discretized to a 1 hour interval was used.

Modification of parameters and flowcharts for NTURWCS.MK4

In the present study, utilizing the developed model (NTURWCS.MK4) which is user-friendly, the major input and output parameters have been logged on an hourly basis. As the catchment in this study is not a roof but consists of paved and turfed areas, appropriate runoff coefficients are chosen to account for the losses in rainfall/runoff.

A flowchart showing the step-by-step process of computation involved in the use of the model NTURWCS.MK4 is shown in Figure 1.

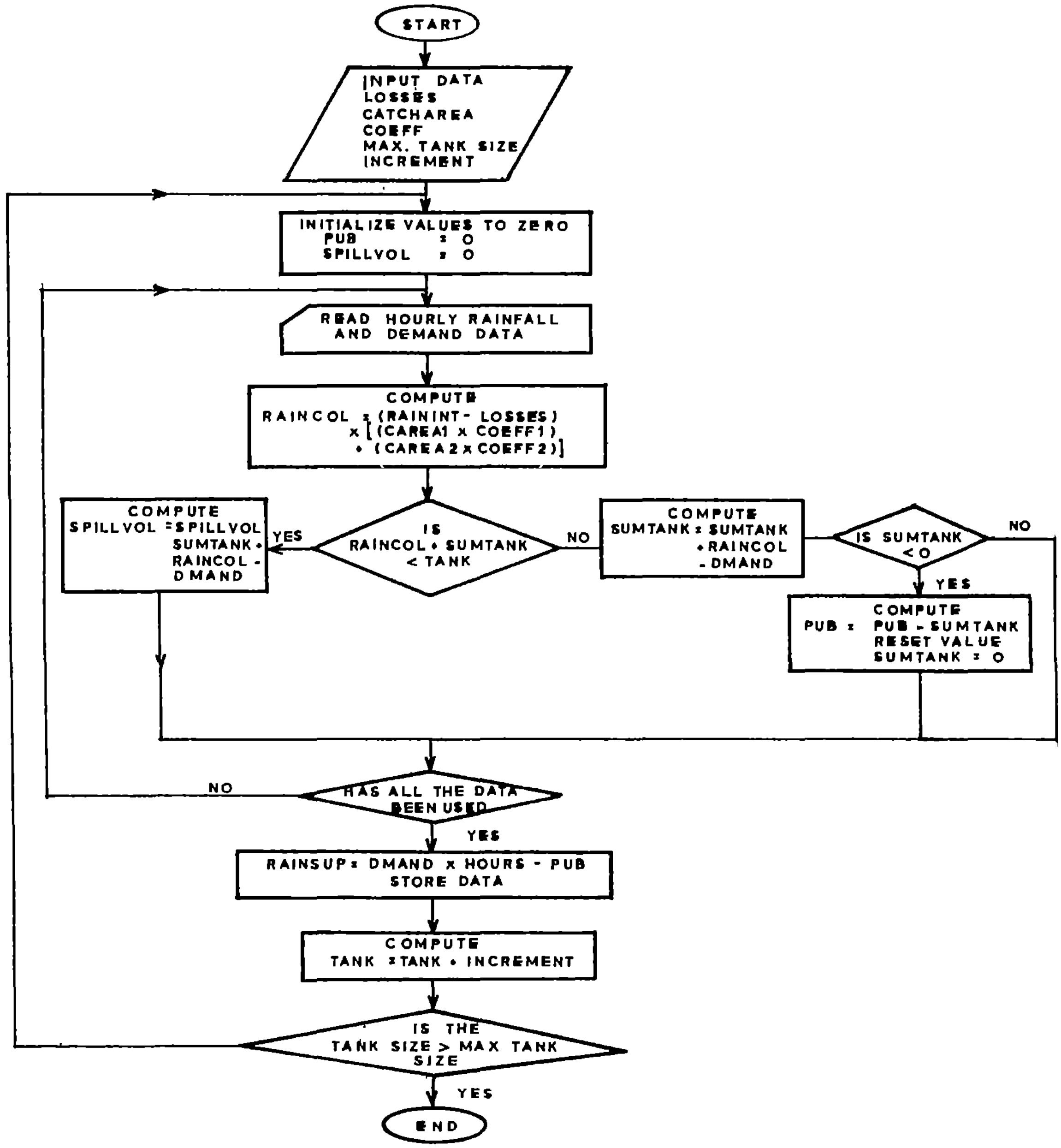

Figure 1. Flowchart for NTURWCS. MK4.

CASE STUDY

Catchment areas

The airport catchment has a total area of 530 hectares. Two sides of this rectangular strip of land are adjacent to the South China Sea. Surface runoff and some of the tidal backflows are collected in three storage reservoirs, the details of which are given in Table 1.

Table 1. Catchment areas and reservoir capacities.

Reservoir	*Catchment area (ha)*		*Capacity (m^3)*
	Paved	*Turfed*	
I	175 9	122.9	320,000
II	102.7	115.3	80,000
III	0.0	12.5	50,000

Water treatment

Currently Reservoir I is the only reservoir being utilized as an impounding reservoir. Raw water from this reservoir is pumped through a skimming device to remove grease, after which it is pre-chlorinated and then dosed with alum and lime. The coagulated water is then flocculated in an upward flow sedimentation tank and the settled water is filtered in rapid sand filters. The treated water is then retained in a 3332m^3 storage reservoir. A pumping station draws out this water and pumps it to the reticulation system where it is used only for non-potable uses like toilet flushing, air conditioner cooling and fire-fighting. Whenever the water demand exceeds the available water in the storage reservoir, an automatic valve is activated and allows some water from the regular potable water supply into the storage reservoir to meet the demand.

Water quality in Reservoir I

Raw and treated water samples were collected and tested, the details of which are shown in Table 2. This reservoir has the least salinity level though the oil-and-grease content is very high. On comparison with WHO values (WHO, 1986), the colour, pH and TSS values fall well within the drinking water quality guideline values.

Diurnal variations of use

Hourly consumption was monitored and is shown in Figure 2. The average demand is 111 m^3/h. The variability in hourly demand is not very prominent and could be due to the fact that the airport terminal is being utilized day and night.

Table 2. Raw and treated water quality.

Parameter	*Raw water*	*Treated water*	*WHO values*
Colour (Hazens)	23.5 - 25.0	4.0 - 9.8	15.0
pH	6.8 - 6.99	6.76 - 7.03	6.5 - 8.5
Turbidity (NTU)	3.4 - 6.2	0.35 - 3.7	5
Salinity (mg/l)	0.5 - 0.5	1.0 - 7.0	not specified
TSS (mg/l)	5.9 - 17.2	2.5 - 4.6	1000
TOC (mg/l)	14.0 - 15.0	13.0 - 16.0	not specified
TDS (mg/l)	3.0 - 4 59	3.2 - 5.7	not specified
Oil -and- grease (mg/l)	62 - 100	89 - 389	not specified

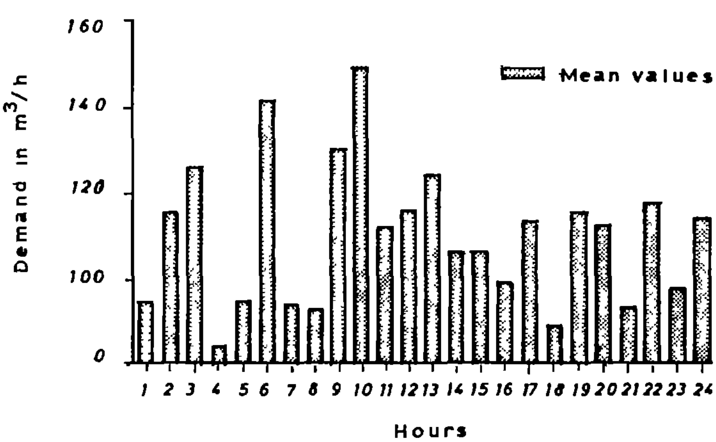

Figure 2. Diurnal variations for non-potable use.

COMPUTER RUNS AND RESULTS

Varying the storage volumes and also the runoff coefficients, not less than 48 runs were carried out.

Storage volume

A typical set of results using runoff coefficients for paved areas (C_p) and turfed areas (C_t) of 0.8 and 0.5 respectively is shown in Figure 3. In this instance, the volumes were varied from 10 to 90,000m^3. The percentage supplement of demand is expressed in terms of the rainwater and the supplementary source. In this study, the supplementary or make-up water is that being supplied for potable uses. The computed optimum storage volume is 80,000m^3 in which case no supplementary source of water will be necessary.

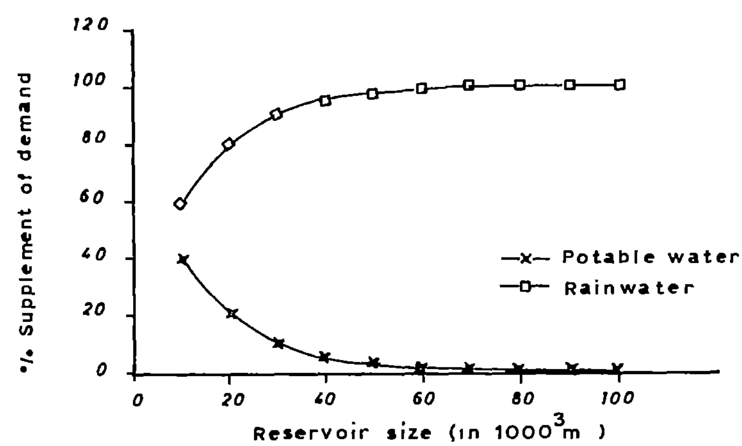

Figure 3. Reservoir storage volume analysis.

Sensitivity of runoff coefficients

Runoff coefficients for paved and turfed areas were varied from 0.7 to 0.9 and 0.4 to 0.6 respectively to appraise the impact on storage volumes. These results are shown in Figure 4.

ANALYSIS AND DISCUSSION

Raw and treated water quality

Both these qualities are of a high order except for the oil-and-grease content. This could be due to spillage during fueling and maintenance of aircraft on the runways, or to the presence of a fuel farm within the catchment. Also, the efficiency of the skimming device in the water treatment plant needs to be improved.

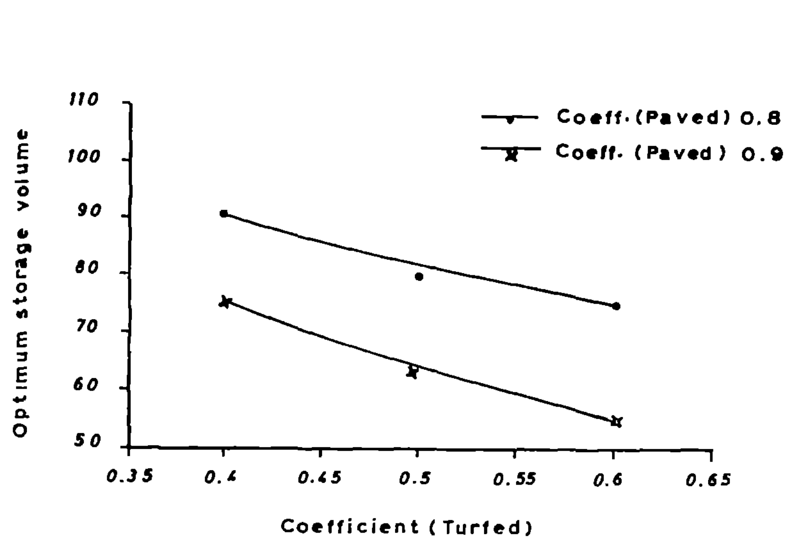

Figure 4. Optimum storage volumes vs (Cp and Ct).

Catchment areas

At present in Reservoir I runoff from only 56.5% of the catchment area is being utilized. The other two reservoirs are closer to the sea coast and subjected to more tidal influence. Consequently, if they are to be utilized as raw water sources, their higher salinity content has to be taken into consideration.

Optimum storage volume

Though the optimum storage volume varies according to the runoff coefficients, the most representative value would be 80,000 m^3. This volume is much less than that of the existing Reservior I. Hence, the storage volume should be more than adequate and there should be no need for a top-up supply from the potable water source. This means that the existing system of pumping raw water to the treatment plant and storing in the storage reservoir needs to be looked into.

Runoff coefficients

A marginal increase of C_p by 0.1 leads to an overall decrease in optimum volume of approximately 15,000m^3, though the same decrease in C_t only accounts for a drop in volume varying from 9,000m^3 to 10,000m^3. This can be attributed to the cumulative effect of larger paved areas and also the higher initial value of C_p.

Economic viability

The current usage of non-potable water varies from 28% to 33% of the total consumption. From the annual use of rainwater from this scheme, it can be computed that the savings per annum amount to \$390,000. However, when the system is improved so that no supplementary potable water is used, the savings should escalate to between S\$430,000 and S\$460,000 per annum.

CONCLUSIONS

The rainwater catchment system in this case study has been shown to be effective in terms of quantity and quality of water for non-potable uses. The scheme is also economically viable though some changes could be made to improve the treated water quality and system of operation.

REFERENCES

Appan, A. (1982). Some aspects of roofwater collection, *Water Resource Research Centre Int. Proc. Conf. on Rain Water Cistern Systems*. pp. 220 - 226. University of Hawaii, Manoa.

Appan, A. (1992). Effects of Discretization of Rainfall Data on RWCS Design Parameters. *Proc. Reg. Conf. of IRCSA on Global Water Use under Limited Water Situation*, (Kyoto. pp. 742-752).

Appan, A., Lim, K.L. and **Loh, S.K.** (1987). The Utilization of High-rise Building Rooftops for Development of a Dual-mode of Water Supply in Singapore. *Proc. 3rd Int. Conf. on RWCS. Khon Kaen,* Thailand.

Appan, A., Alsagoff, F. and **Tab, K.L.** (1988). A Feasibility Study on the Utilization of Surface Runoff from a Small Paved Catchment as a Supplementary Source for Non-potable use. *Proc. 6th IWRA World Congress on Water Resources*, Vol. 4, pp. 260-271. Ottawa.

Appan, A. and **Tay, G.** (1989). The Use of Roofwater as a Supplementary Source in Aquaculture. *Proc 4th Int. Conf. on Rain Water Cistern Systems*, pp. G2: 1 - 14. Manila, Philippines.

Fewkes, A. and **Ferris, S.A.** (1982). Rain and Waste Reuse for Toilet Flushing: A Simulation Model. *Proc. Water Resource Research Centre Int. Conf. on Rain Water Cistern Systems*. pp. 377-389. University of Hawaii, Manoa.

Gordillo, T., Gonzales, E.L. and ***Ganoa, S.V.*** (1982). History of Yucatan System. *Proc. Water Research Centre Int. Conf. on Rain Water Cistern Systems*, pp. 16-22. University of Hawaii, Manoa.

Gordon, L.D., Elizabeth, C. and **Lau, S.** (1984). Storm Quality Runoff at Honolulu International Airport. *Proc. 2nd Int Conf. on RWCS*, pp. D1: 1 - 9. Caribbean Research Institute, St. Thomas, Virgin Islands.

Ikebuchi, S. and **Furukawa, S.** (1982). Feasibility analysis on Rainwater Cistern Systems as an Urban Water Supply Source. *Water Resource Research Centre. Proc. Int. Conf. on Rain Water Cistern Systems*, pp. 118 - 129. University of Hawaii, Manoa.

Reid, G.W. (1982). Lessons of History in the Design and Acceptance of Rainwater Cistern Systems. *Proc. Water Resource Research Centre Int. Conf. on Rain Water Cistern Systems*, pp. 1 - 8. University of Hawaii, Manoa.

WHO, (1986). World Health Organisation Standards.

RAINWATER HARVESTING IN URBAN ENVIRONMENTS A PROPOSAL FOR NAKURU TOWN

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ABSTRACT

Rainwater harvesting as a supplementary source of water has not received any serious attention in urban areas in Kenya. This paper investigates the potential of collecting, storing and using rainwater in Nakuru town. Two approaches, namely individual rainwater catchment systems and institutionalized rain water catchment systems are discussed and recommendations made. The paper concludes that rainwater harvesting may alleviate the critical water problem facing the town and also assist in controlling urban floods.

INTRODUCTION

The concept of rainwater harvesting as a supplementary source of water is well known and practised in rural areas. In urban areas where there was an efficient and adequate piped water supply system, the need for rainwater harvesting has not been seen until recently. The rapid increase in population, changing life-styles and industrialization have resulted in an increased demand, making water shortages a common problem in most urban centres.

Nakuru town is one of the worst hit by this problem. Residents in most areas have long forgotten the luxury of taking a shower or flushing the toilet. People carrying water on their backs and residents clustered around water selling trucks are common sights. The town receives relatively high and reliable rainfall (about 900 mm) which is fairly well distributed throughout the year. Over an area of about 78,000,000 m^2 this rainfall represents about 70 million m^3 of water.

During the rainy seasons this water is seen flowing along roads and other open surfaces before it disappears into the ground by infiltration or into the lake as wastewater via storm drains. Due to blockages in some of the storm drains, this water occasionally causes destructive floods. Can this water be trapped and stored during the heavy rains to be beneficially used during the dry season?

This paper investigates the potential of harvesting, storing and using rainwater as a supplementary source for domestic and industrial water supply in Nakuru town. It considers both individual and institutionalized rainwater collection, storage and distribution systems, using both roof and ground catchment areas.

WHAT IS RAINWATER HARVESTING?

Rainwater harvesting is the deliberate collection of rainwater from a surface (catchment) and its storage and distribution to provide a water supply. This process is concerned with the direct interception of overland runoff and is distinct from the natural collection of precipitation into rivers and other surface water bodies, or aquifer recharge by groundwater inflows. Rainwater harvesting is human intervention within the natural hydrological cycle in an attempt to increase the quantity of usable water by modifying its temporal and spatial occurrence.

Under suitable climatic conditions rainwater can constitute a sufficient water supply system for a small area as in the case of Bermuda Island (UNEP, 1983), or effectively supplement the main water supply system. Four factors are considered in designing a rainwater harvesting scheme.

Catchment type and collection methods

There are two broad catchment types, i.e. roof catchment and ground catchment. Roof catchments have been associated with domestic rainwater harvesting while ground catchment is seen as catchment for non-domestic uses such as agriculture. In this paper both catchment types are considered for domestic water supply.

Roofs provide higher quality catchment, being more impervious and easier to clean. Some roofing material such as iron sheets are capable of self disinfection (solar disinfection). Buildings are fitted with gutters and drain pipes to collect and empty rain water into storage tanks or disposal points, normally a large open body of water (river, lake or ocean). Storm sewers may be underground or open channels along the roads. The amount of water collected is determined by the roofing material and the catchment area.

Groundwater catchments consist of all unbuilt-up areas - roads, pavements and open spaces. Surface or overland runoff is collected and concentrated using open drains, which empty into the main storm sewers, which lead to the point of application or the disposal point.

Collection systems should be designed such that collection is by gravity. This can be achieved through proper location of storage tanks. To be effective, the collection system should be lined, and fitted with debris and silt traps to avoid clogging and silt accumulation in the storage tanks. They should also have grease traps to prevent clogging by grease accumulation (Linsley and Franzini, 1979).

Three approaches to wastewater transportation can be used: completely separate drainage systems for domestic wastewater, industrial wastewater and stormwater; partially combined (domestic and industrial) wastewater and storm water systems; or fully combined (domestic, industrial and stormwater) systems. A completely separate system is the best for rainwater harvesting purposes.

Storage systems

Storage can either be done individually or communally. In individual storage systems, water is collected and channelled to storage tanks which can be located on the roof, at ground level or underground. Such storage systems are common with roof catchments, for individuals, or institutions such as schools, colleges and hospitals. Mayo (1991) described such a system for Dar es Salaam University with a basement storage tank of 80,000 litres.

For institutionalized storage systems, such as a municipal water supply, water from roof catchment is channelled into the storm sewers where it may be combined with water from ground catchment, if both catchment types are being used.

Storage tanks must be covered to control contamination, prevent algal growth stimulation by sunlight and also to destroy potential breeding grounds for mosquitos (UNEP, 1983). Storage systems should be designed with a provision for regular cleaning.

Purification and treatment

For roof catchments the purification process starts with flushing away the first downpour. This clears the catchment area of most physical dirt-dust, leaves and dead animals. Overland runoffs require a series of traps and sieves to remove debris and reduce sediment load. These will include chemicals to break down grease, sieves and other mechanical devices. By the time the water reaches the storage tank it should be free from large solid impurities and ready for treatment.

If the water is intended for domestic use and/or industrial purposes where it will be incorporated into consumable products, then it should be treated to acceptable drinking water standards. If the water is to be used for non-domestic purposes such as flushing toilets or for industrial cooling, then after removing suspended material, only preliminary treatment to improve colour, odour, turbidity and pH will be necessary.

Distribution and usage

If the water has been treated to drinking water standards it may be pumped into the main water supply system for distribution. If the water is of low quality, then separate parallel distribution is required. This system will supply water to W.C. systems or industrial cooling systems without being mixed with the main water supply system.

For an already developed town, the first alternative appears to be more attractive, while in planning a new town the latter should be encouraged. Distribution by gravity is cheaper, both in terms of construction and running expenses (Yu-rui, 1991). However, it is difficult to have a wholly gravity-fed distribution system. Some pumping may be required to provide the necessary head.

For individual supply systems with roof catchments, Fewkes and Jay (1991) recommend two storage tanks, a main underground storage tank and a smaller roof holding tank. Water is pumped into the roof tank using a small electric or diesel (or solar) pump, from where it flows into the house by gravity. Where a surface tank is used as the main tank, the water can be supplied into the house by a siphon and gravity mechanism (Bo and Jiayi, 1991).

RAINWATER QUALITY

Urban rainwater is contaminated by various sources, the main one being air pollution. Rain falling in urban places dissolves the gases from industrial and automobile exhausts. These impurities which contain sulphur dioxide (SO_2), carbon monoxide (CO) and nitrogen oxides (NO_x) among others, raise the pH of rainwater, making it corrosive. There is no evidence of any serious contamination arising directly from roofing material (Wirojanagud *et al.*, 1989).

Surface runoff is further contaminated by dissolving decomposing urban refuse. In areas with poor sanitation, biological impurities such as pathogenic bacteria, also find their way into rainwater. Rainwater collected from farmlands where there has been a high inorganic fertilizer and chemical pesticide use is likely to contain a high concentration of pollutants. Rainwater should therefore be treated before it is used.

RAINWATER POTENTIAL IN NAKURU

Nakuru town is situated in the Rift Valley of Kenya. It covers an area of about 78,000,000 m^2. The town lies roughly between the Menengai Crater (2280m a.s.l.) to the north and Lake Nakuru

(1990 m a.s.l.) to the south. During heavy rains massive amounts of water are seen flowing from the Menengai slopes through the town into the lake. The rainfall characteristics of the town are given in Table 1.

Table 1. Nakuru monthly rainfall data (mm).

	J	F	M	A	M	J	J	A	S	O	N	D
R/Stn	21	23	53	134	112	66	88	100	62	52	51	38
D C.	16	24	60	127	107	80	109	110	67	54	60	30
Met	34	45	88	141	110	70	93	98	95	64	66	31
Av	24	31	67	134	110	72	97	103	75	57	59	33

Source. Jaetzold and Schmidt(1983).

The town receives an average annual rainfall of about 860 mm and a monthly lowest amount of roughly 20 mm, with most months having an average above 50 mm. On average, 70 - 80 % of an urban area will be built-up, 15 - 20 % paved surfaces (bitumen/macadam roads and pavements) and 10% open spaces (parks and other recreational uses). Since Nakuru is not heavily urbanized, percentages of 65, 15 and 20 for built-up, paved surfaces and open spaces, respectively would be appropriate. By giving runoff coefficients of 0.9, 0.8 and 0.6 to the three surfaces respectively, we can estimate the amount of rainwater as follows:

$$Q=\{(0.65 \times 0.9) + (0.15 \times 0.8) + (0.2 \times 0.6)\}AR$$

where

A = Total surface area

R = Annual rainfall in metres

Q = Amount of water in cubic metres

which when simplified becomes

$$Q = 0.825AR$$

Substituting for A = 78,000,000 m^2 and R = 0.862 m we get about 56 billion litres of water per year.

Nakuru town has completely separate wastewater disposal systems. Storm water is disposed off into Lake Nakuru near the domestic wastewater treatment plant on the eastern side, while industrial wastewater enters the lake through the treatment plant near Mwariki on the western shore of the lake. This makes it easy to trap and store the rainwater. Thus if arrangements were made to trap and store this water it would be possible to get at least 50 billion litres of additional water to supplement the existing water supply.

WATER DEMAND ASSESSMENT

Urban water demand is controlled by three main factors, namely, population size, living standards and level of industrialization. Its usage is determined by weather, cost, availability and conservation awareness. Water demand can be estimated using population as follows (Vizarani and Chandola, 1986; Linsley and Franzini, 1979):

RECOMMENDATIONS

With individual systems, it is preferable to use rainwater only for W.C. flushing and domenstic chores, especially with ground catchments where there is direct human contact with the rainwater. Studies done elsewhere (Wirojanagud et al., 1989) have shown that most contaminants in individually collected rainwater are of human origin, arising from poor handling and storage.

For full incorporation of rainwater into the main water supply system, proper treatment has to be ensured. Sanctioning individual water treatment should be based on the perceived risk of inadequate treatment. According to UNEP (1983), this will depend on the quality of the harvested water and the level of education of the consumers, which determines their likelihood to treat the water.

For institutionalized systems, where maintenance of drinking water standards can be ascertained, complete incorporation of rainwater into the main water supply system is preferred to a parallel system, due to the simpler and cheaper infrastructure.

However, for large institutions such as schools, colleges and industries, parallel piping systems look economical. Such institutions generally have large roof surface areas and may build their own internal underground tanks. W.C. and/or industrial cooling supply systems can be connected to both the rainwater storage tank and the main water supply system. Mechanisms to prevent contamination through back siphonage should be provided. Such installations can save institutions up to 30 % and industries up to 80 % of their water bills.

New buildings should be designed with rainwater harvesting in mind. Large roof surfaces, large gutters and drainpipes, large storage tanks and parallel piping systems, should become features of modern-architecture. The same goes for road design and construction. Proper storm drains with debris, grease and sediment traps are required. To control the quantity of runoff, several well-spaced storage tanks are recommended. Parks, playgrounds and other open spaces provide good sites for underground storage tanks.

CONCLUSION

The present study has not carried out any rigorous feasibility studies to determine the financial implications of incorporating rainwater harvesting in existing water supply systems. It has, however, shown that the technique provides a technically simple supplementary source of urban water capable of meeting the annual water demand. Since Nakuru is not heavily industrialized, rainwater harvested in this town will probably not require more than ordinary purification and treatment before being used for domestic and industrial purposes.

Besides supplementing water requirements, rainwater harvesting may provide a solution to flooding. Most floods can be associated with blockages in the storm sewers due to poor maintenance. The economic aspect of rainwater harvesting is likely to provide an incentive for improving drainage-system management. This includes frequent dredging to remove sediments and debris, repair of drainage linings and soil conservation on catchment areas.

REFERENCES

Bo, L. and **Jiayi, L.** (1991). Rainwater Harvesting Systems for Drinking Water Supply in China. *Proc. 5th Int. Conf. on Rain Water Cistern Systems*, pp. 568-573.Keelung, Taiwan, R.O.C.

Chow, Ven. Te (Ed.) (1964). *Hand Book of Applied Hydrology*. McGraw-Hill, New York.

Fewkes, A. and **Jay, A.** (1991). The Use of Rainwater for W.C. Flushing in the U.K. *Proc. 5th Int. Conf. on Rain Water Cistern Systems*, pp. 511-520, Keelung, Taiwan, R.O.C.

Jaetzold, R. and **Schmidt, H.** (1983). *Farm Management Handbook of Kenya*, Vol II/C: *Natural Conditions and Farm Management Information*. Ministry of Agriculture, Kenya.

Republic of Kenya (1988). *Nakuru District Development Plan 1989-1993*. Government Printers, Nairobi.

Linsley, R.K. and **Franzini, J.B.** (1979). *Water Resource Engineering, Singapore*. McGraw-Hill.

Mayo, A.W. (1991). Experience in Rainwater Harvesting in Tanzania. *Proc. 5th Int. Conf. on Rain Water Cistern Systems*, pp. 535-546. Keelung, Taiwan, R.O.C.

UNEP (1983). *Rain and Storm Water Harvesting in Rural areas. Ireland.*

Vizarani, V.N. and **Chandola, S.P.** (1986). *Water Supply and Sanitary Engineering*, Khanna, Delhi.

Wirojanagud, W. et al. (1989). Evaluation of Rainwater Supply Quality: Heavy Metals and Pathogens. *A report submitted to International Development Research Centre (IDRC)*, Canada.

Yu-rui, W. (1991). The Catchment Rainwater System Used as Supplemental Water Sources of Cities and Towns. *Proc. 5th Int. Conf. on Rain Water Cistern Systems*, pp. 529-534, Keelung, Taiwan, R.O.C.

DISCUSSION

Mr Julius Wanyonyi wanted to know whether the coefficients used in estimating surface runoff were justified given that average annual rainfall values only were used. **Mr. Mwasi** responded that the coefficients in question had been determined by others (Chow, V.T., 1964) and that in any case, they were approximate. The coefficients, he said, vary with temperature (evaporation), soil types (infiltration), roofing materials, vegetation cover and type of paving etc.

Mr J. Msangi commented that while the conclusions/recommendations sounded good and convincing, an attempt ought to be made to cost the structures required to trap, purify, treat and distribute the water so captured. Otherwise the conclusions sound empty. He added that comparison ought to be made between rainwater and other alternative sources with costs duly calculated.

Mr Mwasi responded that according to studies done elsewhere, physical contaminants are about the greatest problem, i.e. silt, dead leaves, grease (which does not mix with water) etc. These he said, could be removed by simple mechanical devices. If treatment to potable standard is possible then distribution infrastructure is not a new cost. Otherwise, the cost of piping could not be compared to the environmental cost of depleting clean water resources.

RAINWATER - A POSITIVE CHOICE FOR INSTITUTIONAL WATER SUPPLY

S. J. Burgess

C.P.K. Diocese of Kirinyaga, Kenya

ABSTRACT

The problem faced by St Andrews Institute was water or a lack of it. Several possibilities were considered for the main source. These included pumping untreated water from the river, a borehole, and roof catchment of rainwater.

A dual system was chosen; untreated river water for toilets, washing clothes and watering the garden plus rainwater for cooking, drinking etc.

This paper describes the implementation of a roof catchment system where rainwater is collected from the institution's buildings then piped into a 180m^3 underground storage tank. Clean drinking water is piped to each house and user point through a separate pipe system.

INTRODUCTION

St Andrews Institute, Kabare is situated 130km north of Nairobi on the foot-hills of Mount Kenya. The area has many small streams and rivers flowing off the mountain and a high annual rainfall of 1508mm.

The Institute, belonging to the CPK Diocese of Kirinyaga trains students in theology, community health and development. Since 1975 the Institute's population has grown to about 135 students and staff, and will continue to grow, resulting in the need to expand the buildings and services such as water and electricity.

THE NEED

The Institute's demand for water is great, being a modern set-up with flush toilets and plumbing in the houses and dormitories. The water demand is estimated at:

Present: 135 people at 200 l /h/day = 27 m^3/day
Future: 200 people at 200 l /h/day = 40 m^3/day
Future: plus 50% allowance for expansion = 60 m^3/day

Up to 1990 the water needs had been supplied by the local piped water supply but this is no longer reliable. Built in the 1960s, it is a gravity flow system tapping the Karinga River in the Mount Kenya forest. It also supplies the local community. Population growth has resulted in over demand; the original fibre/cement pipes suffer frequent bursts, both deliberate by upstream users seeking water, and natural due to wear and tear. The Institute therefore needs an alternative source of water urgently, having experienced 3 months with no water at all in 1992.

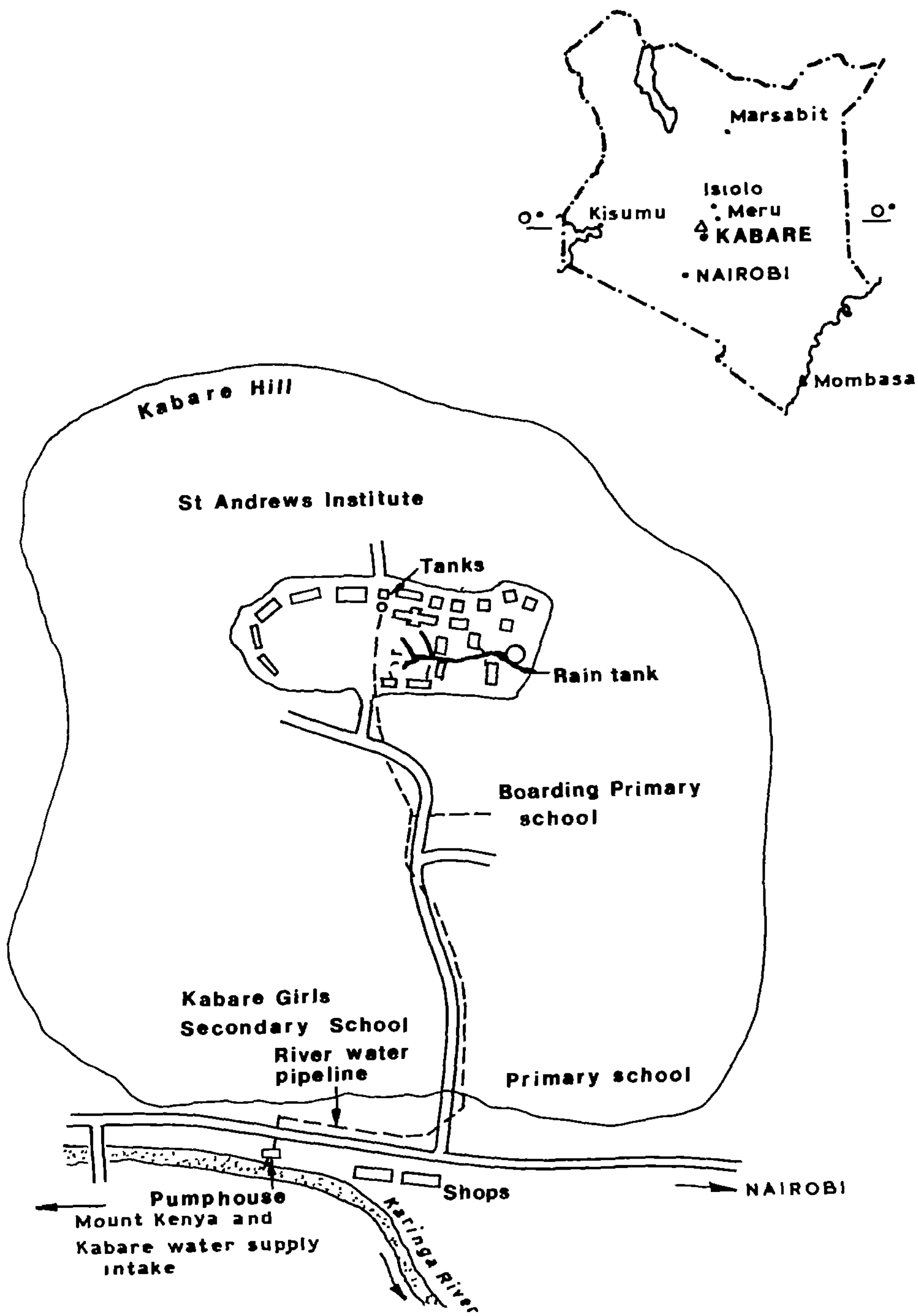

Figure 1. Location of St Andrews Institute.

ALTERNATIVE WATER SOURCES

Several water supply possibilities were examined.

Improve Kabare water system

This is the existing gravity flow system. A new pipe just for the Institute (and three neighbouring schools) could be laid. The source being 20 km north and in the forest meant that the water would be clean and require chlorination only. The cost was thought to be prohibitive at about Kshs 4 million.

Borehole

A hydrogeological test on the Institute site indicated a good probability of groundwater at 150 m depth. This would be a clean source of water although the quantity and possible salinity could not be determined until the borehole was drilled. The cost would be about Kshs 1 million.

Karinga river pumped system

The Karinga river flows just down the hill from the Institute and has adequate water although highly contaminated and with a high silt load. For clean, safe water, full treatment would be required, i.e. chlorination and filtration. While it would be relatively inexpensive to implement the pump system at Kshs 225,000, the filtration/chlorination unit would cost about Kshs 600,000, with a monthly running cost of Kshs 10,000.

Rainwater

The average annual rainfall is 1508 mm and, if collected from the Institute's roofs, could provide significant quantities of clean water. Two systems were considered:

1. Individual roof tanks on staff houses, dormitories, the kitchen etc. This would necessitate individuals collecting water in buckets - a good way to conserve water!
2. A centralized system collecting rainwater into one large storage tank and pumping the water to each house and user point.

CHOICE OF SYSTEM

Due to the urgency of getting a water supply the Karinga river pumped system was implemented in 1992. The river water was tested and showed a high faecal coliform count (MPN of 1800+) and a high silt load, although the chemical quality was suitable for drinking. In 1993, an outbreak of typhoid in the local schools and the Institute heightened the need for clean water. A conventional filtration/chlorination system was considered but finally it was decided to have a centralized rainwater collection system to provide the clean water, resulting in a dual system: river water for the major use for toilets, washing clothes, watering etc., and rainwater for domestic uses of drinking, cooking, washing dishes.

It was recognized that of the expected water use of 200 litres per person per day, 80%-95% of this (160-190 litres) would be "dirty" water use. The cost of filtering/chlorinating this water would be high. Why clean water just to flush it down the toilet? The capital cost of the rainwater system would be comparable to that of the filtration/chlorination unit but the running costs would be negligible.

With the dual system there is a need for two elevated storage tanks to gravity feed the water through two separate pipe systems to the buildings. The existing pipe work is used for the "dirty" water and a new pipe system for the "clean" water. Figure 1 shows the pumped system from the Karinga river.

THE RAINWATER SYSTEM

The system is shown in Figure 2 (piping to the buildings is not shown) and consists of:

Roofs

The total roof area of all the Institute's buildings is about $3500m^2$ which could yield $4222.4m^3$ of water per annum for an annual rainfall of 1508mm i.e. $3500 \times 1508 \times 0.8 = 4222.4m^3$ (a factor of 0.8 is used to allow for losses in the guttering system and evaporation) (Pacey and Cullis, 1986).

However, it is not possible easily to collect rainwater from all the roofs into a central pipe system. The factors considered were:

1. Ease of collection
   The buildings tapped are the classrooms and dormitories in the part of the Institute which will follow the gently sloping land to the tank site. The water flow is by gravity through underground pipes. It is difficult (although not impossible) to collect from both sides of some buildings.
2. Roofing material
   The roof of the large kitchen is asbestos/cement sheets. It was decided not to collect from this roof until clear guidance is found on the possible health dangers. Most roofs are GCI sheets and one of clay tiles.
3. Demand for water
   It is estimated that clean water use would be 10 - 20 litres per person per day. For 200 people the demand would be 2 - 4 m^3 per day. The roof area collected is 1150 m^2 although it would be possible to increase this area.

Using the mean monthly rainfall data, the amount which could be collected in each month for a given roof area was calculated. (Fig. 4 and Tables 1 and 2).

Gutters and down-pipes

The gutters are conventional semi-circular type hung on gutter hooks attached to the facia board. It is intended to improve the guttering system as leakage is noticed on long gutter runs. The gutters feed into 3 inch diameter down-pipes to a collection box at ground level. The collector box joins the down-pipe to the underground pipes.

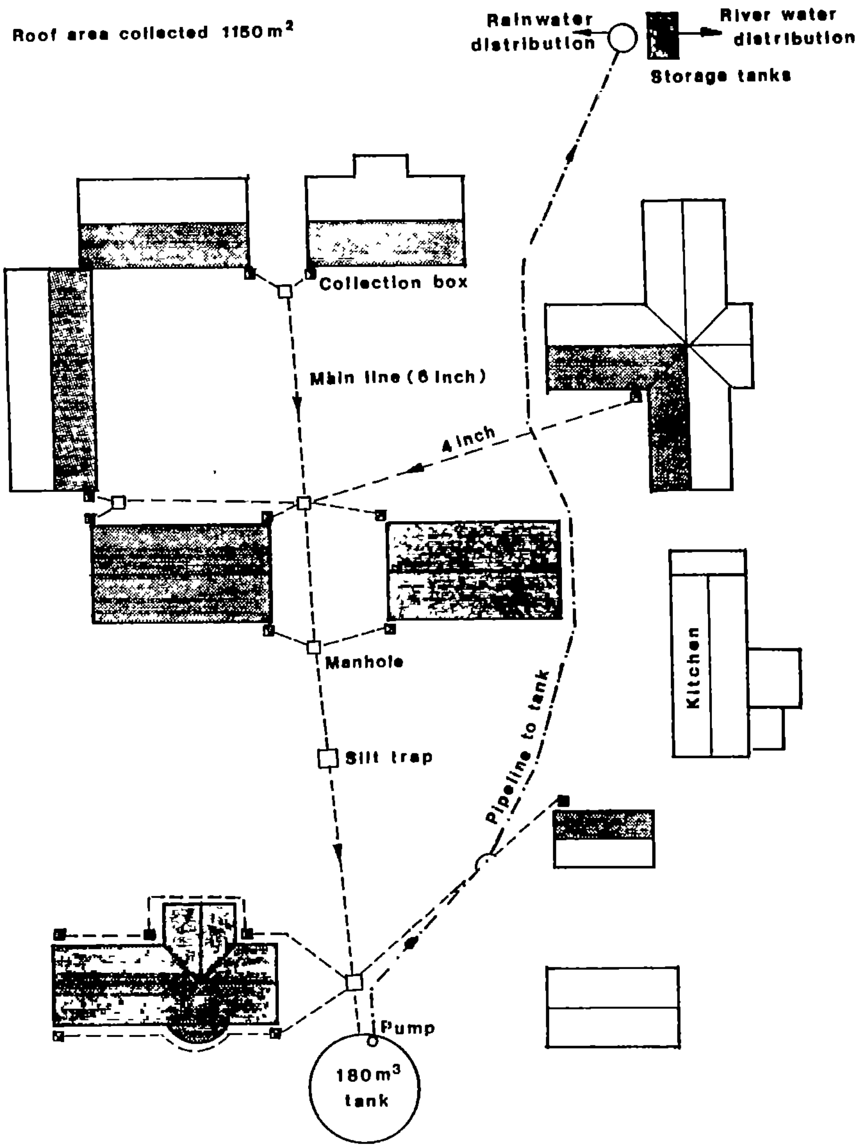

Figure 2. Rainwater collection system at St Andrews Institute.

Underground collector pipes

Water flows from the collector box on each building through a 4 inch diameter plastic drain pipe to a manhole. The manhole serves as a junction box for the pipes from individual buildings, and wire-mesh sieves are put in the outlet pipe to collect leaves and dirt from the roofs/gutters. The outlet pipe, a 6 inch diameter PVC drain pipe, is the main delivery pipe to the tank.

Silt trap

To prevent dirt entering the tank a silt trap was incorporated into the main line. The slope of the land did not allow the lower buildings to be served by this silt trap; it is planned to use first flush devices on the down pipes of these two buildings.

Underground storage tank

The tank has a capacity of $180m^3$. It is 9.9m in diameter and 2.7m high (Fig. 3). A capacity of $180m^3$ was chosen, being 3 days total water demand for the Institute; it would also provide sufficient storage of rainwater to last through the dry months. Costs were also considered.

The construction is of reinforced concrete (1:2:4) for the floor, roof and walls with supporting pillars. Reinforced concrete was chosen rather than other cheaper methods because:

1. The soil has a high clay content and so shrinks and swells. When wet the earth walls could exert considerable pressure on the outside of the tank walls. When dry the shrinkage could cause movement and thus cracking.
2. The area has been known to experience earth tremors.

To reduce the danger of earth pressure on the outside walls, hardcore was placed between the excavation and the walls with a drain to remove excess water. All surfaces were plastered with 1:3 plaster plus nilo.

It was intended to collect rainwater from the tank roof. However it was found that the roof becomes very dirty and it is difficult to keep people and animals off the roof. So drains were put in the lip of the roof to remove surface water and the manhole covers were raised. Since the tank is underground it is not possible to put in a scour/drain pipe; a sump can be built into the tank floor to facilitate water removal for cleaning.

Delivery pump system

The delivery system consists of:

- A submersible electric pump in the tank.
- A control system to switch off the pump if the tank is empty.
- A delivery pipe (1.5 inch PVC) to the supply storage tank. Currently water is pumped just to the kitchen into a separate clean water tank.
- A control system in the supply storage tank to switch off the pump when it is full and switch it on when empty.

The delivery side of this rainwater system is still being implemented. A separate clean water storage tank is being installed to supply the whole Institute by gravity; rainwater will be pumped to this tank. A new supply pipe system is being installed to provide one tap in each house/ user point for clean rainwater.

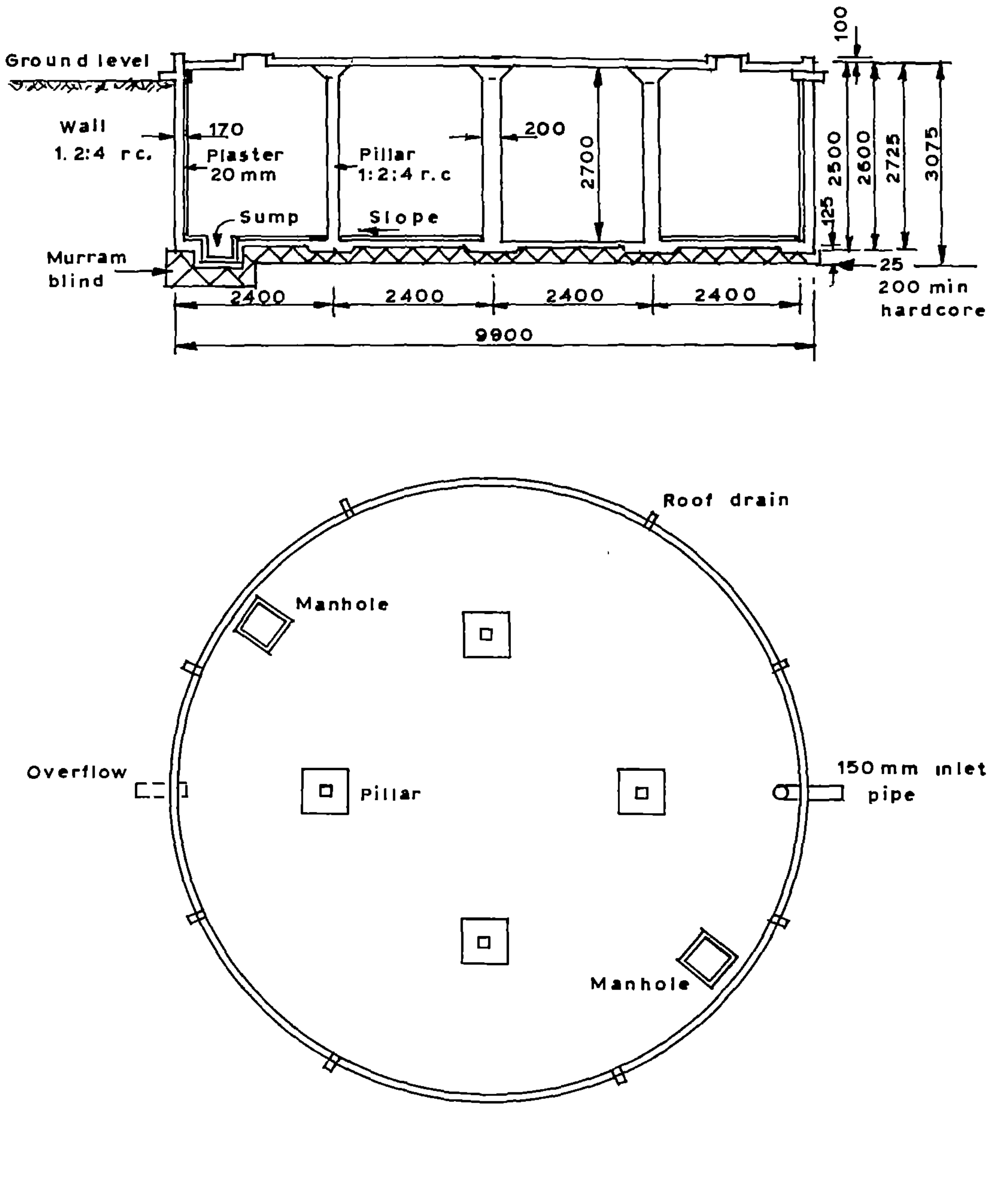

Figure 3.Underground water tank - $180m^3$.

RAINWATER COLLECTED (INFLOW) AND DEMAND

Inflow

The mean annual rainfall is 1508 mm (20 years data); the roof area collected is 1150 m^2 and a loss factor of 0.8 is used. So the water collected (m^3) is 1150 x 0.5 x mean rainfall.

The monthly cumulative inflow is calculated (Table 1) giving an annual total of 1388 m^3 (Fig. 4).

Table 1. Rainfall (inflow) and three levels of demand.

	*Inflow**			*Cumulative demand⁺ (m^3)*		
Month	*Average rainfall (mm)*	*Monthly volume (m^3)*	*Cumulative volume (m^3)*	*10 l/p/day*	*15 l/p/day*	*20 l/p/day*
Mar	119 5	110	110	62	93	124
Apr	363.5	334	444	122	183	244
May	240.2	221	665	184	276	368
Jun	49.2	45	711	244	366	488
Jul	52 3	48	759	306	459	612
Aug	57.3	53	811	368	552	736
Sep	54.2	50	861	428	642	856
Oct	195 1	180	1041	490	735	980
Nov	178.1	164	1205	550	825	1100
Dec	81.4	75	1280	612	918	1224
Jan	68 5	63	1343	674	1011	1348
Feb	49 1	45	1388	730	1095	1460
Total	1508.4	1388	1388	730	1095	1460

Notes:
*Volume collected = roof area x 0.8 x average rainfall
Roof catchment area m^2 = 1150m^2
Effective roof area m^2 = 920m^2 (1150 x 0.8)
⁺Demand is based on three estimates: 10,15,20 litres per person per day. For 200 people, this will be 2, 3 and 4m^3 per day respectively.

Demand

For a demand of 10, 15, and 20 litres per person per day the annual cumulative demand is calculated (Table 1). The annual demand at 10 and 15 l/p/day is less than inflow; at 20 l/p/day it is slightly more than inflow. It is not known exactly what the demand would be until the system is fully used, but at 15 l/p/day for 200 people it would be $3m^3$/day.

Using the methodology described in Pacey and Cullis (1986) for 20 l/p/day, a tank size of $300m^3$ would be required to balance inflow and demand for the year, i.e. the largest difference between the inflow and demand curves. For cost reasons, the tank size built is $180m^3$.

To examine whether the inflow and tank size would satisfy demand a simple balance equation was applied to the monthly inflow and demand data, the maximum storage being $180m^3$.

Storage = start storage + inflow - demand

The results for 15 l/p/day demand are presented in Table 2, which shows that at this demand level the system is sufficient.

Table 2. Inflow and Demand (m^3)

Month	*Monthly inflow*	*Monthly demand at 15 l/p/dy*	*Inflow minus demand*	
			Monthly I - D	*Cumulative S+I-D*
March	110	93	17	17 start s=0
April	334	90	244	261
May	221	93	128	308 start s-180
June	45	90	-45	135 start s=180
July	48	93	-45	90
August	53	93	-40	50
September	50	90	-40	10
October	180	93	87	97
November	164	90	74	171
December	75	93	-18	153
January	63	93	-30	123
February	45	84	-39	84 final s
Total	1388	1095	293	

Storage = storage + inflow - demand. S = S + I - D
Maximum storage: tank capacity = $180m^3$.
For May and June start storage = $180m^3$.

At 20 l/p/day there would be a shortfall of water in 8 months of the year. But increasing the roof area collected by 50% would increase inflow sufficiently to satisfy 20 l/p/day demand with the 180 m^3 tank. Thus there is flexibility within the system to satisfy a range of demand. Applying the balance equation helps to determine the system component capacities.

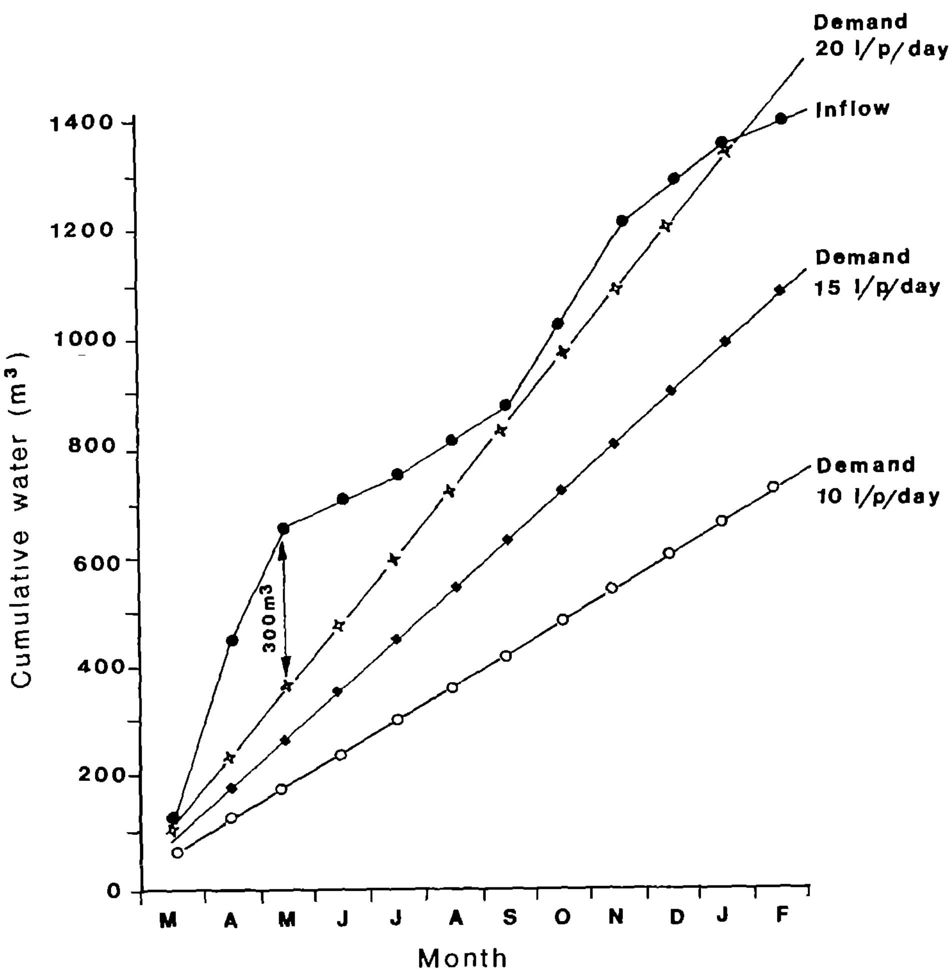

Figure 4. Mass inflow and demand.

COSTS

Implementation

Implementation was carried out in January to May 1993. Costs are known but some skilled input was voluntary and equipment donated, so only estimates are possible. Gutters, down pipes and an 18 m^3 clean water storage tank were in place.

Component	*Kshs*
180m^3 tank. material and labour	279,000
Underground piping, collection boxes, manholes and silt trap·	
Material	60,000
Manual labour	10,000
Submersible pump and control systems	80,000
Skilled labour (estimate)	
	6,000
Delivery	5,000
Tank in kitchen (estimate)	
Pipe system to houses etc. (estimate)	60,000
Clean water storage tank	no cost
Total cost	500,000

The running cost of the system would consist of the pumping cost and maintenance cost; an estimate of Kshs 300 and Kshs 1000 per month, respectively, could be made.

Unit costs

System	*Kshs*
Tank and collection systems	
Cost per m^3 stored	2000
Cost per m^3 allocated annually (1388m^3)	250
Total system	
Cost per m^3 collected annually	360
Cost per m^3 used annually at 15 l/p/day	460

A more realistic unit cost would be the cost per litre of water used. Consideration needs to be given to the life of the system and the annual running cost. Let us assume that the tank will last 15 years and the collection/delivery system 5 years.

Annual cost		*Kshs*
Tank cost	279,000/15	18,600
Collection/Delivery system	221,000/5	44,200
Running cost/year		15,600
Total		78,400
Cost/litre	78400/1095,000	0 07

The total cost of the system was Kshs 500,000 of which Kshs 360,000 was for the tank/collection system and Kshs 140,000 for the delivery system. This is a high capital cost but compares favourably with alternative methods of getting clean water, i.e. filtration/chlorination system: Kshs 600,000, and Borehole: Kshs 1,000,000. The cost per cubic metre stored (tank/collection system) seems high at Kshs 2000 but is comparable to the capital cost of cheaper ferrocement tanks. The cost per cubic metre collected is Kshs 250 or 25 cents per litre which seems good value. The cost per cubic metre of water used (at 15 l/p/day) for the complete system is only Kshs 460.

A more realistic way of comparing cost is the cost per litre of water used, which calculated at Kshs 0.07 (7 cents) per litre (for 15 l/p/day demand, assuming the delivery/collection system will last 5 years and the tank 15 years).

WATER QUALITY AND MAINTENANCE

Rainwater is thought to be pure, uncontaminated and safe for drinking without further treatment. At source this could be true but contamination will occur within the collection/storage /delivery system. Maintenance and management of the system are crucial; the system described here incorporates the following to reduce contamination:

- Regular cleaning of the gutters.
- Collector boxes to prevent dirt entering the underground pipes.
- Wire-mesh sieve in each manhole/junction box.
- Weekly cleaning of sieves in manholes.
- Silt trap. Regular cleaning of silt trap.
- Surface/rainwater drained off the tank roof.
- Manhole covers on tank raised to prevent dirty water entry.
- Annual or bi-annual cleaning of the tank just before the rains.

The tank was cleaned in May 1993 before water entry and sterilized with chlorine using domestic chlorine solution (0.15 ml of 5% solution per litre of water).

The water was tested for bacteriological contamination in June 1993 and found to be clean; no faecal coliforms were present suggesting, that no further treatment is necessary.

Improvements to prevent contamination will be a first flush system and regular chlorination. Education of the users will be implemented.

CONCLUSIONS

The rainwater system has provided clean drinking water for the Institute and although it will not satisfy the total water needs it will provide the clean water requirements.

The system also provides a valuable back-up in case the other supply fails; at 15 litres per person per day this is comparable to many rural water supply systems.

The costs of the system, seem reasonable compared to other systems, and running costs should be less.

Care is needed with management and maintenance to prevent contamination of the clean water.

Questions still remaining concern the best way to chlorinate a tank of water and the health and safety aspects of collecting from asbestos cement roofs. The asbestos cement question needs to be addressed since many of our institutions could "harvest" rainwater but are afraid to do so from roofs of this material.

ACKNOWLEDGEMENTS

The implementation of this system has only been possible through the contribution of many people who include: The Principal, Rev. Canon Moses Njoroge, the Vice Principal, Dr. Ben Knighton, and staff of St Andrews Institute, The members of the Church of the Holy Spirit, RAF Coningsby, UK, for funding and putting in the collection and control systems. My assistant Mr S.M. Mwangi for design work, and Mr M.K. Patel for tank construction.

REFERENCES

Pacey, A. and **Cullis, A.** (1986), *Rainwater harvesting, the collection of rainfall and runoff in rural areas*, p. 56. ITDG Publications, 103-105 Southampton Row, London WC1B 4HH, UK.

DISCUSSION

Dr Appan commented that the input (rainfall/runoff) into the 180 m^3 circular tank cannot be controlled and that with 3 - 4 days retention in the tank, there is bound to be excessive settlement of sludge. He asked **Mr Burgess** to explain how the tank will be cleaned.

Mr Burgess responded that each year, the tank would be emptied with a sludge pump and cleaned manually. The timing of this operation, he said, would be before the onset of the long rains. A sump in the tank floor with the floor sloping towards the sump would facilitate cleaning. He added that, although this was not incorporated into the design, if the tank was divided into two compartments, one side could be cleaned while water was being used from the other compartment. Water entry into the tank in this case would need to be directed into each compartment separately.

Commenting on the water use equation shown below,

$S = S_1 + I - D$

where S = total storage

S_1 = initial storage

I = inflow

D = demand

Mr Chikodzone stated that the constraint/limitation of the tank capacity to $180m^3$ could be added to this equation as a correction factor (i.e. minus overflow), or as a condition to the equation. Another condition could be timing of demand (D, or overflow) and the inflow (I) as the timing seriously affects the resultant storage (S) when holding initial storage (S_1) constant. To this, **Mr Burgess** replied that in the 2 months where the total storage S is greater than the tank capacity of $180m^3$ the initial storage is corrected to $180m^3$ in the subsequent month (Table 2). The excess is overflow from the tank. The timing of demand and inflow needs to be considered if necessary computation on a daily basis is needed, he added. In this case daily demand is $3m^3$ and thus the storage capacity of $180m^3$ allows for 60 days demand. The large storage compensates for fluctuations in demand and inflow.

RAINWATER HARVESTING IN KAJIADO DISTRICT AS A SOURCE OF WATER SUPPLY

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ABSTRACT

Kajiado District is located in the arid and semi-arid lands (ASAL) of Kenya. It is found in the southern most area of Rift Valley Province.

To plan for the development of new water sources and the rehabilitation of existing ones in the district, a field survey of all water sources was carried out to determine the distribution, status and dependability.

This paper attempts to assess the significance of rainwater harvesting systems as a source of water supply, and their potential for development in Kajiado District.

GENERAL DESCRIPTION OF THE STUDY AREA

Geographical location

Kajiado district is located between 30°5′ and 37°55′ east and 1°10′ and 3°10′ south. The district is located on the extreme southern part of Kenya's Rift Valley Province (Fig. 1) and covers an area of 21,106 km^2.

General climate

About 95% of Kajiado District is an arid and semi-arid (ASAL) area (rainfall/evaporation ratio 15-20%). The general climate of the district is largely determined by its latitude and altitude. Rainfall, which is between 300 and 600mm for most of the district, is bimodal with precipitation generally occurring in the months of March to May and October to December.

Temperatures vary with altitude. Average monthly temperatures vary between 30°C at Magadi (900 m above sea level) and 16°C at Loitokitok (1800m above sea level) (TARDA, 1984).

Annual potential evaporation from open water surfaces ranges from about 1700 mm in the Ngong and Loitokitok areas to about 2,500 mm within the Magadi area (TARDA, 1984).

RAINFALL

Origin of rainfall

The origin of rainfall is associated with the movement of the Inter Tropical Convergence Zone over the district.

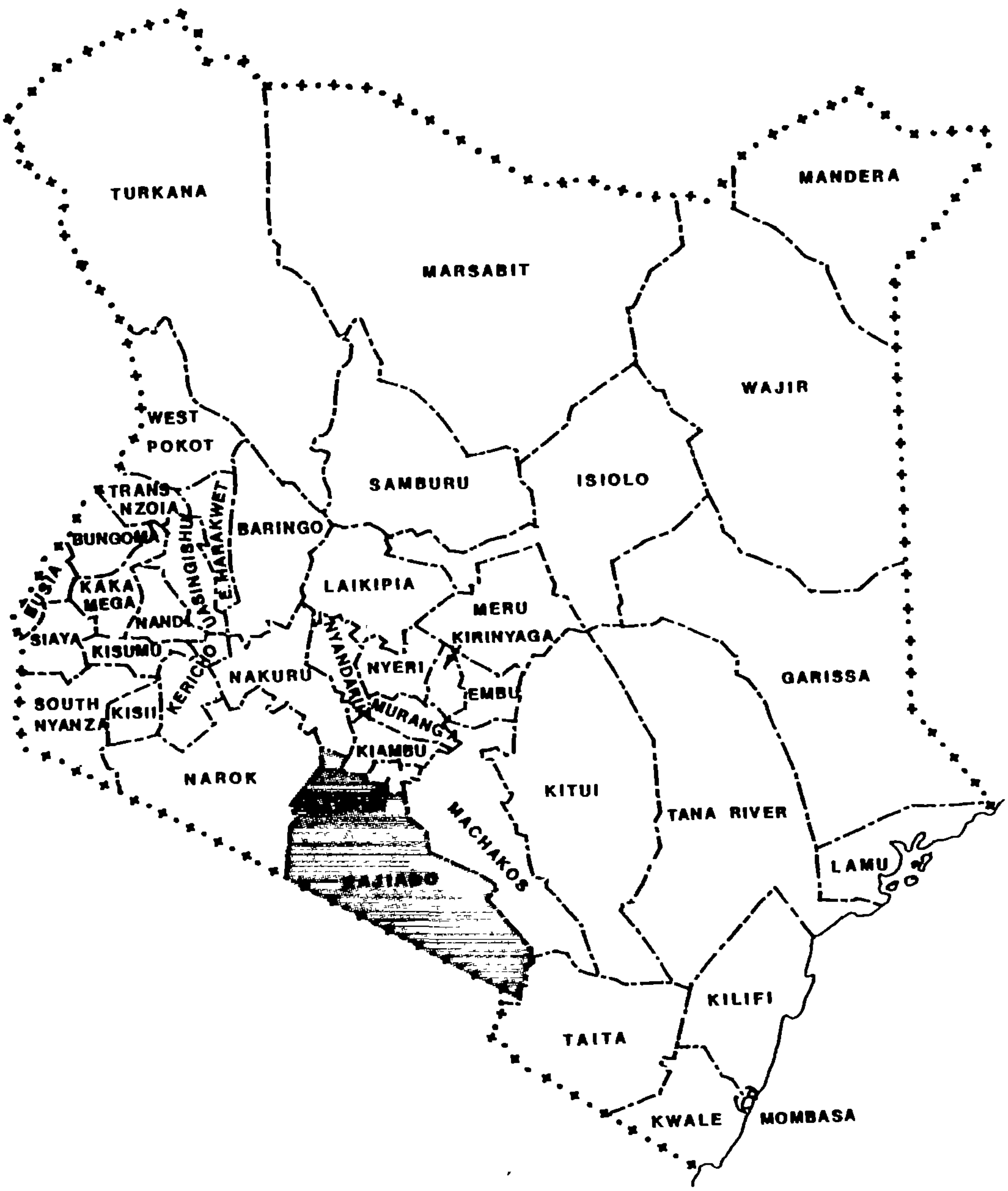

Figure 1. Location of Kajiado District in Kenya.

Monitoring of rainfall

Rainfall data were collected from a network of 32 rainfall stations within and around the district. Data from most of these stations have been available since around 1910.

Monthly rainfall

The statistical characteristics of the monthly rainfall for six rainfall stations representative of the district are summarized in Table 1. The distribution of monthly rainfall occurs in two distinct seasons which contribute about 75% of the total mean annual rainfall. The mean monthly rainfall histograms for the six selected stations in the district are shown in Figure 2.

Table 1: Statistical characteristics of selected rainfall stations in Kajiado District.

Station	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total*
Kajiado district office (1930 - 1992)													
Monthly mean (mm)	43 6	40 6	63 6	120 8	60.4	11.9	5.5	3.1	8.1	23.9	64 6	56.8	502.7
% Annual mean	8.7	8 1	12.6	24.0	12.0	2.4	1.1	0.6	1.6	4 8	12.8	11.3	
Max (mm)	193.3	178 6	316.5	547 9	204.7	92.1	58.8	21.5	90.2	95.0	307.6	348.3	
Min (mm)	0.0	0.0	0 0	0.0	0.0	0.0	0.0	0 0	0.0	0.0	9 4	0.0	
SD (mm)	45.9	42 0	60 8	87.2	48.3	18.8	11.7	5.4	14.5	24.7	48 7	62.2	
CV (%)	105.2	103.4	95.7	72.2	79.9	158.3	214.1	173.2	179.6	103.4	75.5	109.6	
Kimana Game Post (1977 - 1992)													
Monthly mean (mm)	39.92	17.98	42.12	65.2	17.48	0 3	0.33	0 08	0.01	9 97	66 47	52.8	312.2
% Annual mean	12 8	5.8	13.5	20.9	5 6	0.1	0.1	0.0	0.0	3.2	21.3	16 8	
Max (mm)	144.3	81.5	114 5	185.6	96.6	3.0	3.9	0.5	0.1	33.4	222 2	144.3	
Min. (mm)	0 0	0 0	4.4	5 2	0 0	0 0	0 0	0 0	0 0	0.0	0.3	3.3	
SD (mm)	43.7	26 7	34.3	59.1	26 0	1.0	1.1	0.2	0.0	12.7	68.8	46.5	
CV (%)	109 4	148.6	81 5	90.6	148.9	316.7	339.4	200.0	300.0	127.5	103.5	88.8	

Lofktoktok outbound bound school (1961 - 1991)													
Monthly mean (mm)	78 9	65.0	12.94	145 5	26 9	8.6	1 9	3.3	5.1	44.3	212 9	146 8	868 4
% Annual mean	9 1	7.5	14.9	16 8	3.1	1.0	0.2	0 4	0 6	5.1	24 5	16 9	
Max (mm)	256.4	242 0	265.3	395.2	89.2	205.0	9.0	20.3	25.6	198 6	435 5	332 8	
Min (mm)	0 0	1.5	40 8	27.6	0 0	0 0	0.0	0.0	0 0	0.0	12.6	14 4	
SD (mm)	61 3	53 8	70.0	81 0	20.6	36 0	2.4	5.2	7.3	47 8	87 8	82.3	
CV (%)	77 8	82.8	54.1	55.7	76.5	420.2	126.3	156 7	143.0	107 9	41.3	56.1	
Ngong divisional office (1910 - 1992)													
Monthly mean (mm)	44 6	51 6	89 1	194 4	143.4	36.0	15 4	18 1	24.3	41.8	86.7	63.2	805 9
% Annual mean	5.5	6 4	11.0	24 1	17.7	4.5	1 9	2.2	3.0	5.2	10 7	7 8	
Max (mm)	242 5	330.7	407.0	419.8	375.7	147 4	104.5	71 6	121 7	183 8	543.9	308 5	
Min. (mm)	0 0	0 0	0.0	2 8	0.0	0 0	0.0	0.0	0.0	0.0	0 0	0 0	
S.D (mm)	54 8	56.5	81.3	104.1	81.2	32 7	20 0	17.6	27.1	36 0	76 4	59.5	
C.V (%)	123 0	108 9	91.3	53 6	56.7	90.9	129.8	96 9	111.5	86 1	89 2	94 2	

Magadi Soda Co. (1925- 1992)													
Monthly mean (mm)	39 2	43.5	65.9	107.0	55.6	8 1	3.1	3.3	6.5	15.6	35.9	430.1	47 1
% Annual mean (mm)	9 1	10 1	15.3	24.8	12.9	1.9	0 7	0 8	1.5	3.6	8.3	10 9	
Max (mm)	149 9	160.9	206 6	266.7	294.0	81 4	344 0	30.2	70 8	86 7	259.2	241 4	
Min (mm)	0 0	0 0	0 0	0.1	1.0	0.0	0.0	0.0	0.0	0 0	0 8	0.8	
SD (mm)	38.3	33.3	57.3	76.4	44.2	11.5	6.3	6.0	11 9	12.5	31.2	45 1	
CV (%)	97.9	76.5	86 9	71.5	79.4	142 6	199 7	182.9	183.2	80 0	86.8	95 7	
Water Booster (1978 - 1989)													
Monthly mean (mm)	28 6	31 1	26 3	67.2	28 0	0.5	0.3	0.3	0.2	13.8	65.7	61 0	323.1
% Annual (mm)	8 8	9.6	8.1	20.8	8,7	0 1	0.1	0 1	0 1	4.3	20.3	18.9	
Max (mm)	110 7	156 2	75 6	143 8	53 4	4.6	4 1	3.5	2.5	42.6	191.3	131 8	
Min. (mm)	0 0	0.0	0.5	7 9	0.0	0.0	0 0	0.0	0.0	0 0	10 7	11 1	
SD (mm)	39 4	47 2	29 4	44.6	18.9	1.3	1 2	1 0	0 7	14.7	46 7	33.9	
CV (%)	137 9	151.5	111 7	66 3	67.3	280 9	347.1	348.3	342.9	106 7	71 1	55.5	

SD = standard deviation; CV = Coefficient of variation

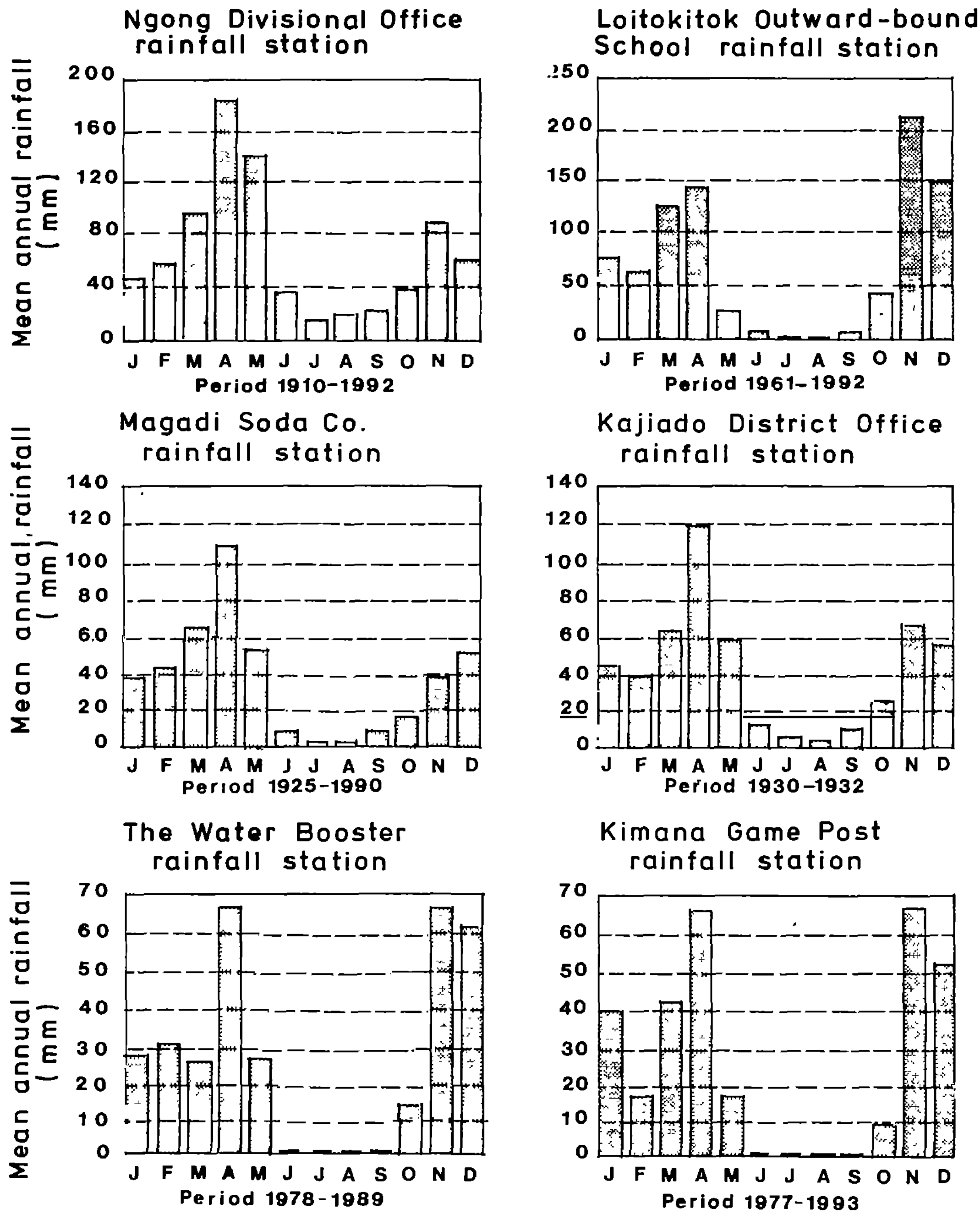

Figure 2. Mean monthly rainfall histograms for selected stations in Kajiado District.

Annual rainfall

The annual rainfall distribution in the district varies in both time and space. The distribution of mean annual rainfall over the area is shown in Figure 3.

FIELD SURVEY OF RAINWATER HARVESTING STRUCTURES

Inventory of all water sources and supplies

During 1991-1992 a District-wide field survey of all natural and constructed water sources was carried out as part of the Water Resources Assessment Project (WRAP) of Kajiado District. Besides ground water and surface water sources, this inventory included all rainwater harvesting systems.

The main objective of the survey was to locate as many water sources as possible and to assess their quality and reliability. Thus, the relative importance of rainwater harvesting could be established, while at the same time conclusions could be drawn about the potential for such systems in the district.

Organization of the survey

For each rainwater harvesting point the information gathered took the following format:
- Type of water point and its location
- Technical information
- Appraisal of the facility
- Water use pattern
- Water quality
- Community opinion on the quality
- Constraint of water point
- Ownership
- Number of people using the point
- Organization of maintenance
- Possibilities for improvement

Special attention was paid point to the status of the rain-water harvesting point during the wet and dry seasons, together with walking distances. All this information was gathered using a prescribed form. In addition to completing a prescribed form for each water source, the geographical location of the water point was plotted on a map to the scale of 1:50,000.

Data handling, storage, processing and presentation

All the data from the field recorded on the inventory sheets have been computerized.

Present use of water resources in Kajiado District

The overall results of the water resources survey are shown in Table 2.

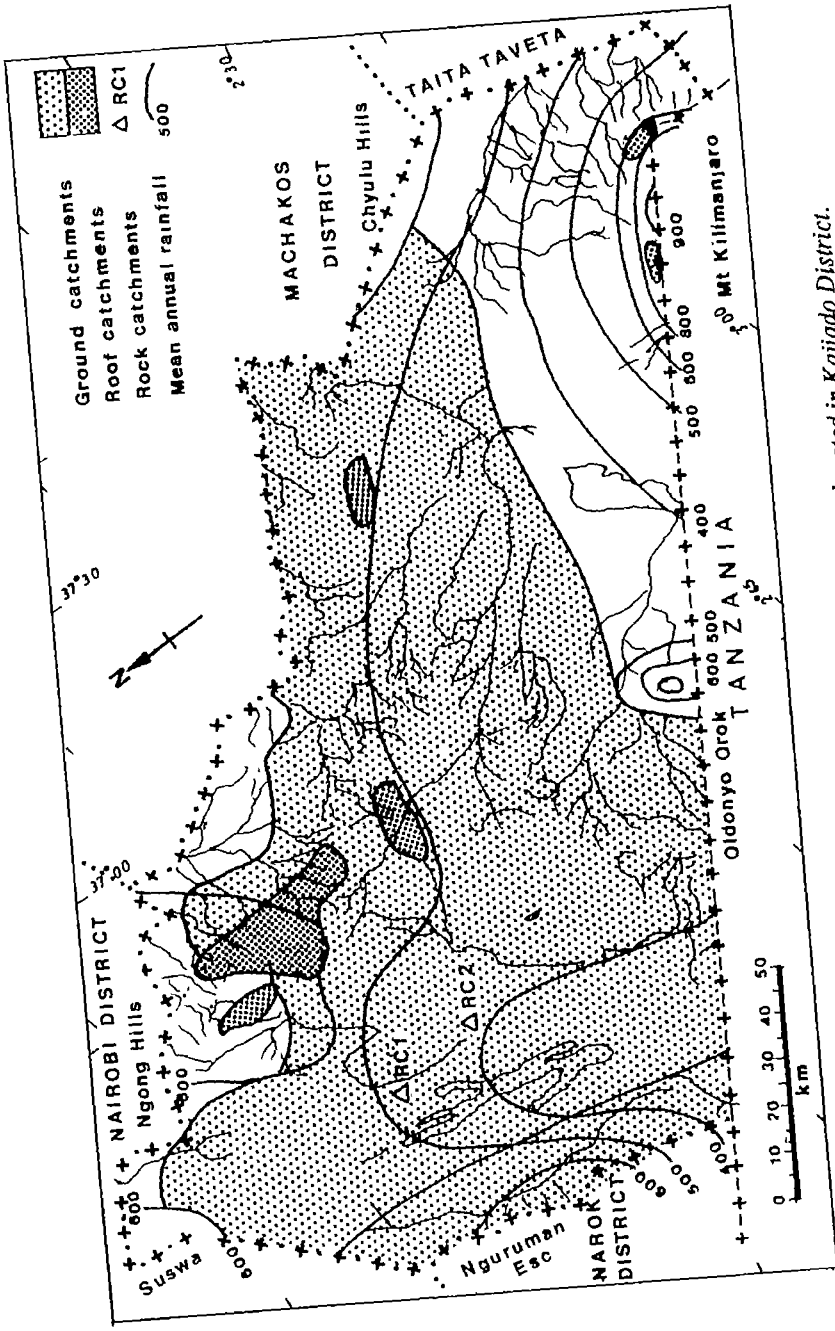

Figure 3. Areas where rainfall harvesting systems are located in Kajiado District.

Table 2. Use of water resources in Kajiado District (1992).

Type of supply	*Total no.*	*Perennial percentage*	*Average no. of users per water source*	*Use for livestock (% of total)*
Ground water				
Operational boreholes	375	100	521	5
Shallow wells	287	0	51	10
Water holes	20	100	314	10
Surface water				
Rivers and streams	28	3	2036	100
Lakes	1	-	0	0
Springs	194	100	457	20
Dams	36	60	376	100
Rainwater				
Ground catchments	379	25	199	100
Roof catchments	32	0	297	0
Rock catchments	2	0	500	0
Total	1354		4751	

Of all the water sources, ground water source make up 50% of the total, surface water sources 20%, while 30% are rainwater harvesting systems serving about 20% of the local population during part of the year only. Rainwater harvesting systems are mainly used to supplement permanent water sources. The types of rainwater harvesting systems found in the district are ground catchments (pans), roof and rock catchments.

GROUND CATCHMENTS (PANS)

Almost 95% of the district is comprised of ASAL with average annual rainfall between 300 mm and 600 mm. Rivers in these areas are seasonal. The inhabitants of these ASAL areas practice pastoralism and depend almost entirely on livestock. They mostly use groundwater and rainwater for their domestic and livestock water needs.

The district was found to have 379 pans. The areas where the pans are located are shown in Figure 3. Most of the pans are located in the semi-arid and arid areas of the district. Usually the pans are circular in shape with maximum storage capacities ranging from 40m^3 to 1000m^3 About 90% of the pans were constructed by individual owners, 6% by the community residing in the area, and the rest by either government or non-governmental organizations.

The water in the pans is used by the communities living near them for domestic and livestock purposes. Very few are used for agricultural purposes by individual owners.

The number of people using water from these pans ranges from 10 to 2500, together with their livestock; on average about 200 persons use each pan. Water is generally drawn from the pans manually, using of containers. Livestock drink directly from the pans.

The pans generally hold rainwater for between a few days up to about 4 months per year. The surface areas of these pans ranges from $3m^2$ to $1350m^2$ with the depth ranging from 0.5m to 4.5m; their present siltation ranges between 2% and 50%. Most of the water from these sources is turbid. Sometimes the water in these pans has a bad odour due to organic pollution since livestock drink directly from them.

The walking distances vary from 0 to 6 km, on average, during the wet seasons and may increase up to 10 km in dry seasons.

ROOF CATCHMENTS

In the district, 32 major roof catchments (associated with schools) were inventoried and there are some private roof catchments. The areas where the roof catchments are located are shown in Figure 3. Rain water from roof catchments is used exclusively to supplement other domestic water sources for drinking water and food preparation.

Most of the roof catchments in the district are found in schools. Privately owned roof catchments are mostly located in areas where there is a fair amount of rainfall, i.e. between 500 and 800mm. The largely pastoral population construct cow dung *manyattas* therefore they are unable to harvest rainfall using roof catchment methods. The areas of most of the roof catchments vary between 50 and $240m^2$. All of the roof catchments are made of corrugated iron and the gutters are made of folded sheet metal. The majority of the storage tanks are constructed using ferrocement. They are usually circular but some are pot shaped; they have a top cover. The tanks have storage capacities ranging from 14 to $180m^3$.

About 95% of the tanks are constructed above the ground. None of those logged had a first flush trap device. Only one tank had a pre-sedimentation tank. The rainwater from these tanks is used entirely for domestic purposes. Since most of the roof catchments are located in schools, it is used by students and teachers for drinking and cooking. The number of users per catchments ranges between 10 and 300 persons.

Collected water lasts for between a few days and about 4 months, depending on the size of the tank and abstraction rate. Rainwater in tanks was found to be of good quality. In some cases the water was found to be turbid, especially where a first device or top cover were lacking.

The walking distances in both wet and dry seasons range from a few metres to about 3km.

ROCK CATCHMENTS

There are only two rock catchments in the district. They are located in the arid region of the district in Magadi Division (see Fig. 3). They were constructed by paving a steep hill using concrete to harvest rainwater, which is then stored in tanks constructed above the ground. Both rock catchment were constructed by NGOs.

The mean annual rainfall where these rock catchments were constructed is about 400mm. They have catchment areas of 300 m^2 and 5000 m^2 and the storage tanks have capacities of 30 m^3 and 50 m^3, respectively. The larger tank has a sedimentation tank. The stored rainwater is used by the communities residing around them. The number of users ranges from 500 to 3000 persons; they use the water as an additional supply for domestic purposes. The rainwater lasts for about 6 months in the bigger tank, the smaller tank and about 4 months.

The walking distances ranges from a few metres to about 3 km both in wet seasons and dry seasons. The rock catchments are completely fenced. The rainwater was found to be clear and of good quality.

RAINWATER HARVESTING POTENTIAL, LIMITATIONS AND RECOMMENDATIONS FOR THE DISTRICT

Ground catchments (pans)

The potential for rainwater harvesting using pans depends on the local availability of rainfall and suitability of sites. Most areas have unreliable and seasonal rainfall. The scarce rainfall, high evaporation rates, siltation and high demand become limiting factors and rainwater harvesting using pans cannot be relied on as a perennial water supply. However, in areas where ground water is scarce, they are an indispensable seasonal source, for livestock in particular.

In most parts of Kajiado District, the high cost of construction boreholes and of their operation and maintenance, and the unavailability of surface water, make pans for rainwater harvesting particularly important. In most cases it was found that the ground catchments in the district need both deepening and desilting. To improve on water quality, better abstraction methods and watering of livestock need to be implemented, e.g. construction of cattle troughs away from the source. Almost all the pans need to be fenced and some needed a spillway to be constructed.

Roof catchments

The potential for roof catchments also depends on the amount of rainfall. Since annual rainfall is unreliable and seasonal, the method cannot be relied on as a perennial water source in most of the district. However, rainwater harvesting should be encouraged as a supplementary water source, particularly for institutions (schools etc.) and houses having iron roofs.

Cultural practices, i.e. nomadism and the construction of *manyattas*, and the high cost of iron roofs and storage tanks of sufficient capacity are major limiting factors in the development of this rainwater harvesting method.

To improve on the water quality the storage tanks should be covered and where possible, first flush traps should be constructed. In all cases bigger and better tanks should be constructed and better designs for gutters and tanks should be implemented.

Rock catchments

In the western part of Kajiado District, in Magadi Division, surface water sources are scarce or non-existent while ground water is mostly saline. Therefore rainwater harvesting here becomes increasingly important. Where there are suitable exposed rock slopes the method of harvesting water using rock catchments is highly recommended. The rainwater quality was found to be good but pre-sediment tanks should be constructed.

REFERENCES

Government of Kenya (1992). *Development Policy for the Arid and Semi-Arid Lands (ASAL).*
Kenya-Belgium Water Development Programme (1992). *Guidelines for Design, Construction and Rehabilitation of Small Dams and Pans in Kenya.*
Ministry of Water Development. *Design Manual for Water Supplies in Kenya.*
Nissen-Petersen, E. et al, *Harvesting Rainwater in Semi-Arid Africa.*
TRDA (1983). *Resources Development Proposals, Kilifi District.* Main Report.
TARDA.* (1984). *Resource Evaluation and Development Proposals,* Kajiado (Kenya), pp. 1-5.
UNESCO and **WHO.** *Water Quality Surveys: a Guide for the Collection and Interpretation of Water Quality Data.*

* Tana and Athi Rivers Development Authority.

RAINWATER CATCHMENT FROM SALT PANS FOR DOMESTIC USE IN BOTSWANA

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ABSTRACT

Water supply for use in western Botswana has been achieved with only limited success through the use of conventional borehole technologies that are well accepted in the rest of the country. The area lies within the Kgalagadi Desert where much of the groundwater resources are either too saline for human consumption or too deep to be accessed. Nevertheless, these areas have long been inhabited by indigenous populations that survived on various unpredictable sources of subsistence water. One of these was rainwater. More reliable sources of local water must be found to ensure the sustainable development of the populations in these areas.

Rural Industries Innovation Centre has embarked on a programme to investigate the potential of harvesting rainwater from the salt pans in the area for domestic use. Initial results have been very promising and the technology may prove to be the best option to ensure the sustainable development of the areas.

INTRODUCTION

Water supply in western Botswana is typically achieved through extensive borehole drilling in areas where the likelihood of either finding no water or finding saline water is high. This area lies within the Kgalagadi Desert, a sand filled basin which covers much of Botswana and lacks any permanent surface water.

In the more distant past and continuing until today, rainwater catchments served as a major source for the domestic needs of indigenous populations and for water for cattle farmers in the area. These catchments are primarily associated with salt pans as the features of the desert offer no other suitable ground catchments. The pan itself acts as an impermeable surface for temporary water storage that can be extended by digging dams in the pan that fill with water during rains. Alternatively, the pan can drain into an aquifer into which wells are dug. In these areas of Botswana nearly all villages are situated near pans.

Most of western Botswana's indigenous population were historically engaged in semi-nomadic hunting and gathering as a primary means of survival. Proximity to a pan was of particular importance to these groups as a primary source of drinking water. Governmental efforts to assist the development of these groups, now termed Remote Area Dwellers, have encouraged settlement. Although much has been achieved in the past 5 years in the provision of potable water to most RAD settlements, lack of access to locally available water in some settlements results in the continued importance of pan catchments.

The RAD settlement of Zutshwa has long been plagued by having no locally available potable water supply. Zutshwa currently has a population of about 250 people. Sub-surface water in the vicinity of the settlement is extremely saline, some boreholes producing water over five times more saline than sea water. While prospects for the economic development of the settlement are good, this lack of locally available water has delayed the long-awaited developments in the social and educational sectors which cannot proceed without water. The settlement currently relies on water trucked from 60km away by the Kgalagadi District Council (KDC), an extremely costly programme, and from limited yields from a solar desalination plant established by the Rural Industries Innovation Centre. Reliance on these supply strategies will restrict further development of this settlement.

RIIC's involvement in the development of the settlement has increased significantly in recent years. The availability of a saline ground water source led RIIC to initiate a community-based salt production project. The success of this project as a source of income for the community has stimulated other production ventures, all of which are administered by the recently formed Maiteko Tshwaragano Development Trust. Understanding that the sustainability of these projects and the long-term development of the settlement depended on a water provision solution, RIIC proposed that the Council develop a pilot rainwater catchment scheme in Zutshwa Pan to provide drinking and cooking water for the entire settlement throughout the year. The Lutheran World Federation (LWF) funded the project and the KDC paid labour costs.

PROJECT DESCRIPTION

A simplified description of the system is given here. Three 5.8m diameter by 3.1m (water depth 2.6m) underground concrete and brick tanks have been constructed in Zutshwa Pan about 80m from the pan edge (Fig. 1). The tanks are connected in series and are covered with pre-cast concrete slabs supported by steel beams (Fig. 2).

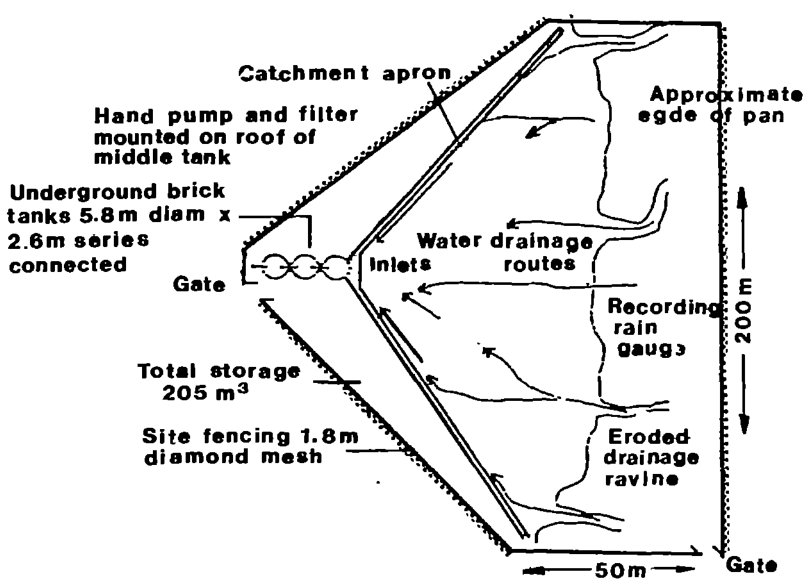

Figure 1. Pilot rainwater catchment scheme on Zutshwa Pan.

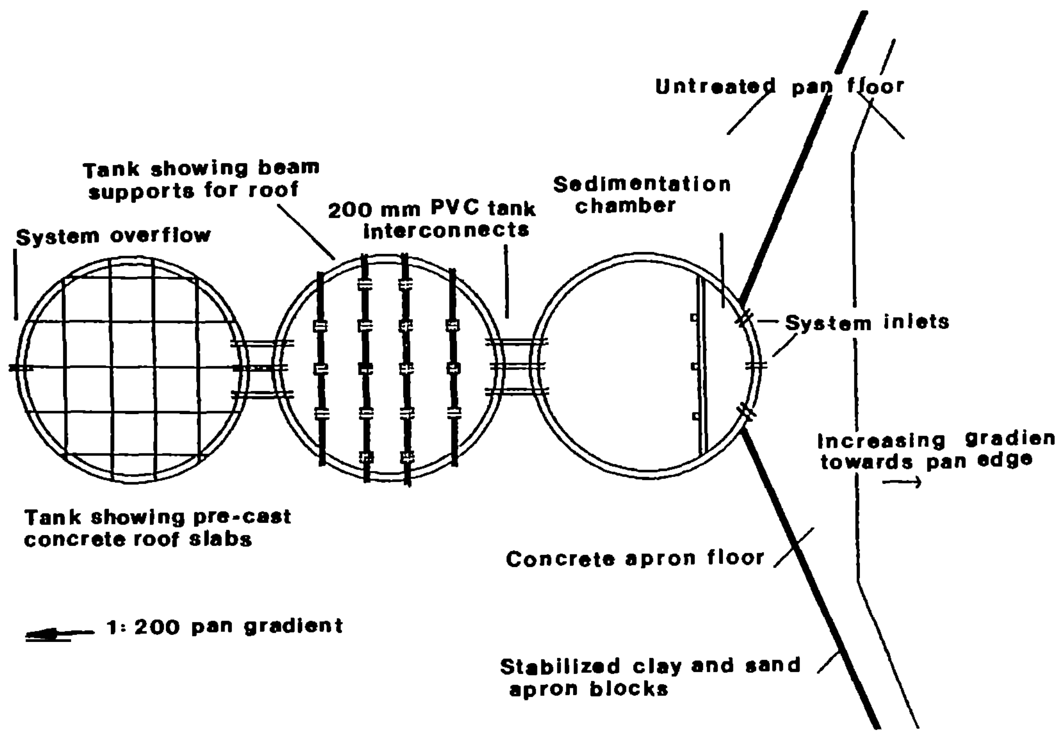

Figure 2. Details of storage tanks. 68m³ (5.8m diameter x 2.5m); double brick walls (no reinforcing); concrete foundation and floor.

These tanks are situated in the southwest corner of the pan, adjacent to the dune. Dunes in the area are located at the south west side of the pan, being formed by the prevailing northeast winds. Sand and clay from the dune have eroded onto this side of the pan, forming a hard sloping surface that carries rainfall rapidly toward the pan centre. This erosion also seems to have altered the geological features of the pan on this side, with excavations revealing only highly compacted sand and clay layers (making hand excavation possible) to a depth of 3 m while the rest of the pan is mostly calcrete.

During any significant rainfall (typically more than about 3 mm), water begins running off the areas adjacent to the pan and from the pan itself toward the pan centre. This runoff is diverted by a catchment apron made from Cinva Ram moulded stabilized sand and clay blocks mounted on *in-situ* moulded concrete slabs. The diverted water drains into the first tank inlet. Once this tank ($68m^3$) is full, water spills over into the second and then the third tank. When full ($204m^3$), excess water overflows onto the pan.

The water distribution technique is dependent on the level of supply a particular system can provide. Low supply levels will necessitate rationing. Options range from utilising handpumps and donkey carts for water delivery to installing a full reticulation system and pumping with an engine-driven centrifugal pump.

INITIAL RESULTS

The storage tank construction has been completed to a point where they can begin collecting water. A temporary catchment apron was erected in December 1992 to test the water collection capabilities of the system during a period when rains were expected. Rainfall since this time and water collected from the trial excavation are given in Table 1, and the data are plotted in Figure 3.

Table 1. Initial rainfall and collection of data.

Date	*Rainfall (mm)*	*Duration (min)*	*Water collected (m^3)*	*Comments*
Trial excavation				
April 92	8	?	20	Trial excavation of 55m³. Apron made from excavation material. Tank full-Estimated overflow 20%.
03/05/92	13	?	45	
Pilot plant				
21/12/93	5	?	3	Apron 60% effective
25/01/93	5.2	10	8	Apron 80% effective
28/01/93	6.6	over 6 hours	9	Apron 80% effective
30/01/93	21.0	45	88	Apron severely damaged during rainfall causing reduced collection. Estimate of lost runoff 50%.
31/01/93				
14/02/93	46.0	?	> 100	200m³ tanks full and overflowing. No estimate of overflow available

Initial results indicate that the system begins collecting water after 3-5mm of rainfall. The 28/01/93 data shows that even with low rainfall and low intensity, the system still is able to collect significant amounts of rainfall. Local rainfall patterns are such that large rainfalls are usually of high intensity and are therefore of primary interest.

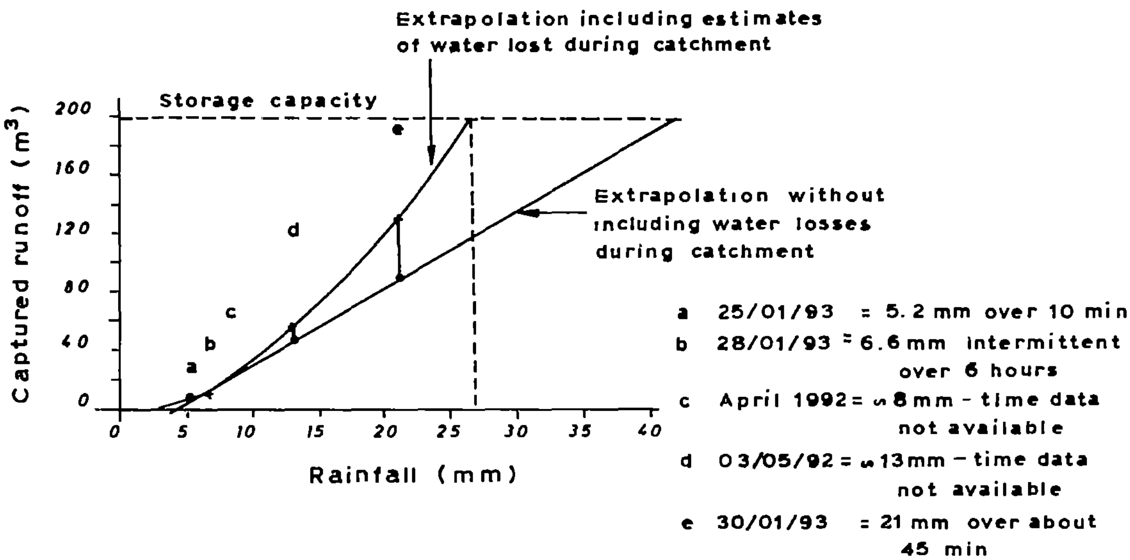

Figure 3. Experimental collection vs rainfall for single events a, b, c and d: captured in trial excavation with evidence of overflow. Actual capture = $45m^3$; with estimated 2% overspill, possible capture would be $56m^3$. e: temporary apron washed away in places, water spilled over the top of the apron, and eroded underneath it, due to high flows. Actual capture = $88m^3$; with estimated 50% losses, possible capture would be $132m^3$.

The water collected so far contains high levels of suspended clay particles that will require filtering before distribution begins. Tests show that salinity levels are good for drinking and there is no bacteriological contamination. The clay particles are of diameter less than 0.5 microns thus necessitating the use of a relatively expensive membrane filter that also filters bacterial or viral contaminants. A sedimentation tank built into the first storage tank is ineffective in removing the contaminant.

DISCUSSION

Project viability

Of primary interest in proving the viability of the system is the rainfall data from 30/01/93. This was a high intensity rainfall, dropping 21 mm in about 45 min (28 mm/h). The temporary catchment apron was not durable enough to withstand the impact of the high volumes of water it was required to re-direct and extensive damage was inflicted causing large water losses. Nevertheless, 88 m^3 were collected in the tanks. Losses have been estimated at 50% indicating that $132m^3$ could have been captured, filling 65% of the entire system's storage capacity. The tanks were full by mid-February, water was used extensively and the tanks were replenished to capacity in late April. No rains are expected from mid-May to mid-September.

The existing data, although meagre, have been extrapolated to determine a relationship between rainfall amounts and water collection. The worst case example, assuming that there was no water loss during catchment, shows a linear relationship between rainfall and captured run-off (lower line, Fig. 3).

A more realistic extrapolation accounts for losses - these will not occur once the system is completed. It should be noted that there is very little data to support the estimates of the losses incurred during the 13mm and 21mm rainfalls shown. However, based on the estimates quoted earlier, one could expect $200m^3$ to be collected after a single rainfall of about 27mm (upper line on graph). This quantity of rain is a distinct possibility, even in drought years. The superlinear nature of this curve is also more realistic than the linear one, at least in the lower rainfall regime, illustrating both the higher runoff coefficients and effective areas of collection associated with higher rainfalls.

System sizing

It is not yet possible to accurately predict the total annual yield from this catchment area because of uncertainty about the nature of individual rainfall events and their corresponding effective catchment areas and runoff coefficients. However, if it is estimated that the catchment area will collect more than $1000m^3$ per year (estimates based on single rainfall events and average annual rainfall of 300mm), then storage is at least 20% of the collected water. If data on the rainfall patterns in Tsabong (250km south) is used in the Ottawa Model, a $200m^3$ storage should yield $500m^3$ annually with 95% reliability (Gould, 1985).

However, when designing a catchment system to serve as the sole means of a remote community's water source, it is essential to determine the applicability of models used to predict eventual yields. Predictions made from the Ottawa Model require accurate knowledge of the runoff characteristics of the catchment area and are therefore better suited for roof structures with constant areas and relatively constant runoff coefficients. In ground-based systems, these characteristics are related to the nature of the rainfall events. From a planning standpoint, this model also does not adequately consider the effect of annual rainfall variability.

Rainfall patterns in the Kgalagadi are very difficult to quantify, particularly since rainfall is often very localized. Average annual or even monthly rainfall figures offer little help in predicting yields from a given catchment area. When ground-based catchments are considered, data should include information about each rainfall event throughout the year and this information must be collected for many years for a pattern to emerge.

P. Healy from the Lutheran World Federation has begun to analyse rainfall data from various meteorological stations nearby Zutshwa (Healy, 1993). The aim is to perform a water balance to determine catchment and storage sizes. However, this analysis departs from conventional balance methods in that a number of balances are necessarily performed for different years and locations, and that runoff yields are generated by analysing each and every rainfall event and comparing it with collected experimental results from the Zutshwa pilot system.

Data on individual rainfall events for a number of years in locations near Zutshwa is still being collected and the results will be presented in a forthcoming paper. Nevertheless, these preliminary calculations have shown, for example, that one particular year having 159 mm of annual rainfall could have yielded 10% more useful water than another having 380 mm. This occurred partly because the rainfall pattern in the year with high rainfall caused high water losses through the overflow of already full tanks (all of this rainfall fell over a 4 month period while in the year with 159mm, rainfall was more evenly distributed). Another significant factor was that the rainfall events of the 159mm year were chiefly of high intensity and therefore resulted in proportionately higher yields.

This information will ascertain in what percentage of years the system will satisfy demand. Information on water availability for the shortfall years will also be available. This is the kind of information that planners without a background in technology will feel more confident about basing their decisions on.

Future development

The technological feasibility of this system as a primary source of Zutshwa's water requirements has been demonstrated and awaits a decision by Council planners on further development. Cost will be an issue. Based on the costs involved in the development of the pilot system, the costs of supplying larger amounts of water through system replication have been generated (Fig. 4). Significant cost reductions are achieved if the individual storage tanks in a catchment are replaced by one large rectangular tank.

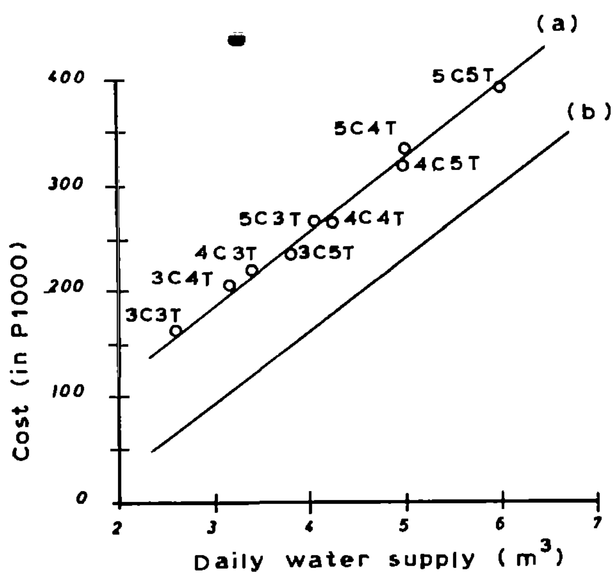

Figure 4. Costs of storage tanks and catchment preparation for various supply levels (labour costs included, transport excluded): (a) costs based on the results of the pilot scheme; (b) approximate cost if one large storage tank is made on each catchment instead of several small tanks.

Level of provision is a sensitive decision that has been debated extensively. It is thought that if unlimited water were available (no rationing) usage would vary between 10 and 15 litres per person per day. Associated costs are given in Table 2.

Table 2. Daily water supply options and system costs.

General population	*Total with institutions*	*System configuration*	*System cost small tanks/large tanks*
10 l/p/d	3.4m^3	4 C: 5 T each	P320,000 / P240,000
15 l/p/d	5.0m^3	4 C: 3 T each	P220,000 / P140,000

(C = catchment, T = tank) (P1 = US$0 45)

Even though pumping and reticulation costs are not included (that may not be necessary or as expensive as elsewhere), P140,000 makes rainwater catchment the best economic choice when the other options are considered. Social considerations also deserve attention: this technology is a traditional survival technique of many Remote Area Dwellers and its limitations in use are well understood; also the technology can be operated and maintained locally.

Rainwater harvesting may be the most practical technological solution to ensure the Zutshwa's sustainable development.

REFERENCES

Gould, J.E. (1985). *An Assessment of Rainwater Catchment Systems in Botswana.* M.Sc. Thesis, University of Alberta.

Healy, P.E. (1993). Personal communication.

RAINWATER AUGMENTATION FOR SMALL VILLAGE WATER SUPPLY

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ABSTRACT

Groundwater is one of the most exploited natural resources in the world due to population pressure, the absence of potable surface water and environmental degradation that affects its availability.

In the remote villages of the Philippines, groundwater is the chief source of pumped wells. These shallow wells with manually driven artesian pumps work well during rainy seasons when the water table is good enough to supply their aquifer. The water is generally potable and safe for human consumption and domestic purposes. During periods of drought the water table drops to a very low level, causing wells to dry up. This situation was corrected by an augmentation process in which collected and stored rainwater seeps through the aquifers that supply groundwater to the wells. The collection pond is easy to construct and maintain. The artificial reservoir can hold about 80 million litres of runoff and can last for 3-4 months. This water flows naturally into the soil toward the wells' aquifer and stabilizes the water table, or at least controls the gradual lowering of water table. Some 500 rural people directly benefit from this system.

INTRODUCTION

Groundwater is the chief source of wells and many springs. Most rural areas and even cities depend heavily on groundwater for their needs.

In generally flat areas in the Philippines groundwater accumulates chiefly from rain that filters through the soil. It also collects from water that seeps into the ground from lakes and ponds. This groundwater is deposited in aquifers where wells are drilled down for many purposes.

In the absence of surface waters like streams, the people tend to drill both deep and shallow underground wells for domestic and agricultural purposes. When several wells are built close together they compete for the available stored water in the aquifer resulting in water table drawdown and overlaping depressions. The severe drawdown impairs the flow of water from wells to a point of zero flow in shallow wells (Fig. 1).

To remedy this problem the groundwater supply may be replenished or recharged by constructing a pond over a permeable area that will serve as a positive boundary to an aquifer. The gradient from the stream to the well causes influent seepage from the stream. The stored water helps stabilize the water table for the wells.

This paper documents the rainwater augmentation system that revives and sustains the village water supply in a remote area of the countryside. The site (in the Central plain of Luzon),

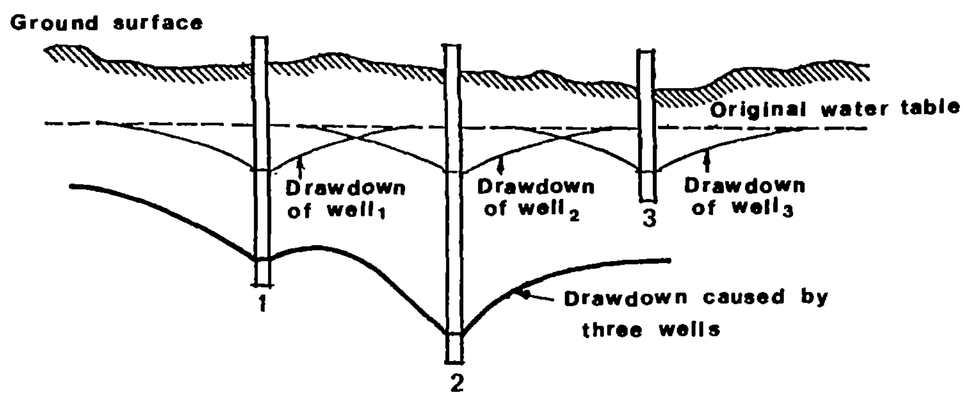

Figure 1: Effect of interference between wells.

where nearly 500 people live, is far from mountain ranges and hills and no major rivers (except natural floodways) traverse or surround the village.

CLIMATIC CONDITION

The study area falls under Type 1 in the climatic classification of the Philippines where there are two pronounced seasons: dry from December to April, and wet during the rest of the year. Most rain occurs from June to October because of the prevaling southwest monsoon. The very dry period lasts from 3 - 5 months (usually from January to April).

The mean annual rainfall observed over a period of 34 years is 1900 mm, with the lowest monthly average and least number of rainy days in the months of December to April, when surface water evaporation is also high. The detailed climatological data for the province is presented in Table 1.

THE RAINWATER AUGMENTATION PROCESS

The main activity is the construction (digging) of a farm pond which serves as an artificial lake in the flood plain and stores runoff during the rainy months. The pond has a circumference of about 350m and an average depth of 10m (Fig. 2). It can hold a maximum of 80 million litres of rainwater that can last for 3 to 4 months (due to infiltration and surface evaporation).

The principle of augmentation is shown schematically in Figure 3 whereby the water table is stabilized or maintained at a level that will sustain clean water for pump wells. Without the artificial pond the drawdown is so low that shallow wells cannot draw up water.

The water stored in the pond seeps laterally towards the wells' aquifer because of the suction forces of the pumps. Since soil particles are the best filters, the water coming out of the wells is not contaminated by pollutants (if any) in the water supplied by the pond.

Table 1. Climatological Data in Nueva Ecija

	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEPT*	*OCT*
Rainfall (mm) [1]Average	6.10	4.00	17.90	22 90	168.6	252 90	321.70	385.70	315 70	200.20
Maximum	67 30	49.50	114.70	261 40	936.90	590.90	1064.70	547 50	628.70	600.70
Minimum	0.00	0.00	0.00	0.00	14.50	64.20	142.50	176.10	140.90	4.00
No of rainy days [2]	2	2	4	4	12	18	20	24	22	12
Relative humidity [3]	70.90	68.20	64.60	63.60	70.10	80.40	83.40	85.70	85 10	80.50
Temperature [4]										
Mean (Celcius)	25.80	26.40	27.60	29.20	29.60	28.50	27.80	27 40	27.80	27.70
Mean Max. (Celcius)	31.60	32.60	34.10	35.30	35.50	33.30	32.40	31.50	31.70	32.50
Mean Min. (Celcius)	20.10	20.00	21.40	22.90	23.80	23.70	23.50	23.60	23.40	23.80
Evaporation (mm) [5]	179.90	188.50	226.20	242.90	199.80	143.60	128.20	100.20	112.50	122.3
Prevailing wind direction [6]wind velocity (km/hr) [7]	NE 7.60	NE 7.60	SE 5.70	SE 5.70	SE 6.70	SE 3.80	SE 5.70	SE 3 80	NE 5.70	NE 3.80
Number of typhoon [8]	0	0	0	1	1	4	1	1	0	3

1/	Period of observation	(1946-80) Cabanatuan City, Nueva Ecjica	5/	Period of observation (1951-80)	C.L.S.U., Munoz, Nueva Ecija
2/	Period of observation	(1951-80) Cabanatuan City, Nueva Ecjica	6/	Period of observation (1951-80)	Cabanatuan City, Nueva Ecjica
3/	Period of observation	(1951-80) Cabanatuan City, Nueva Ecjica	7/	Period of observation (1951-80)	Cabanatuan City, Nueva Ecjica
4/	Period of observation	(1951-80) Cabanatuan City, Nueva Ecjica	8/	Period of observation (1951-80)	Cabanatuan City, Nueva Ecjica

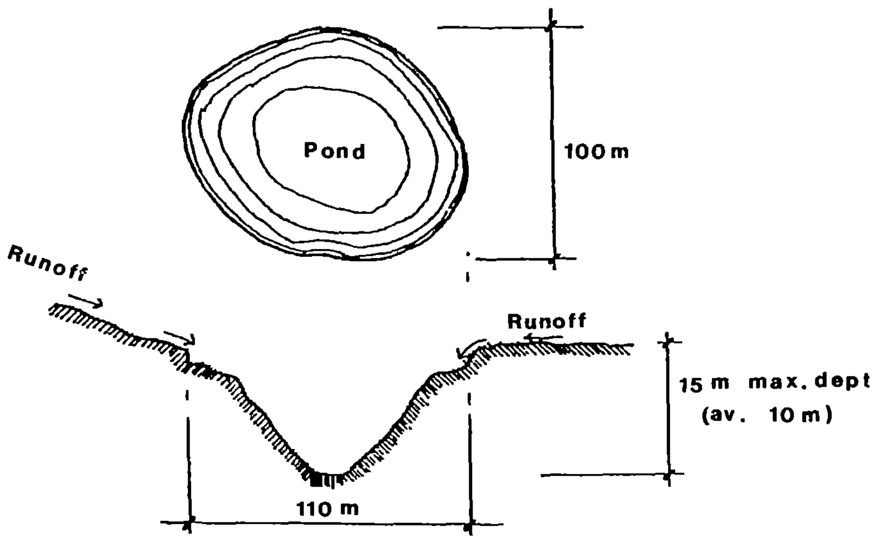

Figure 2. Cross section of artificial pond (unscaled).

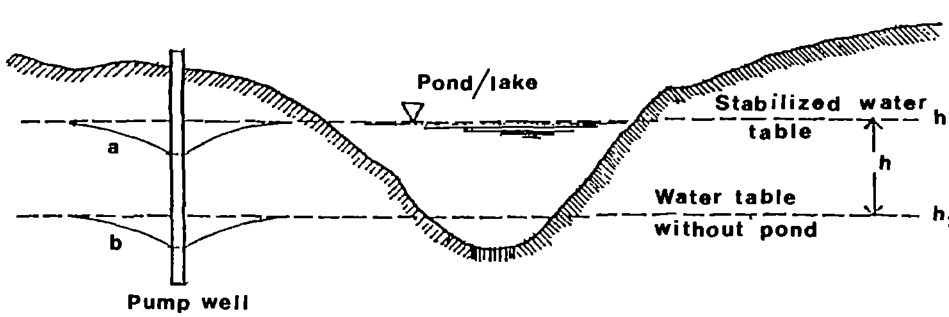

Figure 3. The effect of seepage from pond to pump well aquifer

DETERMINATION OF DRAWDOWN

A series of observation wells were installed near the existing shallow pump well to measure (approximately) the drawdown. The height of the water table at these observation wells was measured before, during and after pumping operations and continuously monitored at various sites. The position of the observation wells is shown in Figure 4.

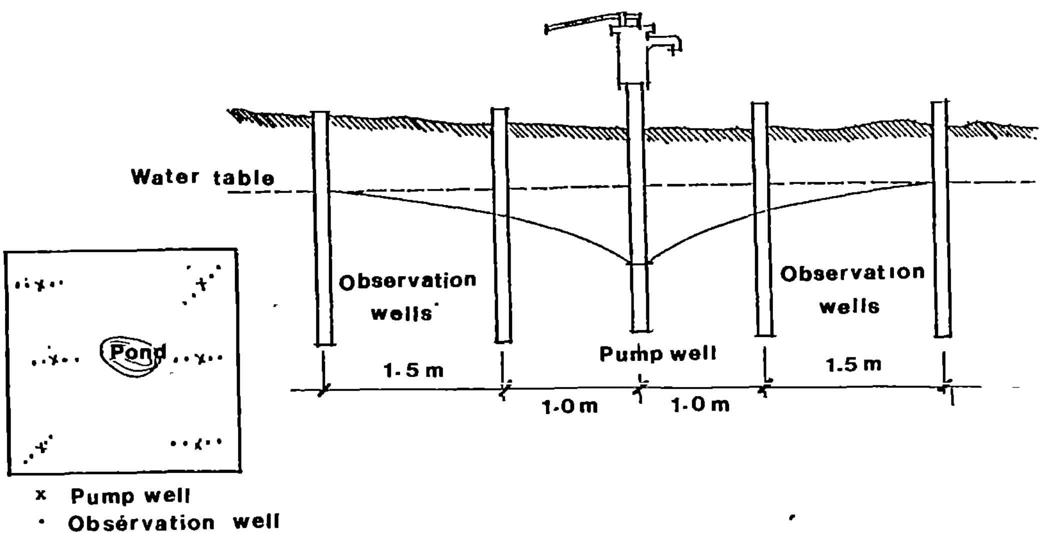

Figure 4 Location of observation wells (inset) and their placement

Measurement is simply done by lowering specially made string to monitor fluctuations of the water table at various times. The observations were conducted the in the morning, noon and evening in the rainy season and during the dry months of January to April, before and after the construction of the artificial pond. The water table stabilized after the construction of the pond and the incidence of pump wells drying up within the village became negligible. In the dry periods before the pond, the water table dipped pool to an average of 2m (range 1.5-4m) below the original wet season height (Fig. 3).

CONCLUSION AND RECOMMENDATIONS

The various channels of groundwater discharge may be viewed as spillways from the groundwater reservoir; when the water table is high, discharge through natural spillways tends to maintain a balance between inflow and outflow. During dry periods natural discharge is reduced as the groundwater level falls, and outflow may even cease. Artesian aquifers may not reflect this natural balance as rapidly as water table aquifers, but sustained drought will decrease water levels in the recharge area and decrease discharge from the aquifer.

As observed during this study, the yield of an aquifer can be increased artificially by introducing water into it by means of rainwater collection. This method of artificial recharge is dependent on the geology of the area and on economic considerations. Storing floodwater in a pond (reservoir) over a permeable area is not so costly if done properly. The pond was excavated using heavy equipment. A financial and economic analysis for the whole system was not performed in this case. Maintenance such as desilting the pond is one area of concern; it is important to maintain the original cross section in order to store adequate water for the augmentation process. The pond could also cater for other farm activities such as fish culture and a bird sanctuary. The pond should not be used as a reservoir for lift pumps to irrigate agricultural crops. If this happens the stored water will not last long and prolonged drought will significantly affect water supply to the artesian wells.

REFERENCES

Linsely, R.K. Jr., Kohler, M.A. and **Paulus, J.L.H.**, (1975). *Hydrology for Engineers*, second edn. McGraw-Hill, New York.

National Irrigation Administration. (1990). *Feasibility Study Report of the Second Communal Irrigation Development Project.* Quezon City, Philippines.

Schwab, G.O., Barnes K.K., Frevert R.K., and **Edminister, T.W.** (1971). *Elementary Soil and Water Engineering.* John Wiley and Sons, New York.

Withers, B. and **Vipond, S.** (1980). *Irrigation: Design and Practices.* Cornell University, Press, New York.

A PHYSICALLY-BASED MODEL OF RAINWATER HARVESTING FOR TANZANIA

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ABSTRACT

A research programme has been established involving collaboration between the University of NewCastle upon Tyne in UK and Sokoine University of Agriculture in Tanzania.

The combination of experimental work in Tanzania and modelling studies in Newcastle aims to:

1. Evaluate agro-climatic constraints on cropping (of maize in particular) in selected pilot project areas in Tanzania;
2. Determine the level of farmer-knowledge of soil-water management practices in Tanzania;
3. Develop and test an agro-hydrological model based on water harvesting trials in the selected pilot project areas, together with data gathered from elsewhere;
4. Use the model to simulate the performance of various water harvesting systems with a view to developing it as a tool for technology transfer.

Techniques under consideration are restricted to within-field methods in which the transfer of water over distances of no more than 50-100m occurs mainly as sheet flow. This includes such techniques as microcatchment, contour ridges, furrow dyking, contour benches, strip planting etc. A further restriction is that water storage is within the soil profile.

Three field sites have been established at different locations in Tanzania and some progress has been made with development of the model. A progress report is presented, focusing on the project aims and methodology and their wider application.

INTRODUCTION

This paper is concerned with rainwater harvesting (RWH) as a method for improving the reliability of rainfed crop production in semi-arid areas.

Although RWH is theoretically feasible anywhere rain falls, its potential is greatest in arid and semi-arid regions where agricultural production is limited primarily by low and/or erratic rainfall (Reij, Mulder and Begemann, 1988). Such areas are characterized by:

1. An erratic and unpredictable rainfall regime. UNESCO (1977) suggests an inter-annual variability of between 25% and 100% in arid and semi-arid climates.
2. Mean annual potential evapotranspiration (ETP) much greater than mean annual rainfall (P). Arid and semi-arid areas are defined by UNESCO (1977) as having a P: ETP ratio of 0.03-0.5, and an annual rainfall of 200-800 mm (summer rain).
3. Loss of rainfall through runoff; insufficient soil-water storage and evaporation from uncropped soil.

4. Poor relationship between periods of soil-water availability and crop requirement, giving growing seasons of 0-100 days (FAO, 1978).

These conditions are found throughout much of sub-Saharan Africa. Although recent studies by Reij *et. al* (1988) and IFHAD (1992) have identified considerable indigenous knowledge of water conservation techniques in Africa, they are not widely adopted by dryland farmers. In order to overcome this problem the system developed must be: technically sound; socially acceptable; economically feasible and effectively extended.

Until recently the majority of scientific study on RWH has been concentrated in the Middle East (Evenari, Shanan and Tadmar, 1971; Ben-Asher and Warrick, 1987), India (Sharma, Singh and Pareek, 1983) and the USA (Nabhan, 1984) where rainfall occurs during the winter (non-growing) season. It is necessary to ascertain whether techniques developed for these climates can be applied to those of sub-Saharan Africa. To achieve these goals, a combination of experimental work in Tanzania and modelling studies in Newcastle is attempting to:

1. Evaluate agro-climatic constraints on cropping (of maize in particular) in selected pilot project areas in Tanzania;
2. Determine the level of farmer-knowledge of soil-water management practices in Tanzania;
3. Develop and test an agro-hydrological model based on water harvesting trials in the selected pilot project areas, together with data gathered from elsewhere;
4. Use the model to simulate the performance of various water harvesting systems with a view to developing it as a tool for technology transfer. This is an efficient alternative to long-term, site-specific experimentation.

This paper provides an outline of the aims of the project, the proposed methodology, progress to date and priorities for the future.

AGRO-CLIMATIC CONSTRAINTS

The main agro-climatic constraints on crop production in the arid and semi-arid tropics can be thought of in terms of the length of the growing season. This can be defined as the period during which the available water in the soil lies within the range necessary for crop growth. Dry spells within this period constitute the end of the season if they exceed a crop-specific magnitude. The combination of low, unpredictable, high intensity rainfall, high temperatures, high evaporation and low infiltration in arid lands produces short, unreliable growing seasons and a high risk of crop failure. RWH has the potential to increase the amount of plant-available water in the root-zone, reducing the severity and length of dry spells and delaying the end of the growing season.

Quantifying these constraints and their amelioration by RWH is vital in judging the suitability of an area for this technique. Statistical analyses using readily available climatic data and a simple approximation of RWH (a runoff threshold and rainfall multiplier) have suggested a possible increase in growing season of between 20 and 60 days (with multipliers of 2 and 5 respectively). These studies also suggest an increase in available water during the season that is proportionally greater during the first than the second rains. In semi-arid Tanzania, it is during this first season that crop failure most often occurs.

The finished model will allow a more realistic assessment of the potential benefits of RWH and - from the farmers' point of view the most important factor - the risk of failure.

EXISTING FARMER KNOWLEDGE

During 1992/3 the project team in Tanzania undertook field surveys using Rapid Rural Appraisal techniques in two target areas (Dodoma and Kisangara). These studies were intended to assess the socio-economic factors which may affect the implementation of RWH in these areas - in particular: the perception of constraints on crop production; the level of indigenous knowledge; the attitude to innovation; and the appreciation of risk. Food crop production is perceived to be limited most by the unreliability of rainfall, a lack of inputs and poor soils. Action taken by farmers to improve crop production and soils include contour tillage, stream diversion and micro-catchments, but these practices are not widespread. The majority of farmer perceived improvements followed implementation of these measures. The results of the studies show not only an awareness of the problems and a will to solve them but also a strong local knowledge of the necessary techniques, backed up by an efficient extension service. However, the high labour demand and the risk of damage by livestock emerged as the reasons for the low adoption of soil and water conservation methods (SUA, 1992).

This is intended as the first step in a process to involve farmers and extension workers in participatory research. Several farmers have already agreed to participate in the next stage involving on-farm trials and a more detailed analysis of socio-economic constraints.

AGRO-HYDROLOGICAL MODEL

The model is being developed to fulfil two main purposes:

1. The design of the most appropriate system given site characteristics;
2. The tool for the transfer of RWH techniques to sites whose soils and climate differ from those at the field sites.

To facilitate the model's use by extension officers as a design tool in the field, it aims to represent the important hydrological processes using physical parameters that can be easily (and cheaply) measured or estimated. The physical nature of the parameters also ensures their transferability to sites for which few data are available. The model will be programmed in Quick Basic as far as possible under the pretext that is widely available (a simplified version is supplied with MS-DOS v5.0), widely understood, and therefore "transparent" to would-be users.

Because of their consequences for the farmer, it is essential that the model considers, in particular, the critical balances between runoff-production and erosion, and soil water storage and water-logging. Quantifying the risks involved in RWH is also a priority.

The final model will be composed of four sub-models:

1. A climate generator constructed mainly around a rainfall model which aims to synthesize rainfall frequency, intensity and duration;
2. A catchment area runoff model simulating runoff on the basis of soil characteristics, land use and topography;
3. A cropped area infiltration-storage model to simulate soil moisture conditions in the root zone;
4. A crop growth model for both maize and sorghum.

The components of the model are at various stages of completion but it should be running by mid-1994 for validation in the second half of the year.

The climatic generator

Availability of climatic data of the high temporal resolution needed in physically-based runoff and soil-water models is a major constraint in developing countries. The climate generator will therefore fulfil two purposes: the provision of data for areas which have none and the infilling and extrapolation of data for areas which have little.

The approach chosen is a stochastic one - physically-based rainfall models are far too complex, and as yet unreliable, for use in such a model. The technique used is similar to that of Hutchinson (1990) which generates point rainfall from a three-state continuous Markov occurrence process. This gives rise to clusters of showers which, because event durations are incorporated directly into the model structure, occur sequentially. Intensity for each shower is modelled as an instantaneous rise with exponential decay.

The other variables necessary for the soil moisture and crop growth sub-models (i.e. temperature, evaporation, humidity, etc.) will also be generated stochastically but the probabilities will be conditional upon the state of the simulated day (i.e. clear, cloudy or raining).

The runoff sub-model

There are two main approaches to runoff modelling. These are:

1. Simple empirical models such as the Rational Method or the US-SCS Curve Number approach (with or without antecedent precipitation index);
2. Physically-based infiltration excess models based upon either the Green-Ampt model or numerical approximations of Richards equation.

The second approach has been chosen because although it is complex to implement, requires rainfall data of a high temporal resolution, and needs to be calibrated, it simulates both the volume and intensity of runoff, making it consistent with the soil-water and crop growth models. Because its parameters are physical in nature, they are not dependent upon subjective user judgement. One of the greatest constraints upon the runoff model is the availability of suitable accurate calibration and validation data.

Pedotransfer function

Both the runoff and the soil-water sub-models require hydraulic conductivity (HC) as a parameter. The determination of HC in the field is costly, time-consuming and often unreliable. In this model, HC will be estimated from readily available soil data such as texture, organic matter content and bulk density. Several authors including Vereecken, Maes and Feyen (1990) have developed *pedotransfer* functions to accomplish this for European and American soils. Work presently under way in Tanzania will provide calibration data and assess the suitability of the various functions to Tanzanian soils.

The soil moisture sub-model

The numerical approximation of Richards equation by the transient, one-dimensional finite difference approach is probably the most popular of the various methods for quantifying soil moisture changes spatially and temporally. In its various forms it has been used in SWATRER (Dierckx, Belmans and Pauwels, 1986), PARCH (Bradley and Crout, 1992), WEPP (Nearing *et al.*,1989), etc. The explicit form of the finite difference scheme (as used in PARCH) is simple and flexible but can become unstable without careful management of the temporal and spatial steps. The more stable but also more complex implicit scheme is used in SWATRER.

Alternatively, there is the "book-keeping" approach adopted by many modellers (Parkes, Naysmith and McDowall, 1989). Inflow and outflow of water in the separate layers is simulated on a daily basis, the inflow to the top layer being infiltration. An upper limit of storage is defined and any excess is assumed to drain into the next layer down. Water is extracted by evaporation and transpiration. Although modifications can be made to account for macropore flow, hysteresis and delayed drainage, this approach cannot cope with situations where upward capillary flux is significant, such as where a water-table is perched near the root zone. At this stage the various approaches are under consideration.

The crop growth model

Although a simple soil water status output would give an idea of the effects of RWH, in order to quantify these effects in terms of what the farmer is interested in (the yield), some idea of the implications for crop growth is necessary. A crop model fulfils this role and also allows investigation of the possible risks of waterlogging and drought.

Crop systems are extremely complex and are generally modelled by a combination of empirical and physical techniques. Penning de Vries *et al.* (1989) suggest that there are four levels of crop growth models. Level 1 models consider only climatic variables; those in level 2 model the effects of soil-water availability as well; level 3 models include an account of soil fertility; and those in level 4 attempt to include all other possible stress factors.

The Tropical Crops Unit at the University of Nottingham has developed a crop growth model, PARCH (Predicting Arable Resource Capture in Hostile environments) for sorghum. Although it simplistically models weeds and nutrient stress, it focuses on water stress and thus falls into level 2. As part of the RWH project a version for maize is being developed. This model is physically-based and will be the basis of the crop model.

EXPERIMENTAL WORK

The experimental component of the project provides both quantitative data on the effectiveness of various forms of tillage and RWH, and calibration and validation data for the model.

Three sites were chosen to represent three different land resource zones within Tanzania. The sites at Morogoro and Hombolo village (near Dodoma) receive c.800 mm and c.500-600 mm of rainfall respectively in two unreliable seasons. Kisangara (near Same) receives 400-600 mm annually but it is unimodally and not bimodally distributed (NRI, 1987). The total of 310 plots are divided between the three sites and represent six related experiments: RWH; RWH with storage tank; Catchment; Large catchment; Tillage and Soil and water conservation.

The RWH experiment consists of various sizes of bare, compacted catchment area (c. 200, 100 and 0m) directing water onto an area cropped with maize or sorghum. The RWH with storage is similar except that runoff is directed into a storage tank from which the crop is irrigated when soil moisture falls below a certain level.

The catchment experiment is simply $100m^2$ and $50m^2$ catchments treated as bare, bare and compacted, natural vegetation and low-management crop. These shed runoff into collecting tanks where volume and sediment load are monitored. The large catchment experiment consists of two large, bare catchments at Kisangara whose runoff will be monitored by a flume. These experiments will help validate the runoff model and will also provide data on erosion.

The tillage experiment consists of four blocks of randomized 5m x 20m plots with treatments that include: mulching, tied ridging, flat cultivation, tractor cultivation, etc. (SUA, 1992). The soil and water conservation plots allow comparison of maize yield under different treatments, namely: flat cultivation, zero tillage, contour ridging, stone strips and vegetative barriers, the last three at 5m intervals down the slope.

All experiments are monitored for soil moisture (using neutron probes) to provide data for the soil moisture model and biomass is monitored throughout the growing season and at harvest to provide the parameters for the crop model. An experiment this size is an enormous undertaking and problems with equipment and skilled labour necessitate stringent quality control procedures.

ACKNOWLEDGEMENTS

The modelling work in the UK is funded by the Natural Resources Extra Mural Contract X0200. Experimental work in Tanzania is the responsibility of Sokoine University of Agriculture under EMC X0210.

REFERENCES

Ben-Asher, J. and **Warrick, A.W.** (1987). Effect of Variations of Soil Properties and Precipitation on Micro-catchment Balance. *Agricultural Water Management*, **12**(3), 177-194.

Bradley, R.G. and **Crout, N.M.J.** (1992). *PARCH - User Guide*, v. 1.03. Tropical Crops Research Unit, University of Nottingham.

Dierckx, J., Belmans, C. and **Pauwels, P.** (1986). *SWATRER, a Computer Package for Modelling the Field Water Balance*. Reference Manual 2. Laboratory of Soil and Water Engineering, K.U. Lueven, Belgium.

Evenari, M., Shanan, L. and **Tadmor, N.H.** (1971). *The Negec, the Challenge of a Desert*. Havard University Press, Cambridge, Mass.

FAO (1978). *Report on the Agro-Ecological Zones Project*. Vol.1, *Methodology and Results for Africa*. Rome, Italy.

Hutchinson, M.F. (1990). A Point Rainfall Model Based on a Three-state Continuous Markov Occurrence Process. *Journal of Hydrology*, **114**, 124-148.

IFAD (1992), *Soil and Water Conservation in Sub-Saharan Africa*. GCA, Amsterdam.

Nabhan, G.P. (1984). Soil Fertility Renewal and Water Harvesting in Sonoran Desert Agriculture: the Papago Example. *Arid Lands Newsletter*, **20**, 21-38. University of Arizona, Phoenix.

Nearing, M.A., Foster, G.R., Lane, L.J. and **Finkner, S.C.** (1989). A Process-based Soil Erosion Model for USDA: Water Erosion Prediction Project Technology. *Transactions of the American Society of Agricultural Engineers*, **32**(5), 1587-1593.

NRI (1987). *Tanzania: Profile of Agricultural Potential*. Natural Resources Institute, Chatham, Kent., UK.

Oron, G. and **Enthoven, G.** (1987). Stochastic Considerations in Optimal Design of a Micro-catchment Layout of Runoff Water Harvesting. *Water Resources Research*, **23**(7), 1131-1138.

Parkes, M., Naysmith, D. and **McDowall, M.** (1989). Accounting for Slow Drainage and Hysteresis in Irrigation Scheduling. *Irrigation Science*, **10**, 127-140.

Penning de Vries, F.W.T., Jansen, D.M., ten Berge, H.F.M. and **Bakema, A.** (1989). Simulation of Ecophysiological Processes of Growth in Several Annual Crops. *Simulation Monographs*, 29. Pudoc, Wageningen, the Netherlands.
Reij, C., Mulder, P. and **Begemann, L.** (1988). Water Harvesting for Plant Production. *World Bank Technical Paper*, No. 91. The World Bank, Washington, D.C.
Sharma, K.D., Singh, H.P. and **Pareek, O.P.** (1983). Rainwater Infiltration into a Bare Loamy Sand. *Hydrological Sciences Journal*, **28**(3), 417-425.
SUA, (1992). Soil-water Management in Semi-Arid Tanzania. *1st Interim Technical Report for IDRC*. Morogoro, Tanzania.
UNESCO (1977). Map of the World Distribution of Arid Zones. *Man and Biosphere, Technical Notes*, No. 7.
Vereecken, H., Maes, J. and **Feyen, J.** (1990). Estimating Unsaturated Hydraulic Conductivity from Easily Measured Soil Properties. *Soil Science*, **149**, 1-12.

A SIMPLE STRATEGY FOR THE IMPLEMENTATION OF RAINWATER CATCHMENT SYSTEMS : A CASE STUDY FROM EASTERN KENYA

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ABSTRACT

Rainwater catchment systems are probably better developed in Kenya than in any other country in Africa. Experiences and lessons learnt in Kenya are likely to have relevance to other parts of the continent where this technology is now being introduced for the first time, especially in neighbouring East African countries where similar physical and socio-economic conditions are found.

In Eastern Kenya the history of constructing rainwater catchment systems goes back several decades; the last 15 years however, have been the most productive. Through trial and error and considerable experimentation many different technologies and implementation strategies have been attempted. These include a variety of rock, roof and ground catchment systems as well as other related low-cost appropriate water supply technologies such as sub-surface dams and shallow wells.

The most successful rainwater catchment technologies and a simple implementation strategy are presented with emphasis on the initial project identification, community involvement, training, design and financing methods. Some of the less successful aspects of project design and implementation are also considered, and the lessons learnt highlighted.

INTRODUCTION

The purpose of this paper is to examine some of the different types of rainwater catchment systems used in Eastern Kenya and to highlight some of the most successful designs. The key elements of some of the best implementation strategies are identified and a simple step-by-step approach for implementing a sustainable rainwater catchment project which can be designed, built and maintained by the community itself is outlined. The three types of rainwater catchment systems considered here are roof, ground and rock catchment systems for domestic or community water supplies. These are illustrated in Figures 1-3. First a brief history of the development of rainwater catchment systems and their current state in Eastern Kenya is given.

HISTORY AND CURRENT STATE OF RAINWATER CATCHMENT SYSTEMS IN EASTERN KENYA

Whilst evidence is scant, scattered examples of roof catchment systems at missions and similar buildings have existed in Eastern Kenya since around the turn of the century. Traditional systems, however, collecting runoff from thatched roofs and ground surfaces have undoubtedly been used for centuries.

In the 1950s a number of rock catchment systems were built by the local authority in Kitui. Some of these were refurbished in the 1980s and are still operating today. The more general use of roof catchment systems began with the increasingly widespread use of *mabati* corrugated iron roofing material in recent decades, and especially since independence. Major roof catchment projects, however, only began in the late 1970s with the implementation of a number of designs developed by UNICEF at the now defunct Village Technology Unit. In north Kitui the Catholic Church promoted cement jars, while Action Aid built hundreds of basket-work-framed (ghala baskets) demonstration tanks at schools. Most of these tanks failed after a couple of years due to bacterial, fungal or termite attack of the basketwork and are no longer recommended (Lee and Visscher, 1992).

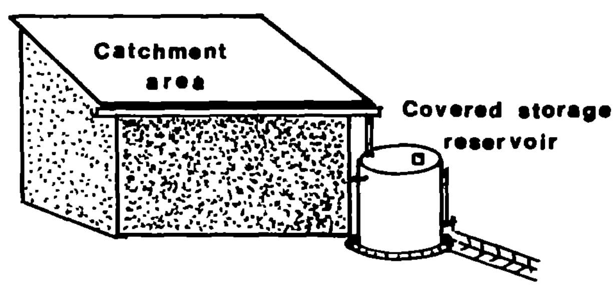

Figure 1. Roof catchment system.

A more successful design has been the concrete ring tanks built using corrugated iron cylindrical formwork which have been implemented by the Diocese of Machakos since 1983. Several thousand of these tanks with volumes between 4.5m^3 and 15m^3 have been constructed over the last decade, financed mainly through revolving funds (De Vrees, 1987).

The Mutomo Soil and Water Project developed a number of ferrocement designs for roof catchment tanks during the 1980s. The most successful of these (based on a smaller UNICEF design) are the 46m^3 and 23m^3 ferrocement tank designs (see the paper by Gould in these proceedings, Fig. 2), the construction of these is illustrated in photo-manuals by Nissen-Petersen (1990, 1992). These have been built at hundreds of schools since 1990 by the Kitui Integrated Development Project. A variety of ground and rock catchment systems were also developed at this time and many hemi-spherical sub-surface ferrocement tanks varying from 50m^3-80m^3 were built in Eastern Kenya and elsewhere during the last decade. A number of rock catchment systems with reservoir volumes mainly ranging from 500m^3 to 10,000m^3 have also been constructed around Mutomo since the early 1980's, (Lee and Visscher, 1992).

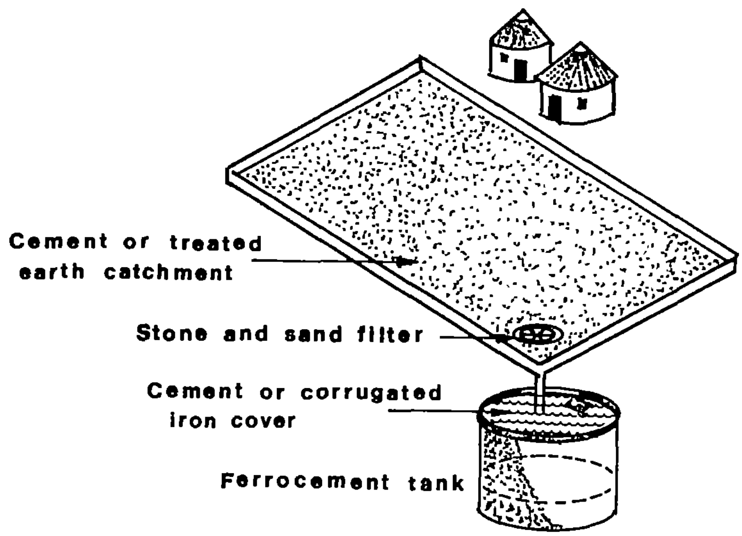

Figure 2. Ground catchment system.

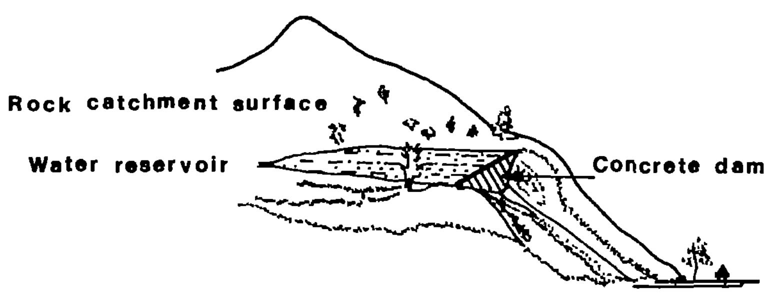

Figure 3. Rock catchment system.

PROJECT IMPLEMENTATION STRATEGY

The steps required for implementing a sustainable rainwater catchment systems project involve identification, training, design and construction, financing, operation and maintenance, and repair. It is essential that the community are actively involved at every stage to ensure the long-term success of any project.

Identification

The community will identify:
- Individuals to be trained in the project survey, design, construction and maintenance.
- The most appropriate sites for building systems (this is especially important for community supplies, demonstration tanks and for rock or ground catchment systems dependent on collecting surface runoff).
- Existing systems requiring rehabilitation.

Training

The community, in conjunction with the project manager/trainer, should select local people for training in:
- Survey and evaluation of potential sites for rainwater catchment systems.
- Simple design techniques and technology selection, e.g. designing a staircase with tap for ground catchment tanks.
- Basic construction techniques, e.g. building stone masonry gutters for rock catchments.
- Selection of suitable local building materials.
- Operation, maintenance and repair of systems.

Construction and design

The implementing agency should prepare all relevant designs in consultation with the community to ensure their needs are being met. The past performance of the designs in similar situations should be considered and any necessary modifications implemented.
- Community members should be involved in as much of the construction as possible but under the careful supervision of skilled builders. They should provide labour for excavation, and for collecting locally available materials to reduce costs, e.g. river-sand for ferrocement tanks; rocks for stone masonry; aggregate for concrete.
- An accreditation system needs to be adopted to categorize skilled masons, foremen etc. according to their experience and ability to ensure quality control and maintian a high standard of workmanship.

Financing

Financing will depend on the resources of the project recipients; where they can pay the full cost of the system they should be required to do so. Where necessary, assistance can be given by the setting up of revolving funds or credit facilities. Where project recipients are too poor to meet the full cost of the system they should be required to contribute at least.
- Unskilled labour for construction;
- 10% of the cement required;
- People capable of being trained as builders surveyors and supervisors.

The donor or government should provide motorized transport, all materials not locally available and the salaries of any permanent project personnel. Where recipients are too poor to even meet the cost of providing 10% of the cement required, the possibility of setting up income generating activities to preceed the implementation of the project and help to fund it should be explored.

Operation, maintenance and repair

To ensure the long-term success of any project it is essential that responsibility is taken for the up-keep, regular maintenance and occasional repair of the systems.
- Regular maintenance, e.g. cleaning the tank, gutters and catchment surfaces, should be the responsibility of the individual users themselves.
- The community should also select a few individuals for training in basic repair skills, e.g. mending leaking taps, patching cracked tanks etc.

LESSONS LEARNT FROM EXPERIENCE IN EASTERN KENYA

Among the lessons learnt in Eastern Kenya with respect to rainwater catchment systems design and implementation are the following:
1. Organic "reinforcement" should be avoided.
2. Corrugated iron covers don't last, ferrocement dome covers are better.
3. Community managed systems are more difficult to maintain than individually owned ones.
4. Free communal labour (*Harambee*) is discouraged by paid labour projects in the same locality at the same time.
5. Clear simple payment schedules are always needed.
6. A real "felt need" is an essential pre-condition for any project.
7. Community involvement in the design, construction, operation and maintenance of systems is vital for the success of any scheme.

CONCLUSIONS

While the experience from successful projects in Eastern Kenya does prove beyond doubt the potential for rainwater catchment system technologies in Africa, especially in semi-arid regions, care should be exercised when trying to replicate these systems elsewhere on the continent.

Although a number of catchment system designs appear to have considerable potential in other parts of Africa, the cost, quality of materials, labour and transport can vary dramatically between countries. These factors must be carefully considered when plans for a project are being drawn up. The willingness of the community to participate in any project and their readiness and ability to pay will vary markedly from place to place and requires detailed assessment when developing the most appropriate implementation strategies. Considerable local knowledge amongst personnel in any external agency involved is also essential at this stage of project design.

Despite the need for caution, there are good reasons to believe that some of the more successful designs and implementation strategies developed in Eastern Kenya could provide a useful starting point for project design elsewhere in Africa.

REFERENCES

de Vrees, L. (1987). *Machakos Diocese Rainwater Tank Programme.* Development Office, Diocese of Machakos, P.O.Box 640, Machakos, Kenya.

Nissen-Petersen, E. (1990). *How to Build a Cylindrical Water Tank with Dome. (46m^3). A photo manual.* KIDP/DANIDA, Nairobi.

Nissen-Petersen, E. (1992). *How to Build Cylindrical Water Tanks with Domes (Volumes 23m^3 and 46m^3).* ASAL Consultants, P.O. Box 867, Kitui, Kenya.
Lee, M.D. and **Visscher, J.T.** (1990). *Water Harvesting in Five African Countries.* Occasional Paper 14. I.R.C., The Hague, The Netherlands.
Lee, M.D. and Visscher, J.T. (1992). *Water Harvesting: A Guide for Planners and Project Managers.* Technical Papers Series 30. I.R.C. The Hague, The Netherlands.

DISCUSSION

Mr Oliver Cumberledge commented that the high evaporation rate from catchments was mentioned and that the same is true for hemi-spherical sub-surface tanks. He described a technique tried by CPK Nakuru in which similar tanks had a central pillar (made of a steel water pipe) to which many wires were attached from the tank edge. Plastic was then placed on top of these and the plastic protected by placing thatching on top of it.

Mr. Nissen-Petersen responded to this by stating that the life of the sisal structure is only about 4 years. However it is cheap and easy to replace as the plants are used for fencing fields in the area described.

RAINWATER HARVESTING DESIGNS FOR SUSTAINABILITY IN DIVERSE CLIMATE AREAS OF KENYA

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ABSTRACT

Harvesting rainwater can provide water for regions whose other sources are too distant or too costly, or where wells are not practical because of unfavourable geology or excessive drilling costs. The potential for developing new water supplies by means of rainwater harvesting is tremedous. Rainwater harvesting is practically suited to supplying water for small villages, schools, households, livestock and wildlife.

The three most important elements of rainwater harvesting are the rainfall characteristics, catchment area and the storage capacity necessary for the sustainability of the exercise. The catchment area and the storage capacity depend on the water-use demand and on the rainfall pattern in a region.

This paper will study the influence of these elements as they affect the dependability of the system.

INTRODUCTION

Water harvesting can be defined as the process of collecting rainwater for different uses from surface areas that have been treated to increase run-off. This paper is concerned with rainwater harvesting to provide a potable water suply to small villages, schools and households in regions where other sources are too distant or too costly, or where wells are not practical because of unfavourable geology or costly drilling.

A rainwater harvested water supply must be provided with adequate storage facilities where the water supply is limited and water use exceeds the supply rate. Storage is generally by means of confinement in either excavated pits, ponds, bags or tanks. The storage capacity should be balanced against the quantity of precipitation for the area and the reliability of recieving this precipitation. The precipitation quantity and dependability are often difficult to determine due to inadequate precipitation records in some places.

Whatever is done, it is necessary to remember that climate and especially precipitation is subject to short, medium and long term variation. Rainwater harvesting is a necessity, but it is also necessary to anticipate the possibility of a drought more severe than has ever occurred. All solutions which are at the limit of the possibilities are dangerous as there is no security margin (Colombani, 1992).

PRESENT WATER SUPPLY IN KENYA

In many parts of Kenya, people live in areas where water is scarce. Water often has to be carried over long distances, particularly during dry periods. The scarcity of water sometimes causes people to use sources that are contaminated and dangerous to human health. A large number of families live in settlements where there is no adequate water system.

In 1973 Carruthers reported that nearly 20% of the total Kenyan population was served by a modern water service, but with the annual rate of increase in the population at 3.3% (which means doubling of the population every 20 years), and the fact that very few water supply projects have been implemented since then, the situation could be worse today. There is a need therefore, to harness all possible sources to make water available to the people. The scattered nature of rural settlements often precludes the possibility of conventional water supply schemes. Hence the need to devise suitable means of meeting the water requirements of the people in rural and peri-urban areas. The collection and storage of rainwater for domestic use adequately meets these requirements and the quality is generally within the recommended limits for drinking water (Owoade). In many areas of Kenya where rainwater harvesting is practiced there is hardly ever enough water stored to see the users through the dry season, because of poor designs.

RAINFALL ADEQUACY AND RELIABILITY

There can be little doubt about the importance of rainfall reliability in all fields of human endevour. The main factor controlling the productivity of water-resource developments is the reliability of rainfall with other climatic factors like temperature and evaporation having little long-term influence. Rainfall variability introduces an element of uncertainity into economic planning and increases the construction cost of new water supply installations as they have to be able to cope with extreme rainfall or drought conditions (Nieuwolt, 1978).

The effects of rainfall reliability have been illustrated by a series of unusually wet years followed by a period of rather dry years. It is important, therefore, to obtain more information about rainfall variability, its spatial distribution and reliability before any rainwater supply work is undertaken. One characteristic of rainfall variability with special consequences for rainwater harvesting is the occurrence of periods with very unreliable rainfall or no rainfall at all. These periods may be of different duration and they cannot be identified from annual totals. Therefore monthly rainfall figures together with their probability of occurrence must be used to ascertain which monthly totals to use to ensure sustainability. Variations in monthly rainfall from year to year and from one locality to another are considerable and have different degrees of reliability. The distribution of rainfall is thus irregular in both space and time and water is a problem almost everywhere (Nieuwolt, 1978). In many areas of Kenya, where rainfall is both marginal in volume and restricted to seasons, its reliability is more critical than in temperate latitudes (Griffiths, 1972). Rainfall in Kenya is so highly variable that the usual arithmetical calculation of the mean is of limited value. The mean is influenced by extreme values which are generally on the high side. The average annual rainfall in Kenya generally varies widely being as low as 250mm in North Eastern Province and over 2000mm in the highlands.

Unreliability of rainfall is expressed in several ways. There is variation in annual or seasonal totals around their mean and there is variation in the time at which expected seasons materialize. Although wet and dry seasons follow one another with some regularity, it is common observation that dry spells occur when rain is expected and that wet spells can occur in the dry season (Pratt and Gwynne, 1978). The complexity of the rainfall pattern in Kenya is shown in Fig 1.

SYSTEM DESIGN

Although rather sophisticated computer programmes have been developed to aid rainwater system design, they only consider a few of the numerous factors involved and no procedure is available to provide optimum design. So the system is designed using compromise methods that consider a few factors, plus the experience and judgement of the designer. The size of the catchment is normally based on average annual or seasonal rainfall and storage is often determined by usage.

Some work referred to by Waller and Scot (1988) indicates that, in Nova Scotia, systems designed on the basis of average values suffered periodic water shortages. If water harvesting is to meet the criterion of sustainability, which is defined as the integration of economic, environmental and social ojectives, it should provide a service with minimum failure, especially where there is no easy alternative available. As far any other trouble-free development system, and taking the huge variability of rainfall as the main factor in determining the suitability of a project, a design criterion should be developed. For a water supply from run-off river flows, it is desirable to have a 95% probability of assured monthly rainfall (Hargreaves and Samani, 1990).

Another recommendation for livestock and domestic water schemes is to aim for a 90% rainfall reliability (Nelson, 1985; Pieck, 1985) rather than the average (Pacey and Cullis, 1986). The actual amount of water harvested will finally depend on the runoff coefficient of the catchment. Thought should also be given to the effect of dry spells occurring when rain is expected.

CONCLUSION

The cost of water obtained from rainwater harvesting will depend upon the cost of the structure and the amount of rainfall runoff obtained during the period in question. The optimum relationship between size of catchment and volume of storage must be determined for each site. In any case, water is worth whatever the cost if the need is sufficiently great. The feasibility of water harvesting must be determined by a comparison of the cost of alternative water sources and by the cost water users can afford to pay (Myers, 1964).

The potential for developing new water supplies in Kenya by means of water harvesting is tremendous since rainwater harvesting is possible in areas with as little as 50-80 mm average annual rainfall (Arar, 1983). Water harvesting systems may provide the only source of water in some areas and can provide a low energy input, economical water source in many others. It is noted that none of the rainwater harvesting systems in Kenya has been subjected to a long-term economic analysis. There is, therefore, a need for large field trials in different areas to build up a database that will lead to a better understanding of the economic viability of different economic environments.

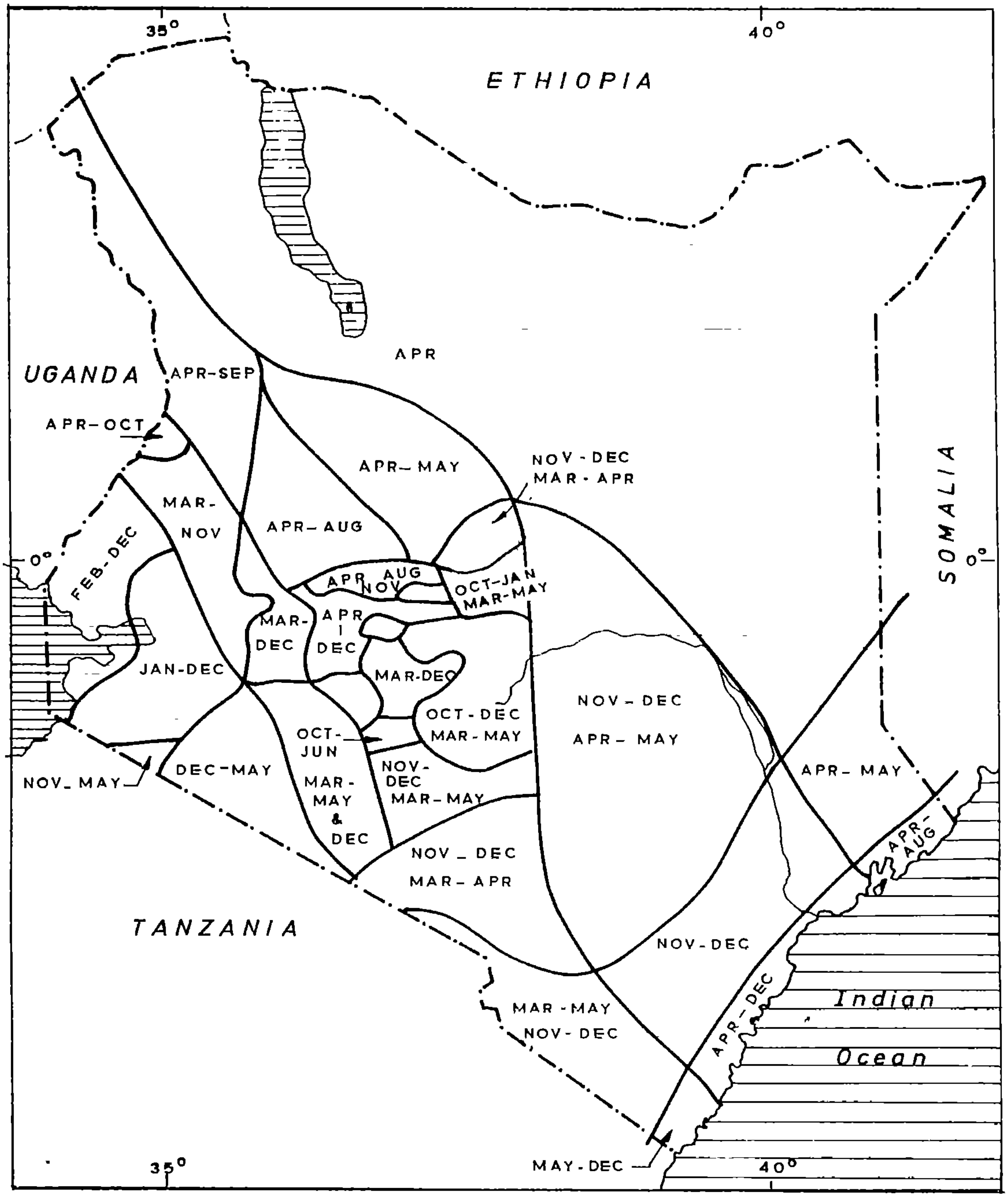

Figure 1. The rainfall regions of Kenya· months recieving a mean rainfall of 50mm or more are indicated (Griffiths, 1972).

REFERENCES

Arar, A. (1983). Water Harvesting and Other Techniques of Water Use in Arid Areas. *Report on the Training Course on Watershed Management for Africa*, pp. 221-224. FAO, Rome.
Bille, J.C. and **Hemstra, H.H.** (1979). *An Illustrated Introduction to the Rainfall Patterns of Kenya.* International Livestock Centre for Africa, Nairobi, Kenya.
Colombani, J. (1992). Some Notes About Rainwater Harvesting. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems.* Nairobi.
Griffiths, J.F. (1972). Climate. *East Africa: Its Peoples and Resources*, Ed by W.T.U. Morgan, pp. 107-118. Oxford University Press.
Hargreaves, G.H. and **Samani, Z.A.**, (1991). Weather Predictive Models. *Semi-arid Lands and Deserts*, Ed by J. Skujins, pp. 581-603. Marcel Dekker Inc., New York.
Kenworthy, J.M. and **Glover, J.** (1958). The Reliability of the Main Rains in Kenya. *East African Agricultural Journal.* **23**; 267 - 272.
Myers, L.E. (1964). Harvesting Precipitation. *Bulletin Intnl Assoc. Sci. Hydrology,* **65**, 343-351.
Nelson, K.D. (1985). *Design and Construction of Small Earth Dams.* Inkata Press, Melbourne.
Nieuwolt, S. (1978). Rainfall Viability and Drought Frequencies in East Africa. *Erdkunde*, **32**, 81-88.
Owoade, A, Rainwater Harvesting. *Development World Water*, pp. 283 - 284, Grosvenor Press International.
Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas.* Intermediate Technology Publications, UK.
Pieck, C. (1985). *Catchment and Storage of Rainwater. Tool Foundation,* Amsterdam.
Pratt, D.J. and **Gwynne, M.D.** (1978). *Rangeland Management and Ecology in East Africa,* pp. 13 - 18, Hodder and Stoughton, London.
Waller, H.D. and **Scott, R.S.** (1988). Rainwater as an Alternative Drinking Water Source. *Proc 3rd Nat. Conf. on Drinking Water "Small Systems Alternatives".* St John's, Newfoundland.

ROCKS AS CATCHMENT SYSTEMS FOR HARNESSING RAINWATER

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ABSTRACT

The imposition of hydrometeorological and climatical conditions upon the regional geology of an area provides the setting for a hydrogeological discussion. Due to the strong relief, precipitation in Kenya varies widely over short distances. The amount of water available in any one area can accurately be summarized by the natural vegetation and rainfed crops found in a region.

Most of the surface runoff is transported by stream networks of the major river systems. In the arid and semi-arid areas, however, the streambeds and gullies are dry except for short periods after flash-floods following torrential rainstorms. Since impermeable rocks like granites, gneisses and quartzites can be used to hold rainwater or surface runoff just as well as to contain ground water, it is being proposed in this paper that where the bedrock is strong, rigid and suitable dams should be constructed. The necessary precautions must be taken to ensure equilibrium between surface and ground water regimes before such constructions are built.

The construction of artificial lakes for water supply, irrigation, hydro-electric power and flood control have been major concerns of engineering works for a long time. It is therefore imperative that similar constructions should be built to impound flash-floods or to contain rainwater in areas where water availability is a constraint for settlement or for other development purposes.

INTRODUCTION

The surface area of Kenya is 582,646 km^2. Based on agricultural potential, vegetation, annual rainfall and annual evapotranspiration, it can be divided into four main categories:

1. High potential land covering 11.9% of the surface;
2. Medium potential land covering 5.6% of the surface;
3. Low potential land covering 74.0% of the surface;
4. Other lands which include rugged, steep, bare rock and very high altitude, covering 8.6%.

Agricultural potential refers to the ability of land to support rain-fed agriculture (statistical abstracts, Kenya Government).

The low potential zones have an annual rainfall of between 635 and 762mm and include arid and semi-arid areas of Kenya. These lands are suited for livestock raising and/or wildlife (Fig.1).

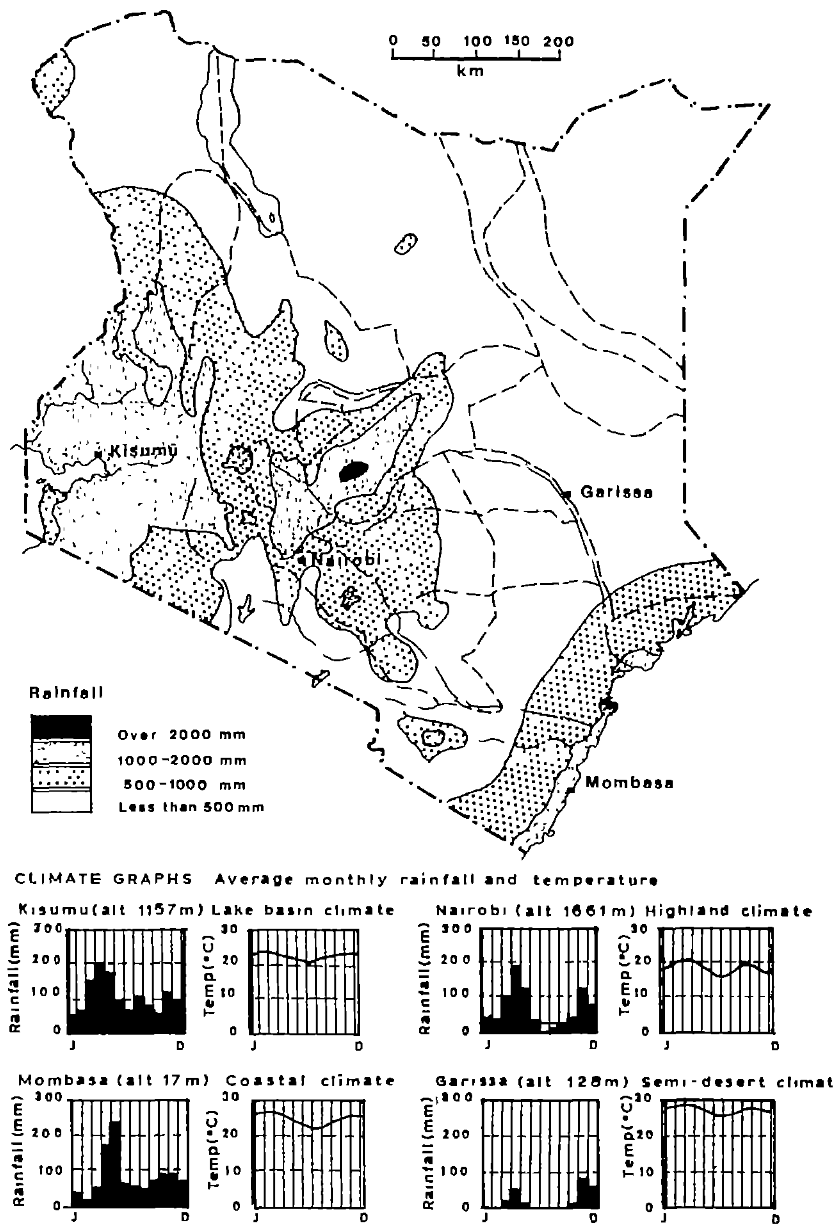

Figure 1. The climate of Kenya.
(after Kenya Primary School Atlas)

Surface runoff water in Kenya converges in streams and river systems which discharge in internal basins, especially in the Rift Valley; or into the sea, as do the Tana and the Athi river systems; or into Lake Victoria as do the Nzoia and Yala rivers.

Accurate gauging of streams and rivers forms a good basis for quantifying surface water resources. Since most of the base flow is sustained by ground water, this is part of the total water resources of a region and hence ground water may be a good basis for quantitatively estimating it through surface runoff data.

Evapotranspiration is, on the other hand, a more difficult parameter to evaluate in the water balance equation. In Kenya the figures have varied rather widely with positive figures in highland areas which are covered by woodland and forests, while a large deficit is noted in other areas like savannas and scrubland (Fig. 2); in the latter case there is negligible recharge to ground water (Obasi and Kiangi, 1975; Woodhead, 1968). Potential evaporation in these areas far exceeds rainfall by one order of magnitude.

The most important aquifers in Kenya recieve ground water recharge through the streams and river systems and hence are influent (Swarzenski and Mundorff, 1977). The Rift valley lakes are similarly influent by nature (Allen and Darling, 1992) and hence meteorological data (precipitation, evaporation and runoff) would only be useful in determining or estimating water balance in some catchments.

PHYSICAL FEATURES

Kenya can be divided into six physiographic divisions:

1. Narrow coastal plain.
2. A range of coastal hills in the south which rises between 300mm and 500m above mean sea level.
3. An extensive inland plain covering the eastern half of the country rising from 250m to 900m in elevation.
4. Extensive mountain ranges of Precambrian rocks occuring at the interior margin of the plain, rising to 2500m in height.
5. Volcanic plateau and associated high volcanoes such as Mt Kenya and the Nyandarua range (Aberdares), the Nyambani range and Mt Elgon.
6. The Rift Valley depression traversing the volcanic highlands from northern Turkana and to Lake Magadi (Fig. 3).

GEOLOGICAL SETTING

The principal geological formations in Kenya are shown in Figure. 4.

The Nyanza Shield

The Nyanza Shield is composed of mainly lavas and pyroclastics of the Nyanzian Group and grits, sandstones, greywackes and conglomerates of the Kavirondian Group. Both these groups are tightly folded about axes trending between northest and southeast and they are intruded by numerous granitic bosses and batholiths. Towards the south of the Nyanza Shield, the Kisii Formation consisting of volcanics and quartzites is found.

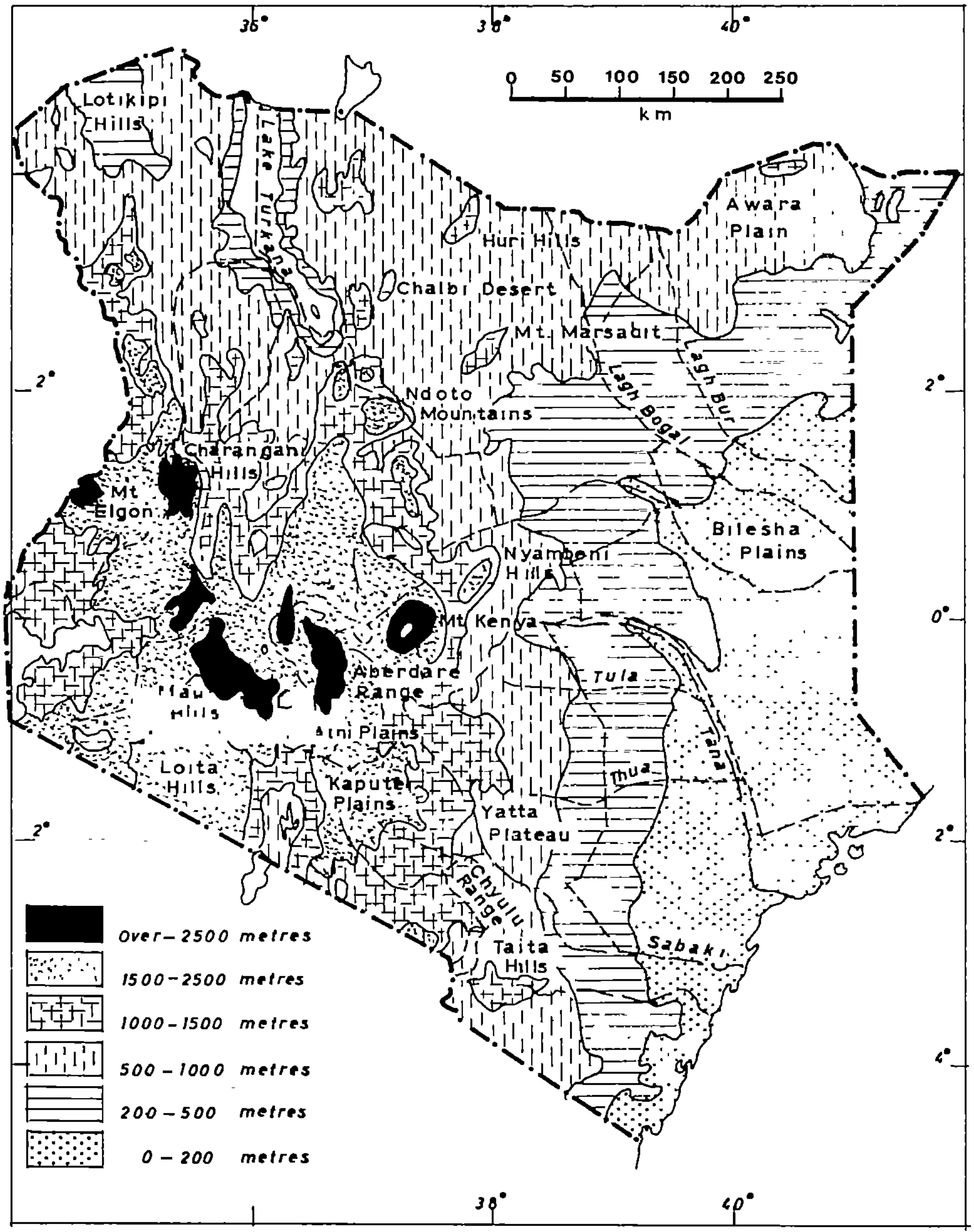

Figure 2. The relief features of Kenya.
(after Kenya primary School Atlas)

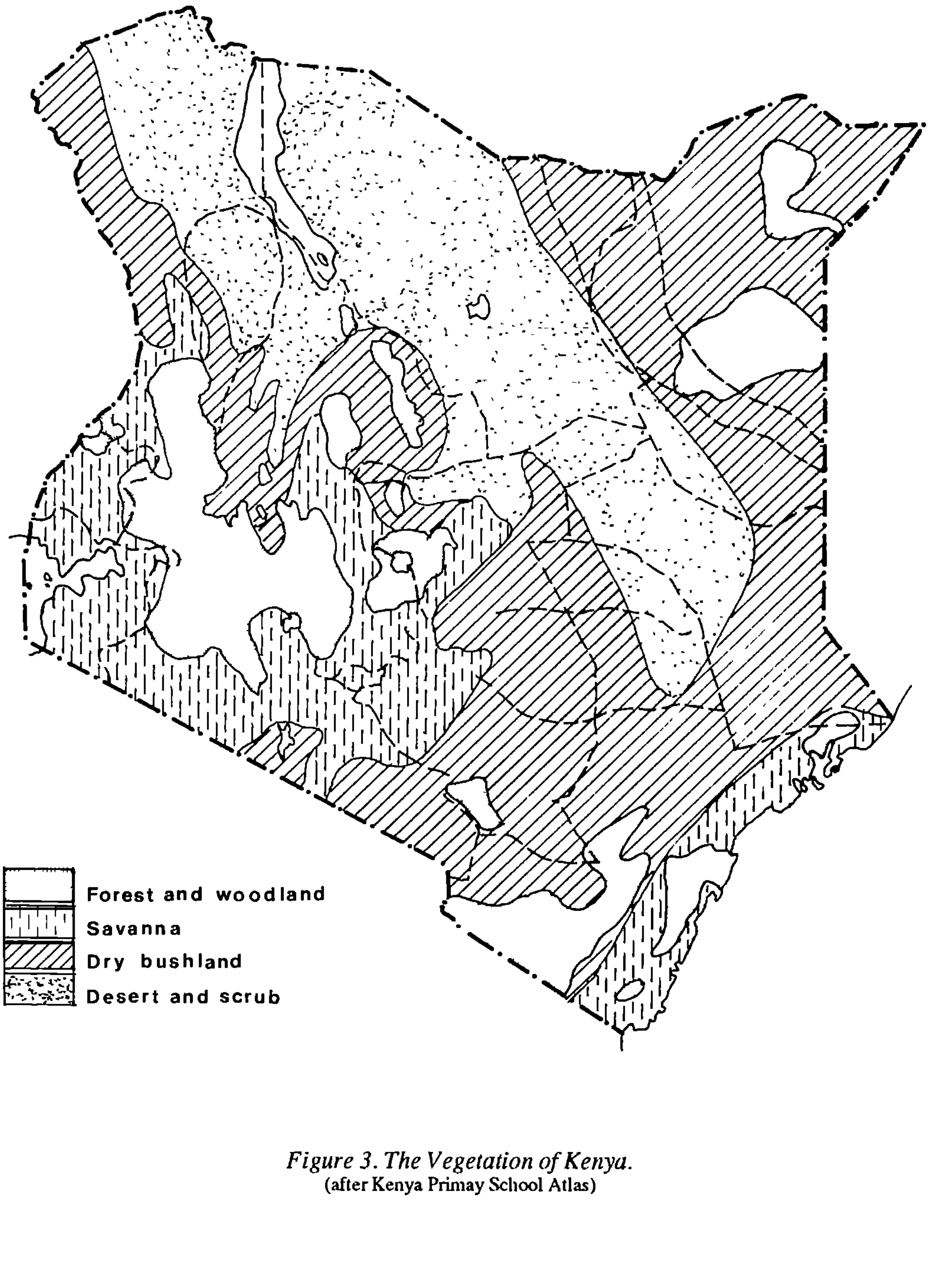

Figure 3. The Vegetation of Kenya.
(after Kenya Primay School Atlas)

The Mozambique belt

This is a structural unit with a wide variety of metasedimentary and igneous rocks showing a broad structural style and metamorphic history. It is represented by the Ukamba Group, The Turoka Group and the Loita and Turbo Groups.

Karroo Formation

The Karroo Formation consisting of basal sediment, grits, sandstones and shales are found in the coast hinterland and in north-eastern Kenya.

Mesozoic rocks

These occur in two separate areas in the north east and along the coastal belt.

Tertiary rocks

The Tertiary is represented by coastal sediments, sediments of the interior and by volcanic rocks of the Rift Valley system.

Recent

Young volcanic rocks of the Rift Valley, soils alluviums, beach sands, alluvials and lacustrine sediments of the Rift Valley, coral reefs and sandstones of the coast represent the young rock formations of the country.

SUMMARY OF KENYA GEOLOGICAL SUCCESSION

Recent

Soils, alluvials, beach sands, evaporites etc. Fossil coral reefs and sandstones at the coast. Alluvials and lacustrine sediments of the Rift Valley. Younger volcanic rocks of the Rift Valley and the younger volcanoes.

Tertiary

Coastal sediment. Late Miocene and Pliocene volcanics. Terrestrial and lacustrine inland sediments. Early Tertiary formations not represented at the surface. (Major hiatus in the geological succession.)

Cretaceous

Sediments of the coast and in north-east Kenya.

Trias permian carboniferous

The Karroo Formations of the coast hinterland, possibly including the basal sedimentary formation in north-east Kenya. (Major hiatus in the geological succession.

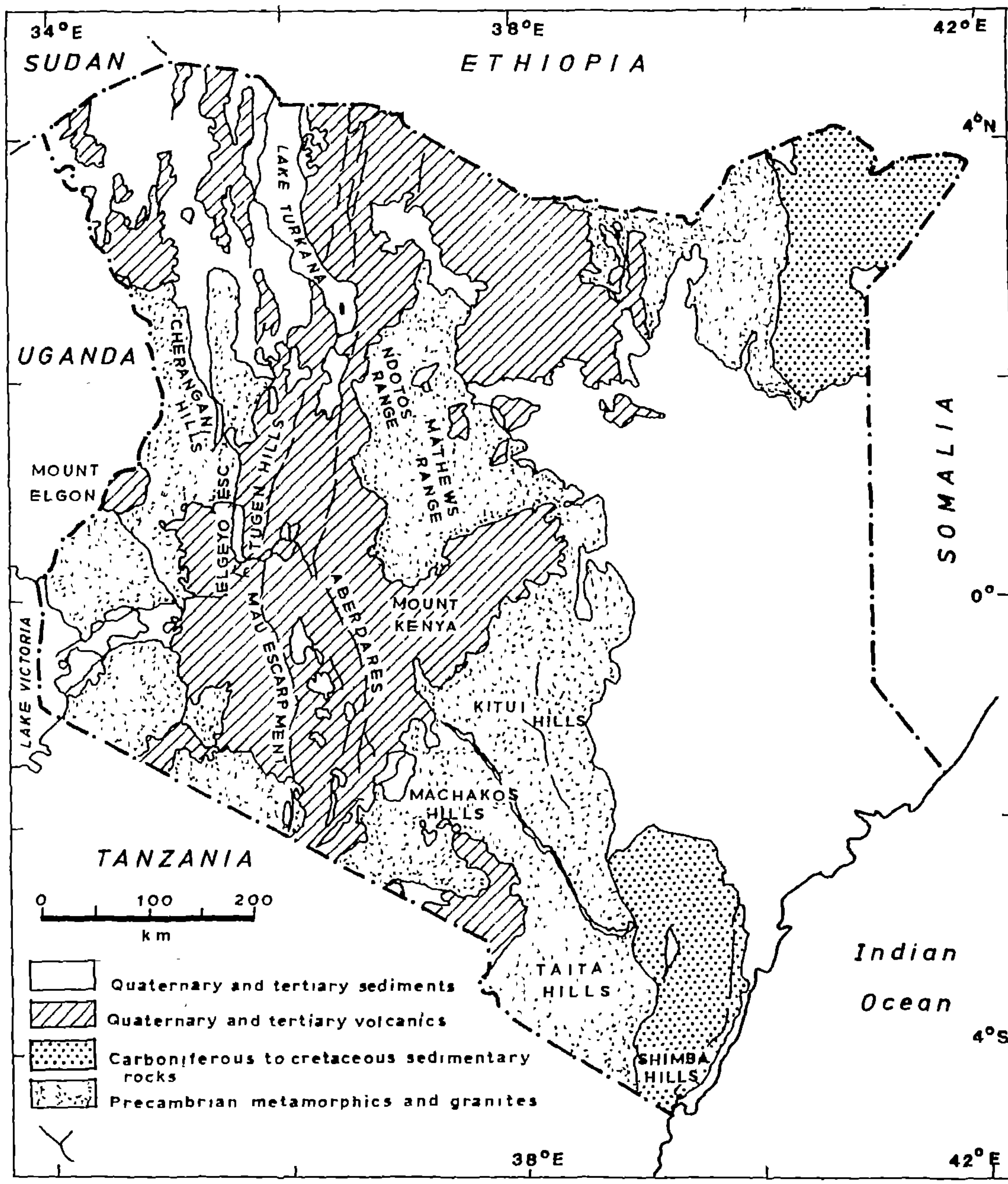

Figure 4. The geology of Kenya.
(after Rowntree, 1989)

Late precambrian

Formations of the Mozambique belt
Kisii Formation (Bukoban system);
Turbo Group, Loita Group and Turoka Group: Metamorphosed meta-sediments, granitized rocks, meta-intrusives etc. (Formerly part of the Basement system.)

Early precambrian

Ukamba Group - intensely granitized meta-sediments and intrusives. (Formerly part of the Basement system.)

Formations of the Nyanza Shield
Granites, syenites, dolerites;
Kavirondian Group;
Granites, epidiorites;
Nyanzian Group.
(After Walsh, 1969).

ROCK CATCHMENTS

The major rivers like Tana, Athi and the Uaso Nyiro and their tributaries rise in the high rainfall belt and flow towards the south east and south respectively through the semi-arid region.

The process by which rain or runoff water infiltrates into the soil and how it reaches fractured rock is not well known. It is, however, a function of rainfall, type and depth of soils, deep percolation, topographic slope, vegetative cover and potential evapotranspiration. One other important thing on which storage and transmission depend is the availability of local storage.

Hard rock and/or earth dams have been known to hold and support water, which sustains a patch of greenery around it, especially in drought-prone semi-arid regions. It is proposed that earth dams be constructed in dry river courses and sub-surface dams in sand rivers to hold surface run-off which is a result of heavy precipitation upstream. The delay of lag imposed on the run-off by the dams, if sited in suitable hard rock structures, may sustain water for weeks (4-6 weeks) after the rainy season. Such rocks are found in the igneous terrain (granitic and volcanic rocks) and in the metamorphic terrain (gneisses and quartzites). Suitable characteristics in the sedimentary terrain, like the presence of clays, renders the sedimentary rocks suitable too. The petrographic parameters which should be utilized in the characterization of rocks include grain size, grade of metamorphism, and absence of fractures, faults and joints as these will favour ground water storage and low degree of weathering.

REFERENCES

Allen, D.J., **Darling, W.G.** and **Burgess, W.G.** (1989). Geothermics and Hydrogeology of the Southern Part of the Kenya Rift Valley with Emphasis on the Magadi-Nakuru Area. *British Geological Survey Research Report*, SD/92/1
Allen, D.J. and **Darling, W.G.** (1992). Geothermics and Hydrogeology of the Kenya Rift Valley between Lake Baringo and Lake Turkana. *British Geological Survey Report*, SD/92/1

Kenya Government (1979). *Development Plan 1979-1984.* Government Printers, Nairobi.
Kenya Primary School Atlas, (1978). Collins/Longman.
Obasi, G.O.P. and **Kiangi, P.M.R.,** (1975). Water Balance in Kenya. *The Kenyan Geographer*, 1. 61-79.
Rowntree, K.M. (1989), *Landslides in Kenya: A Geographical Appraisal,* Ed by E.E. Brabb and B.L. Harold, pp. 253-259. A.A. Balkema, Rotterdam.
Swarzenksi, W.W. and **Mundorff, M.J.** (1977). *Geohydrology of North Eastern Province, Kenya.* U.S. Geological Survey Water Supply paper 1757 N.
Walsh, J. (1969). *The Geology and Mineral Resources of Kenya* Bulletin No. 9, Geological Survey, Kenya.
Woodhead, T. (1968). *Studies of Potential Evaporation in Kenya.* East African Agricultural Forestry Reseach Organisation, Nairobi, Kenya.

DISCUSSION

Dr Onyango Ogembo asked whether the cost implication of involving a geologist at the village site had been looked at.

Dr Gaciri responded that the cost of the geologist is taken care of through the appointment of a geologist at the district level by ensuring that a geologist sits on the district development committee as a technical advisor.

THE RESTORATION OF THE BUBISA RESERVOIR, MARSABIT DISTRICT, KENYA

Rupert L.E, Douglas-Bate, Stephen J. Burgess and Peter.H. Stern

Christian Engineers in Development

ABSTRACT

The paper summarizes the history of the $400m^3$ capacity excavated reservoir originally constructed in 1982 by African Community Technical Service (ACTS) under the Church of the Province of Kenya's development programme at Bubisa, north of Marsabit in North Eastern Kenya. The reservoir was designed to collect storm flood runoff by means of a diversion structure on a tributary of the Bubisa *Wadi*. Problems arose from silting and damage at the intake, and from the deterioration of a butyl rubber lining to the reservoir, which had only been full once in the 7 years between 1982 and 1989. At the end of 1989 Christian Engineers in Development (CED) were invited by ACTS to assist with the rehabilitation of this project. This involved re-designing and completely re-constructing the works and installing a roof over the reservoir. The new design of the storage facility in ferrocement is described, and some salutory conclusions are drawn about the importance and advantages of proper investigation and design studies prior to embarking on this type of development.

BACKGROUND

Bubisa has been a small settlement in North Eastern Kenya for many years; it was shown on a 1:2 million scale map of East Africa published in 1941. It lies on the main road from Marsabit to the border town of Moyale and about 55km north of Marsabit (Fig. 1). It is located near a *Wadi* or natural surfaces drainage system running from the south-east to the north-west, which carries water for short periods after rainfall in the locality, and causes ponding in a temporary lake. Originally this must have been the only source of water for the settlement. There is an alternative borehole source, where the water is said to be at 280m below ground level and brackish.

For many years Bubisa has been a centre for the Church of Kenya among the Turkana people, with a school and resident minister. In 1977 ACTS (African Community Technical Service) based in Canada, prepared a report for the then Diocese of Mount Kenya East which recommended the construction of a reservoir at Bubisa to collect and store flash-flood water in the *wadi* to improve water supplies for the community. World Concern (USA) undertook to fund the project as part of the Church of Kenya's development programme, under the general direction of ACTS. Construction started in 1982, with an ACTS volunteer on site employing direct labour, under the general supervision of a water engineer, Mr Mike Harries of Thika, who visited the works from time-to-time.

The original design consisted of an excavated circular chamber 14 m in diameter with a capacity of about $400m^3$, lined with butyl rubber. Water from the *wadi* was diverted by a weir and intake structure into a pipeline, to flow by gravity into the reservior. In the 7 years between

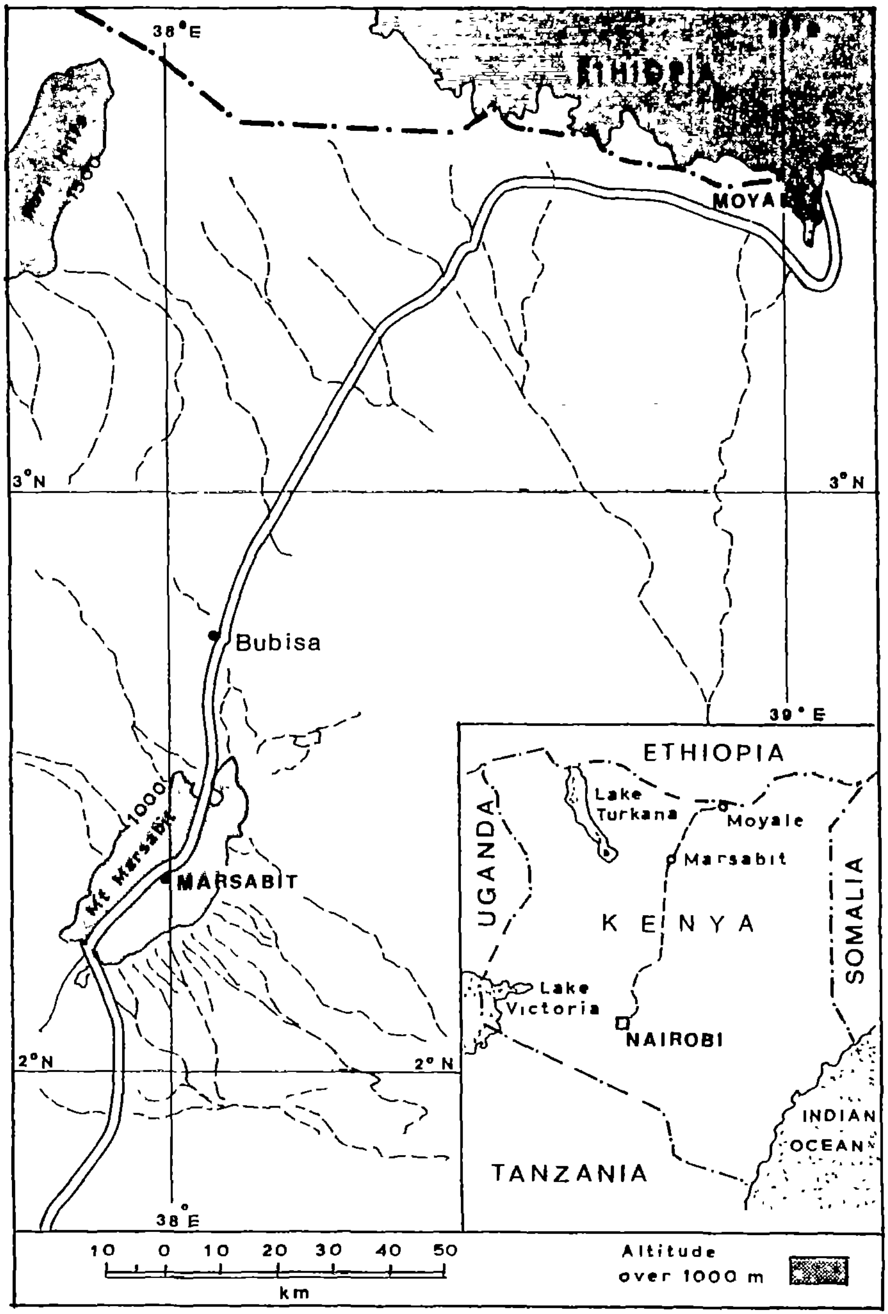

Figure 1. Location of Bubisa.

1982 and 1989 the reservior had only been filled once. A few years after construction, the butyl rubber lining deteriorated and at about the same time the intake arrangement silted up.

In 1987 a prefabricated roof for the reservior was constructed in Nairobi, but by January 1990, it had not been taken to the sight and erected. In an environment where annual evaporation amounts to some 2.5m, a storage 3m deep needs to be protected from evaporation. Also in 1987 an ACTS team then in Kenya undertook a review of the scheme and made recommendations for its rehabilitation.

At the end of 1989 Christian Engineers in Development (CED) were invited by ACTS to help with the restoration of the reservoir and diversion arrangments. At that time ACTS had a representative based in Nairobi and he was able to provide logistic support to a CED Engineer, Rupert Douglas-Bate, who arrived in Kenya in January 1990.

DESIGN CONSIDERATIONS

In remote areas basic hydrological data are scarce, and this was found to be true at Bubisa. Research into the original design work indicated that little was known about the physical characteristics of the catchment feeding the *wadi*, the length and slope profile of the *wadi* channel and the incidence and magnitude of flood discharges. All that was known was that floods occurred once or twice a year and lasted for anything between 8 and 36 hours. For one period of 14 months there was no flood.

The layout of the scheme is shown in Figure 2. Little is known about the original design of the intake works on the *wadi*; which diverted water into a PVC pipe 56m long, filling the reservoir by gravity. In a letter to the CED in January 1990 the Director of ACTS attributed the silting-up of the intake to the lack of a silt-exclusion facility and to the pipe having been laid too nearly horizontal.

As originally designed the reservoir was to have had a vertical concrete wall with a butyl rubber lining. For some reason, presumably on grounds of economy, the concrete wall was omitted and the lining was laid against the soil and secured by a cast concrete ring round the periphery. In the course of a few years the vertical soil wall collapsed behind the lining and the lining itself deteriorated and became holed. Following the recommendations of the review team of 1987, ACTS decided to replace the original intake works, to reconstruct the entire reservoir and to erect the roof which had been constructed but not installed.

THE 1990 DESIGN

A new intake arrangement was designed incorporating a concrete stilling basin 9.1m x 2.4m x 1.1 m deep, and gabion bank protection. The re-design of the reservoir was based on a standard UNICEF design in ferrocement, circular in plan as before, with a diameter of 12.49m inside a vertical ferrocement wall 3m high, the top of which is 1.98m below the ground level and is capped with a circular concrete retaining ring, surrounded by an outer circular concrete retaining wall, inside diameter of 14.02m, carried up to ground level (Fig. 3). The existing roof structure is supported by this retaining wall. The storage is provided with a door and steps for access and all openings are covered with mosquito netting. Water is drawn from the reservior by means of an SWS filtration Rower pump, placed at ground level outside the structure.

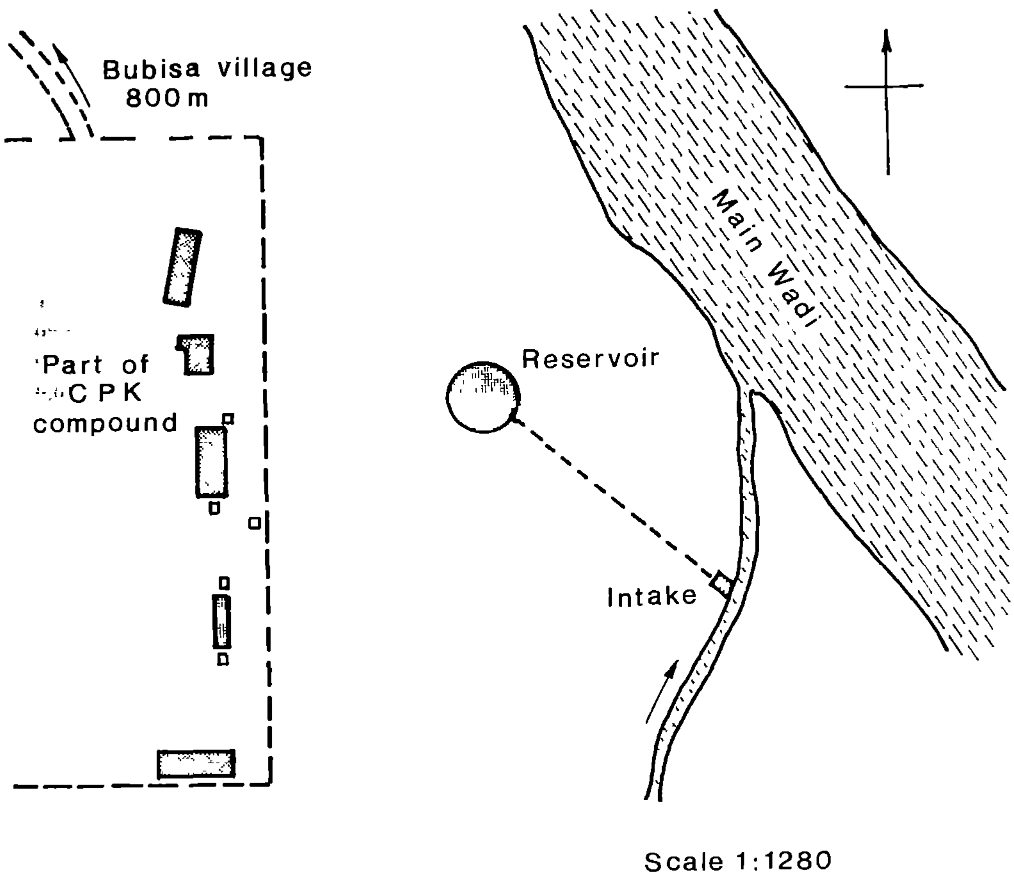

Figure 2. Layout Plan of the reservoir area.

CONSTRUCTION

Work started on site on 5 March 1990 under the direction of the Rev Andrew Adano the CPK Pastor and William Wako the CPK Project Manager, with a labour force drawn from the Bubisa community and Rupert Douglas-Bate (CEC) reponsible for the technical organization and supervision. By the middle of April the reservoir itself was substantially complete.

Excavation for the new intake began on 19 March and a week later there was a *wadi* flood discharge which caused some damage to the work and the loss of five bags of cement. The intake structure and the reservoir were completed early in April and the roof was assembled by 17 April. The Rower hand-pump was installed on 18 May, and on 20 May the works were handed over to the CPK Bubisa Development Committee.

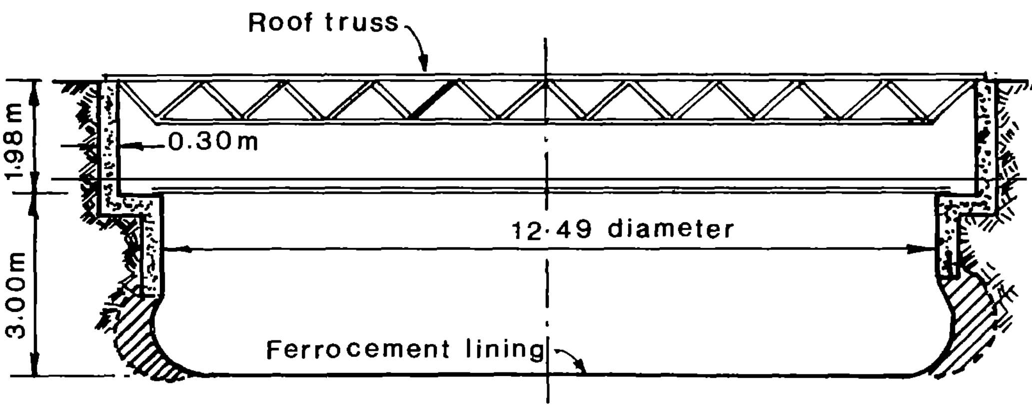

Figure 3. Cross-section of the restored reservoir.

FINANCIAL ASPECTS

The original works in 1982-83 are understood to have cost US$13,000 (about Kshs 200,000). The work undertaken by CED in 1990, including engineering design supervision and management, cost Kshs 260,000. Of this Kshs 260,000, ACTS contributed Kshs 123,000 and CED Kshs 137,000. The CED contribution included a grant of Kshs 96,000 from the Jerusalem Trust (UK) for the services of the engineer. The cost of the pre-fabricated roof was Kshs 57,500. The total cost of the installation would have been approximately Kshs 517,500 (equivalent to US$ 34,500 or £13,000).

OPERATION AND MAINTENANCE

Before finally leaving Bubisa the CED engineer made arrangements with the Bubisa Development Committee for the on-going maintenance of the system and prepared a schedule of maintenance checks to be carried out. He also recommeded that the Development Committee should appoint a permanent reservoir attendant and that the Church of Kenya should make financial provision for future maintenance.

CONCLUSIONS

1. The restoration of this water diversion and storage system has clearly been beneficial to the community at Bubisa. Although it has not provided an additional permanent water supply, it has substantially augmented the water available to the community for periods after local rainfall.

2. This development has been a good example of organizations with high motives and expectations undertaking works of an engineering nature without sufficient engineering inputs, particularly in the early stages. The inevitable consequences of this are seen in the way in which the scheme was prepared and executed.
3. Eight years is an inordinately long time for the construction of a small engineering development.
4. The lack of an investigation and survey of the physical and hydrological features of the site, followed by a project study was a very serious omission. The importance of proper engineering investigations cannot be over-emphasized if resources and funds are not to be wasted.
5. There was no consideration of alternative schemes for collecting and storing runoff. Without any attempt at a hydrological analysis of the catchment area and its runoff, it is impossible to assess the efficiency of the collecting system. If, for example, when there is flow, we assume an average water cross section of $0.5m^2$ and a velocity of 0.5m/second, the discharge would amount to $900m^3$ in an hour. It has been reported that the *wadi* flows for between 8 and 36 hours, which suggests that the total flow may be between 7,000 and $30{,}000m^3$; of which only $400m^3$ can be diverted and stored. An initial engineering investigation could have looked into the possibilities of a system of well-points in the vicinity of the natural ponding area, or a suitable site for a sub-bed dam and *wadi* bed storage, both of which would have made use of natural ground storage and would have contained very much more water, with the additional advantage of minimizing evaporation losses.
6. Any stream diversion works on intermittent flood discharges is hazardous and may be liable to damage through either silting or erosion, and can be a constant source of trouble. The diversion arrangements will need permanent monitoring.
7. A storage of $400m^3$ for a population of 400, using 15 litres per head per day, will provide them with water for 67 days, or just over 2 months. At an investment cost of Ksh 517,500 or Kshs 1,300 (equivalent to US$ 87, £33) *per capita*, this is an expensive water supply.
8. The provision of a hand pump for withdrawing water from the reservoir and preventing access by people to the storage is a wise measure and will minimize the risk of pollution.

ACKNOWLEDGEMENTS

The authors would like to thank Mr Jim Wardroper, Director of ACTS, for the opportunity to undertake this work, and for much of the background information on the project which he was kindly able to supply. Thanks are also accorded to Calvin Collins, the ACTS representative in Nairobi at the beginning of 1990, for the copy of the rehabilitation proposals which he and three other ACTS members produced in 1987, and for his co-operation with and assistance to the CED engineer during the 1990 operations.

REFERENCE

Douglas-Bate, R. (1990). *A Report on the 1990 Restoration of Bubisa Reservior, N.E. Kenya.* Christian Engineers in Development, Chichester, UK.

CEMENT RAINWATER JARS IN SOUTH-WEST UGANDA

Joseph Anguria, Andrew Maclean and James Mwami

WaterAid, Uganda

ABSTRACT

South West Uganda lies just south of the equator at an altitude of 2000-3000m above sea level. It is one of the most densely populated regions in the country with about 200 people per square kilometre.

Like most rural areas in Uganda, the people here earn a living through subsistence agriculture. The main water sources are rivers, swamps, springs and rainwater. There is a minimum average annual rainfall of 1500 mm distributed throughout the year. Drier seasons are not as pronounced and regular as elsewhere in Africa but can last for 3 or 4 months with only light rains. With this climate, food production here is quite successful compared to other regions in the country. Consequently in 1991 the *per capita* income of the local people was US $61.19 which was higher than the national average of $49.18.

Despite these blessings the paradox is that the quantity of water in this region is very low. Our recent survey in Rukungiri district revealed the *per capita* consumption to be 5.7. litres per day. The factors affecting this usage include:

1. Distance to a water source which is usually less than 1km;
2. Heavy workloads of those involved in water collection (women and children);
3. The terrain is hilly or mountainous;
4. Rainwater is greatly under-utilized due to poor collection methods and lack of affordable large durable containers.

In general the supply of drinking water in this region has long been a problem. Since the early 1980s the Uganda Government has tried to solve the problem through the involvement of various agencies alongside the Water Development Department. However activities have concentrated on provision of clean water with little emphasis on increasing quantities in households. WaterAid, working in partnership with the Church of Uganda, has changed the direction of its rainwater collection programme from community level to household level. This has been achieved through the production of 250 - 500 litre cement mortar jars by women's co-operatives. The water is collected from *mbati* roofs (about 37% this area) and used to augment other sources which become security for dry periods.

This paper, based on two years' experience with the jars in Rukungiri district, examines a number of issues related to the community-based rainwater jar programme, and village response to this new technology. Issues stressed include: current storage problems, acceptance and ownership, ease of construction, use of the jar water, water quality, domestic hygiene and water quantity and economic aspects.

It is concluded that the programme has been successful, especially construction by women's groups and the technology has been accepted and is now locally sustainable with no

external inputs. What remains is to ensure that the full health potential of the jar programme is achieved.

INTRODUCTION

Background information

South West Uganda lies just south of the equator at an altitude of 2000-3000m above sea level. It is one of the most densely populated regions in the country with 200 people per square kilometre. In this area there is a lot of disease including malaria, AIDS, typhoid, diahorrea and most other tropical diseases.

Like most rural areas in Uganda the people earn a living through subsistence agriculture. The main water sources are rivers, swamps, springs and rainwater. There is minimum average annual rainfall of 1500 mm distributed throughout the year. Drier seasons are not as pronounced and regular as elsewhyere in Africa but can last for 3 or 4 months with only light rains. With this good climate, food production is successful and consequently in 1991 the *per capita* income of the local people was US$ 61.19 which was higher than the national average of US$ 49.18. Most rural housing is constructed from wood and mud (over 95%) but 37% of houses are at least partly roofed with *mbati* (corrugated iron). Prices in this report are given in Uganda shillings and the exchange rate in March 1993 was US$ 1.00 to 1250/=.

History of rainwater projects

Since 1985 the Church of Uganda North Kigezi Diocese in Rukungiri has run a water programme funded by WaterAid, a UK charity. Initial projects included rehabilitation of hospitals and spring protection and also rainwater collection systems for clinics, schools and churches. These projects involved the construction of large tanks and the installation of plastic guttering imported from UK.

The tanks were constructed from brick masonry plastered inside, up to 20,000 litre capacity. The earlier (1987) 20,000 litre tanks were rectangular in plan (6m by 2.2 m) and about 1.5 m high. Some were built underground and provided with a semi- rotary pump to lift the water out, whilst others were built at ground level and fitted with taps. Later tanks (1989) were of 10,000 litre capacity and circular in plan (2.5m diameter and 2m high). They were built above ground and fitted with taps. Finally two ferrocement tanks were built in 1991, to the same dimensions as the circular brick tanks, in an area with no stone or bricks available. The early tanks were fitted with terram (a geo-textile) screens to prevent debris entering the tank, and the ferrocement tanks had coarse screens fabricated out of *sufurias* (local aluminium saucepans). The water was collected from large buildings with *mbati* roofs such as churches, clinics,.schools and hospitals. UPVC gutters (160 mm diameter)were used with 110 mm diameter UPVC pipework.

These rainwater collection systems were technically good and some are still proving very useful to the communities that they serve. For institutional buildings where a large amount of good clean water is essential (e.g. clinics and hospitals) rainwater collection is a good option either as a first supply or an emergency reserve. However there are two drawbacks to community or institutional rainwater collection systems.

Rainwater collection provides a limited amount of water from an intermittent supply. As the demand is fairly constant this means careful management is required if the water is to last for some time. The larger the group of people sharing the water the more difficult the management becomes. It is noticeable that the successful schemes have been in places where there has been good strict management. Without good management the quality of the water in the tank deteriorates as no one ever cleans the screen or the tank. If people are given unrestricted access then water will be used very rapidly instead of lasting through the dry season. Maintenance and repair of the large tanks is also difficult for a rural community. If taps begin to leak all the water can be lost and yet the nearest hardware shop selling taps is in Mbarara which is 120 km away. A leak in the tank can also result in the loss of all the water and abandonment of the system. Several of these systems built are now dry due to leaks or broken taps and the community has not bothered to mend or replace them, which indicates that they placed little value on the system.

The schemes are, of necessity, large, with imported gutters and large tanks. This means the costs are high and beyond the reach of all but the richest members of the society. As a result there is little or no replication of the project and it is an expensive way of providing a little water to a few people. The only places that copied the system have been one well-managed boarding school, the local hospital and a few rich businessmen.

For these reasons rainwater collection systems were discontinued by the project staff in order to concentrate on water sources that benefitted more people at a lower cost.

INDIGENOUS WATER USE

Quantity

For such a wet area the quantities of water used in the average rural household are suprisingly low. In a survey during a dry spell it was found that the average daily water consumption in Rukingiri district was 5.7 litres per head. In one village the average was 3.1 litres per head. When it rains the quantities used increase dramatically to an average of 12 litres per head because people collect water in basins, saucepans etc. This water is used in the home so it includes water for bathing but not washing of clothes.

The low quantities of water used in rural households results in a lot of disease such as diarrhoea and skin problems such as scabies which are clasified as water washed, and could be reduced by making more water available for the house. The benefits of the increased water available when it rains do not last because the containers used to collect the water are small and are needed around the home. The water is therefore only used on the day it rains and the consumption immediately drops to the lower level.

Quality

In a survey covering 100 households, it was found that water in both collection and storage containers was heavily polluted. The samples were taken mainly from plastic containers (which were often clogged with algae) and the traditional clay jars. On average there were 75 counts of coliforms in samples taken originally from a protected source and 150 counts for samples from unprotected sources.

The collection containers ranged from 5 l to 20 l in capacity and in most cases served as storage containers as well. With this limited volume of water the quality of household hygiene was always poor.

THE WATER JAR PROGRAMME

The use of water jars is not a new idea in village life in this part of the country. Traditionally people store drinking water in small clay pots (20-30 litres), but these are too small to meet the demand, especially in a dry season. The water is normally drawn from ponds, springs and boreholes.

Taking advantage of the socio-acceptability of rainwater catchment systems, a cement water jar programme was started in the 37% of houses with *mbati* roofing. This was done by training women's co-operatives at 3-day courses; and they would then make them on their own for sale to the community. The aspects emphasized during training were construction quality, water quality and domestic hygiene associated with the jars.

The jars were found to be simple to construct, with low maintenance and are cost-effective. In addition the quality of the water is generally better than that from ponds, wells and surface facilities. The programme, which aimed at providing water jars to all those who could afford them in Rukungiri and the neighbouring districts, needed a careful implementation strategy. This was done by training women's co-operatives in various parts of the region, making follow-up visits and educating people about the use and cost effectiveness of the jars.

Although the implementation strategy was not the normal WaterAid procedure which emphasizes community participation for sustainability, hundreds of water jars have been constructed, distributed and purchased. Early reports indicated that some villagers doubted the safety (fear of being poisoned) of their water, as jars are left outside, while others objected to the taste of water stored in the cement container.

FINANCIAL MATTERS

Affordability

The total cost of materials for a 250 litre jar is based on the price of cement as the sand is relatively cheap. A bag of cement can be used to make between two and three jars depending on the quality of sand available. To the cost of materials must be added the cost of moulds which last for about 10 jars, and the filler. The total material cost is therefore:

Cement	Ushs 4,200/=
Sand	Ushs 400/=
Moulds	Ushs 300/=
Filler	Ushs 300/=
Total	Ushs 5,200/=

A jar can be made by a group in a few hours and two or three can be made in a day. When jars are made for members of the co-operative the price appears low as they do not cost the time spent working on the jars. Instead they see it as benefiting each other. However when selling the jars commercially the price asked for various from Ushs 12,000/= to 15,000/= and sometimes even more. The group is therfore charging up to Ushs 9,800/= for labour and profit, and can earn Ushs 29,400/= for a day's work.

The jars are bought commercially by members of the public; the first purchases outside the co-operatives were community leaders. Poorer households do not have *mbati* roofs and would have to save for some time to have enough money to buy a jar on the open market. The best way to help poorer members of society is by including them in co-operatives where they can use their own labour to reduce the amount of cash needed to buy a jar, and where they may be able to earn some money making jars for richer people.

Different sizes of jars have been produced with a 700 litre version being the largest so far. Larger sizes than this would probably need to be reinforced with wire. The 700 litre jar is about three times the price of the 250 litre jar as it uses a whole bag of cement. It is therefore too expensive for most people and the production groups have become interested in making a smaller jar alongside the 250 litre version.

Subsidy

The jars are sold without any subsidy although the producing groups are assisted with moulds and tools. Logistical support is given occassionally such as when coffee husks are required from the factory and no transport is available, or when taps are required which are not available locally and have to be bought from Mbarara or Kampala.

Advantages of subsidy
- Low cost to individuals, so faster sales.
- Raises awareness of the jars at an early stage of production so that a larger market is created.

Disadvantages of subsidy
- Higher cost to the funding agency.
- Long-term problems as local production will collapse when funding ceases.
- Limitation on the number of jars sold due to limited funds.
- Disincentive to private enterprise as local manufacturers cannot compete with subsidy.
- Users buy because price is so cheap and may not value the product or be fully aware of why it can help.

Material availability

Cement is available locally in Rukungiri and outlying trading centres. The cement is manufactured in Uganda and is priced at around Ushs 10,000/= per 50 kg (March 1993). Good quality sand is found within the district but is located in the Rift Valley; in some areas the available sand is very poor.

New and second-hand hessian sacks are sold in Rukungiri and most rural markets. New sacks cost Ushs 1000/= and second-hand sacks cost Ushs 600/=.

The main filling material used so far is coffee husks which are available at no charge from coffee factories in Uganda. Other groups have tried using sawdust and many agricultural husks are available but often not in very large quantities.

Sustainability of manufacture

The groups have proved well able to produce the jars after the initial training and assistance. They have purchased materials, bought sacks and made new moulds when old ones have worn out and have promoted their products so that customers have been found. The groups have varied in their aims so that some groups only intend to make jars for the members of the co-operative while others are more commercially minded. The profits from manufacture are not very large as there is a lot of work involved in preparing materials and making the jars. This has led to groups gradually increasing their commercial prices and a decline in the number of people buying jars.

REFERENCES

Guidelines for Drinking Water Quality, Vol. 3. Drinking Water Quality Control in Small Community Supplies.
Kerr, Charles (1989). *Community Water Development*. Intermediate Technology Publications.
(1989). *Proc. 4th Int. Conf. on Rainwater Cistern Systems*. Manila, Philippines.

OPTIMIZING THE CAPACITY OF RAINWATER STORAGE CISTERNS

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ABSTRACT

The use of rainwater in developed countries for either drinking water or alternative uses is a simple and practical method of reducing the demand on the public water supplies. In developing countries the use of rainwater may be the only source of water. In both situations the size of the storage cistern is critical in the economic design of such systems. For a given collection area, demand rate and rainfall pattern, an optimum storage capacity will exist.

The investigation and solution of this problem is not straightforward because the rainwater input to the store and the output demand both vary in volume and time.

This paper reviews some of the models proposed by other workers in this field of study which vary in complexity and consequently accuracy. An alternative method of approaching the problem is proposed using a computer model which employs a numerical technique to model the stochastic nature of the input and output time series to a rainwater cistern system. These simulated event patterns are used to investigate the system operation and optimize the storage capacity.

The model is versatile and can be easily modified to suit other countries by modifying the input data.

INTRODUCTION

A promising alternative use of rainwater in the UK is the use for WC flushing where approximately 30% of the potable water supplied to the domestic sector is used for the transportation of foul waste. The economics of a rainwater collection system are related to its storage capacity because this is the one parameter controlled by the designer; the roof area is determined by other considerations and the rainfall is an uncontrollable natural resource. This paper describes a method of determining the optimum volume of the storage cistern. A computer model has been developed which simulates a systems operation.

The investigation relates to the use of rainwater for WC flushing, but the model developed is general in nature and can easily be applied to other uses of rainwater by the inclusion of appropriate demand data.

THE DESIGN PROBLEM

The operation of a single tank system is modelled, which collects rainwater from the household roof and uses a pump and accumulator to distribute water to the WC. The system is available commercially and is considered in detail elsewhere (Fewkes, 1993).

The design problem is the evaluation of the optimum size of storage vessel, that is, the smallest tank capacity which will satisfy the WC flushing demand for a given collection area, demand, rainfall level and system reliability or efficiency. The determination of the optimum storage capacity is not straightforward because both the rainwater supply patterns and the WC flushing demand patterns are non-deterministic and follow time dependent, non-stationary stochastic processes (Gibson, 1978).

DESIGN METHODS

The sizing of storage reservoirs for water storage was originally considered by Rippl (1883). A simple storage system will perform adequately provided the relationship:

$$S \geqslant \text{Max} \left\{ \int_{t_1}^{t_2} [x_o(t) - x_i(t)]\, dt \right\} \quad \ldots. (1)$$

is satisfied. Where:
S = storage capacity
$x_o(t)$ = stored quantity output
$x_I(t)$ = stored quantity input
t = time and $t_1 < t_2$

In the mass curve developed by Rippl the variable rainfall input is subtracted from a constant demand output. The maximum cumulative difference is the storage required for a system which is 100% reliable or efficient.

The work of Rippl has been developed by Maver (1966) to hot and cold water storage tanks. More specifically a number of workers have modified the mass curve and applied it to the sizing of rainwater cisterns (Jenkins *et al*, 1978; Perrens, 1975; Schiller and Latham, 1982). The following assumptions were made in the models developed previously:

- The demand for rainwater is constant.
- The performance of the system is adequately modelled using monthly rainfall data.

In an attempt to model more accurately the rainwater collection system, the model developed in this study does not make either of the above assumptions. The rainwater input and output are both modelled to follow time dependant, non-stationary stochastic processes. The performance of the rainwater collector is simulated using daily supply and demand patterns.

MODEL DEVELOPMENT

The model consists of two parts:

1. Simulation of rainfall supply and WC demand patterns or time series.
2. System simulation model.

Two methods of obtaining the time series which describe adequately the stochastic nature of rainfall supply and WC demand patterns were considered: either the use of historical rainfall and WC flow patterns or their simulation using a numerical technique. The first method was rejected because historical daily data is often not available. The manipulation of 25 or even 50 years daily rainfall and WC usage patterns into a form suitable to model the storage system is inefficient and time consuming. Moreover the resultant model is inflexible and limited to the period covered by the flow patterns. However, time series can be generated for unlimited periods using a numerical simulation model provided the relevant data in the form of cumulative probability distributions are available. The method used is also flexible and enables the sensitivity of the system simulation model to changes in various parameters such as the time interval and pattern of the input time series to be investigated.

The simulated rainfall and WC usage time series are used as the input into the system simulation model which contains a series of mathematical relationships to simulate the operation of the rainwater collector.

Numerical simulation of rainfall and WC time series

The volume of rainwater collected daily by a given roof area is simulated for each month of the year using cumulative probability distributions of rainfall in the Nottingham and Bath areas (Hydrological Memoranda 10 and 16, 1963). Similarly the daily flow to the WC is generated using cumulative probability distributions of both the number of appliance uses per day and the volume of each usage (Thackray, Crocker and Archibald, 1978).

The Monte Carlo technique provides a method of simulating the rain and WC time series; the probable daily volume of each flow is defined by using random numbers to index the cumulative probability distributions. Although a specific value is determined by chance, the mean and distribution of an infinite number of values determined by this process will fit the originally defined distribution and have the same mean and variance (Hammersley, 1964).

The random numbers are defined by a continuous uniform distribution;

$$f(x) = \begin{cases} \dfrac{1}{B - A} & A < x < B \\ 0 & \text{Otherwise} \end{cases} \qquad \ldots.(2)$$

where the limits of A and B determine the numerical range over which the random numbers are generated.

The method of simulating daily rainfall levels is described as an example, but the WC time series are generated in a similar manner. The distribution of the random variable R_j describes the daily rainfall level during month j and the probability function is $f(r_j)$ and $F(r_j)$ is the distribution function or cumulative probability function, that is:

$$F(r_j) = \text{Prob}\left\{ R_j \leqslant r_j \right\} \qquad \ldots.(3)$$

Alternatively

$$F(r_j) = \int_0^{r_j} f(r_j).\, dr_j \qquad \ldots.(4)$$

where $f(r_j) \geqslant 0$, the $\int_0^{r_j\,max} f(r_j).\, dr = 1$ and $r_{j\,max}$

represents the maximum level of daily rainfall during month j.

The rainfall level is simulated by generating a random number from the uniform distribution f(x); the limits of equation (2) become B = 1 and A = 0, thus defining x within the range 0 x 1. The model iteratively compares the value of x with $F(r_j)$ for progressively increasing values of R_j, that is:

$$r_{j1}, \quad r_{j2}, \text{-----}, r_{j1}, \text{--------}, r_{j\,max} \qquad \ldots.(5)$$

$$\text{where} \quad r_{j2} = r_{j1} + \Delta r_j \quad \text{or} \quad r_{j1} = r_{j1-1} + \Delta r_j$$

The increment r_j is the discrete increase in the value of r_j. In this case r_j = 2.5 mm rainfall, but finer resolution would be achieved with a smaller increment.
The comparison between $F(r_j)$ and x continues until

$$F(r_{ji}) \geqslant x = \text{Prob}\left\{ R_j < r_{ji} \right\} \qquad \ldots. (6)$$

provided that at the previous increment,

$$F(r_{ji-1}) < x \qquad \ldots. (7)$$

The simulated level of rainfall that day is equal to r_{ji} which is equivalent to the solution of:

$$\int_0^{r_{ji}} f(r_j).\, dr = x \qquad \ldots. (8)$$

The nature of the function is not known but a general method of solution is provided by the iterative technique.

The simulation of the WC flows uses the same technique but in addition to the volume the number of uses is also simulated.

The system simulation model

The rainfall and WC flushing time series are used as input data to the system simulation model which simulates the operation of the rainwater collection system. The system model is based upon a yield after storage (YAS) algorithm and evaluates the volume of WC flushing water conserved expressed as a percentage of the total flushing demand. The model of the system includes several assumptions:

- The rainfall is vertical and is on the entire roof area.
- Evaporation losses are negligible.
- Any effects due to droplet size and variations in wind and pressure around the roof are also ignored.

These aspects may be included in the model as they become pertinent to a particular design.

The model determines the stored volume (V) at regular time intervals (t), each of 1-day duration, from the beginning of the period (T_1) to the end (T_2). The period T_1 to T_2 is 1 year. The volume of water conserved is evaluated progressively and at the end of the period (T_2) expressed as a percentage (P) of the total flushing demand. The operation of the system is simulated for 50 years.

SYSTEM PERFORMANCE

The performance of a rainwater collection system is evaluated with tanks ranging from 200 to 4000 litres capacity; the evaluation is undertaken using rainfall data for the cities of Nottingham and Bath. The average annual rainfall levels range from 600 mm for Nottingham to 785 mm for Bath. The mean volume of rainwater collected per annum expressed as a percentage of the total flushing demand is determined for each storage vessel using 50 years of simulated data. The results relate to family sizes of two, four and six people. The combinations of roof area and tank size to meet various levels of water conservation are illustrated in Figures 1 - 4.

Generally a system in Bath conserves a higher percentage of water due to the higher annual rainfall level. This is indicated by the displacement of the performance curves towards the horizontal axis (Figs 3 and 4).

A two person household in Nottingham with a catchment of 50 m^2 can supply 90% of the WC flushing water with a storage capacity of 1200 litres. A further increase in tank size to 2000 litres only results in a 3% improvement in water conservation. The enlargement of the catchment area is required to improve system efficiency significantly. In Bath similar roof and tank sizes result in a system efficiency of nearly 97%.

SENSITIVITY ANALYSIS

The sensitivity of the system simulation model to the time interval of the input and output time series is investigated by determining the system performance using weekly and monthly time intervals (Fig. 5). The performance predicted by the weekly model is comparable to the results obtained using a daily time interval. The monthly model underestimates significantly the system performance. Unless the system simulation algorithm is modified (Schiller and Latham, 1982) the use of monthly data whilst convenient will not model the system performance adequately.

The resultant performance curves using constant WC flushing demand patterns in both the daily and monthly time interval models are illustrated in Figures 6 and 7. The results indicate the system simulation model is relatively insensitive to the pattern of WC flushing demand.

The validity of simulating the rainfall patterns using the Monte Carlo method is investigated by evaluating the system efficiency using both simulated and actual rainfall data (Fig. 8). For a household size of four persons and a roof area of 60 m^2 the maximum difference between system performances is in the order of 7%. The difference is considered acceptable but further research is in progress to refine the simulation of rainfall supply patterns.

CONCLUSIONS

A rainwater collection system has been evaluated using a simulation model. Time series based on a minimum time interval of a day are generated using the Monte Carlo technique. These series provide input into the system simulation model to evaluate the optimum storage capacities for different combinations of roof area and family size.

The results indicate a system simulation model based upon a YAS algorithm produce satisfactory results using input data based upon either a daily or weekly time interval. The manipulation of monthly input data is more convenient but will only produce satisfactory results if the system simulation algorithm is modified. The accurate modelling of WC output demand patterns is not necessary, average demand data produces satisfactory results.

The flexibility and accuracy of the Monte Carlo method has been demonstrated. Large quantities of real data do not require manipulation and the technique of sensitivity analysis is easily applied using this modelling procedure.

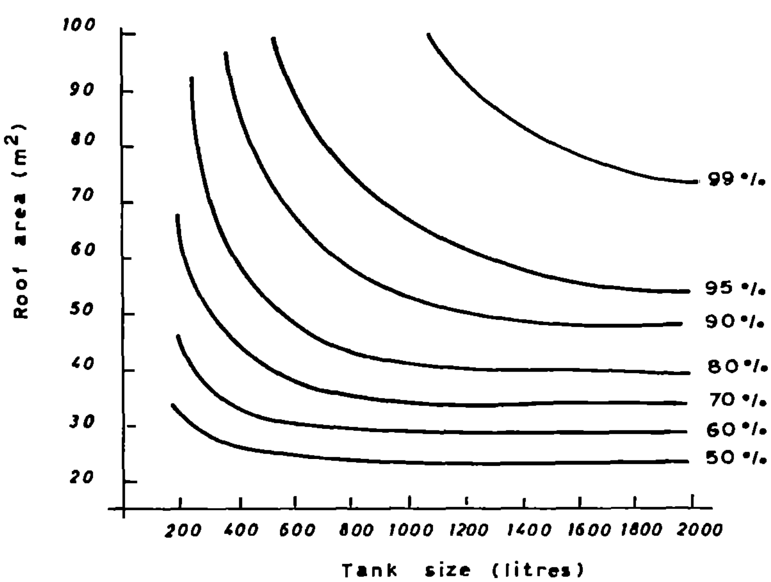

Figure 1 Combinations of the roof area and tank size to meet various levels of water conservation for the Nottingham area: family size two.

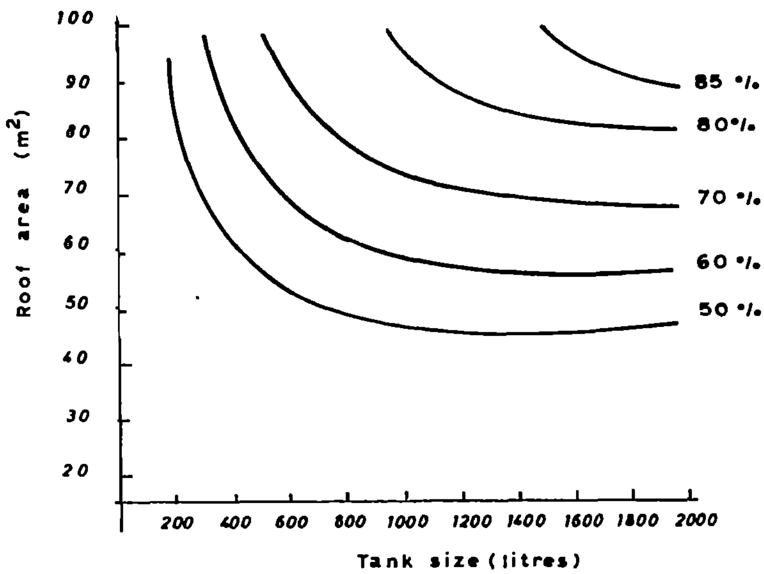

Figure 2. Combinations of roof area and tank size to meet various levels of water conservation for the Nottingham area: family size six.

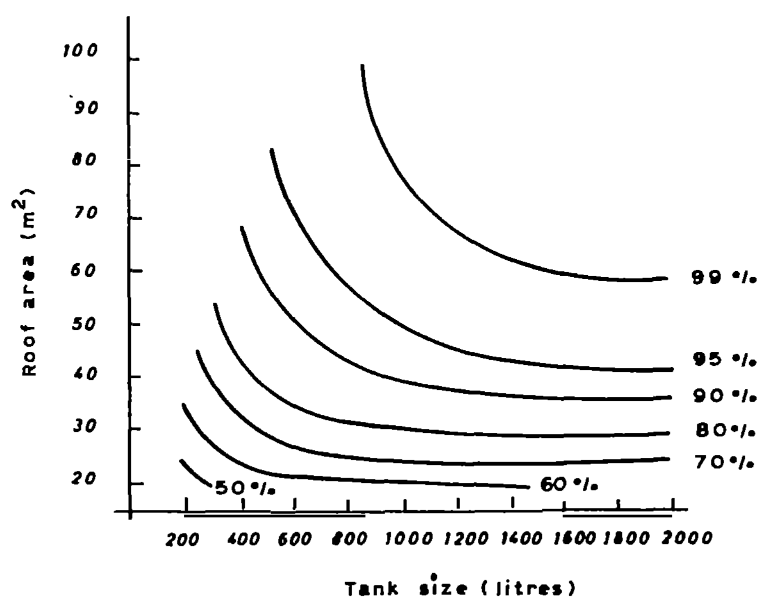

Figure 3. Combination of roof area and tank size to meet various levels of water conservation for the Bath area family size two.

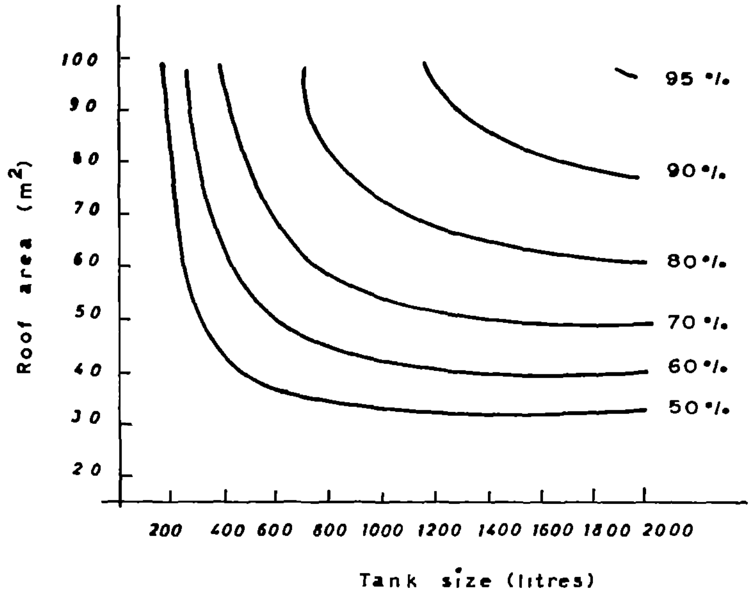

Figure 4. Combination of roof area and tank size to meet various levels of water conservation for the Bath area. family size six.

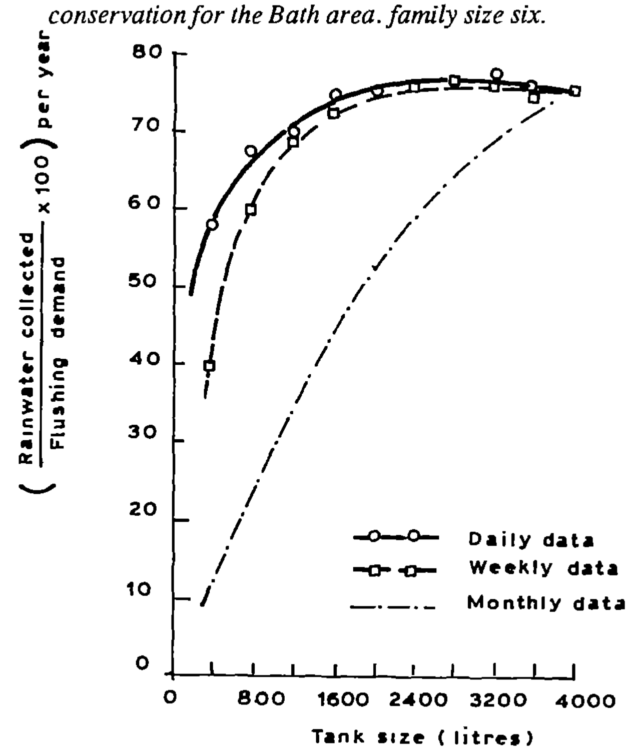

Figure 5. The effect of the minimum time interval of the rainfall and WC flushing patterns on system efficiency (household size, four; roof area 60 m^2).

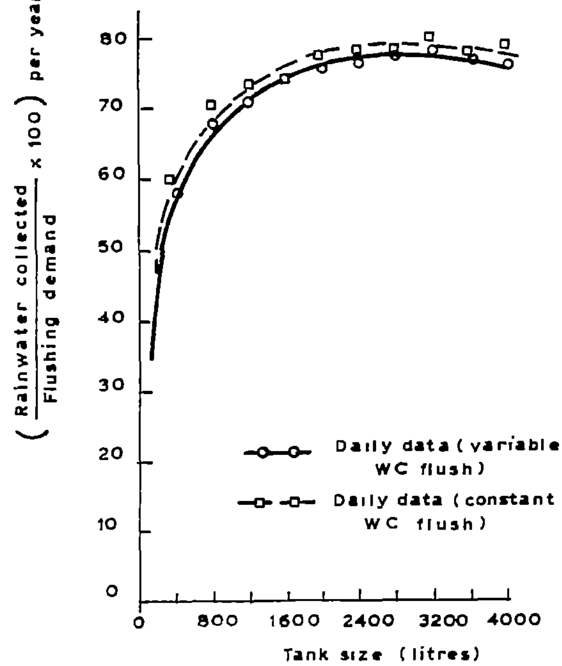

Figure 6. Performance curves for constant and variable daily WC flushing demand patterns (household size, four; roof area 60 m^2)

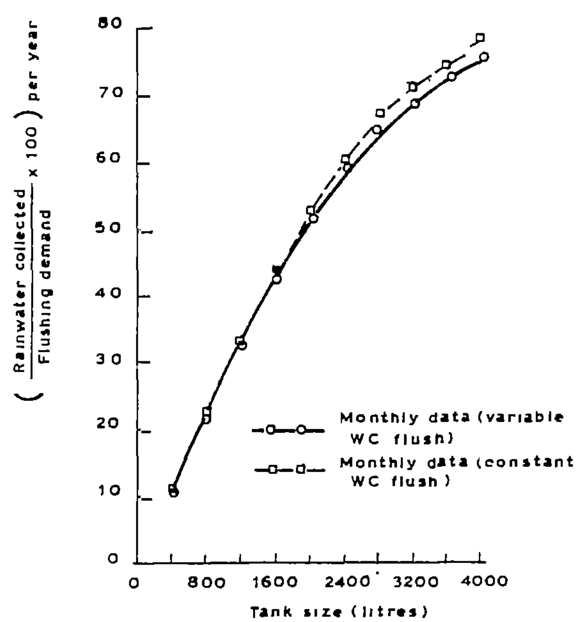

Figure 7. Performance curves for constant and variable monthly WC flushing demand patterns (household size, four; roof area 60 m^2).

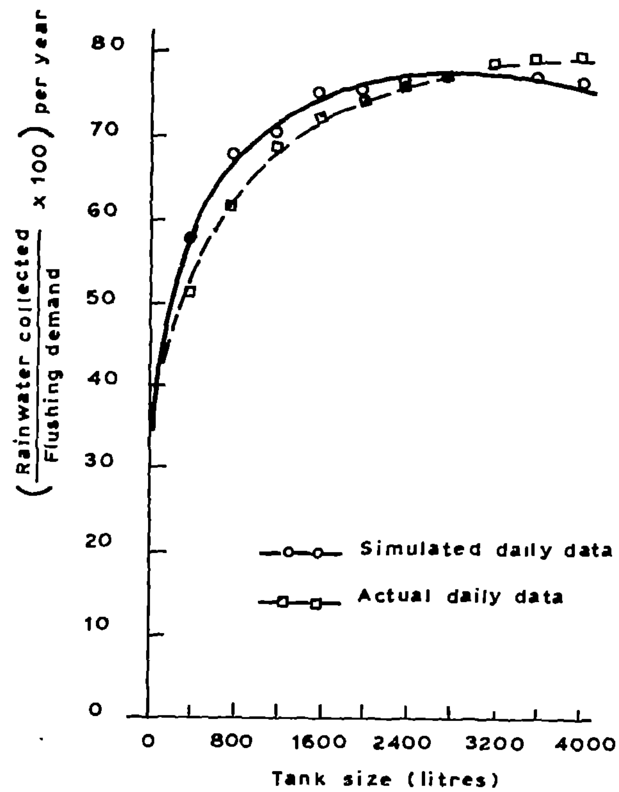

Figure 8. Performance curves using simulated and actual daily rainfall data (household size, four; roof area 60 m^2).

REFERENCES

Fewkes, A. (1993). The Instrumentation of a Rainwater Collection System for Field Trials in the UK. *Proc. 6th Int. Conf. on Rainwater Cistern Systems.* Nairobi, Kenya.

Gibson, E. (1978). The Design of Water Storage Systems for Buildings. PhD Thesis, University of Glasgow, Scotland.

Hamersley, J. M. and **Handscombe, D. C.** (1964). *Monte Carlo Methods*, Methuen, London.

Hydrological Memorandum, No 10 (1963). *Rainfall Over the Area of the Trent River Board, 1916-50.* Meteorological Office, Bracknall, Berks, England.

Hydrological Memorandum, No 16 (1963). *Rainfall Over the Area of the Catchment Areas of the Somerset and the Bristol Avon River Boards, 1916-50.* Meteorological Office, Bracknell, Berks, England.

Jenkins, D; **Pearson, F**; **Moore, E**; **Sun, J. K.** and **Valentine, R.** (1978). *Feasibility of Rainwater Collection Systems in California.* Contribution No 173, California Water Resources Center, University of California.

Maver, T. W. (1966). Water Plant Sizing. *J.I.H.V.E*, **33**, 303-313.

Perrens, S. J. (1975). Collection and Storage Strategies for Domestic Rainwater Supply, pp 168-172., *Hydrology Symposium*, Institute of Engineers, Armidale, Australia.

Rippl, W. (1883). The Capacity of Storage Reservoirs for Water Supply. *Proc. Inst. Civil Engineers*, **71**, 270-278.

Schiller, E. J. and **Latham, B.** (1982). Computerised Methods in Optimising Rainwater Catchment Systems. *Proc. Int. Conf. on Rainwater Cistern Systems* University of Hawaii, Manoa.

Thackray, J. E; **Crocker,** V and **Archibald, G.** (1978). The Malvern and Mansfield Studies of Domestic Water Usage. *Proc. Inst. Civil Engineers*, **64**, 37-61.

THE INSTRUMENTATION OF A RAIN WATER COLLECTION SYSTEM FOR FIELD TRIALS IN THE UK

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ABSTRACT

Water conservation has never been a strong point in the average British household, but things could change because of greater awareness of environmental problems and perhaps more significantly, the advent of water metering. The use of rainwater for non-potable use in the UK would significantly reduce the demand on the mains supply network. In fact, a rainwater collector is now commercially available in the UK. The rig consists of an 1100 or 2000 litre polyethylene storage tank, pump, pressure vessel and level switches.

It is proposed to install one of the systems in a UK property and monitor its performance and efficiency over a 12 month period. The data collected will be used to verify and refine a computer model which has been developed to simulate the operational efficiency of the rainwater collection system.

This paper considers the data which need to be collected and utilization of the data to verify the computer model. The instrumentation required to collect the data is identified and discussed. Finally, a suitable method of data collection and retrieval is described.

INTRODUCTION

Inhabitants of the arid areas of the world are only too aware of the need to conserve water; consequently their water has repeated usage and is finally used for land irrigation. In developed countries such as the UK, one flush of the WC typically uses 9 litres of purified water; the result is that 30% of this expensive potable water supplied to the domestic sector goes down the foul sewer.

The feasibility of re-using rainwater is related to the annual water charges experienced by householders. Currently the majority of domestic consumers are charged for water based on the value of their property and not the volume consumed. There is no financial incentive to conserve water but recent legislation (Water Act, 1989) has changed both the structure of the water supply industry and the method of charging for water. The widespread metering of domestic properties is expected by the year 2000. Water conservation devices are likely to become financially attractive in the UK within the next decade.

The use of rainwater for WC flushing is a simple and practical method of reducing the demand on both the public supplies and waste treatment facilities. In addition this method will appeal to environmentalists because both ground water abstraction rates and the development of new surface water reservoirs will be reduced.

This paper considers the proposed field testing of a commercially available rainwater collector. It is proposed to install the system in a UK property and monitor its performance and efficiency over a 12 month period. The data which need to be collected from the rainwater collector are identified. The data collected will be used to verify and refine a computer model which has been developed (Fewkes, 1993) to simulate the operational efficiency of the rainwater collection system. Finally the instrumentation and method of data collection and retrieval is discussed.

THE RAINWATER COLLECTION SYSTEM

A number of different rainwater collection systems have been proposed. These have ranged from 1 and 2 tank systems (Fewkes, 1989) to systems which have utilised garage roofs to collect rainwater (Stephens, 1976).

The proposed system is a commercially available single tank system which uses a pump and accumulator to distribute water to the WC (Fig. 1).

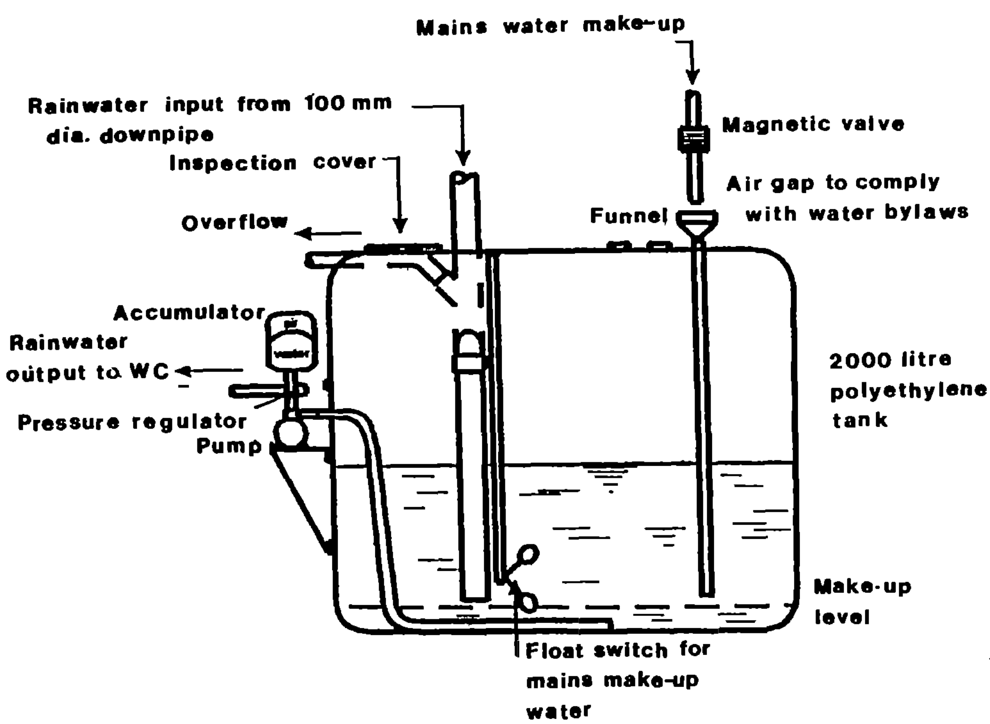

Figure 1. Wilo rainwater collector.

Rainwater is collected from the house roof by gravity feed via a 100 mm diameter downpipe into a 2000 litre capacity polyethylene tank. A coarse filter fitted into the downpipe ensures that debris (such as leaves) does not collect in the tank. An overflow is fitted to the storage tank which discharges into the household's surface water drain.

Water is supplied under pressure from the accumulator or pressure vessel. The system is pressurized by the pump which pumps water into the accumulator until the pressure switch deactivates the pump at a pressure of approximately 4 bar.

The operation and control of the system using an accumulator and pressure switch offers a number of advantages. Firstly, all of the system controls are located on the rainwater collector. Consequently, there is no need for float switches or other electrical controls to be located within storage cisterns inside the dwelling. Secondly, regular but small draw-offs of water will not cause the pump to continuously "hunt" and overheat.

When insufficient rainwater is available, a float switch fitted near the bottom of the tank activates a magnetic valve which allows mains water to flow into the collector. To comply with the water companies' bylaws the mains water is not connected directly to the tank but is fed via a funnel connected to the top of the collector.

Rainwater collection systems used in developing countries for the supply of drinking water often incorporate a device to divert the first flush of rainwater which is more heavily polluted than the subsequent runoff (Michaelides, 1989). The incorporation of a diverting valve complicates the system design and increases its initial cost. However, previous research (Fewkes and Tarran, 1992) has indicated diverting valves are not necessary when the rainwater is for a non-potable use such as WC flushing.

PERFORMANCE OF THE RAINWATER COLLECTOR

To enable the use of rainwater at the lowest cost, the collector must be carefully designed. The parameters affecting the design of the rain water collector are:

- Rainfall level and pattern;
- Demand level and pattern;
- Roof area for collection;
- Storage volume;
- Desired reliability or system efficiency.

The cost of the collector and its installation are related to its storage capacity because for a desired level of reliability this is the one parameter controlled by the designer; the roof area is determined by other considerations and the rainfall is an uncontrollable natural resource. Installation costs are particularly sensitive to the volume of the collector if it is located below ground level because excavation is required. The preferred location is below ground to maintain cool conditions and minimize the risk of odours and growths (Fewkes and Tarran, 1992).

The determination of the optimal storage capacity is not straightforward because both the rainwater supply pattern and the WC flushing demand pattern are non-deterministic and follow time dependent, non-stationary stochastic processes. The stochastic nature of the supply and demand patterns to and from the collector have been computer modelled using a numerical technique. The simulated rainfall supply and WC usage patterns provide data for a mathematical model which simulated the operation of the single tank collector (Fewkes, 1993).

The operation of the rainwater collector using a range of tank capacities and roof areas has been simulated for a period of 50 years. For each combination of roof area and tank capacity the system performance is evaluated as the average percentage of flushing water conserved per annum. A typical set of results indicate that in order to conserve more than 90% of flushing water a roof area greater than 75 m^2 and a cistern capacity in excess of 1500 litres are required.

FIELD TESTING OF THE RAINWATER COLLECTOR

It is proposed to install a rainwater collector in a UK property and monitor its performance and efficiency over a 12 month period. Wilo Sampson Pumps Limited have provided the rainwater collector for field testing, and a national house building company is giving consideration to the installation of an experimental system.

Objectives of field tests

The objectives of the field testing are summarized below:

1. Monitor and record the rainwater inflows and outflows from the collector to determine the percentage of water conserved per annum (system efficiency).
2. Use the collected data to verify the computer model.
3. Refine the computer model using the field data.
4. Use the refined computer model to develop a series of design curves relating collection area, demand, rainfall level, system reliability and storage volume.
5. Propose design modifications and refinements to the rainwater collector.

A pilot study has been undertaken which investigated the quality of rainwater (Fewkes and Tarran, 1992) and indicated the need for further research. However, the scope of the current research is restricted to the sizing of the rainwater collector.

DATA COLLECTION AND INSTRUMENTATION

To achieve the objectives identified in the previous section, the following data requres collection:

1. The volume of rainwater inflow to the collector;
2. The volume of rainwater outflow to the WC;
3. The volume of rainwater overflowing from the collector;
4. The time and duration of rainwater flow events;
5. The level of rainfall (mm) at the test site;
6. Prevailing wind speed, direction and air temperature.

A schematic diagram of the rainwater collector and the instrumentation required to collect the data is illustrated in Figure 2.

Monitoring rain and mains water supply and demand patterns

The flow rate of water flowing from the collector to the WC will be measured using a positive displacement flow meter. A data logger will record the water flow rate and the times when the flow starts and finishes. From this data the volume of rainwater used for WC flushing during any given time interval can be calculated. The inflow of mains make-up water will be monitored using the same method.

The measurement of rainwater flowing into the collector from the roof is not straightforward because the downpipe will not be flowing full bore. A positive displacement meter or similar cannot be used. In situations where open channel flow occurs the common approach is to use a "V" notched weir or similar. The water flow rate is determined by the configuration of the notch and the height of the flow above the weir. This method was discounted because the intensity of rainfall during the year varies considerably (Bilham, 1932) and consequently so would the height of flow over the weir. The sizing of the weir to ensure the desired level of accuracy over the anticipated flow range could not be guaranteed.

An indirect but potentially more accurate method of measurement will be adopted. The level of water in the collector will be measured using a continuous reed transmitter or a non-contact ultrasonic liquid level sensor, and will be recorded on the data logger at predetermined time intervals. The measurement of water levels will only occur when rainwater flows into the collector. A flow switch located in the downpipe will initiate the measurement and logging procedure. The volume of water flowing into the collector can be calculated from this data.

The measurement of overflows from the system presents a similar problem, although a different solution is proposed. Rainwater overflowing from the system will be collected in a 250 litre spill tank. Discharge into the drain will be via a 25 mm diameter pipe to ensure full bore flow. The data logger will record the time, duration and overflow rate.

The percentage of WC flushing water can be calculated from the above data. Comparison of the field results with the computer predicted efficiencies will provide an initial basis for predicting both the accuracy and validity of the computer simulation.

Rainfall, wind speed and direction measurements at the test site

For each rainfall event the computer model calculates the volume of water collected from the following expression;

$$V_R = \frac{R \times A}{1000} \quad \ldots\ldots\ldots (1)$$

where: V_R = volume of rainfall collected (m^3)
R = rainfall level (mm)
A = plan area of pitched roof (m^2)

This expression assumes the rainfall is vertical over the entire roof area, effects due to wind speed and pressure variations around the roof are ignored. Runoff losses due to absorption by the roofing material and evaporation are also assumed to be negligible.

The volume of water collected from the roof is more accurately modelled by the expression:

$$V_R = \frac{R \times A \times C}{1000}$$

where: C = runoff coefficient, and $C<1$

The value of C is determined from:

$$C = \frac{\text{volume of rainwater actually collected by roof}}{\text{amount of rainwater falling on the roof}}$$

The value of the numerator can be determined from the measurements discussed in the previous section and the denominator from the rainfall level measured at the test site.

A tipping-bucket rainfall gauge will monitor the rainfall level at the test site. The wind speed, direction and air temperature will also be monitored. The collected data will be used to determine an empirical value of the runoff coefficient and investigate the factors which influence the magnitude of this coefficient.

CONCLUSIONS

The need for water conservation in the UK and the potential feasibility of using rainwater for WC flushing has been identified. The need for water conservation is rapidly being recognized as indicated by the commercial availability of a rainwater collector.

An important aspect of the collector design is the volume of the storage tank. The efficient design of rainwater collection systems requires the provision of simple design curves relating collection area, demand, rainfall level, system reliability and storage volume. The first stage in the development of such design aids is the modelling of the systems performance and operation which has been briefly reviewed.

The verification and refinement of the model requires the collection of field data. Data relating to the flow rate of rainwater input, output and overflow are required to ascertain the collector's efficiency. The measurement of rainwater input to the collector is not straightforward because unsteady open channel flow conditions exist. A method is proposed which monitors the level of water in the storage tank.

The rainfall level at the test site must also be recorded to verify or modify assumptions made in the development of the original model.

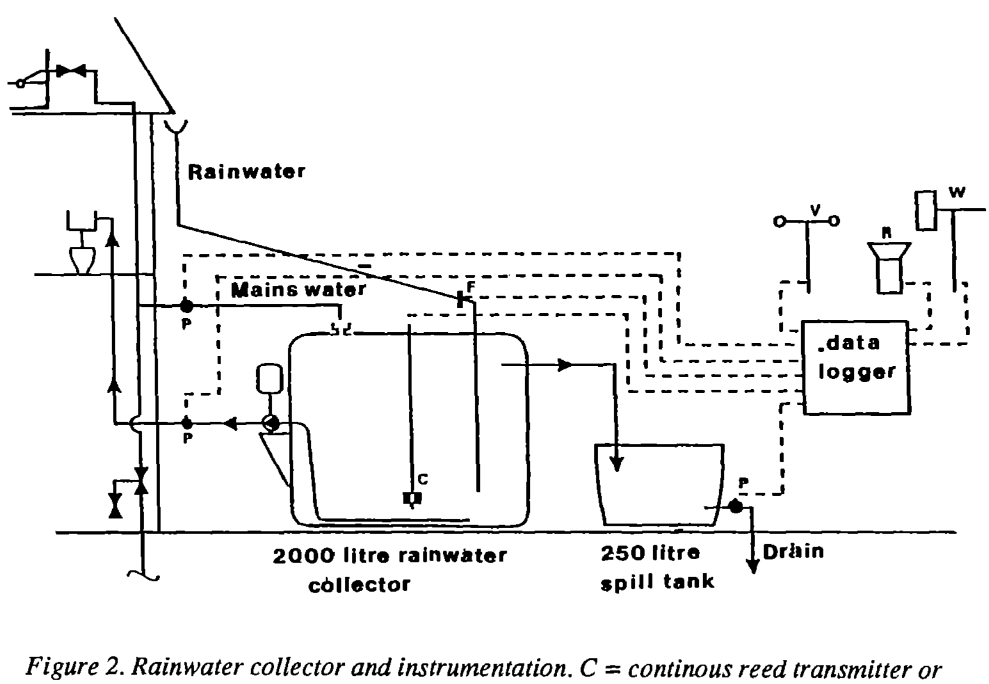

Figure 2. Rainwater collector and instrumentation. C = continous reed transmitter or non-contact ultrasonic liquid level sensor; P = positive displacement flow meter; F = flow sensor; R = tipping bucket rainguage; V = vane anemometer; W = wind direction indicator.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support of Wilo Salmson Pumps Limited for providing the rainwater collector for field testing.

REFERENCES

Bilham, E. G. (1932). The Frequency Distribution of Daily Rainfall. *British Rainfall*, pp 268-277.

Fewkes, A. (1989). The Design and Evaluation of Rainwater Cistern Systems for WC Flushing. *Proc. 4th Int. Conf. on Rainwater Cistern Systems*. Manila, Philippines.

Fewkes, A. (1993). Optimizing the Capacity of Rainwater Storage Cisterns. *Proc. 6th Int. Conf. on Rainwater Cistern Systems*. Nairobi, Kenya.

Fewkes, A. and **Tarran, C.** (1992). Rainwater Quality for WC Flushing in the UK. *Proc Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyota, Japan.

Michaelides, G. (1989). The investigation into the quality of roof harvested rainwater for domestic use in developing countries. *Proc. 4th Int. Conf. on Rainwater Cistern Systems*, Manila, Philippines.

Stephens, D. M. (1976). Water Storage Roofs. *The Architect*, December, **The Water Act**, (1989) pp. 77-81. . HMSO, London.

A PRACTICAL, LOW-COST DRINKING WATER PURIFICATION SYSTEM

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ABSTRACT

The paper describes a simple, low-cost, hydropneumatic device for purifying drinking water which can be assembled from standard plumbing parts by an averagely handy individual. It is an especially useful complement to rainwater systems where the lack of pressurization rules out the use of most commercial filters.

The water to be treated should be relatively clear which may require pre-filteration. Disinfection is handled by adding chlorine to the pressure vessel. It is recommended that a good quality filter, which contains activated charcoal, be used for final filtration as this will remove the disagreeable taste of any residual chlorine. The effectiveness of the treatment in killing coliform bacteria can be monitored with a simple chemical test which can be administered by the user himself.

Solar UV purification represents an attractive alternative to chlorination but, at this stage, a practical, reliable system for general application has not yet been developed, although preliminary research shows some promise.

INTRODUCTION

Providing clean, safe drinking water for everyone remains an elusive goal. Given intractable institutional, economic and cultural constraints in most developing countries, it is probably wiser to shift attention toward devices which promote individual user control, rather than helping governments to improve the quality of public water systems.

Commercial fibre or ceramic filters, containing an activated charcoal element, provide a relatively low-cost and convenient means of improving the physical-chemical quality of drinking water. However, in areas where piped water is not available or where pressure falls below the required minimum, these filters normally do not work. Furthermore, they are not very effective in removing pathogenic organisms.

It is, however, possible to construct a simple, hydropneumatic device from standard plumbing parts which will not only permit filters to function but will also facilitate disinfection.

DESIGN

The details of the system can best be understood by reference to Figure 1. which shows the assembled apparatus. Following is a brief explanation of each of its major components.

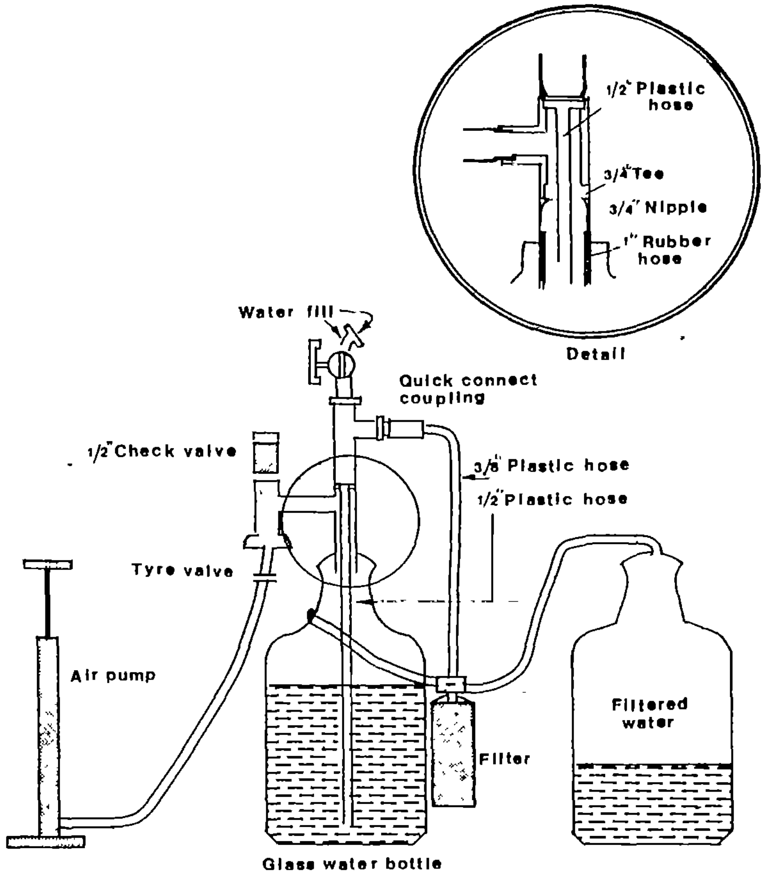

Figure 1 Portable Water Treatment Plant.

The pressure system

To begin with the pressure vessel is filled to a certain level, sealed, and then pressurized by means of a small hand-operated air pump (the type used to inflate bicycle tyres).

The pressure vessel

A large (18 l), glass bottle which is widely used to dispense mineral water, provides a convenient and cheap container. It is easy to obtain almost everywhere and has the virtue of being transparent so that the effects of the treatment are immediately apparent. This also helps motivate the user to keep it clean.

There are two important design features which protect against accidental breakage from over pressure. The first is that as soon as air pressure is applied, water is allowed to flow through the filter and into the storage container thereby limiting the pressure build-up. The second safety feature is that the short length of rubber tubing (1 inch) inserted into the mouth of the bottle, will pop out before the glass breaks, in the unlikely event that there is an obstruction in the water line or the filter. Also, the user will tend to detect any obstruction as pumping will be more difficult and water will not flow easily from the outlet.

Valves

For the air inlet, a simple solution is to use a standard, tubeless tyre valve which can be attached to the plumbing parts by drilling an appropriate hole in a 1/2 inch plumbing cap and pulling the valve through in the same manner as it is inserted in the metal rim of the tyre. A simple tool is available for this purpose which can be purchased from a tyre distributor or repair shop.

It is also necessary to attach a 1/2 inch spring-operated check valve to the air side in order to permit the pressure to be bled off; with no valve on the water outlet, this is the only way to stop the flow of water when the system is pressurized. Also, this provides a way for the air to escape when the bottle is being filled with water.

Water inlet

In order to pour the water into the bottle, and then to seal the top, there are two options. If pressurized water is available then a convenient solution is to install a tap to which a garden hose can be attached. Once the water has entered the tap valve can be shut to provide the necessary seal before pressurization. An alternative is to use 3/4 inch, male plug. This can be removed and a funnel inserted into the 3/4 inch Tee into which the water can be poured. The plug is then replaced and the system is sealed for pressurization.

Separating the water and air circuits

This step requires a bit of skill and an electric drill. There is a small ledge at the bottom of the threaded opening in the 3/4 inch Tee left by the threading machine. The objective is to have the flat head of the hose coupling rest squarely on this ledge. However, the diameter of the disk is slightly too large to fit in the hole; therefore, it must be reduced. This can easily be done by chucking the shank of the hose coupling in the drill, placing it in a vice, and while the drill is rotating, using a small file to trim the diameter.

Once a hose coupling is seated squarely on the ledge of the 3/4 inch Tee, with a short length of 1/2 inch hose attached, a standard hose gasket is placed on top of it. In order to get a good seal between the air and water circuits, the 3/4 inch nipple is screwed all the way down in the 3/4 inch Tee until it presses against the gasket forcing the hose coupling to seat properly. The seal is essential for the working of the system.

Quick coupling

For ease in disassembly, it is advantageous to use a quick-disconnect coupling (of the type commonly used for pneumatic hose lines) between the filter and the water bottle. The filter may be conveniently hung around the neck of the bottle with a strand of plastic covered cable. In this way, the components can be easily separated for transport or storage.

Cost

The cost of the system will vary from place to place, depending on local prices, but should lie in the range of US $ 50 - 100. The most expensive individual item is the filter which accounts for more than one half of the total material cost.

Disinfection

Perhaps the simplest and most reliable method is to add a dose of chlorine. Ordinary household bleach, which consists of a solution of sodium hypochlorite and water, will serve and is widely available. Caution is in order, however, when selecting the brand as some manufacturers add perfumes or other substances which should not be ingested. If the product is suitable for purifying water it will normally state so on the label. Two such brands in Venezuela are Cloro Rubi and Cloro Mabos.

Dosage

The dosage printed on the label is two drops of liquid bleach (about 2 mg of chlorine) per litre of water. With this dosage a 1 litre bottle of bleach will treat approximately $12m^3$ of water. This should be enough for an average family of five for more than a year, at an annual cost of less than US $1.

However, the printed dosage should be regarded as only a rough approximation since chlorine demand will vary for different water sources. Also the desired level of residual chlorine needs to be taken into account.

Cairncross and Feacham (1983) state that "Even quite clean water is likely to have a chlorine demand of about 2 mg/l. Wirojanagud (1992) recommends a much higher dosage of 15-25 mg/l for rainwater cisterns. This high dosage is presumably necessary because of the problem of contaminated sediment which often accumulates in the bottom of the tank.

Residual chlorine

There are also substantial differences among the experts about the desirable level of residual chlorine. Cairncross recommends a minimum of 0.3 mg/l while Wirojanagud proposes 1 mg/l. Venezuelan official norms call for a minimum level 3 mg/l.

The determination of the level of residual protection depends on an assessment of the risk of subsequent contamination as well as on the tastes of consumers. An added advantage of the treatment system discussed here is that the treated water does not have to be transported, as in the case of centralized treatment systems. Thus, if it is properly stored, for example in a standard bottled water dispenser, then the risk of subsequent contamination is minimal.

Measuring residual chlorine

The best procedure is to utilize one of the cheap and simple chemical tests which can be purchased in kit form (Orthotolidine test or DPD test) and applied by the user himself. By varying the amount of chlorine and measuring the residual, allowing for about 15 minutes of contact time, he can, by trial and error, determine the chlorine demand for a particular water sample. For daily use, a bit of extra chlorine can be added as a safety precaution against unforeseen fluctuations in the quality of the raw water.

Dechlorination

It is important, however, to avoid overdosing with chlorine, not only for reasons of taste and health (too much chlorine can cause stomach upset), but to conserve the filter as well. While a good, activated charcoal filter, such as the AquaPure AP 200, will remove residual chlorine, its capacity to do so is limited.

Dosage and residual protection

Experience in Venezuela indicates that for relatively clean sources such as rainwater or clear spring water, a dosage of 2-3 mg/l should be sufficient. While the presence of residual chlorine in the water is a good indicator that is has been disinfected, these results should be confirmed from time to time by tests for coliform bacteria. However, until recently the procedure for doing this was too cumbersome and expensive to be accessible to the average householder.

However, thanks to a method developed by Manja, Maurya and Rao (1982), coliform tests can now be carried out in the field by unskilled persons with no special equipment. The test consists of a sliver of filter paper impregnated with a specially prepared reagent, placed in a small vial containing the water sample, which turns the liquid black within 24 hours if hydrogen sulphide, produced by the bacteria, is present. The results correlate very well with those of much more complicated and time-consuming tests, such as the membrane filter or the MPN (Fujioka and Rijal, 1992).

Alternative Methods

Solar disinfection has frequently been mentioned as a possible, desirable alternative to chlorination. It has the advantage that it requries no chemicals and does not produce unwanted tastes, odours, or potentially toxic chemical compounds. Nevertheless, it has a number of other drawbacks.

Principally, direct sunlight is not always available. Also it is only the UV portion wavelengths less than 400nm, which constitute less than 9% of the solar radiation striking the earth's surface, which has a bactericidal effect. The peak destruction of *E. coli* from UV radiation occurs at wavelenth between 250 and 260nm (Nash, 1993). Unfortunately (in this case), a disproportionate amount of the radiation below 300nm is absorbed by the atmosphere. If a glass container is used, another large portion of the UV is absorbed by impurities. Thus, in practice the amount left over for disinfection is rather small.

Nonetheless, Wirojanagud (1992) found that in Thailand, a 2 litre flask of rainwater could be completely disinfected within 3 hours of exposure to direct sunlight with an intensity varying from 190 to 900 watts/m^2. We found similar results in Venezuela for small amounts of water but, when we tried to develop a larger system for village application in the form of a panel using ordinary window glass, only partial reduction in coliform density was observed after exposure times of 5 hours or more.

As an alternative, small UV units for treating domestic water supplies are available commercially but they are rather expensive and require mains electricity, which make them unsuitable for remote applications.

SUMMARY AND CONCLUSIONS

Water quality management, for years almost exclusively the province of scientists and engineers, has in recent years become more and more a concern for the individual householder. Thus, in the industrialized countries there has been an enormous expansion of the market for a wide variety of home-treatment devices such as filters, UV and ozone purifiers, distillers, and reverse osmosis plants.

However, at the village level in the developing countries, the individual consumer is either left to his own traditional devices or is entirely dependent on a centralized treatment system which is notoriously unreliable. About the only technology that is available and promoted by public health officials for home-disinfection of drinking water is boiling. While potentially effective, boiling has the disadvantage of using lots of energy and leaves the water with a flat taste.

Because of the complexities of testing for bacteriological contamination in the past, it has been very difficult if not impossible for villagers to monitor the quality of water they drink. When testing is done, usually only after an epidemic of some disease has broken out, the results are often found to be unsatisfactory. Nevertheless, the obvious solution of individual chlorination is considered to be either too costly, too complicated or too dangerous.

In response, this paper presents a simple, safe, home water-treatment system which can be assembled and operated by the user himself, largely using off the shelf components at a cost which is affordable by even low-income families. Proper use of this system will assure a long-term supply of pure drinking water produced from averagely contaminated surface, sub-surface or rainwater sources and will permit the consumer to exercise much greater control over his own and his family's health.

REFERENCES

Cairncross, S. and **Feacham, R.G.** (1983). *Environmental Health Engineering in the Tropics,* John Wiley & Sons, Chichester.

Fujioka, R. and **Rijal, G.** (1992). Effect of UV and Bacterial Tests on Cistern Waters. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Nash, J. (1993). Assistant Director, Applied Engineering Research Laboratory, University of Notre Dame. Personal communication.

Wirojanagud, W. (1992). Rainwater Contamination and Control. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems.*Kyoto, Japan.

NATURAL CLOUD WATER HARVESTING FOR MOUNTAIN AGRICULTURE

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ABSTRACT

Many of the mountains in the summer capital of the Philippines are blessed with a favourable climate for terraced vegetable production. The cool weather and the presence of night clouds support the water requirements of these vegetables.

An attempt was made to estimate the amount of available moisture from fogs that come into direct contact with crops grown in the area, located about 300 to 1000m above sea level. The simple collectors were made of foam cubes measuring 30cm x 30cm x 30cm placed strategically along the terraces. The average daily moisture was measured at 2.90mm, enough to augment crop water requirements.

The results lead to the conclusion and recommendation that fog collectors could be developed and installed on higher ground to store cloud water for the use of farmers.

INTRODUCTION

The paper on fog as an alternative to rainwater collection (Schemenauer and Cereceda, 1992) stimulated the interest of the author (de Guzman), to look into similar situations in the Philippines, i.e. the optimal use of cloud moisture in mountain vegetable production where there is insufficient groundwater and surface water to supply water requirements.

No attempt has been made to measure the amount of water in the fogs that cover the high mountains of the northern Philippines. These fogs, which occur in dry season months, are important to mountain farmers who cultivate leafy vegetables and root crops in beautifully terraced farms at elevations ranging from 300m to 1000m above sea level.

A very rough estimate of available cloud moisture that directly drops and comes into contact with soil and plants was conducted in the vegetable bowl of Luzon Island in the Philippines in March and April 1993.

CLIMATE

The area under investigation falls under type 1 of Philippine climate categories where there are two pronounced seasons: dry from November to April and wet during the rest of the year. The maximum rain occurs from June to October during the prevailing southwest monsoon. The dry season lasts from 3 to 6 months.

The average annual rainfall is 3450mm with the heaviest downpours occurring in the months of May to October. The driest months are December to April. In these dry periods the vegetables will potentially grow and produce better due to the prolonged sunshine increasing photosynthesis. This is only possible, however, if there is an adequate supply of water and/or moisture to satisfy the crop water requirements.

MOISTURE DETERMINATION

Unlike rain the tiny droplets in the fog are trapped on leaves of crops and also dropped on the topsoil. The accumulated moisture flows from the leaves to the stem, then to the moist soil and finally to the root system.

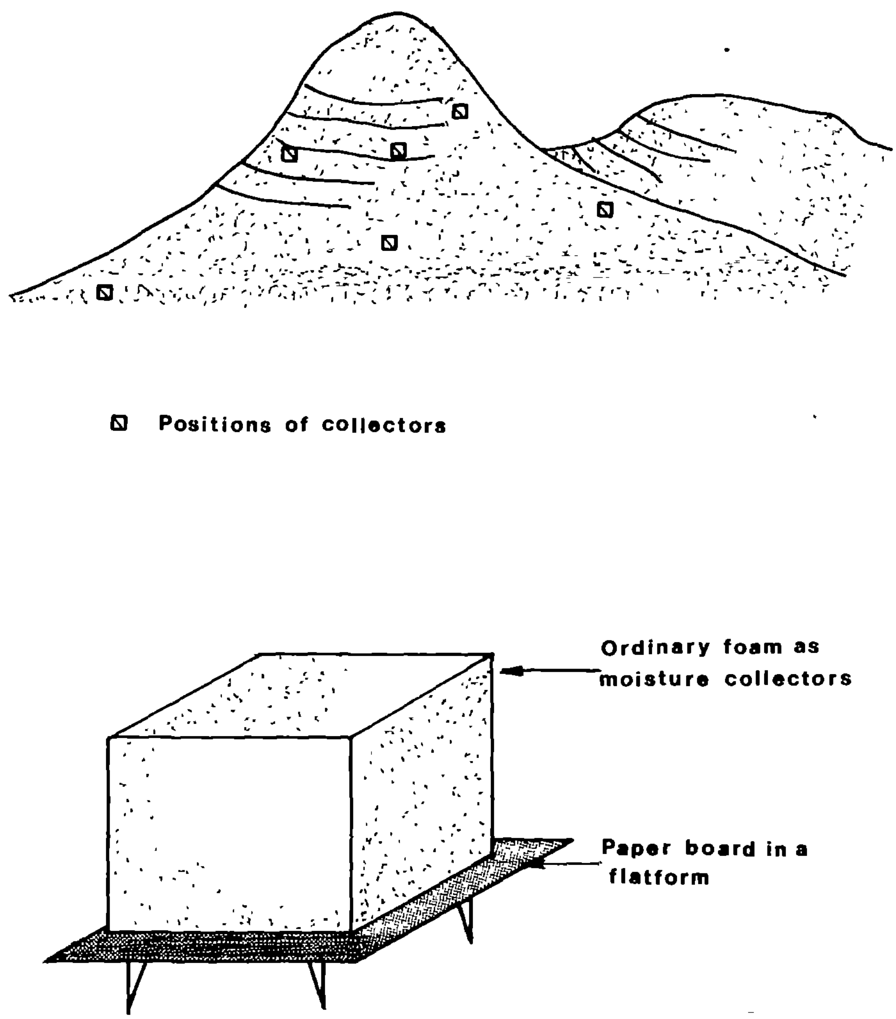

Figure 1. Foam moisture collectors and their positioning.

The amount of cloud water from the atmosphere that can be collected by plants was estimated using foam collectors. The foam cubes, each measuring 30cm x 30cm x 30cm were strategically placed in different locations and set 10cm above the ground (Fig. 1). The difference between the dry and wet weight of the collectors is the estimated volume of water per unit area at a certain period of the day (and night).

A thermohydrograph was also installed to collect data on relative humidity and temperature at the time of observation.

Observations were conducted in March and April 1993. Complete cloud cover occurred from 4.00 p.m. to 6.00 a.m. and occasional cloud with brief light rainshowers occurred between 1.00 p.m.and 3.00 p.m.

Results

The collected daily moisture averaged 270g 70% of which was gathered between 4.00 p.m. and 6.00 a.m. This is equivalent to 2.90mm of available water.

The relative humidity ranged from 73 to 100% and the mean night temperature dropped to as low as 5° celsius (2-6 a.m.). Daytime temperatures varied from 10.3° to 16.5° celsius.

The mean consumption by vegetables which include pechay, radish, carrots and sweet peppers could be partly supplied by cloud water or fog (Table 1). Farmers supplement the irrigation requirement from rainwater stored in small cisterns (containers). More progressive farmers utilize piped spring water that is trapped from higher sources.

Table 1. Consumption vs available moisture

Vegetables	*Consumption (mm/day)*	*Available moisture (mm/day)*	
		March	*April*
Pechay	3 1	2.8	2.9
Radish	3.2	2.8	2.9
Carrots	3.2	2.8	2.9
Sweet peppers	3.2	2.8	2.9

CONCLUSION AND RECOMMENDATIONS

Based on a very simple experiment and the results given above it can be concluded that some leafy vegetables and tubers can be grown in high mountain area of the Philippines. These crops can be supported either fully or partially by fog.

To maximize utilization of available water from all sources, both in the dry and wet seasons, a suitable cropping pattern and crop rotation should be developed by farmers in the area. Moreover other types of fog collectors could be introduced on the highest peaks to collect and store water to augment irrigation requirements during drought periods.

ACKNOWLEDGEMENT

The authors commend the services of the researchers - Isidro Arcangel, Rosalino Galapon, Julio Mariano, and Mario Aguilar - all from the Regional Irrigation Office 1 of the National Irrigation Administration.

REFERENCES

National Irrigation Administration (1989). *Feasibility Report of the 2nd Communal Irrigation Development Project*, Quezon City, Phillipines.

Schemenauer, R.S. and **Cereceda, P.** (1992). Fog as an Alternative to Rainwater Collection. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc.*, pp593-601, Kyoto, Japan.

HIGH ELEVATION FOG AS A WATER RESOURCE FOR DEVELOPING COUNTRIES

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ABSTRACT

In certain locations, the combination of meteorological conditions and topography are such that persistent fogs cover coastal and interior mountains. The droplets from these fogs can be collected by appropriately designed collectors to provide large volumes of water for domestic, agricultural or forestry uses. The largest project to date has provided, since February 1992, an average of 11,000 litres of water per day to a village of 330 people in the arid coastal desert of northern Chile. This project, and others in Peru, Ecuador, and the Sultanate of Oman will be reviewed, as will future applications in Southeast Asia and Africa.

Water yields and water costs will also be discussed, using examples from existing projects. Before beginning a large operational project it is essential to evaluate the fog water production rates and the length of the fog season. These data are critical to the assessment of the viability of a fog water supply system and also will allow an estimate of water costs to be made. Fortunately, the measurements of fog water production rates are simple and inexpensive, and can be carried out by local groups in each counntry.

INTRODUCTION

In parts of the world with negligible rainfall, no rivers or lakes, and no potable groundwater, the living conditions are harsh. These areas make up the desert and semi-desert regions of our planet. Yet for historical, cultural, or industrial reasons, or regrettably, because of dislocation due to war, people need to survive these conditions with minimal water. In many of these regions a persistent cloud cover envelopes the higher hills and mountains, and the fogs that result offer hope of a significant new water resource (Schemenauer and Cereceda, 1991).

In the last 6 years, fog water evaluation projects have taken place in Chile, Peru, Ecuador and the Sultanate of Oman. An overview of the results of this work will be given here along with a brief assessment of the prospects for the future.

CHILE

Up until 20 years ago the village of Chungungo, on the north coast of Chile, received water from the mine of El Tofo. Subsequently, water was trucked to the 330 villagers from a well 40km away. The sole source of income in Chungungo is fishing, primarily shellfish, in the cold coastal waters. A 1988 survey of all the households in the village (Cereceda, Schemenauer and Suit, 1992) found that the water usage was only 14 litres/person/day and that, at a cost of US\$2/m^3, this represented 10% of the total family income. Even at this rate the water was heavily subsidized by the municipality, the true cost being US$8/m^3. The purchase of water at this latter rate would be an impossible burden for the villagers. The cost is one of the main factors limiting consumption, the other is the unreliability of delivery. The water problems of Chungungo are typical of many other isolated villages in the coastal deserts of Chile and Peru.

The coastal ridgeline (780m elevation) at El Tofo is frequently covered in fog, which is produced as low decks of marine stratocumulus are blown onshore (Cereceda and Schemenauer, 1991). The cloud layers are thin, 100-300m, and rarely produce drizzle or rain. They vary in altitude from perhaps 500m to 1200m depending on the height of the temperature inversion that persists throughout the year. Since 1987, El Tofo has been the site of a large pilot project to evaluate the potential for using high elevation fog as a water supply in the arid north of Chile.

At the El Tofo site, 50 large fog collectors (Schemenauer and Joe, 1989), each consisting of 48m^2 of a double layer of polypropylene mesh, were constructed by the Corporación Nacional Forestal in late 1987 with funding from the International Development Research Centre (IDRC, Ottawa), as part of a multi-agency scientific and operational programme. In 1992, 25 additional collectors were constructed and a 6km pipeline to the village of Chungungo was completed. A 100m^3 storage tank is located above the village and fog water flows through a PVC distribution system to each house. The water supply system has been operational since February 1992.

The average water production from the El Tofo collectors has been approximately 3 l/m^2 of collecting surface per day since November 1987. This is an average production of 11,000 l/day. Production rates vary with conditions, from zero on clear days, to a maximum of about 100,000 l/day. There is a seasonal minimum in the winter (June-July) at the 780m altitude. With the current array size, each of the 330 villagers should receive about 30 litres of water per day. A community-run water authority records the amount of water used in each house and bills each household. Water costs for the maintenance of the system are well under $1/m^3.

Water from the fog collectors can be expected to be of good quality. It will contain some marine salts and soil dust but little contamination from anthropogenic sources due to the remote locations of most proposed sites. The ion and trace element concentrations at the El Tofo site have been studied in detail (Schemenauer and Cereceda, 1992a) and found to meet Chilean and WHO drinking water standards. These studies did not address the question of bacterial concentrations, but work by the University of Chile (unpublished) has shown the absence of fecal coliforms as would be expected. Other bacteria will be eliminated by the small chlorination plant that is required by law for domestic water supplies in Chile.

PERU

There has been a history of small fog collection experiments along the coast of Peru (e.g. Pinche-Laurre, 1986). The desert coastline is mostly sand and rock except where it is cut by small rivers carrying water from the Andes. The rural villagers are extremely poor and suffer from both a lack of water and contaminated water.

In 1990 the Canadian International Development Agency (CIDA, Ottawa) provided funding to carry out an assessment project near Lima, with the assistance of the Canadian Embassy and the Servicio Nacional de Meterología e Hidrología. A site at 430m was selected just north of the city (11° 49' S, 79° 09' W) using previously established criteria (Schemenauer, Fuenzalida and Cereceda, 1988). It was 3.5km from the coast and above a *pueblo joven* (squatter settlement) of 6000 people. The water usage of the people of Los Rosales was not measured but, since the entire supply was from one illegal connection to a nearby pipeline, it is unlikely that it exceeded 10 litres/person/day.

Fog and drizzle were frequent at the Cerro Orara site during June and July when the site and the instrumentation were prepared. Field measurements using a set of standard $1m^2$ collectors began in July and continued well into December when the fog, though less frequent, was still present. A continuously recording meteorological station operated throughout the period. The results showed that at this site a collection rate of 9 $l/m^2/d$ could be expected for at least 7 months of the year (Schemenauer and Cereceda, 1993; Cereceda, Schemenauer and Suit, 1993). On an annual basis, the site should have a greater productivity than the El Tofo site in Chile. This results in part from higher wind speeds and in part from drizzle that falls from the thicker cloud decks.

These results formed the first rigorous base on which to build fog water supply systems in Peru. Subsequently, two private companies were established to build system; $1200m^2$ of mesh were installed near Lima to provide fog water to a school, $500m^2$ of mesh were installed in a park north of Lima to produce fog water for reforestation purposes, and several other small projects were undertaken. In addition, in 1993, IDRC will fund a large agricultural project on the edge of Lima to use fog water to produce agricultural and forest products to support the desert community of Collanac.

ECUADOR

Ecuador has stretches of semi-arid coastline where the people experience water shortages and high water costs, as in Chile and Peru. There are coastal mountains that are seasonally fog covered and an evaluation of the fog collection potential began in late 1992 near Puerto López, with support from CIDA. Two small evaluation projects were also initiated in the high Andes at elevations of 2830m at Pululahua near Quito and 2000m near Celica in the south of the country. These sites are operated by NGOs (CISA in Puerto López and Pululahua; ARCOIRIS in Celica), with some scientific and technical assistance provided through CIDA. The two mountain sites have produced large amounts of water from the fog collectors (10-40 $l/m^2/d$), from December 1992 through March 1993. The high production rates result from drizzle and rain also being present plus the long periods each day with fog. The coastal fog collection season is expected to begin in May. These results are very encouraging and would support the undertaking of a more extensive evaluation program.

THE SULTANATE OF OMAN

A major fog collection experiment was undertaken in the Sultanate of Oman in 1989 and 1990, based on the work in Chile. The project was funded initially by the United Nations Development Programme, the World Meteorological Organization, and the Government of Oman through the Planning Committee for Development and Environment in the Southern Region (PCDESR). In the second year work was carried out under the auspices of PCDESR. During the southwest monsoon (*khareef*), the mountains (*jebel*) of Dhofar (17° 00′ N, 54° 04′ E) are covered in a thick deck of fog with frequent drizzle. The maximum duration of the khareef is from mid-June to mid-September and it is often some weeks shorter.

Data were collected with both standard $1m^2$ as well as much larger collectors. In the upper elevations, from 900m to 1000m, average collection rates of 30 $l/m^2/d$(Barros and

Whitcombe, 1989; COWIconsult, 1990) were obtained for a 3-month period. Because of the extended dry period between collection seasons, and because of the other options available in Dhofar (boreholes, desalination), a private sector evaluation was undertaken to determine if fog water collector arrays should be included in the next 5-year plan for the region. If they are, the most likely application will be reforestation of the *jebel.* However, a study of the water quality (Schemenauer and Cereceda, 1992b) has shown that the water is potable and, therefore, suitable for all purposes.

CONCLUSIONS

The small-scale applications discussed here may ultimately lead to fog collection sites being established in many countries where there are demands for safe and reliable water supplies. Pressures due to demand and contamination will require that non-conventional water supplies such as this be explored and utilized.

Schemenauer and Cereceda (1991) have documented references to 47 locations in 22 countries on six continents where there are indications that one might consider fog as a water resource to be investigated. In some of these locations, such as California, the wealth exists to solve water shortages in more conventional ways. But in other locations, particularly in developing countries, such as the Cape Verde Islands, Namibia, Yemen and Peru, fog collection deserves to be considered. Care must be taken in order to choose a productive site but the collectors themselves are simple, require no energy and deliver their water by gravity flow. Generally the area of the collector array would be fenced but, if desired, grazing animals could simply pass underneath the collectors. The cloud decks bring an essentially unlimited amount of water to the mountain sites, so in principle the amount of water that can be collected is limited only by the number of collectors that one chooses to install.

It is also important to note that in the humid tropics, cloud forests owe their existence to the input of water from both precipitation and from fog (Stadtmüller, 1987). It is clear that deforestation on tropical mountains will lead to reduced fog water inputs, which results in less water in aquifers and the streams which these aquifers feed. This, coupled with the erosion that deforestation generates, can result in both seasonal aridity and the production of semi-arid highlands. On the positive side, fog covered hills are often encountered in the humid tropics outside of the rainy season, for example in the Philippines, India, Kenya, Hawaii, Central America and the Caribbean. This offers the possibility of collecting fog water in these countries, both for reforestation and for human consumption.

REFERENCES

Barros, J. and **Whitcombe, R.P.** (1989). Fog and Rainwater Collection in Southern Region 1989 Research Programme. Draft Report to the Technical Secretariat of the Planning Committee for Development and Environment in the Southern Region, Salalah, Oman.

Cereceda, P. and **Schemenauer, R.S.** (1991). The Occurrence of Fog in Chile. *Jl. Applied Meteorology*, **30**, 1097-1105.

Cereceda, P., Schemenauer, R.S. and **Suit, M.** (1992). An Alternative Water Supply for Chilean Coastal Desert Villages. *Intl. Jl. Water Resources Development*, **8**, 53-59.

Cereceda, P., Schemenauer, R.S. and **Suit, M.** (1993). Producción de agua de nieblas costeras en Perú. Submitted to *Alisios.*

COWIconsult, (1990). Draft Report: Dhofar Khareef. Feasibility Studies of Fog and Rainwater Collection, and Guidelines for Pilot Projects. Salalah, Oman.
Pinche-Laurre, C. (1986). Estudio de las condiciones climáticas y de la niebla en la costa norte de Lima. Thesis, Universidad Nacional Agraria La Molina, Dept of Physics and Meteorology, Lima, Peru.
Schemenauer, R.S. and **Cereceda, P.** (1991). Fog Water Collection in Arid Coastal Locations. *Ambio*, **20**, 303-308.
Schemenauer, R.S. and **Cereceda, P.** (1992a). The Quality of Fog Water Collected for Domestic and Agricultural Use in Chile. *Jl. Applied Meteorology*, **31**, 275-290.
Schemenauer, R.S. and **Cereceda, P.** (1992b). Monsoon Cloud Water Chemistry on the Arabian Peninsula. *Atmospheric Environment*, **26A**, 1583-1587.
Schemenauer, R.S. and **Cereceda, P.** (1993). Meteorological Conditions at a Coastal Fog Collection Site in Peru. Accepted by *Atmósfera*.
Schemenauer, R.S. and **Joe, P.I.** (1989). The Collection Efficiency of a Massive Fog Collector. *Atmospheric Research*, **24**, 53-69.
Schemenauer, R.S., Fuenzalida, H. and **Cereceda, P.** (1988). A Neglected Water Resource: the Camanchaca of South America. *Bull. of the American Meteorological Society*, **69**, 138-147.
Stadtmüller, T. (1987). *Cloud Forests in the Humid Tropics*. The United Nations University, Tokyo.

THE COMPLEMENTARY ASPECTS OF RAINWATER CATCHMENT AND FOG COLLECTION

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ABSTRACT

Water droplets in the atmosphere typically range in size from the smallest cloud or fog droplets, with a diameter of 1 micrometre, to the largest raindrops with diameters of about 5mm. The fog droplets have negligible fall velocities and their trajectories are determined by the speed and direction of the wind. Raindrops have fall velocities (2-9m/sec) comparable to typical wind speeds and, therefore, will fall at an angle, except in unusual circumstances where the wind speed is zero. An understanding of the fall angle of the rain can lead to a better orientation and design of rooftop rain catchment systems and to the collection of several times the normal amount of water. This leads to four recommendations: first, in foggy environments rainwater catchment systems should be modified to collect fog water as well; second, as the wind speed increases or drop sizes decrease, rainwater catchment systems should be near vertical rather than near horizontal; third, use should be made of upwind walls of houses as rain collectors; and fourth, tree plantations in arid regions should be designed in a manner that optimizes their role as fog and precipitation collectors.

INTRODUCTION

Operational rainwater catchment systems exist worldwide and the results of experimental and applied programmes have been widely discussed. Applications are limited to areas with substantial annual or seasonal rainfall. In areas with low annual rainfall rates (1-500mm/year) rain is normally not collected unless it falls intensely for short periods of time, in which case the storage and use periods are also relatively short. Improvements in rain collection systems, to substantially improve the amount of water collected, would be of great benefit in these areas.

Fortunately, in some arid environments, another form of atmospheric water can also be used. Schemenauer and Cereceda (1991) have described locations in the arid regions of 22 countries on six continents, where one might collect high elevation fog and use it for domestic, agricultural or forestry purposes. Most of these are developing countries where the need for rural water supplies is acute. They did not focus on seasonally arid regions, but doing so would lead to the inclusion of many more countries stretching from Southeast Asia, to the Middle East, Africa, South America, Central America and numerous island groups. The fog collectors have been described by Schemenauer and Joe (1989); the fog collection project in Chile by Cereceda, Schemenauer and Suit (1992); the project in the Sultanate of Oman by Schemenauer and Cereceda (1992a); and the project in Peru by Schemenauer and Cereceda (1993).

COLLECTING RAIN AND FOG

Rain

The collection and use of rainfall has been widely described in the literature. There are two basic approaches: the use of an artificial collector such as a rooftop (e.g. Mayo and Mashuri, 1991), or the manipulation of the terrain to increase and store the runoff (e.g. Evanari, Shanan and Tadmor, 1971). In both cases the expected water collection is assumed to be the product of the annual rainfall amount and the plan area (horizontal projection) of the roof or terrain. This is the normal approach in the literature. However, it has been recognized for a very long time that this calculation will be incorrect whenever there is wind. This has been discussed, for example, by Fourcade (1942).

Rain or drizzle droplets will fall at an angle determined by the droplet fall velocity and the wind speed. This means that there will be a rain shadow behind every vertical obstacle and, equally as important, a sloping collecting surface will receive not only all the rain that would have fallen on its horizontal projection but also all of the rain that would have fallen in the rain shadow.

The implication of this for the design of rainwater collectors is that the stronger the winds, and the smaller the drops, the more vertical the collector should be. Raindrop fall velocities can be found in standard cloud physics texts (e.g. Mason, 1971). A 0.5mm diameter drop, which is at the boundary between drizzle and rain, falls at 2m/sec and the largest raindrops, with diameters about 5mm, fall at 9m/sec. Clearly, therefore, even wind speeds of a few metres per second will impart a significant angle to the fall of the drops.

If one assumes a rainfall drop size distribution (e.g. Marshall and Palmer, 1948), then for each rainfall rate a median drop size can be calculated (Atlas, Srivastava and Sekhon, 1973). Each drop size will have a specific vertical fall velocity (Mason, 1971). The inter-relationships between rainfall rates, drop sizes and drop velocity are shown in Figure 1. If desired, other drop size distributions can be chosen (e.g. Jones, 1992, for tropical rain), and other parameters of the size distribution chosen, e.g. the mode or the mean volume diameter; however, the principles remain the same. Higher rainfall rates are characterized by larger median droplet sizes and higher fall velocities. In principle these large drops should be less affected by wind; however, high rainfall rates are produced by deep convection such as thunderstorms, monsoons and typhoons, which in turn are associated with strong winds. Therefore, even large raindrops can often be expected to fall at significant angles. For example, in a 10m/sec wind, 5mm diameter raindrops will fall at an angle of about 45° to the vertical. This point has practical significance and should be reflected in the design of rainwater catchment systems.

Fog

The small sizes of fog droplets result in fall velocities ranging from < 1cm/sec to approximately 5cm/sec. They therefore travel almost horizontally in virtually any wind conditions. Because of this, a fog collector should be a vertical surface. In operational fog collection systems, the polypropylene-mesh collection panels are typically 4m high and 12m long and are located in mountainous areas with frequent fog and moderate wind speeds. The understanding of the relative amounts of fog and precipitation that can be collected at a site is vital to the optimization of the collecting surfaces to be used. That fog can be a significant source of potable water has been demonstrated by Schemenauer and Cereceda (1992b).

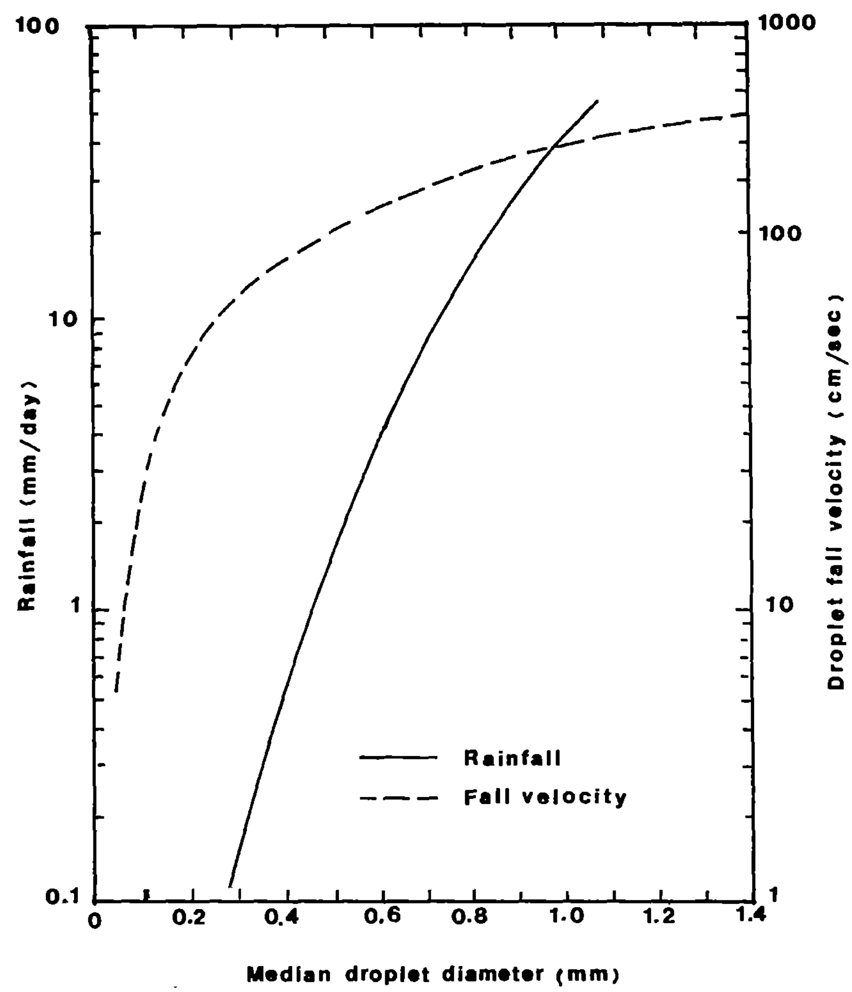

Figure 1. Rainfall rate and fall velocity as a function of median droplet diameter (for drizzle and small raindrops).

Modifying rooftop collectors

A flat roof is an inherrently inefficient rainwater collector. Any vertical rise to the roof will increase the collection, and the stronger the winds, the greater will be the increase in catch. However, the normal centre peaked roof is not optimum. A better design would be a single slope facing the prevailing wind during rain events. If the slope angle was maintained the same, this would double the rain-shadow water that can be collected. The vertical wall on the upwind side should have a trough at its base. The vertical wall on the downwind side could also have a trough at the base, if rain sometimes occurs with winds from the opposite direction. If this shape of roof is impractical or undesirable, increasing the slope angle will increase the catch of wind-driven rain. Existing centre peaked roofs can be simply modified by placing a vertical panel along the centre ridgeline. A solid panel will increase the catch of wind-driven rain. A mesh panel, of suitable material, will collect both fog and rain.

Rain Collection in Oman

The importance of differentiating between fog and rain contributions to the water balance of the Dhofar *jebel* in Oman was discussed by Schemenauer (1989) and a series of specialized collector experiments was proposed. The first of these is described by Barros and Whitcombe (1989). They found that a roof at the Aghshay site, at a 30° angle to the horizontal, collected 55% more precipitation per square metre than a standard raingauge. This could be explained by drops falling at an angle of 25° to the horizontal, which is in excellent agreement with calculations using a mean drop size of 0.3mm, a fall speed of 1m/sec, and the measured mean wind speed of 2.5m/sec. At a higher altitude at Qeiroon Heiritti, with smaller drops and higher wind speeds, the same roof collected 530% more water per square metre than a horizontal raingauge. This is in part due to undercatch by the raingauge, but is principally due to the collection by the sloped roof of drizzle and rain whose drops had a strong horizontal component. The drops in this case were calculated to fall with an angle of only 5° to the horizontal. One concludes that at Aghshay a rainwater collector should be angled at about 65° to the horizontal and at Qeiroon Heiritti at about 90° (vertical). The latter may not be a practical angle for a roof, but it is for a specialized collector.

CONCLUSIONS

Rainwater collection and fog water collection are inter-related issues. In certain locations it is clear that only one or the other approach will produce significant amounts of water. However, there are many locations where fog and rain are present together. These include some sea level sites and both coastal and inland mountain sites. The latter experience frequent fogs because of the advection of clouds over the terrain. In a time of increasingly frequent shortages of potable water, it is important to evaluate both rainwater and fog water as means to augment existing supplies. In addition, rainwater catchment systems should be modified to maximize the collection of wind-driven rain and fog by:

1. Using wind direction information to optimize the orientation of the house;
2. Using wind speed and rainfall rate information to optimize the shape and slope of the roof;
3. Collecting, with suitable troughs, precipitation striking the upwind wall, or walls, of houses;
4. Constructing, where conditions permit, vertical panels on rooftops to increase the collection of precipitation;
5. Adding, in foggy locations, rooftop panels made of a suitable mesh to provide both fog water and rainwater for the household;
6. Giving consideration, in arid regions, to designing tree plantations to intercept fog water (if present) and to relocate precipitation (if desirable).

REFERENCES

Atlas, D., Srivastava, R.C. and **Sekhon, R.S.** (1973). Doppler Radar Characteristics of Precipitation at Vertical Incidence. *Rev. Geophysics and Space Physics,* **11**, 1-35.
Barros, J. and **Whitcombe, R.P.** (1989). Fog and Rainwater Collection in Southern Region 1989 Research Programme. Draft Report to the Technical Secretariat of the Planning Committee for Development and Environment in the Southern Region, Salalah, Oman.
Cereceda, P., Schemenauer, R.S. and **Suit, M.** (1992). An Alternative Water Supply for Chilean Coastal Desert Villages. *Intl. Jl. Water Resources Development,* **8**, 53-59.
Evanari, M., Shanan, L. and **Tadmor, N.H.** (1971). Runoff Agriculture in the Negev Desert of Israel. *Food, Fiber and the Arid Lands,* Ed by W. McGinnies, B.J. Goldman and P. Paylore, pp.311-322. University of Arizona Press, Tucson.
Fourcade, H.G., (1942). Some Notes on the Effects of the Incidence of Rain on the Distribution of Rainfall Over the Surface of Unlevel Ground. *Trans. Royal Soc. South Africa,* **29**, 235-254.
Jones, D.M.A. (1992). Raindrop Spectra at the Ground. *Jl. Applied Meteorology,* **31**, 1219-1225.
Marshall, J.S. and **Palmer, W.M.** (1948). The Distribution of Raindrops with Size. *Jl. Meteorology,* **5**, 165-166.
Mason, B.J. (1971). *The Physics of Clouds.* Clarendon Press, Oxford, UK.
Mayo, A.W. and **Mashuri, D.A.** (1991). Rainwater Harvesting for Domestic Use in Tanzania, a Case Study: University of Dar es Salaam Staff Houses. *Water International,* **16**, 2-8.
Schemenauer, R.S. (1989). Potential for Fog Water Collection in the Dhofar Region of Southern Oman. Report to the World Meteorological Organization Technical Coordination Division, Geneva, Switzerland.
Schemenauer, R.S. and **Cereceda, P.** (1991). Fog Water Collection in Arid Coastal Locations. *Ambio,* **20**, 303-308.
Schemenauer, R.S. and **Cereceda, P.** (1992a). Monsoon Cloud Water Chemistry on the Arabian Peninsula. *Atmospheric Environment,* **26A**, 1583-1587.
Schemenauer, R.S. and **Cereceda, P.** (1992b). The Quality of Fog Water Collected for Domestic and Agricultural Use in Chile. *J. Appl. Meteorology,* **31**, 275-290.
Schemenauer, R.S. and **Cereceda, P.** (1993). Meteorological Conditions at a Coastal Fog Collection Site in Peru. Accepted *Atmósfera.*
Schemenauer, R.S. and **Joe, P.I.** (1989). The Collection Efficiency of a Massive Fog Collector. *Atmospheric Research,* **24**, 53-69.

RAINWATER FROM ROCKS: EXPERIENCES AND PROSPECTS FROM BOSTWANA

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ABSTRACT

Botswana is a semi-arid country which periodically experiences acute water shortages both for domestic use and agriculture. The most common sources of water supply are surface dams and groundwater abstraction. Recently, the collection of rainwater has been popularized among small-scale farmers by the introduction of government programmes and packages. Catchment surfaces for harvesting groundwater have been modified for the purpose. Several parts of Botswana are rich in rock surfaces, which could be considered suitable for rainwater harvesting. This paper examines the development and future potential of this aspect of rainwater collection.

As in most semi-arid regions Botswana's rainfall is typified by short duration, high intensity downpours that generate large volumes of runoff. Most of the rain that falls on bare rock ends up as runoff. Many settlements around Gaborone and Kanye village are clustered around hills which are ideal for rainwater collection. The communities would definitely benefit from such a development.

A major problem with the rainwater harvesting projects implemented so far concerns proper storage. Most of the tanks built have shown one defect or another: mainly cracking, silting-up and general pollution of the water. The paper explores suggestions for design and construction of tanks to improve functioning and hygienic storage.

INTRODUCTION

Botswana is a semi-arid country that periodically experiences acute water shortages for domestic and other uses. The main sources of water supply to settlements are surface dams and groundwater from deep boreholes. However, bold steps have been taken to develop rainwater collection technology to supplement these sources. Development has mainly been carried out in areas where the two main types of water sources are not possible. Popularization of the rainwater collection technology has been entrusted to the Arable Lands Development Programme (ALDEP) of the Ministry of Agriculture. This programme has been active for about one decade now.

The designs used by ALDEP revolve arcund two catchment surfaces: threshing floors smeared with earth and/or cowdung and galvanized iron roofs; they also encourage a combination of the two. In many parts of the country there are, however, plentiful rock surfaces which are considered suitable for rainwater harvesting. Most of these are bare, relatively large in area and close to settlements. Moreover, they would generate a large volume of runoff, partly due to the high intensity, short duration rainfalls characteristic of the region, and also in part due to low infiltration of the rock. Nissen-Petersen (1985) observed that a rocky outcrop is an excellent surface for harvesting rainwater because it can yield nearly 100% runoff. To date, an insignificant number of such rock surfaces have been developed for rainwater harvesting in Botswana.

Storage of the rainwater collected is equally important. ALDEP has used a couple of tank designs, but they have had operational and maintenance problems such as leakage, silting-up, collapse etc. These problems need to be addressed before proposing a suitable design of tank for rainwater collection from rock catchments.

BACKGROUND

The Botswana people have been involved in rainwater collection for centuries (Jay and Gould, 1993). There is some evidence of pits being used for collecting rainwater surface runoff, as well as pots used to collect water from the roofs of thatched houses. Many people still follow this practice, although it requires improvement so as to enhance the water quality. Rainwater catchment from rock surfaces has been developed at Oodi, a village near Gaborone.

Many old government buildings have rainwater collection tanks that were incorporated at the time of construction: schools and clinics are also commonly equipped with a rainwater tank, usually made of corrugated galvanized iron sheets. In 1969, the Intermediate Technology Development Group (ITDG) undertook a major study on rainwater collection in Botswana. This resulted in the construction of a number of rainwater collection tanks for schools in Eastern Botswana. More recently, the Botswana Technology Centre (BTC) has built ferrocement rainwater tanks based on the design of Watt (1978). However, these tanks did not perform well, chiefly due to poor workmanship and supervision problems (Gurusamy, 1991).

In 1982, the government introduced the Arable Lands Development Programme (ALDEP). The main aim of this programme was to assist subsistence farmers to acquire basic farm equipment and draught animals. It was soon realized that farmers spend most of their time fetching water and taking it to the fields, to the detriment of other farming activities. It was therefore decided that provision of water where the "lands are" (where the arable farm holdings are located) should be a priority. Accordingly, a water tank was included as a component of the ALDEP package. The envisaged source of water was harvesting of rainfall.

A number of tank designs and types of catchment surface have been implemented since the inception of this programme. A brief description of the most common types is given below:

- Underground brick tank with the threshing floor as the catchment surface.
- Polyethylene tank with a corrugated galvanized iron roof as the catchment.
- Underground brick tank with a corrugated galvanized iron roof as catchment. This type of tank is the most popular (Fig. 1).

Rock surfaces as catchment areas

As indicated in the preceding sections there are various surfaces from which rainwater can be harvested. It was also mentioned that suitable rock surfaces exist in some parts of Botswana on which to develop this technology. At Oodi a fairly flat rock surface measuring approximately 220m x 20m has been used to collect rainwater (Fig. 2). The water, stored in two shallow reservoirs at either end of the rock, is used by a cooperative women's group that weaves various woollen products. Another rock catchment for collecting rainwater is found in Thamaga. The water collected here is used for a pottery enterprise. In these two villages, a number of other suitable rocks exist, which could also be developed for rainwater harvesting.

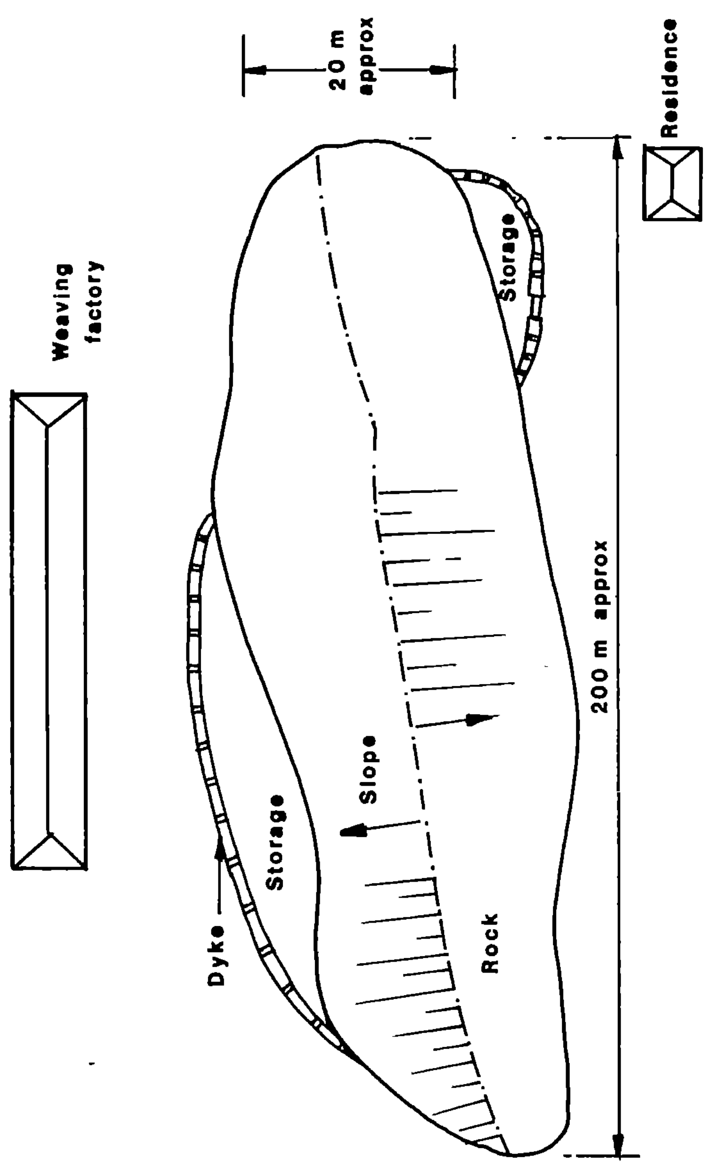

Figure 1. ALDEP underground brick tank with plan of the domed roof.

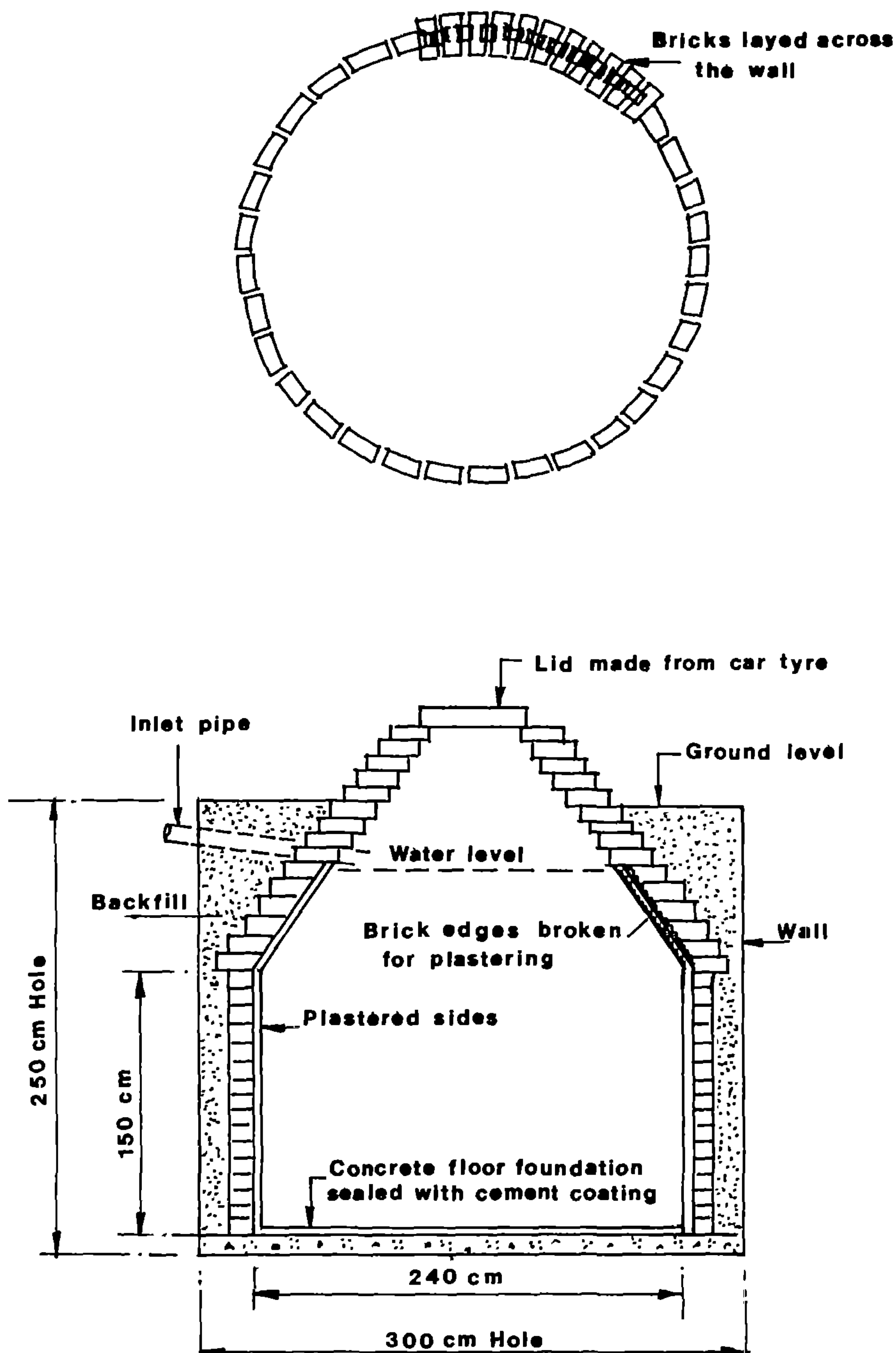

Figure 2. Plan of the rock catchment at Oodi village (not to scale).

Developing these rock surfaces for rainwater collection requires the participation of the community. This is usually readily available if they need the water, and also if they have seen that the technology works. There is no doubt that people require water for other purposes, other than domestic use, in these semi-arid areas. This demand should be quantified. Together with the rainfall records, the area or extent of the rock to be protected for water collection may be determined. This also goes for the calculation of the suitable storage volume. When rainfall falls on a surface (as on a rock outcrop), not all the water becomes available as runoff. The runoff coefficient expresses the quantity that will become available as runoff. A useful formula for calculating runoff is:

$V = C \times R \times A$ .... (1)

where V = runoff volume (1)
R = rainfall (mm)
A = catchment area (m^2)
C = runoff coefficient

Various outhors suggest different values of C relating to rock surfaces. Pacey and Cullis (1986) give a range of 0.2-0.5 for C while Nissen-Peterssen and Lee (1990) suggest a value of 0.9. Perhaps a value of 0.7 is reasonable as some of these rocks are covered in some sections with pockets of tree and bush vegetation. One advantage of building these rock surfaces for rainwater harvesting is that other aspects such as the cofficients of runoff can also be studied if adequate instrumentation is installed.

Storage of the rainwater

The water collected has to be stored for use at a later time, unless the aim of collecting it is for runoff farming. The storage techniques practised at the two sites where rainwater has been collected from rocks in Botswana are simple. In one case, at the Oodi Weavers, the base of the rock has been improved by building a surrounding wall of two courses of cement blocks forming a dyke. In the other, the hollow part of the rock is also used for storage after constructing a course of blocks on one side. Both of these methods have the advantage of small cost. However, they have several disadvantages, including limited storage, no protection against pollution, and leakage through rock joints/faults. Also, large evaporation losses occur from these fairly shallow reservoirs. Nissen-Petersen (1985) has given a good description of the construction of similar but larger storage natural hollows in rock in Kitui, Kenya.

For larger catchments, dams are suggested; owing to the usual abundance of rock around the site, they would be constructed as gravity dams, firstly because the structure should satisfy its storage requirements (water tightness), and also because of the desirability of transmitting the water by gravity. This would therefore favour a dam built within the rock slope itself.

If site conditions are not favourable for construction of a dam within the rock catchment area, the alternative would be to build one at the rock base. However, reconnaissance visits to some of the good rock sites, indicate that the rock extends for longer distances at a shallow level thus making excavation and water-tightness of the dam difficult to achieve. It is envisaged under such circumstances that a ground water tank could be constructed. This can be of stone masonry and may even be compartmentalized. It is more feasible to provide some form of roofing for such compartments, thus cutting down losses due to evaporation as well as reducing pollution and growth of algae. It has been tried in Zimbabwe (*dwala* technology) and has been found successful (Mukandi, 1993).

The volume of water collected and stored can be increased by installing masonry gutters or channels at the sides of the rock where the runoff flows away from the storage structure (Nissen-Petersen and Lee, 1990). The rock at Oodi taps only a fraction of its surface because of lack of these gutters. They can be designed and built in such a way that they not only convey the runoff but also retard the velocity of flow of the water and trap, silt and other sediments that may be carried to the storage structure. This feature can be enhanced by intermittent obstructions along the length of the gutter (Fig. 3).

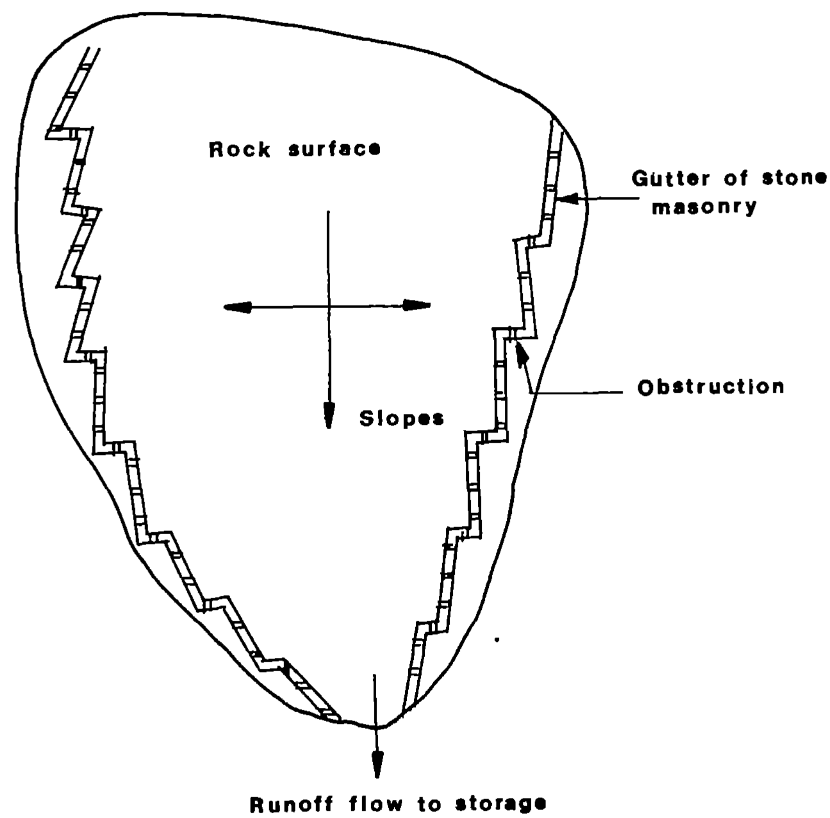

Figure 3. Gutters on rock - note the intermittent obstructions.

Jay and Gould (1993) suggest that stored rainwater can be used as a supplementary back-up supply in villages with existing reticulated supply from a borehole. The implication here is that rainwater collected from the catchment should be of a sufficiently high quality that it is possible to carry out this exercise with little or no treatment. Most of the rock catchments have many animals living in the vicinity, especially rock rabbits. These and other pollutants pose a potential contamination hazard. It is therefore important to fence off the area surrounding the catchment as well as the reservoir itself. The water should also be treated, i.e. disinfection with chlorine, before being piped into the main village supply.

CONCLUSIONS AND RECOMMENDATIONS

Botswana being a semi-arid country implies that water resources are limited so any technology that aims at collecting water should be encouraged. Rainwater harvesting is an appropriate technology for rainwater collection both in rural and urban areas where conditions are favourable.

Threshing floors (mud and cow-dung covered) and galvanized iron roofs are the two most common catchment surfaces in Botswana with the latter becoming the most popular probably because the water collected is of a relatively better quality. It is recommended that the rock catchments be developed in suitable places. This type of catchment has performed well in the few places where it has been developed. To popularize rock catchments, it is suggested that government extend assistance to such projects, much as it now does with ALDEP projects.

REFERENCES

Gurusamy, K.N. (1991). Development of Ferrocement Construction in Botswana. *Proc. 4th Int. Conf on Ferrocement*, Cuba.

ITDG, (1969). *The Introduction of Rainwater Catchment Tanks and Micro-irrigation to Botswana.*

Jay B. and **Gould J.E.** (1993). An Overview of Rainwater Catchment Systems in Botswana. *Proc. Workshop on Rainwater Catchment Systems Application and Technology.* Gaborone/Kanye, Botswana.

Mukandi, C. (1993). Rainwater Catchment in Zimbabwe. *Proc. Workshop on Rainwater Catchment Systems Application and Technology,* Gaborone/Kanye, Botswana.

Nissen-Petersen, E. (1985). Water from Rocks, *Waterlines.* **3.**, (3), 8-11.

Nissen-Petersen, E. and **Lee M.** (1990). Rock Catchment Dam with self closing Water Tap *Harvesting Rainwater in Semi-arid Africa,* No. 3. ASAL Rainwater Harvesting, Nairobi, Kenya.

Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural areas.* IT Publications, London.

FINDING THE CATCHMENT RUNOFF COEFFICIENT FOR RAINWATER HARVESTING FROM TREES

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INTRODUCTION

In the olden days, before many people could afford iron shets for roofing their houses, people used to collect water from trees. Even now the practice is still in use in some areas. Compared to water harvested from roofs of grass-thatched houses, that collected from trees is normally better in quality.

Rainwater is normally collected from specific trees like *Ficus natalensis* (bark-cloth tree) and *Artocarpus heterophyllus* (jack fruit). Both these trees usually have short boles with thick crowns and heavy foliage; their barks are grey, smooth and clean. It is these factors that determine their use for water collection.

Ficus natalensis is a forest species usually found as an epipyte, but because of its importance as the source of bark cloth and its widespread use as a living fence and shade tree for coffee, it is cultivated all over the area. It is now to be found growing as an independent tree (raised in stakes) in and around villages and on the site of old habitations in all types of terrain. In Buganda a father traditionally plants a *Ficus natalensis* tree for his son and heir to signify his staying in the clan.

Jack fruit is native to tropical Asia from India to Malaysia. There are two types: the common variety has a crispier pulp than the less common variety. The pulp and composite of the latter are soft, sweet and strong smelling. Ripe jack fruit pulp or arils are eaten raw. The seeds can be boiled, roasted or mixed with other ingredients to make snacks.

The most common method of collecting rainwater from these trees is to tie a freshly cut undamaged banana leaf onto the bole of the tree. The leaf is adjusted to form a funnel shape for rainwater collection from the bole, and is tied at an angle with the bole so as to allow the water to pour into a container, normally a pot (Figs. 1 and 2). Another method is to use a sheet of soft metal bent into a similar shape. The metal is nailed very firmly on the bole. Rainwater falling on the foliage, runs down the bole, from where some of it flows over the banana leaf and is collected in the pot.

OBJECTIVES

1. To study the effectiveness of rainwater harvesting from trees.
2. To find the catchment runoff coefficients.
3. To identify the weaknesses and constraints of rainwater harvesting from trees, and suggest the potential for improvement and wider applicability.
4. To disseminate as much information as possible about rainwater harvesting from trees for the use of researchers and development workers.

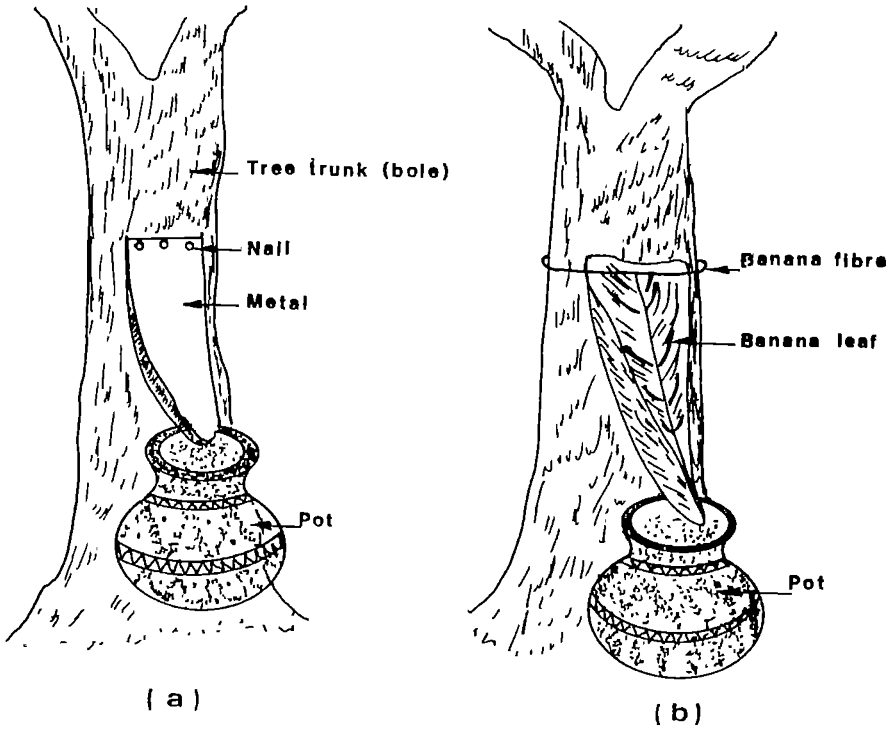

Figure 1 Rainwater harvesting from trees using (a) metal and (b) banana leaf for catchments.

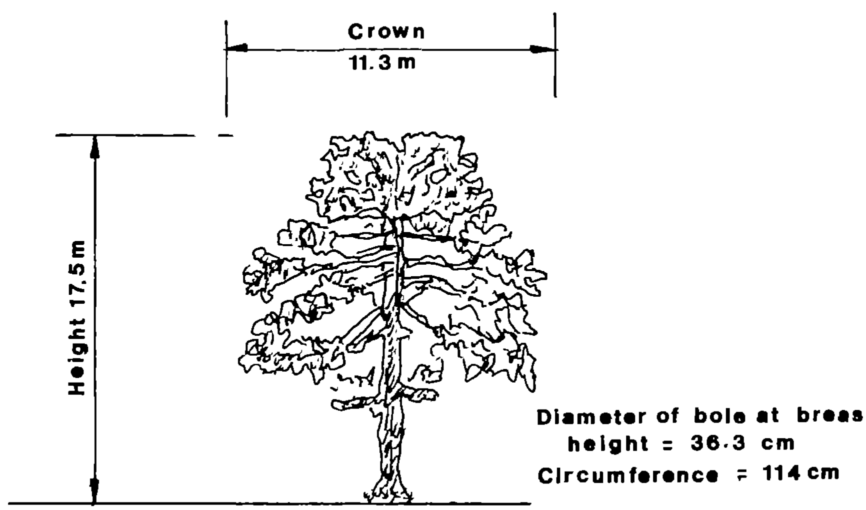

Figure 2. Tree measurements made.

METHODOLOGY

Mr Mukasa has been collecting rainwater from his jack fruit trees for over 1 year. He designed and constructed the collector which consists of a shaped metal plate nailed onto the bole of the tree about 1.5m from the ground. He allowed me to carry out some research on his system.

Whenever it rained the amount of rainwater collected was measured using a calibrated clean bucket (the water was used after being measured). The rainfall was also measured using a rainguage (in mm). Measurements were made on 10 different days.

The area of the catchment (metal) was measured using string and a ruler, as was the distance from the ground. The tree height was measured using a Sunto. The tree crown was measured using two people with very long sticks. The diameter at breast height was calculated from the measurement of the circumference.

RESULTS

- Area of catchment = $0.9m^2$
- Distance of catchment from ground = 1.5m
- Tree height = 17.5m
- Tree crown = 11.3m
- Circumference (s) = 114cm
- Diameter = S/π = 114/3.14 = 36.3cm = 0.0363m

Formula for catchment runoff:

Amount of catchment runoff (R) in m^3 = CIA, ...1

where C = catchment runoff coefficient

I = Rainfall intensity (m)

A = Area of catchment (m^2).

In a perfect situation where all the runoff is collected and nothing is lost, C for hard roof = 1.

ANALYSIS OF THE RESULTS

The width of the metal catchment area (which depends on the girth) together with the rainfall intensity determine the volume of water harvested. Tree crown measurements may be closely correlated with trunk diameters, especially for trees on open round. The larger the crown measurement and the catchment area, the greater the volume of water; also greater volume of rainwater is harvested with higher rainfall intensity.

The amount of rainwater which is not harvested is very high - in fact more than three times the amount which is harvested. Thus the value of the catchment coefficient runoff is very low. It is as the same as that of soil surface runoff which is 0.25; for roads and compounds the value is 0.5; for grass thatch roofs it is 0.5; for polythene sheets it is 1, and for papyrus reeds it is 0.75.

CONCLUSION AND RECOMMENDATIONS

The value of the rainwater catchment runoff coefficient from trees is quite low, but this should not discourage people from harvesting rainwater from trees. The cost of constructing most water harvesting systems is high compared to the incomes of most end-users of those systems, so the

Table 1. Rainfall measurements

Date	*Actual rainfall (mm)*	*Theoretical value where C = I(litres)*	*Actual volume (litres)*
4.10.92	127	114.3	22.86
13.10.92	425	382.5	9.18
15.10.92	135	121.5	34 02
16.10.92	147	132.3	42.43
18 10.92	105	94.5	34.02
26 10.92	114	102.6	20.52
13.11.92	135	121.5	29.16
15.11.92	290	531.0	148.68
20.11 92	117	105.3	33.70
22.11.92	178	160 2	57.67
Total 10 days	2073.00	1865.70	432.15
Average	207.30	186.57	43.21

Using the values of averages·
Rainfall intensity I = 207.3mm = 0.2073m
Area of catchment A = $0.9m^2$
Amount of actual volume collected V_o = 43.21 litres = $0.04321m^3$
Amount of theoretical volume (where C = I) = 186.57 litres = $0.18657m^3$
Amount lost = 186.57 - 43.21 = 143.36 litres = $0.14336m^3$
From equation (1) catchment coefficient of runoff = V_o/IA

$$= \frac{0.04321}{0.2073 \times 0.9} = 0.23$$

majority of households cannot easily afford them. It is therefore recommended that this technology of rainwater harvesting from trees be improved and encouraged, because it is cheap and can prove valuable. Collecting over 40 litres of water from nearby is a great achievement, especially when the alternative water source is very far away. If the rainwater collected is stored in large amounts it can make a significant contribution to solving the problem of water supply facing the majority of the country's population. Compared to rainwater collected from grass-thatched roofs, the quality of that collected from trees is better. The dark colour of runoff from grass-thatched roofs together with the bad smell and poor quality makes it unsuitable for drinking. Even so, people should test the quality of runoff from trees since it may be contaminated with bird droppings, dead insects and leaves and twigs.

There is very little literature available on rainwater harvesting in Uganda, hence the short-comings in water harvesting techniques are not well known in the few places where it has been practised.

More research should be carried out on the best tree species for rainwater harvesting.

Also the use of large tree girths and other material placed vertically in contact with the tree crown to act as the catchment area, should be investigated. Adaptive research to fit the needs, economies and materials available in developing countries should be undertaken so that rainwater harvesting methods will prove to be of immediate value. External agencies and donors should contribute to research and training in rainwater harvesting.

People should be encouraged to plant those tree species which are fit for rainwater harvesting. Apart from providing water, they will produce fruit and fuelwood; the tree will also be protecting the environment by acting as a carbon sink.

Water harvesting systems are not yet a mainstream technical option in Uganda and hence have little institutional support. Therefore the potential of rainwater harvesting from trees, as a supplement to the existing water supply, is quite high.

REFERENCES

Avery T.E., (1975) *National Resources Measurements*, second edn.

Best, W.D., *The Student's Companion*

Edwards, E., Keller, K. and **Yohalem, D.** (1984). A Workshop Design for Rainwater Runoff Catchment Systems. *Wash Technical Report No. 27.*

Eggeling, J.W. *The Indigenous Trees of Uganda*

Kagwa, P. Personal Communication.

Kaneza, C.K. (1992). Rainwater Harvesting from Thatched Roofs *Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Japan.

Mukasa, E. Personal Communication

Mungkorndin, S. (1992) *Artocarpus Species*: The Fruit of Thailand. *Farm Forestry News*, 5.(3) 7.

Rutashobya, D.G., (1992) Rainwater Harvesting as a Potential Solution to Water Supply Problems in Tanzania. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc* Japan.

DJABIA RAINWATER HARVESTING SYSTEMS FOR DOMESTIC WATER SUPPLY IN LAMU, KENYA

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ABSTRACT

Within the coastal zone of Lamu reticulated water supplies are non- existent, groundwater sources are saline except for dunal and coral reef formations, and where shallow wells are sunk, the very high demand for fresh water has accentuated the problem of salinization through over-exploitation and subsequent sea water intrusion.

In order to cope with this critical fresh water shortage, the local communities have for a long time depended on the traditional *djabias*, masonry structures used to harness rainwater for domestic water supply. A *djabia* consists of a man-made (induced) sloping catchment area and a tank to store the water. The catchment area is usually a continuous concrete slab with garlands on the sides to direct runoff water into the reservoir and also minimize rainwater losses by splash.

This paper examines the criteria used in designing *djabias* with a view to sizing the water-harvesting systems to meet the very high water demand during the dry season. Pertinent design considerations include alternative sizes of catchment area based on available rainfall data and water demand; adequate storge tank capacity based on water demand throughout a dry season; improved quality of stored water through appropriate sediment screening devices, and quantities of materials required for construction of *djabias*.

INTRODUCTION

Domestic water supply and demand

In many developing countries the majority of people live in rural areas with little or no access to clean or treated water supplies. Water quality from the limited water sources has deteriorated over recent years due to an increase in non-pointed source pollution, especially from salinization.

In response to this increasing demand for safe drinking water, the United Nations declared the period 1981-1990 the International Drinking Water and Sanitation Decade. Over this period it was reckoned that many countries would strive to improve the supply and quality of domestic drinking water (UNEP, 1983).

In Kenya, the Government embarked on a very ambitious plan in which they proposed to provide safe and adequate drinking water to every home by the year 2000. A Kenya Water Master Plan was launched with the aim of providing every individual with 20 litres of water per day by the end of this century. This goal is yet to be realized.

An assessment of domestic water supply in Lamu reveals that supply is very much a function of rainfall and storage facilities available to conserve rainwater (GOK, 1982). Lamu Island is mainly supplied with water from underground shallow wells. The people of Faza, Manda, Ndau and Kiunga areas of Lamu, depend on *djabias* for their domestic water needs and on shallow wells for livestock water supply. Apparently these traditional *djabias* do not have sufficient storage capacity to carry them through an extended dry season; thus they cannot be relied upon as a long-term solution to the fresh water shortage problem in Lamu. In fact, the current water demand is more than these water-harvesting structures can provide. This therefore emphasizes the need to optimize the designs of these structures to provide enough water for a given number of people throughout the dry season, while at the same time taking care of increased demand due to population increase.

Alternative water sources

In Lamu, a study of water sources showed that most areas are supplied with water from underground shallow wells (GOK, 1982). Hydrological surveys conducted indicate that most of the groundwater sources are saline except for dunal and coral reef formations. Where shallow wells or boreholes have been sunk into freshwater aquifers, the very high demand for water has accentuated the problem of salinization due to over-exploitation or deepening of wells.

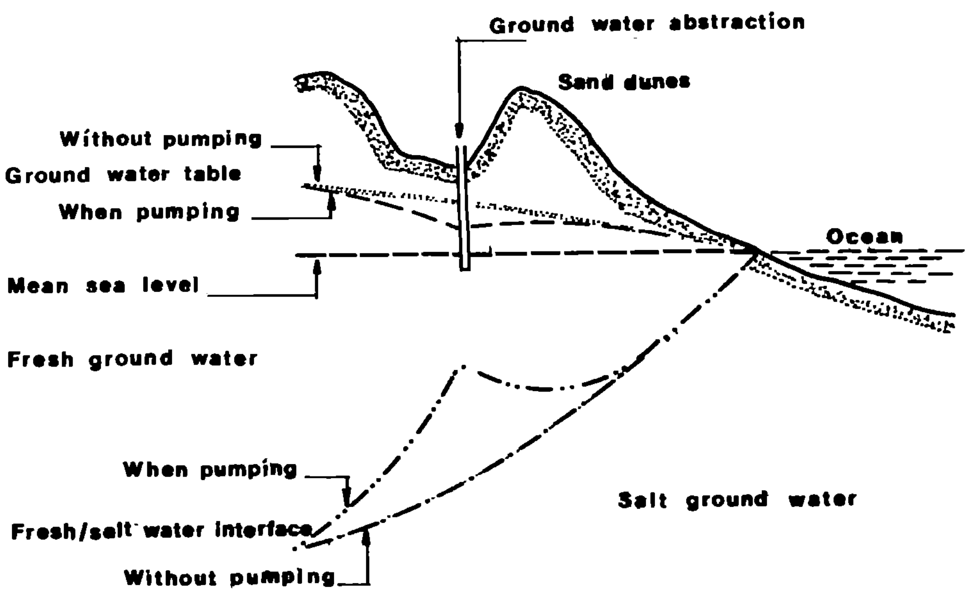

Figure 1. Sea water intrusion (GOK, 1983).

Because of the very low elevations (in relation to sea level) in most of Lamu, sea water intrusion is a potential threat to the quality of water in the wells.

The development of surface water retention reservoirs, like earth dams, is not feasible for various reasons. The problems include silting of dams due to the nature of predominant soils (sandy loams to sandy clay loams), the occurrence of sink holes where the top soil is underlain by some limestone formations, and non-availability of good soil borrow areas for building dam embankments. High sediment loads and evaporation water losses also threaten the expected life of earth dams.

The possibility of obtaining fresh water through small-scale desalinization of sea water is not feasible due to prohibitive investment costs. As observed earlier on, the traditional *djabia* water-harvesting structures are not reliable because they are not well designed and hence are not based on the expected rainfall and water demand. Whereas there is need to optimize the design of these structures, the cost of construction and maintenance of *djabias* is prohibitive to the very disadvantaged communities facing acute water problems.

Another possible source of fresh water is the harvesting of rainwater from roof catchment made of corrugated iron sheets. In the coastal areas of Lamu, this is not possible due to the high incidence of corrosion of iron sheets which makes the water harvested of poor quality and unfit for human consumption.

The *djabia* water-harvesting system

A *djabia* water-harvesting system consists of a man-made (induced) sloping catchment area and a reservoir to store the water. The catchment is usually a continuous concrete slab with garlands along the boundary. The garlands direct runoff water into the reservoir and also minimize rainwater losses by splash.

The *djabias* used in Lamu have induced catchments ranging in size from 10m x 10m to 20m x 20m with wall heights of 1.5-2m. In Mukokoni and Kiunga, the *djabias* are 15m x 15m with cuboidal or cylindrical tanks. In Kizingitini, Faza Islands, a *djabia* of size 15m x 20m and a reservoir volume of $175m^3$ has filled only three times since it was constructed over 30 years ago. This shows that either the storage tank was over designed or the catchment area was undersize (Biamah, 1990).

The traditional *djabias* have a problem with cracks on the induced catchment due to expansion joints not being provided. Low storage capacity is also a problem due to lack of consideration of rainfall data, water demand and the length of the dry season; so too is the poor quality of harnessed water due to the presence of trash and sediment in the storage tank, and splash water losses due to low garlands (Fig. 2).

This paper examines the existing design of the *djabia* with a view to making provisions for alternative sizes of induced catchment area (based on available rainfall data and water demand); adequate tank storage capacity (based on the water demand throughout the dry season); improvement of water quality through appropriate sediment screening devices, and estimated quantities of materials required for construction. It attempts to optimize the existing design by sizing the water-harvesting system to meet the domestic water requirements of the local communities (Fig. 5).

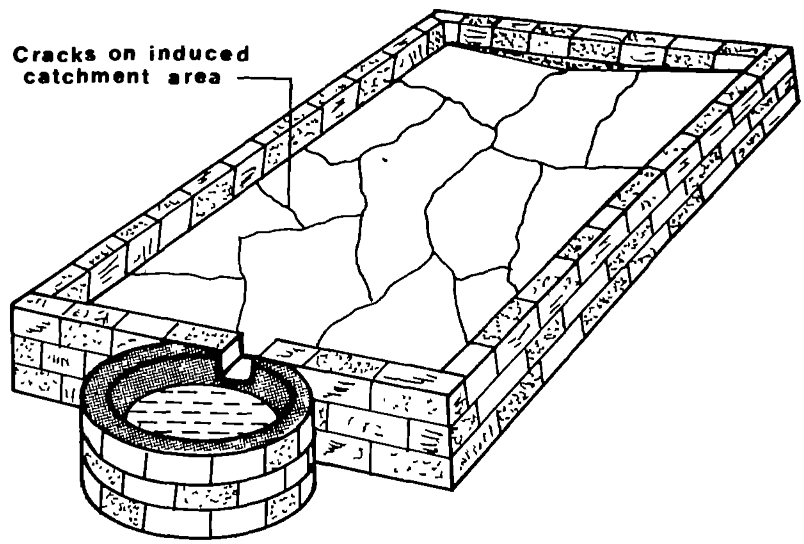

Figure 2. Design of a traditional water-harvesting system (Choge, 1991).

DJABIA DESIGN CONSIDERATIONS

Rainfall distribution, intensity and duration

Mean annual rainfall in Lamu ranges from 500mm in the hinterland to 1100mm along the coastal strip (Fig. 3).

The rainfall pattern is bimodal with long rains falling during the months of April to June with May being the wettest month. The short rains are usually recieved in the months of November and December (Table 1). Rainfall intensities are usually high and may reach a maximum of 100mm/hour for 10-15 minutes. Except for the month of May, the potential evapotranspiration, which varies from 220m in March to 160mm in June with a mean annual total value of 2327mm, exceeds the monthly rainfall.

Design period and storm

According to available rainfall data (Table 1), most of the rainfall in Lamu falls during the wettest months of April, May, June and July with the rest of the months being dry. Thus it is justifiable to design the *djabia* using the wettest period rainfall. The four months' rainfall is what must be conserved to meet the water demand over the eight months' of dry season. An appropriate storm for design of *djabias* in Lamu is the 100 mm/hour rainfall intensity that has a duration of 10-15 minutes. From the rainfall intensity/duration/frequency relationships, this

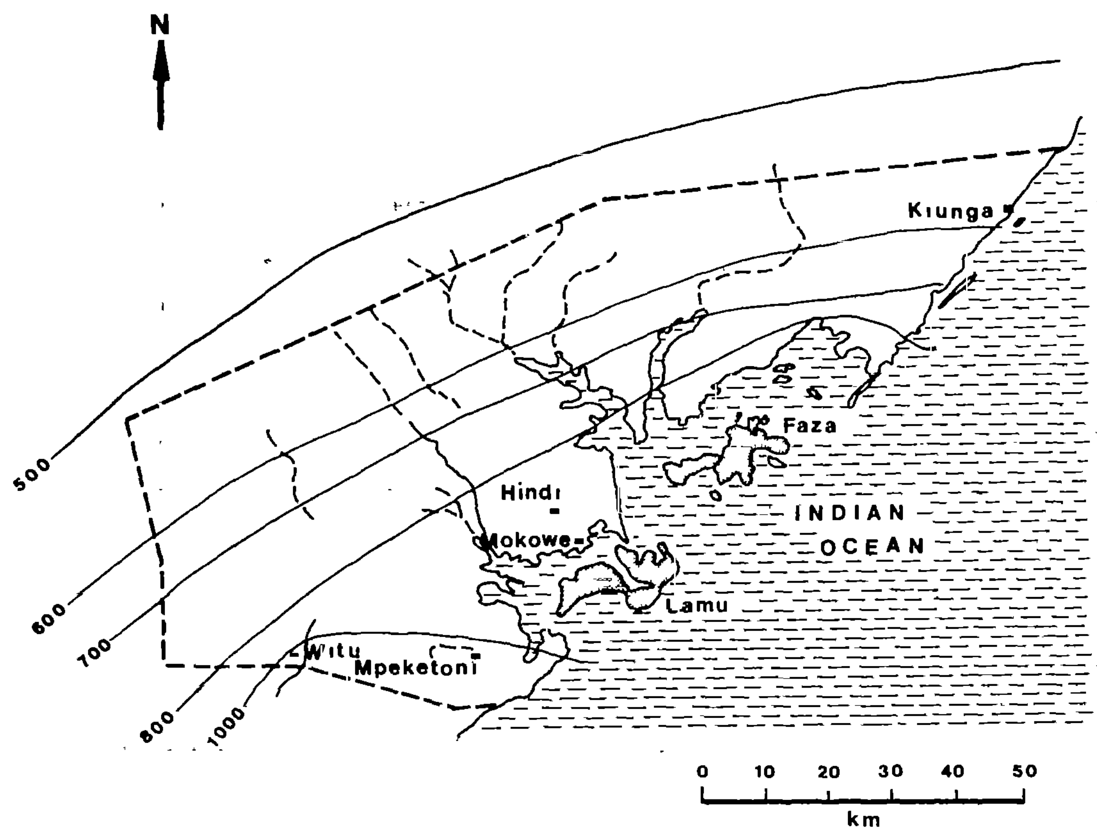

Figure 3. Rainfall distribution in Lamu (GOK, 1978)

design storm has a return period of 10 years. This storm over the return period, is recommended for the estimation of the catchment discharge and determination of the outlet size.

Catchment area and reservoir capacity

Using a maximum daily water consumption rate of 20 litres per head per day, the volume of water required to last through the dry season (reservoir capacity) is obtained by multiplying the number of people by the daily consumption per head and by the number of dry days (Table 2). Thus the catchment area chosen should be such that it can harness enough rainwater to fill the demand-driven reservoir capacity. When determining the net runoff generated from the catchment, water losses through depression storage, infiltration and evaporation are considered negligible. Likewise the designed catchment area should be able to cope with the maximum rainfall intensity of 100mm/hour with a 10 year return period. Computed relationships between

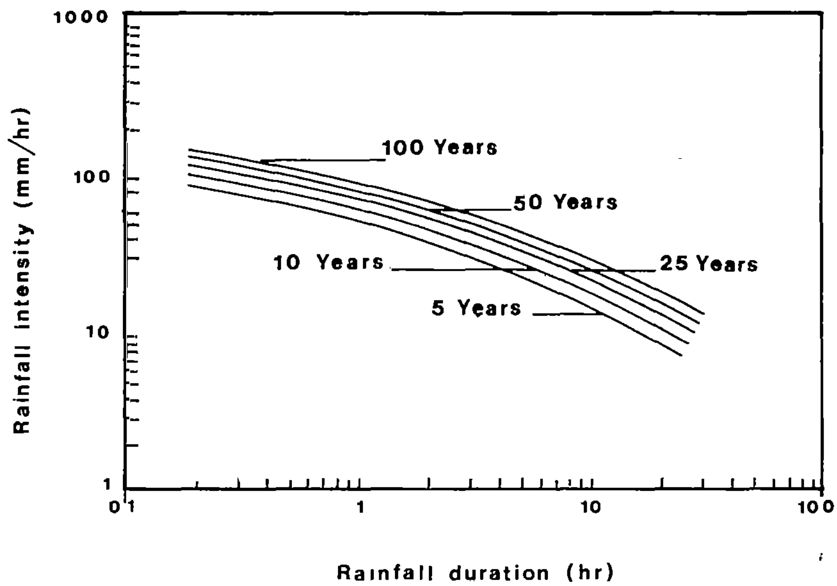

Figure 4. Rainfall intensity/duration/frequency relationships for Lamu (GOK, 1988).

population, catchment area, tank storage capacity and wettest months' rainfall are presented in Table 2.

Catchment expansion joints

Traditional *djabias* have failed to generate maximum runoff due to rainwater losses through cracks on the catchment surface. To solve this problem, the catchment surface should have expansion joints provided through the use of concrete slabs separated by mortar and bitumen. The bitumen placed in-between slabs would help to prevent the occurrence of cracks on the catchment surface. Concrete slabs which are commonly used in building construction are recommended for *djabia* catchments; they measure 61cm x 61cm x 5cm.

Catchment and tank material

Concrete blocks or clay bricks are recommended for the construction of catchment walls. For the blocks, the nominal mix ratio of cement, sand and ballast is 1;3:6 respectively. Where there is a wall of 1.5m height, a foundation strip is essential to avoid any uneven settlement of the wall in areas with light soils.

Materials required for the construction of tank walls and foundation strips for various tank sizes are presented in Table 4. Roofing of the tank with corrugated iron sheets is recommended to prevent exposure of stored water to any pollutants (Fig. 6).

Table 1. Mean monthly and annual rainfall at representative stations, Lamu

Station and Period	*Mean monthly rainfall (mm)*												*Mean annual rainfall (mm)*
	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	
Lamu (1906-1980)	5	3	24	138	336	155	70	40	41	40	37	28	917
Kiunga (1937-1980)	0	0	6	79	204	121	61	21	24	37	17	7	577
Mpeketoni (1972-1980)	26	4	43	117	327	171	158	67	31	47	75	68	1134
Witu (1931-1980)	29	10	37	131	290	146	86	54	60	63	97	98	1101
Mokowe (1955-1960)	7	8	17	118	245	125	61	22	20	11	50	28	712
Faza Islands (1952-1981)	4	1	13	104	226	126	84	32	39	32	32	14	707

Water quality

To improve the quality of stored water, it is important that sediment and trash accumulated from the induced catchment by runoff be prevented from entering the water storage tank. Besides, the water in storage has to be treated. The sediment and trash can be removed by using a silt trap placed before water is allowed into the storage tank. This is followed by a screening mechanism (wire mesh) at the outlet to remove the trash and other pollutants like dead insects. The silt trap also reduces the velocity of water flow which is usually very high in very intense rainstorms.

Stored water can habour pathogenic organisms which are harmful to human health. The chemical method often used to help get rid of these organisms is the addition of chlorine in correct concentrations. Physical methods of getting rid of pathogenic organisms are boiling and filtration. Often filtration is done by gravity using sand (Fig. 8) or other substrates.

The chemical method involves the addition of a dose of chlorine (bleaching powder) to the water. The amount depends on the quality of the water. Usually bleaching powder is added in solution with 2.5%, or maximum 5%, by weight of active chlorine. For stored water, the dose has to be within certain limits, therefore it is important that one member of the community be charged with the responsibility of adding the chlorine. A reasonably good dosing method for continuous disinfection for stored water is the pot chlorinator (Fig. 9). It is made from a porous clay pot filled with a mixture of chlorine and coarse sand at a ratio of 1:1 to 1:2 on a weight basis (Pieck, 1985).

Table 2. Computed relationships of population, tank storage capacity and induced catchment area to wettest months' rainfall (Choge, 1991)

No. of people	*Tank size (m^3)*	*Induced catchment area (m^2) for wettest months rainfall*									
		450mm	*500mm*	*550mm*	*600mm*	*650mm*	*700mm*	*750mm*	*800mm*	*850mm*	*900mm*
1	8.3	26.4	23.7	21.6	19.8	18.3	17.0	15.8	14.3	14.0	13.2
2	16.6	52.7	47.5	43.2	39.6	36.5	33.9	31.6	29.7	27.9	26.4
3	24.9	79.1	71.2	64.7	59.3	54.3	50.8	47.5	44.5	41.9	39.6
4	33.2	105.4	94.9	86.3	79.1	73.0	67.8	63.3	59.3	55.8	52.7
5	41.5	131.8	118.6	107.8	98.8	91.2	84.7	79.1	74.1	69.8	65.9
6	49.8	158.1	142.3	129.4	118.6	109.5	101.7	94.9	89.0	83.7	79.1
7	58.1	184.5	166.0	150.9	138.4	127.7	118.6	110.7	103.8	97.7	92.3
8	66.4	210.8	190.0	172.5	158.1	146.0	135.6	126.5	118.6	111.6	105.4
9	74.7	237.2	213.5	194.0	177.9	164.2	152.5	142.3	133.4	125.6	118.6
10	83.0	263.5	237.2	215.6	197.7	182.5	169.4	158.1	148.2	139.5	131.8
11	91.3	289.9	260.9	237.2	217.4	200.7	186.4	173.9	163.0	153.5	145.0
12	99.6	316.2	284.6	258.7	237.2	218.9	203.3	189.7	177.9	167.4	158.1
13	107.9	342.6	308.3	280.3	256.9	237.2	220.2	205.6	192.7	181.4	171.3
14	116.2	368.9	332.0	301.9	276.7	255.4	237.2	221.3	207.5	195.3	184.5
15	124.5	395.3	355.7	323.4	296.5	273.7	254.1	237.2	222.4	209.3	197.6
16	132.8	421.6	379.5	345.0	316.2	291.9	271.1	253.0	237.2	223.2	210.8
17	141.1	448.0	403.2	366.5	336.0	310.1	288.0	268.8	252.0	237.2	224.0
18	149.4	473.3	427.0	388.1	355.8	328.4	304.9	284.6	266.8	251.1	237.2
19	157.7	500.7	450.6	409.6	375.5	346.6	321.9	300.4	281.6	265.0	250.3
20	166.0	527.0	474.3	431.2	395.3	365.0	338.8	316.2	296.5	279.0	263.5
21	174.3	553.4	498.0	452.7	415.0	383.1	355.8	332.0	311.3	293.0	276.7
22	182.6	579.7	521.7	474.3	434.8	401.3	372.7	347.8	326.1	306.9	290.0
23	190.9	606.0	545.4	495.8	454.5	419.6	389.6	363.7	340.9	320.9	303.0
24	199.2	632.4	569.1	517.4	474.3	437.8	406.6	379.5	355.7	334.7	316.2
25	207.5	658.8	592.9	539.0	494.0	456.1	423.5	395.3	370.6	348.8	329.4
26	215.8	685.1	616.6	560.5	513.8	474.3	440.8	411.0	385.4	362.7	342.4
27	224.1	711.5	640.3	582.1	533.6	492.6	457.4	426.9	400.0	376.7	355.7
30	249.0	790.5	711.4	646.8	592.9	547.3	508.2	474.3	444.6	418.5	395.4

Table 3. Catchment size and construction materials for walls and foundation strip (Choge, 1991).

	Catchment size (m^2)					
	50	100	150	225	300	400
Cement (bags)	31	41	51	61	71	81
Sand (tonnes)	4.99	6.62	8.25	9.88	11.52	13.15
Aggregate (tonnes)	11.02	14.62	18.22	21.82	25.42	29.02

Table 4. Materials required for tank walls and foundation strip for various tank sizes (Choge, 1991)

	Tank capacity (m^3) and cross-sectional area (m^2)			
	80, 27	100, 234	120, 40	150, 50
Concrete (m^3)	19.83	22.03	23.87	26.81
Cement (bags)	90	100	106	121
Sand (tonnes)	14.38	15.97	17.31	19.44
Aggregate (tonnes)	15.85	17.62	19.10	21.45

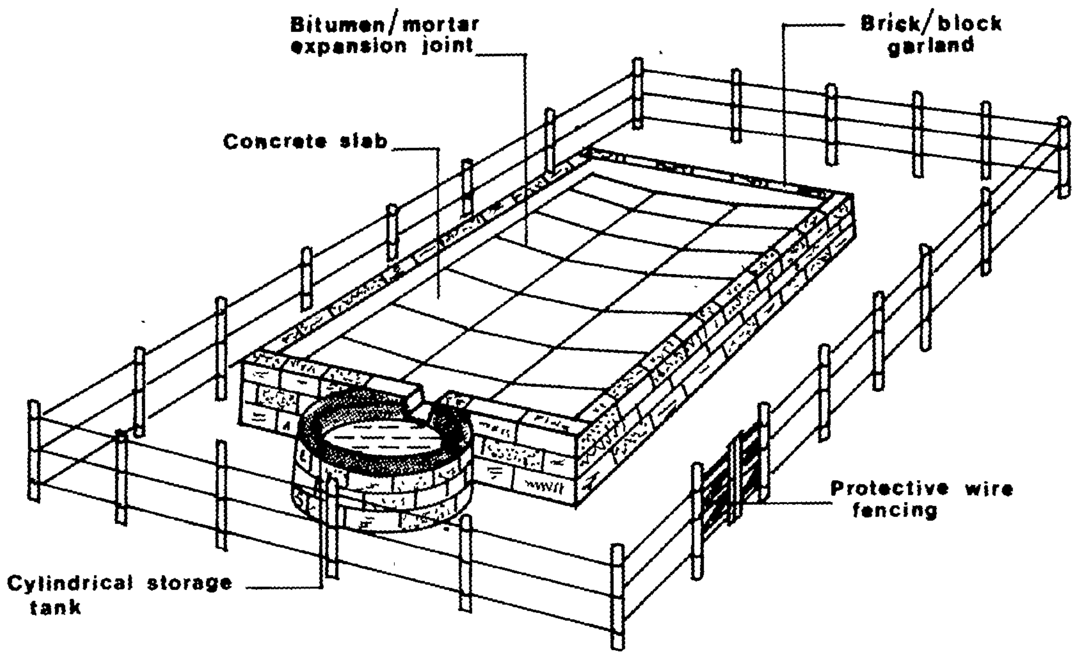

Figure 5. Improved design of 'djabias' including expansion joints and protective fencing (Choge, 1991).

CONCLUSION

The tank sizes and catchment areas considered in this analysis were 80m^3, 100m^3, 120m^3, 150m^3 and 50m^2, 100m^2, 150m^2, 300m^2 and 400m^2 respectively. A 100m^3 tank can comfortably serve between 12 and 17 people. This tank size requires a catchment area of 316m^2 in an area with wet season rainfall of 450mm and 158m^2 where the rainfall is 900mm. The amount of water required by each person throughout the dry season is about 5000 litres, based on a *per capita* consumption rate of 20 litres per day. Storage capacity increases to about 6000 litres when a water loss allowance of 20% is included.

From the foregoing analysis, *djabias*, when well designed (for an appropriate number of people) and constructed, can provide adequate water supply for drinking and cooking purposes throughout a dry season.

Therefore the local communities in Lamu should be encouraged to incorporate the suggested modifications when constructing new *djabias*. This would ensure that there is adequate water supply for the intended use.

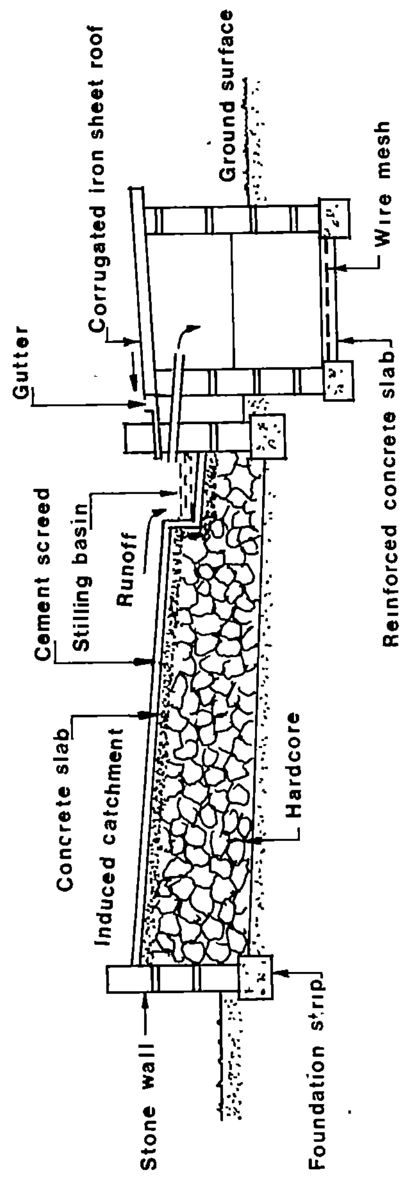

Figure 6. Cross-sectional view of 'djabia' showing construction materials (Choge, 1991).

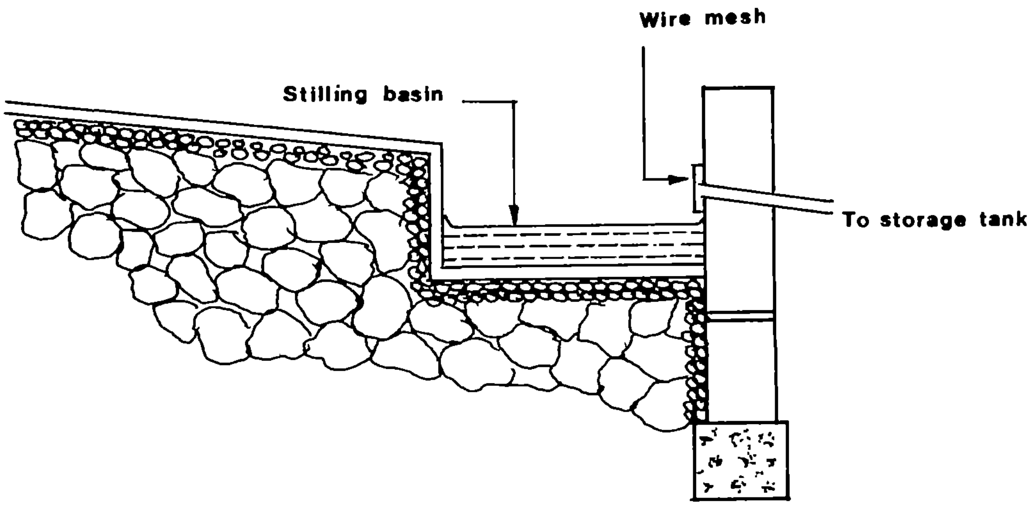

Figure 7. Sediment and trash removing mechanism (Choge, 1991).

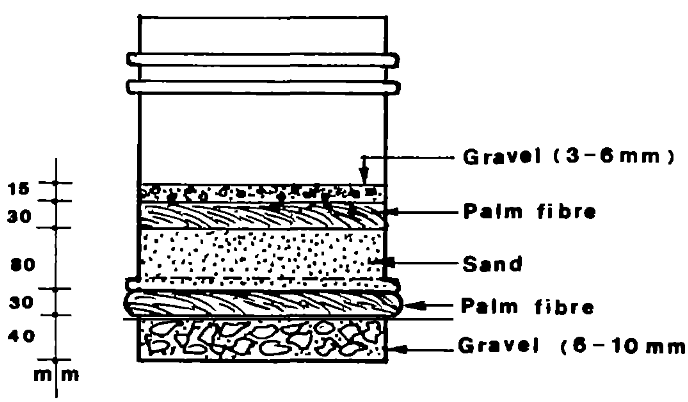

Figure 8. Gravity filtration using sand (Pieck, 1985).

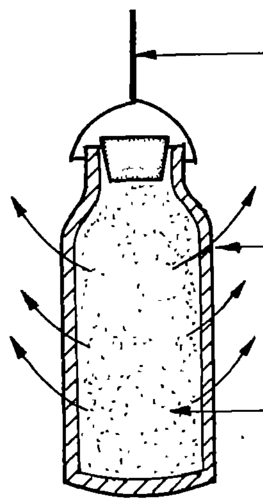

Figure 9. Suspended pot chlorinator (Pieck, 1985).

REFERENCES

Biamah, E.K. (1990). Soil Conservation, Water Harvesting, and Small-Scale Irrigation for the Kenya Coast ASAL Project Areas.

Choge, J.K. (1991). Optimal Design of a *Djabia*. Undergraduate Project Report, Dept. of Agricultural Engineering, University of Nairobi.

GOK, (1978). *Rainfall Frequency Atlas of Kenya.* Ministry of Water Development, Nairobi, Kenya.

GOK, (1982). *Lamu District Planning Study Report*, Vol.2. Mwenge International Associates, Nairobi, Kenya.

GOK, (1983). *Lake Kenyatta Water Supply Project: Preliminary Design Report.* Ministry of Water Development, Nairobi, Kenya.

GOK, (1988). *Water Resources Reconnaissance Study in Lamu District* Ministry of Water Development, Nairobi, Kenya.

Pieck, C. (1985). Catchment and Storage of Rainwater. *Technical Development with Developing Countries.* Tool Foundation, Amsterdam, The Netherlands.

UNEP, (1983). *Rain and Storm Water Harvesting in Rural Areas.* Tycooly International Publishing Limited, Dublin, Ireland.

RAINWATER CISTERNS FOR RURAL COMMUNITIES IN THE BRAZILIAN SEMI-ARID TROPICS

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ABSTRACT

Access to and use of rainwater in the Brazilian semi-arid tropics is complicated by climate (long dry season), social and political factors (dependency and exploitation), leading in many cases to rural exodus. But rainwater storage is feasible as a result of sufficient annual rainfall (about 500mm).

IRPAA trains grass-root technicians entrusted with developing low-cost solutions to water problems in local communities, and works especially on the improvement of hand-dug rock cisterns and the construction of lime-mortar and brick cisterns up to 40,000 litres. This paper deals with construction technology with lime-mortar, measuring, digging, building, plastering and covering of this type of cistern.

INTRODUCTION

Brazil is a big country with a surface of 8,511,965 km^2 and 155 million people. There are several different types of climate and vegetation. About 12% of Brazil's surface is semi-arid land.

The semi-arid region, mostly covered with tree and shrub vegetation called *caatinga* is located in the northeast of Brazil, an area of nearly one million square kilometres (twice the area of Kenya) and a population of 17 million.

Annual rainfall is below 1000mm with less than 650mm in the central part of the semi-arid region, where there are sometimes (every 10-15 years) years with only 200mm rainfall (as in 1993). This region is subject to irregular rainfall with great variations both within and between seasons. Even in seasons of good rainfall there are prolonged droughts, which make crop production very risky. Potential evaporation is above 2000mm. For these reasons the region is called "the polygon of droughts".

The semi-arid region has been inhabited for at least 50,000 years. From the 16th to the 19th centry it was exploited for slave-labour based sugarcane production and large-scale cattle-breeding. Today the government focusses upon big irrigation projects on the Sao Francisco River, where the local people are employed as day laborers. The peasants in the semi-arid region frequently farm in a way not adapted to the climate, especially to the annual dry season. Moreover the people suffer from social and political dependence and exploitation; as a consequence there is an exodus from rural to urban areas.

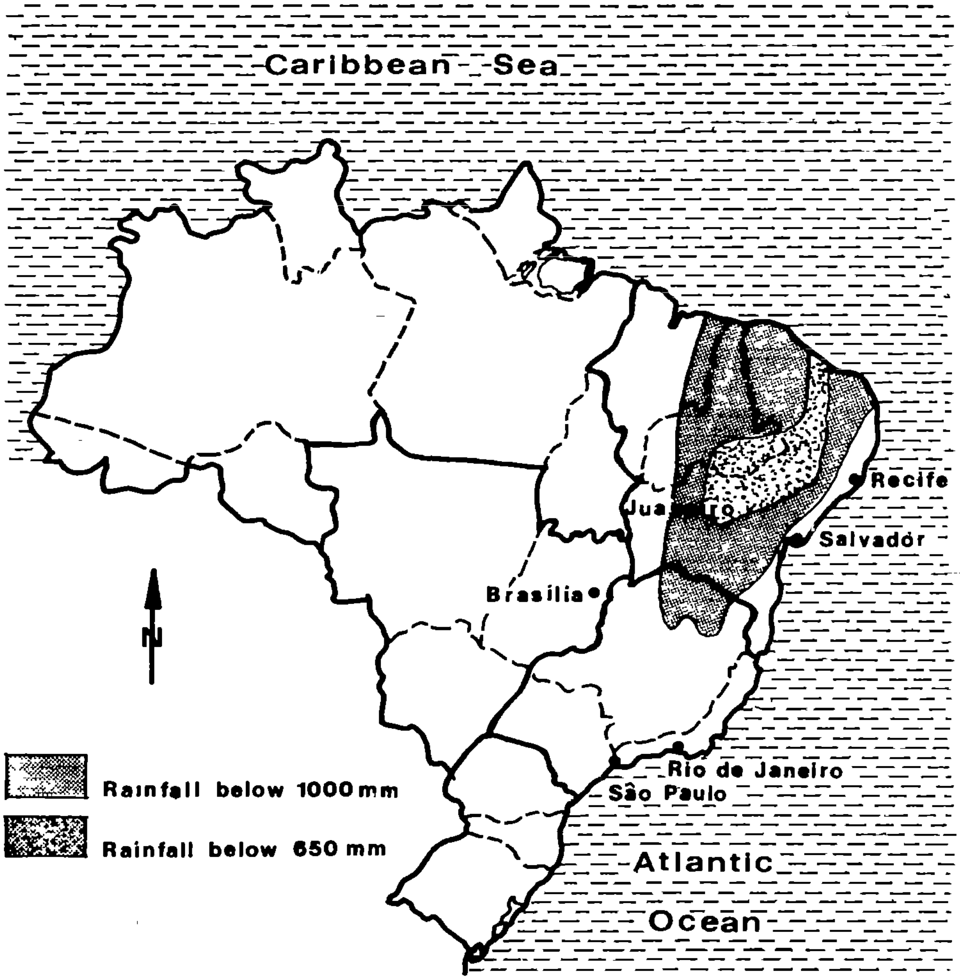

Figure 1. Map of the semi-arid land in northeast Brazil. Hatched: rainfall below 1000mm; cross-hatched: rainfall below 650 mm.

THE REGIONAL INSTITUTE FOR SMALL-SCALE APPROPRIATE AGRICULTURE (IRPAA)

We work at the Regional Institute for Small-scale Appropriate Agriculture (IRPAA), a non-governmental organization with its headquarters in Juazeiro, Bahia, in the centre of the Brazilian semi-arid region. Our strategy is to promote the understanding of Brazil's northeast not as a disaster area as it is usually described - but as a viable land on which to live and work using the existing rainfall and ground water and other natural resources in a sustainable way.

We deal with three areas of interest to the peasants:

1. How to conserve water and what must be done to have water during the 6-8 months long dry season;
2. How to raise small farm animals, especially goats well-adapted to semi-arid and *caatinga*-vegetation, and how to feed them thoroughout the dry season;
3. How to plant and harvest crops appropriate to the dry climate.

Our principal concern is in sharing the knowledge that the peasants need to transform existing conditions. We work with Christian communities, peasant associations and rural workers' unions, all of which send members to our seminars and subsequently try to share their acquired knowledge with their colleagues at home. We also have seminars for decision-makers like fieldworkers, technicians, community educators, church people, etc.

In the long term we hope that this work will help change the unjust social structures by showing peasants the possibility of a secure life on the land.

WATER CONSERVATION FOR THE DRY SEASON

Especially in the case of water conservation IRPAA tries to lead peasants to an appropriate understanding of the climate, rainfall, drought, the provisions that can be made to prevent drought disasters, the occurrence of ground water in the subsoil, etc. IRPAA teaches practical ways (construction of cisterns, shallow wells, small dams, modified ponds, hand-augered boreholes, etc.) to resolve the problems of water shortage.

We understand that the water problem has to be managed in three directions. It is necessary to have:

1. Drinking water for every family;
2. Community water for washing, bathing and for animals;
3. Emergency water for drought years.

Rainwater storage in the northeast of Brazil is feasible as a result of normally sufficient annual rainfall. Traditional ways of storage are clay-pits, pot-holes and hand-dug rock cisterns.

In some areas, e.g. at Pintadas, Bahia, there exist 15,000-50,000 litre cisterns made of cement plates and wire (comparable to reinforced concrete cisterns in Africa). The technical know-how probably came from local bricklayers who built this type of cistern in São Paulo, where they worked during the dry seasons. Certainly these cement cisterns would be a good solution for a government-subsidized programme to resolve the water supply of families in rural areas; they can be constructed rapidly, are waterproof and the water is of good quality. The problem is that the Brazilian government is not interested and the people don't have the money to build them.

The government-run Agricultural Research Centre of the Semi-arid Tropics (CPATSA) at Petrolina, Pernambuco, did some interesting experiments with different types of truncate pyramidal rural cisterns made of PVC sheets, bricks, polythylene and cement (Silva, Brito and Rocha, 1988). But unfortunately these experiments were not shared with the rural population by the government rural extension service.

Using cisterns to collect rainwater from the roofs of houses or from ground areas is probably the most viable option to provide drinking water for families in rural areas. For these reasons IRPAA works on improving hand-dug rock cisterns and constructed brick and lime-mortar cisterns up to 40,000 litres.

HAND-DUG ROCK-CISTERNS ("CAXLOS")

In some parts of the central northeast region (like Casa Nova, Bahia; Remanso, Bahia and Petrolina, Pernambuco), there is a subsoil of micaceous rock, and it is possible to dig into this rock with mattocks and pickaxes because the degree of hardness micas is only number 2. During the big drought of 1981-83 the peasants of Casa Nova remembered that in former times the people dug *caxios* to collect rainwater. *Caxios* are deep rectangular holes dug vertically into this micaceous rock, which receive rainwater from a nearby ground catchment area. The measurements are 3m x 6m and 3-4m deep, or bigger. Often two *caxios* are dug together, one for drinking water and the other for water for the animals. Frequently the *caxio* is protected by a wooden fence.

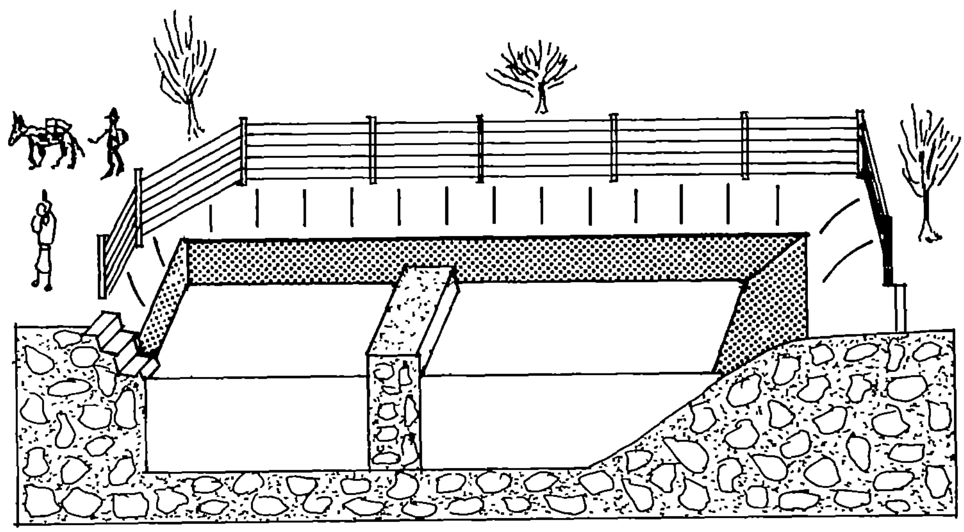

Figure 2. Hand-dug rock cistern ("caxio").

The advantages of this type of rainwater collection system are:

- The *caxio* is an invention of the local rural people and the construction can be organized totally by rural communities;
- It is labour-intensive, but not cost-intensive to construct (only digging equipment must be bought);
- The evaporation rate is low because of the 4m depth and the vertical walls;
- Even in the current drought year of 1993, with only 200mm rainfall the *caxios* are full of water, and there is no water shortage for people or animals.

The only disadvantage is that the occurrence of this type of rock is limited. But there are places with micaceous subsoil in northeast Brazil, where this system of water-harvesting has not yet been adopted.

BRICK AND LIME-MORTAR CISTERNS

IRPAA has reinvented a technique for making cisterns from bricks and lime-mortar, a technique that was introduced by the Portugese and commonly used until 30 or 40 years ago, when lime was replaced by cement.

The brick and lime-mortar cistern is a cylindrical underground tank with a hemispherical bottom (Gnadlinger, 1993). The cistern has the shape of the "thick half" of an eggshell; it is important to dig it in this shape at once to facilitate the construction of the wall. A plummet is recommended when the cylindrical part of the hole is dug.

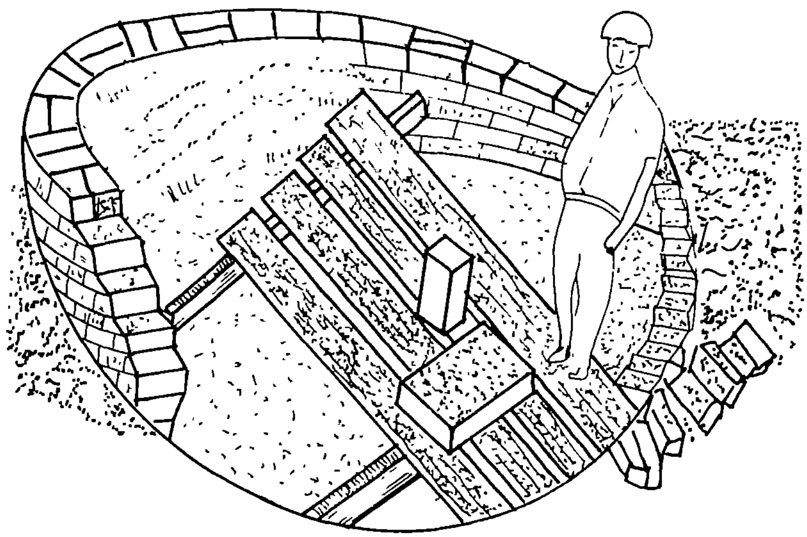

Figure 3. Lime-mortar and brick cistern under construction.

The size of the cistern is adapted to the drinking water requirement of each family, i.e. 14 litres of water per person a day (Silva *et al*, 1988), or 3360 litres per person in the 8 month long dry season. For example a family of seven needs 23,720 litres of water (3360 x 7 = 23,720). It is necessay to calculate the probable rainfall on the roof too. The construction materials are burnt loam bricks (20cm x 10cm x 5cm) mostly fabricated in rural communities, and lime-mortar.

The advantages of using lime instead of cement

Some advantages of lime compared with cement (Intermediate Technology Group, 1991) are:

- Lime as building material needs less energy to produce than cement.
- Lime is made and sold by small rural communities, and not by international concerns as cement is.
- lime is cheaper to buy than cement.
- Using lime you dispense with steel and wire which are expensive.

- Lime-mortar dries slower than cement-mortar. For this reason it is not necessary to hurry during the construction of a cistern.
- Lime is more elastic and does not crack so easily as cement.
- It is easier to repair a lime cistern than a cement cistern.
- Using lime, local communities can assume construction and maintenance.

It may be argued that a disadvantage of lime is that it is a more labour-intensive technique, but on the other hand it can improve the employment situation for the rural population in the dry season.

How to work with lime

In this region old bricklayers still know how to work with lime and in some regions of the northeast limestone is still burnt in community-owned limekilns; lime powder is available almost everywhere.

For cisterns this lime powder is mixed with well graded angular sand; three 18-litre cans of sand with one 18-litre can of lime powder (sand to lime ratio of 3:1). It is necessary to sift both lime powder and sand before mixing them; then add some water to make the mortar. This has to be "beaten" with a wooden stick for 30 minutes. The mortar is then mixed again. This process has to be repeated three times to dissolve small lime lumps in the mortar. The mortar has to "rest" for at least 3 days before it is used.

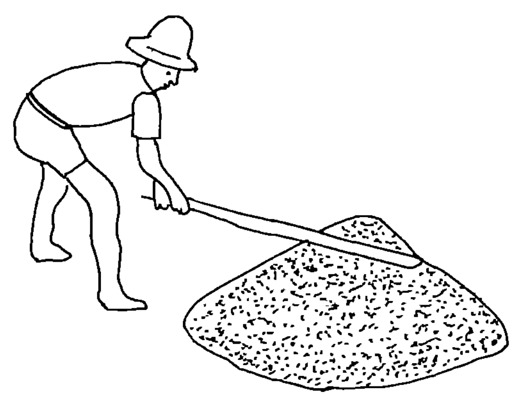

Figure 4. "Beating" the lime-mortar.

To build a brick and lime-mortar cistern, you must first dig the eggshell-shaped hole according to the size of cistern required (Table 1). The cistern wall should be 20cm thick, and construction must begin in the middle of the bottom, placing the bricks standing (the bricks follow the curve of the bottom). When you come to the cylindrical part of the cistern, the bricks in one row are placed lengthwise and in the next row crosswise, leaning them against the soil; only in this way is the wall able to support the weight of the water. For this reason too the wall should not be more than 0.5m above the ground. Don't use a plummet (as in cement constructions). When construction is finished you must wait 6 weeks for drying before you can plaster it.

This method is the traditional Brazilian way to work with lime and it is relatively easy to learn. It is rather labour-intensive, but in the dry season unemployed peasants are available. An advantage for a semi-arid region is that very little water is needed.

We also used a second method of working with lime - a method used in Europe (Warth, 1903, Induni, 1988). It is less labour-intensive, but it requires more water. You need quick lime, which is burnt in some rural communities, and you must slake it. Lime is slaked in an empty metal oil barrel and then run through a sieve (to remove unslaked lumps) into a pit or tank, where it is allowed to settle and to slake fully for at least 4 weeks. Slaked lime will keep indefinitely if kept covered with water, so it is important not to let it dry out.

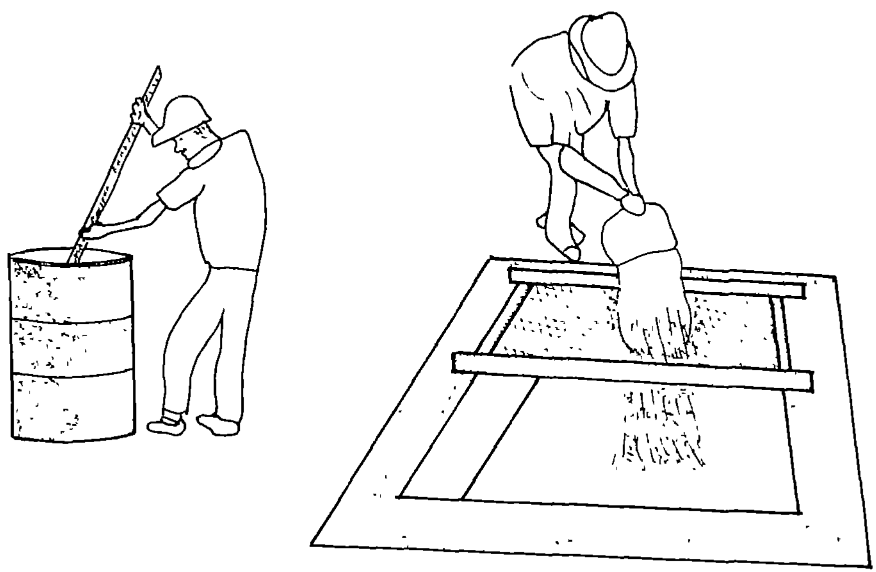

Figure 5. Slaking quick lime and sifting slaked lime through a sieve for settling in a tank

After 4 weeks you can use the slaked lime for building cisterns. You can make the mortar with a sand to lime ratio of 4:1 and use it as in the first method. If there are still any lumps in the slaked lime, we recommend that the mortar should be "beaten" at least once.

Plastering the cistern from inside

The lime-mortar and brick cisterns have to hold water, so care is necessary when you plaster the tank on the inside. In former times in Brazil whale oil was used to waterproof lime constructions (Santiago, 1992). In place of whale oil we experimented with many different types of plant oil and found that soybean oil holds water very well because it becomes a resin. First the plaster mortar is made in the same way as the mortar for the wall (sand to lime ratio of 3:1 or 4:1), but after resting for 3 days, you have to add 4% cement and 1% soybean oil to prepare the mortar for plastering. Three 0.5 cm thick layers of plaster are applied, one on top of the other.

Another way of waterproofing the cistern is to paint the plastered wall three times with soybean oil. It is necessary to wait at least 3 months before putting in any water. In this time the soybean oil paint becomes a waterproof resin.

Covering the cistern

The cistern can be covered with a low roofhouse; the walls are made of lime-mortar and bricks and the roof with laths and tiles. The advantage of this cover is that you can harvest the rainwater from this single pitch roof in addition to that harvested from the dwelling house.

Some peasants with enough wood at their disposal cover the cisterns with timber boards.

The gutters and downpipes that channel the rainwater from the cistern roof are made from PVC tubes or zinc sheets, but sometimes gutters are made of sisal stems, palm trees or even tin-cans.

Achievements

We know that the construction of brick and lime-mortar cisterns is a long-term programme. We have covered this type of cistern in all our water harvesting seminars and there is an increasing awareness of the possibilities of rainwater collection among the participants who are selected by the communities. These people become grassroots technicians entrusted with developing this solution to water problems in their local communities.

The brick and lime-mortar cisterns are well accepted, because the technical know-how can be managed by the rural people and a large part of the building materials are available in the rural area too. There is good participation of community members in obtaining construction materials and in labour, so financial resources from outside the community are reduced. There are already some Christian communities constructing lime-mortar and brick cisterns, and we are organizing a workshop for brick and lime-mortar cisterns in a rural workers' labour union.

REFERENCES

Gnadlinger, J. (1993). Redescobrindo o cal para construir cisternas. Jauzeiro, Brazil.

Induni, B. and **Induni I.**, (1990). *Using Lime*, Somerset, U.K Intermediate Technology Group (1991). *Low-cost Cements*, No. 1. Rugby, UK.

Santiago, C.C. and **de Oliveira, M.M.**, (1992). Organic Additives in Brazilian Lime Mortars. *Lime and Other Alternative Cements*, Ed. by N. Hill *et al*, pp. 203-210, London.

Silva, A. de S., Brito, L. T. de L. and **Rocha, H. M.**, (1988). *Captacão e conservacão de ãgua de chuva no semi-ãrido brasileiro*. CPATSA, Petrolina, Brazil.

Siroupulos, J. (1985). *Small-scale Production of Lime for Building*. Braunschweig, Germany.

Warth, O. (1903). Allgemeine Baukonstruktioslehre. *Die Konstruktionen in Stein.*, **1**, 446-453. Leipzig, Germany.

Table 1. The size of the cisterns and the necessary quantity of bricks and lime.

No. of persons per family	Water needed for 8 months dry season	Cistern		No.of bricks	Lime powder (18 l cans)	Quick lime (18 l cans)
		Width (m)	depth (m)			
3	10.080	3.20	2.60	3,500	55	16
4	13.440	3.40	2.80	4,200	70	21
5	16.800	3 80	2.90	5,000	87	26
6	20.160	4 10	3.00	6,000	107	31
7	23.520	4 20	3.20	7,000	122	36
8	26.880	4.60	3.30	8,000	140	42

Notes

1 All the numbers are approximate;

2. The measure of the width of the mouth and the depth indicates the size of the hole to dig;

3 The size of the bricks is 20cm x 10cm x 5cm If you use bricks of 20cm x 10cm x 4cm, the quantity of bricks will increase 20% The bricks area normally produced in the rural areas,

4. You have the choice, to use either lime powder or quick lime;

5. It is interesting to make a price comparison (values from 15 January 1993 at Juazeiro), for a cistern of 20,000 litres you need:
either 31 cans of quick lime at Cr$ 12,000 each. That is Cr$ 336,000 or US$ 28.61,
or 105 cans of lime powder at Cr$ 5,000 each That is Cr$ 525,000 or US$ 40.38,
or 18 bags of cement at Cr$ 85,000 each. That is Cr$ 1,530,000 or US$ 117.96

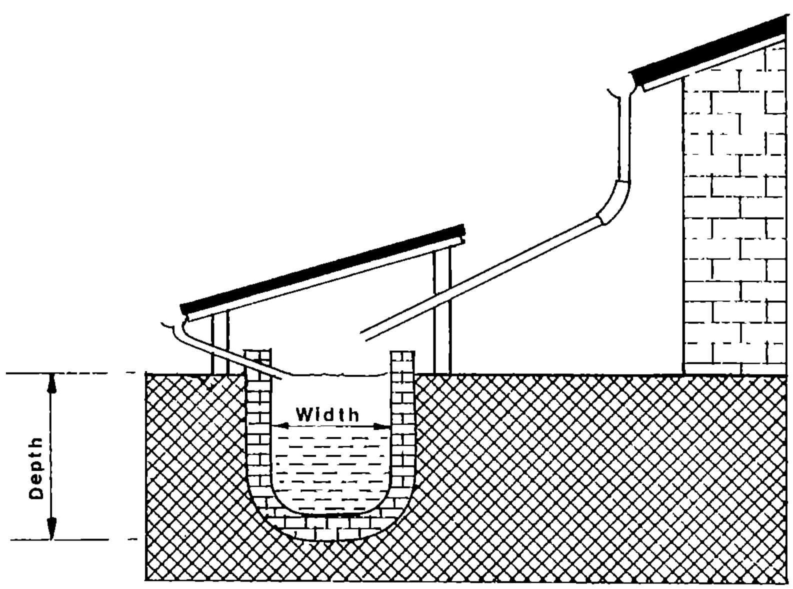

Figure 6. Side view of a lime-mortar and brick cistern with roof-house.

INGENIOUS SYSTEMS OF WATER HARVESTING IN THE M'ZAB REGION OF ALGERIA

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ABSTRACT

The oases of M'Zab, located in the centre of the Algerian Sahara and situated 600km south of Algiers, are in a desert climate zone. For several centuries they have been an example of ingenuity in water management.

In a small plain (20km long and 2km wide) Mozabite people obtain surface water by a system of deduction damming upstream and retention damming downstream. They also obtain underground water by digging wells called *tirest* which are surrounded by prohibited areas called *harim*. In these ways they irrigate the palm groves creating real garden villages and prosperous agriculture.

Over several centuries the Mozabites have developed a series of techniques for domestic water management: collection of rainwater from sloping roofs by means of a channel called *soufir*, water storage and water supply.

The various steps from water harvesting to its utilization by Mozabites is described, stressing the special aspects of conservation and the ingenuity of these populations.

INTRODUCTION

In Algeria's Mozabit district located 600km south of Algiers (latitude 32°-33° 2') there are calcareous rock formations with a north-south orientation which extend to the Tadmait tableland where they promote an underground watertable. The eastern side (Ghir valley) is famous for water wells, while the Saoura (Gourara, Touat and Tidikelt valleys) in the west, is noted for *foggara* (underground conduits) (Damerdji, 1990).

During the 11th century, Ibadite people left the northern towns (Sedrata and Tihert) to settle in the centre of the Algerian Sahara, in a region called *Chebka* (comprised of a set of conical hills, summits and ravines) which were inhospitable and unsuitable for life or human settlement (SNED, 1970).

El Ateuf (1011), Bon Noura (1048), Ghardaia (1053), Melika (1124) and Benisguen (1347) were settled according to a specific and rational plan. During the 17th century, Guerraza (1630) and Bezziane (1679) joined this association of settlements (d'Armagnac, 1934). Because of the arid climate (50-100mm rainfall per annum) Mozabites have been ingenious and active in water management.

In the very dry regions storms may occur suddenly and following the main flow some water remains in *gueltas* or *ghdirs* in the bed of the water course (*owed*). If improved, those water pockets retain water for a long time. These cisterns are used to water cattle: they are inadequate for any kind of irrigation but are useful for pastoralists and nomads.

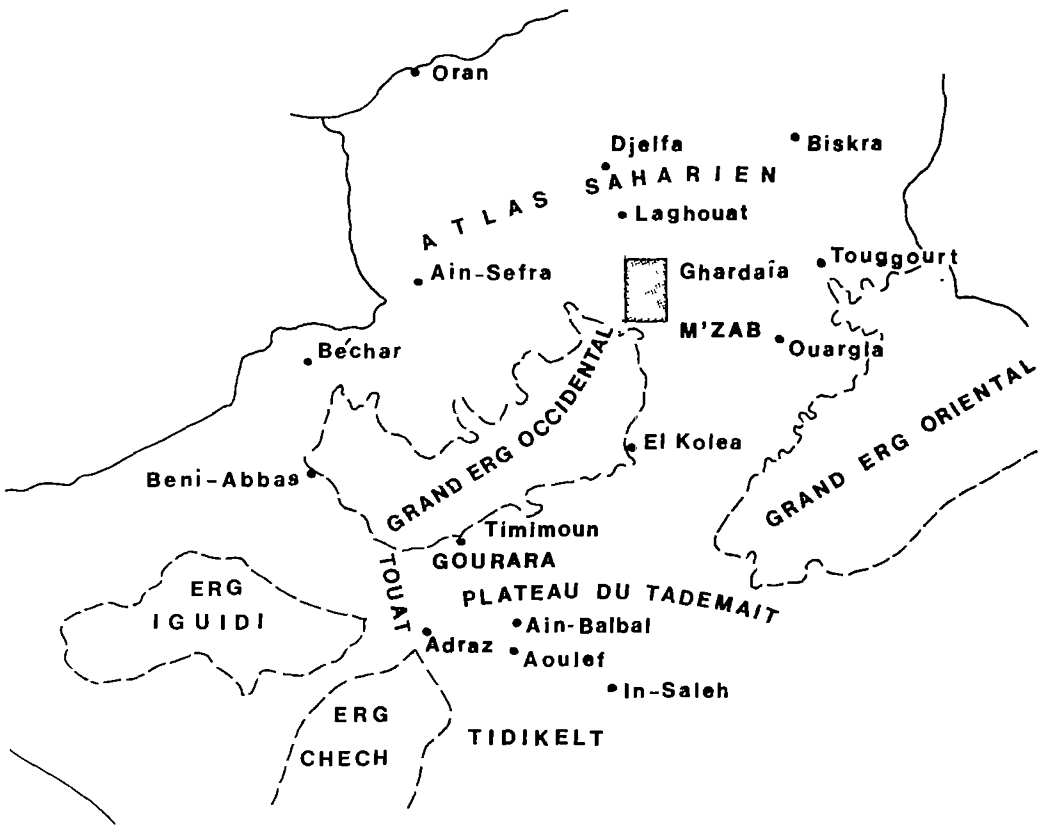

Figure 1. The Mozabit district.

Mozabites have, however, built dams (*es-seed*) in a valley (around 20km long and 2km wide and installed storage to retain floods and to provide large quantities of water in order to facilitate cultivation, town planning and settlement.

Dams are built using *mollous* and *timchent* the country's ochre -coloured or nearly pink plaster. The dam spillway conveys the flood flow water towards gardens, hence through holes in the walls of each garden which regulate its ration of water.

The dam allows water to spread over the whole width of the bed of the watercourse, which enhances infiltration to replenish the underground water table.

The dyke is constructed with an arcade bridge as an overflow (Saidi, 1983). Towers are constructed along the valley to enable supervisors, using a smoke code, to control the flood movement. Following their instructions, operators arrange for people to benefit from the flood (Benyoussef, 1988).

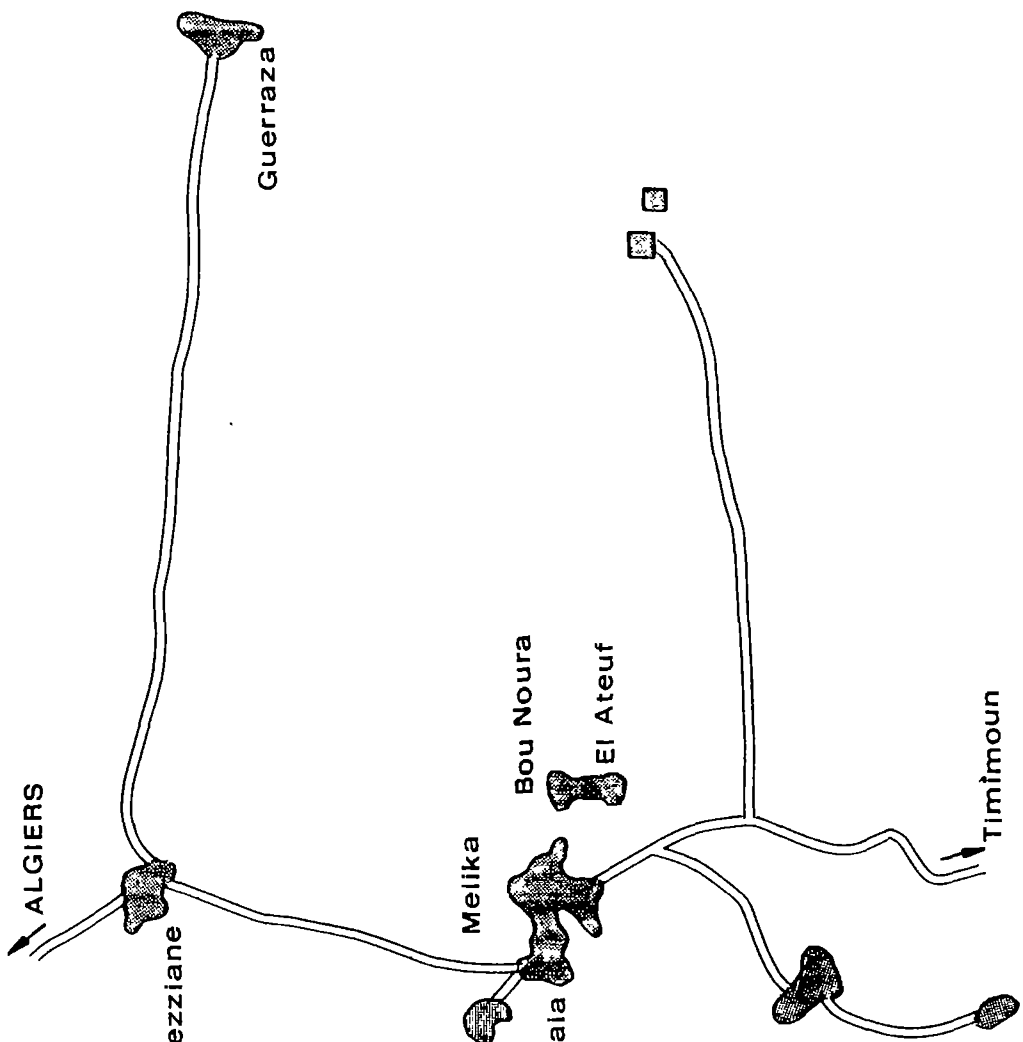

Figure 2. Detail of the Chebka region.

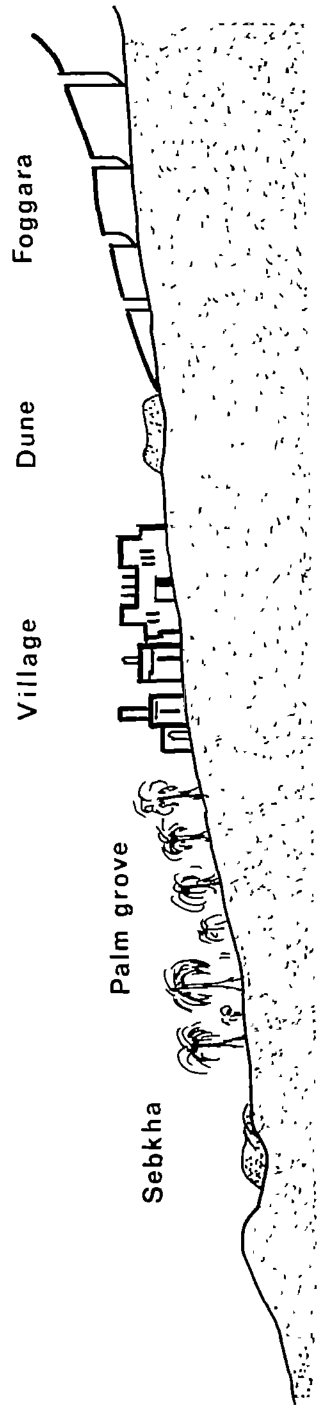

Figure 3. Section of the Oasis with 'foggara'.

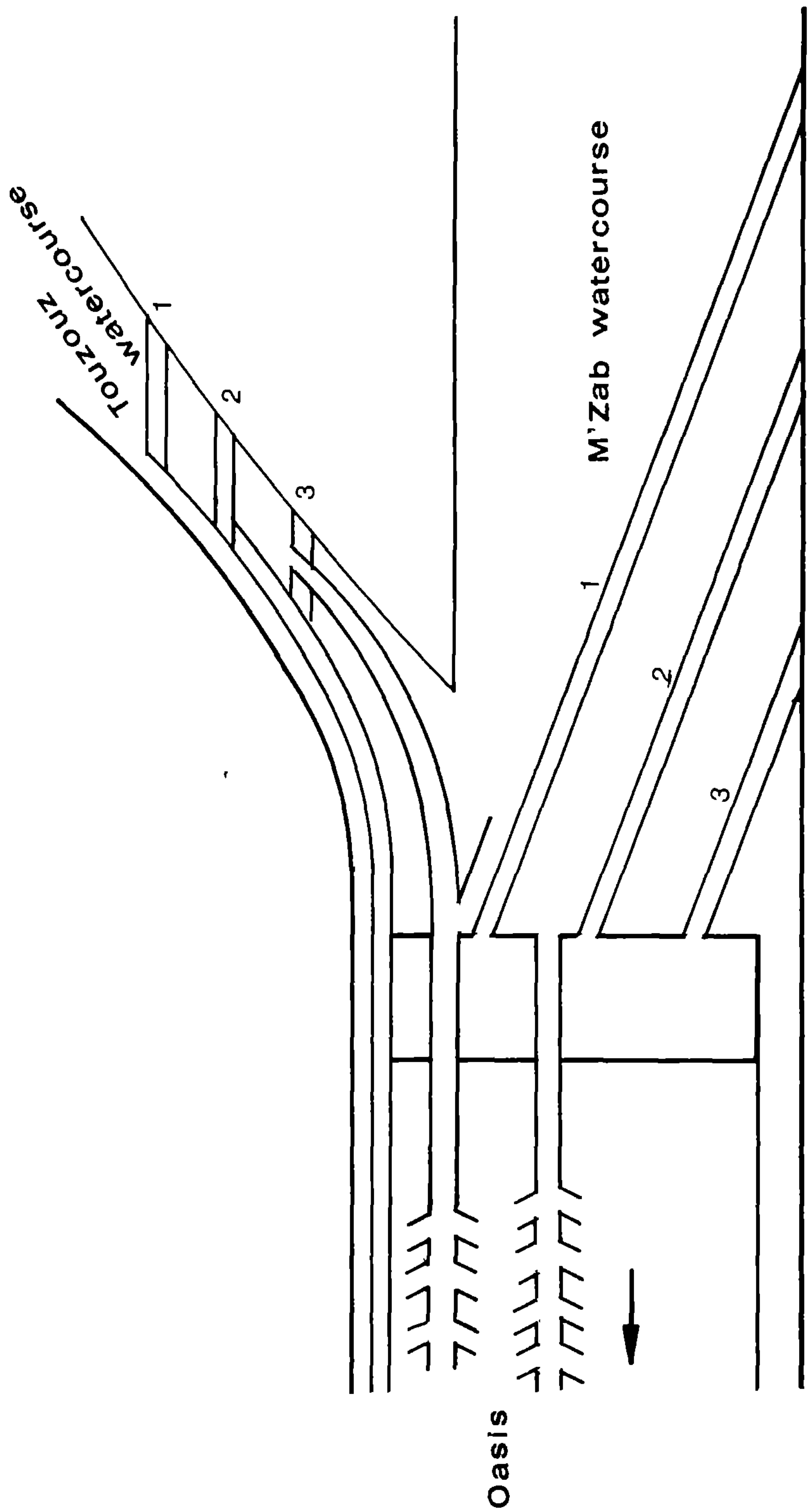

Figure 4. A deduction dam.

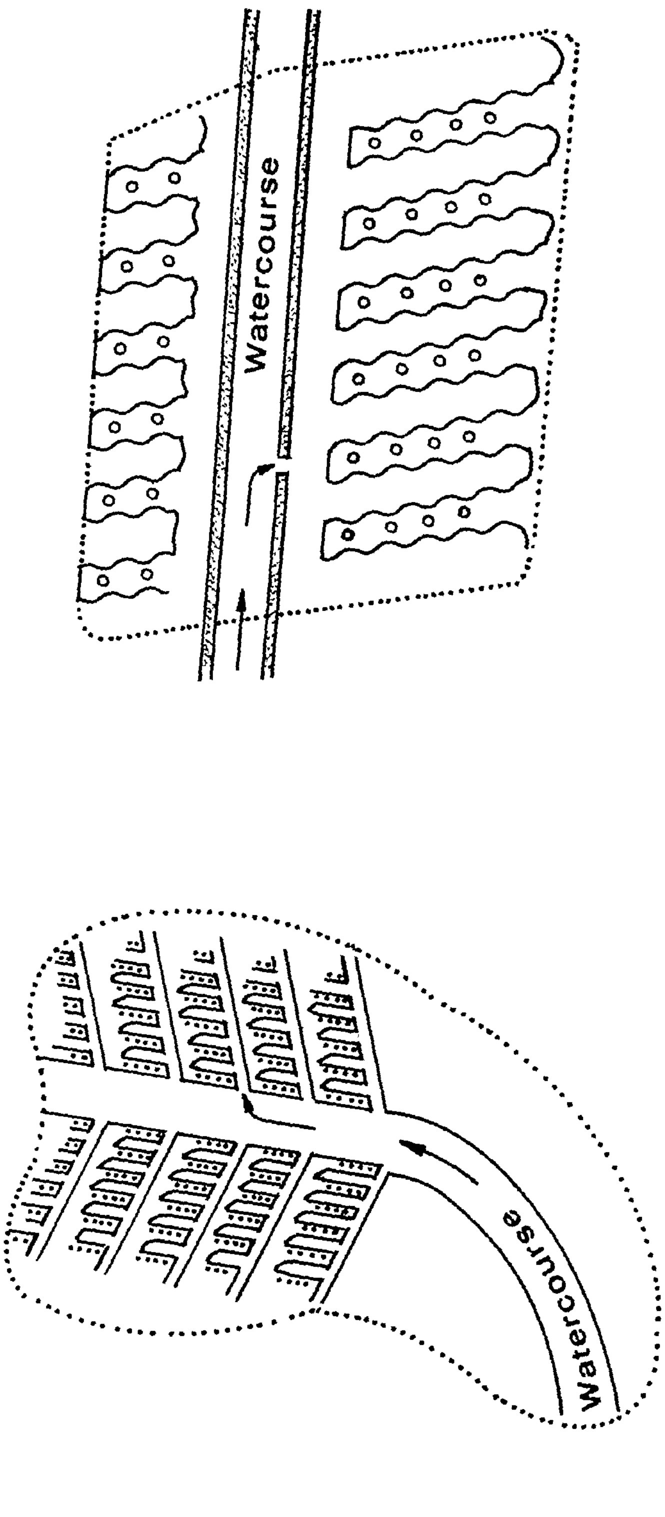

Figure 5. Flood water storage with the M'Zab.

As a result the flood is controlled and fairly distributed.

In the M'Zab region the well is called *Khetazza* or *Tirest.* It is dug from 20m to 60m deep and lined with stones and equipped with a pulley. Each quarter owns a well, the most important one being owned by the mosque, located in the town centre. The well is a public utility. Drawing water is done either by a man raising it vertically, or by an animal moving horizontally in the palm grove. The first settlers introduced a prohibited area (*harim*) around the well to protect the structure and avoid it being over-used and drying up.

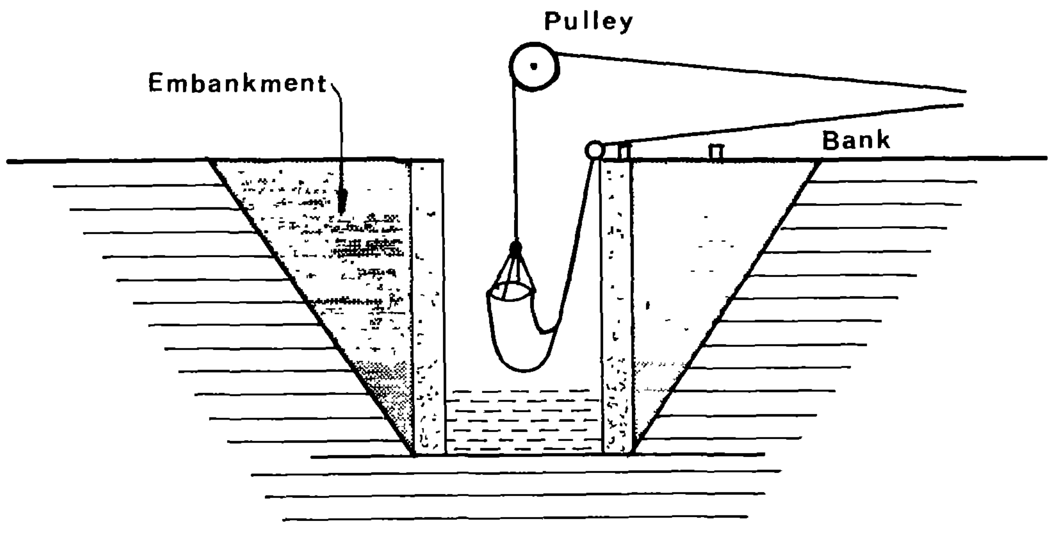

Figure 6. A well with pulley.

This practice shows an empirical, even scientific, awareness of hydrogeological laws (FAO, 1976). This ingenuity of the Mozabites has transformed the palm-groves into real gardens in the desert.

Under the palm trees (*Phoenix dactyliphena*) they cultivate fruit trees and vegetables. There is also a pavilion for relaxation. In the early morning, the women and children fetch and carry water from well to home to supply thier daily needs, while the men irrigate the palm grove. In the houses, water is stored in earthenware containers called *quacria* or *mehbes* kept in the kitchen.

The *guerba* is a water-skin µsed for preserving and cooling drinking water. The well water is briny (salt content around 2g/litre) but it is used for most domestic purposes while drinking water is brought from distant wells or springs.

The bathroom (*m'ghassel*) doesn't occupy more than $1m^2$. A vessel called *laprik*, designed to pour water with a very restricted flow is used for a shower bath so as not to waste water.

The flat roofs of the houses are built with a slope and are plastered to ensure they are waterproof. *Soufirs* or *spout* made of earthenware more than 40cm long, direct the rainwater through the front into jars called *tkhabit* standing below outside the house.

In conclusion, if present scientific knowledge to do with climatology, hydrology, hydrogeology, solar energy, sewage water treatment, desalinization and new materials (polymers etc.) were employed in harmony with ancient practice, significant progess could be achieved, provided, of course, the ecological impact on the environment is studied. Man cannot survive without the will to conquer and settle the desert (Damerdji, 1980's).

REFERENCES

d'Armagnac (1934). *Le M'Zab et les pays Chaamba.* Baconnier Algiers.

Benyoussef, B. (1988). Le M'Zab, vie quotidienne dans la vallee des cing cités jardins. *L'eau et le Maghreb: un apercu sur le present, l'heritage et l'avenir.* PNUD.

Damerdji, M.A. (1984). Peut-on creer de petites oasis? Seminaire sur l'utilization de l'energie Solaire ICTP Trieste, Italy.

Damerdji, M.A. (1990). La foggara. L'eau dans les oasis et les villages perchés de L'aire mediterraneanne: Rabat et oasis d'Er-rachidia. UNESCO - ONEP et IAU Hassan II, Rabat.

FAO, (1976). Le driot des eaux dans les pays musulman. ONU- FAO, Rome.

Saidi, A. (1983). Les systemes de captages traditionnels dans les oasis sahariennes. INRH, Algiers.

SNED (1970). *L'architecture algerienne.* "Art et culture" series. Ministerè de L'nformation.

SOCIO-ECONOMIC

OVERVIEW: SOCIO-ECONOMIC ASPECTS

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The experiences reviewed on the socio-economic aspects of rainwater catchment for this section, tend to focus on the following issues:

Community participation, and the promotion and support of local organizations

Community participation in planning, implementing and maintaining rainwater systems is essential to achieve their sustainable operation. Thus, participation is not seen just as the community contribution in cash and labour for project execution, but also as its involvement in decision making at the various phases of project implementation. In this regard, the establishment of partnerships between the public sector, NGOs and community organizations is a requisite to make efficient use of all the capacities available at the local level.

The achievement of effective participation requires training and support activities to strengthen community organizations, and to develop the individual and collective skills necessary for the planning, construction and operation of rainwater catchment systems. Some instruments to be applied in this regard include: preliminary socio-economic surveys, awareness programmes, organizational capacity building, and inventory of local skills and resources.

The role of women in rainwater catchment projects

Women play a key role in the demand for and use of water for domestic purposes, especially in rural areas. Projects, if they are to be successful, have to take into account gender issues and prevailing forms of gender division of labour.

Rainwater catchment initiatives should target women in the implementation of their activities and promote the work of women's groups and associations.

Attention to rural water needs for domestic and productive activities in an integrated manner, and taking into account other benefits such as the control of soil erosion

Rainwater catchment systems should be planned and operated within an integral concept of water resources management. Water from different sources-surface, ground or rainwater-has to be treated as a unitary resource to cope with rising and competing agricultural, domestic and industrial demands.

Rainwater catchment systems should be planned to satisfy the demand from different users in an integrated manner. The impact of rainwater catchment systems on the protection of the environment (e.g. prevention of soil erosion) should also be considered at the planning stage.

Technology selection

There is the need to take into account local cultural and socio-economic patterns in the selection of technologies for rainwater catchment, as well as in the construction, operation and maintenance of the same.

Technology development plays a decisive role in achieving the sustainable operation of rainwater catchment systems. Thus, the attainment of technological progress requires the removal of administrative and institutional obstacles to technological innovation, and the strengthening of the local capacity for the research and development of appropriate technological options.

There is the need to recuperate the knowledge of indigenous technologies and apply them, when appropriate, according to current local conditions.

The need for a realistic appraisal of the community capacity and willingness to pay for water

The projects offering the best possibilities of successful completion and operation are those responding to effective demand, expressed mainly through the community's willingness to contribute to the construction and operation of rainwater catchment systems.

Project planning should include the appraisal of the technical, economic and social feasibility of the proposed activities, and an accurate evaluation of community demands and willingness to contribute towards project implementation.

RAINWATER CATCHMENT SYSTEMS IN SOUTH PACIFIC ISLANDS: EXPERIENCE OF PROJECT IMPLEMENTATION

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ABSTRACT

Rainwater catchment systems are used throughout the South Pacific island countries. Governments, NGOs and various United Nations agencies (notably UNCDF, UNDP/DESD and WHO) have supported this. The water supply situation varies considerably depending on whether the island lies in the path of the tradewinds or in the equatorial doldrum belt; furthermore, the higher volcanic islands can receive greater rainfall due to orographic effects than the low lying coral atolls. While some islands depend largely on rain catchment, during times of drought this has to be supplemented by groundwater or, in case of dire emergency, by water barged in from larger islands or from desalination plants.

Many types of rainwater tanks are employed including: reinforced concrete, ferrocement, fibreglass, galvanized or coated steel, plastic and prefabricated wooden tanks. Most are cylindrical; however, prefabricated cubic tanks have been widely used. In project implementation logistics poses major problems and costs to all projects. This can only be partially mitigated by careful planning, buying in bulk and making special arrangements for shipping and storage. Communities on small isolated islands are highly motivated to solve water supply problems and show interest and pride in the work of building catchment systems; nevertheless, provision must be made for training and supervision. Urban areas present special problems in that space for tanks may be limited and the response to requests for voluntary contributions of materials and/or time is not always positive; therefore, these may become public works responsibilities requiring a budget for most materials and labour. Nevertheless rain catchment in urban areas is becoming a high priority, especially on small islands which are depleting available ground water supplies; this calls for innovative low cost solutions to the storage problem.

One recent project in Tuvalu (with funding from UNCDF and technical assistance from UNDP/DESD) is supporting construction of about 1500 ferrocement household tanks (being built at the rate of 500 per year and ranging in size from $5.5m^3$ to $12m^3$) plus 15 reinforced concrete community tanks (ranging in size from $30m^3$ to $400m^3$). Recent cost figures for these and other types are presented.

INTRODUCTION

The Pacific island countries vary considerably in many respects. They are scattered over a wide area (Fig. 1) spanning several time zones and the international dateline. The northern islands straddle the equator and extend up to 10° north, whereas the southern islands go beyond 20°

south. Size and population range from over 462,000km^2 in Papua-New Guinea with a population of over 3.2 million, to small countries such as Nauru (22km^2) and Tokelau (11km^2) with populations of 8000 and 1600 respectively.

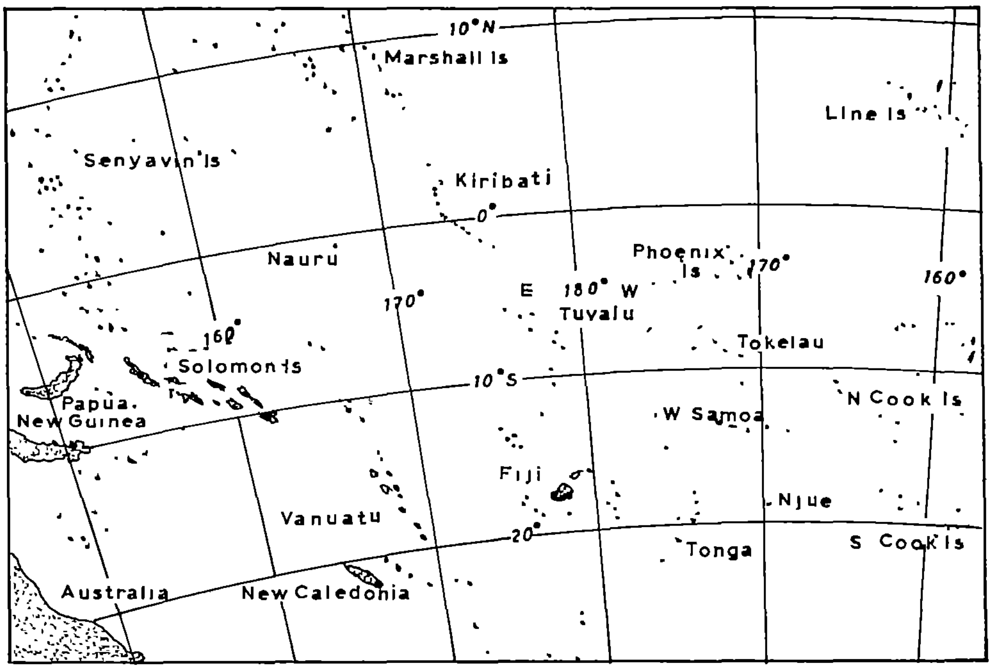

Figure 1. The Pacific Islands.

Geologically the countries include high volcanic islands (some of which are quite large, e.g. Fiji, Papua-New Guinea, Solomon Islands, Vanuatu and Western Samoa; however, some are smaller such as FSM and Palau), low lying coral atolls (such as Kiribati, Marshall Islands, Tokelau and Tuvalu) and some are raised atolls (such as Cook Islands, Nauru, Niue and Tonga). The rainfall varies considerably (Figs. 2 and 3) depending on whether the island lies in the path of the tradewinds or is in the equatorial doldrum belt (this is an area which shifts with the season but is roughly plus or minus 5^o from the equator). The high volcanic islands also receive additional rain due to the orographic (lifting) effect of the wind striking the mountains.

The United Nations Development Programme (UNDP) supports a regional programme to advise and help individual countries on the planning and implementing of projects to improve their water resources management. So far country projects have dealt with water resources assessment, long-term planning, training, water legislation and construction of appropriate water supply facilities such as ground water development by wells and galleries using hand and solar powered pumps and rainwater catchments. The UN Capital Development Fund (UNCDF) has provided resources to several countries of the region to construct water supply improvements and UNDP has funded experts and volunteers to help oversee the work and to

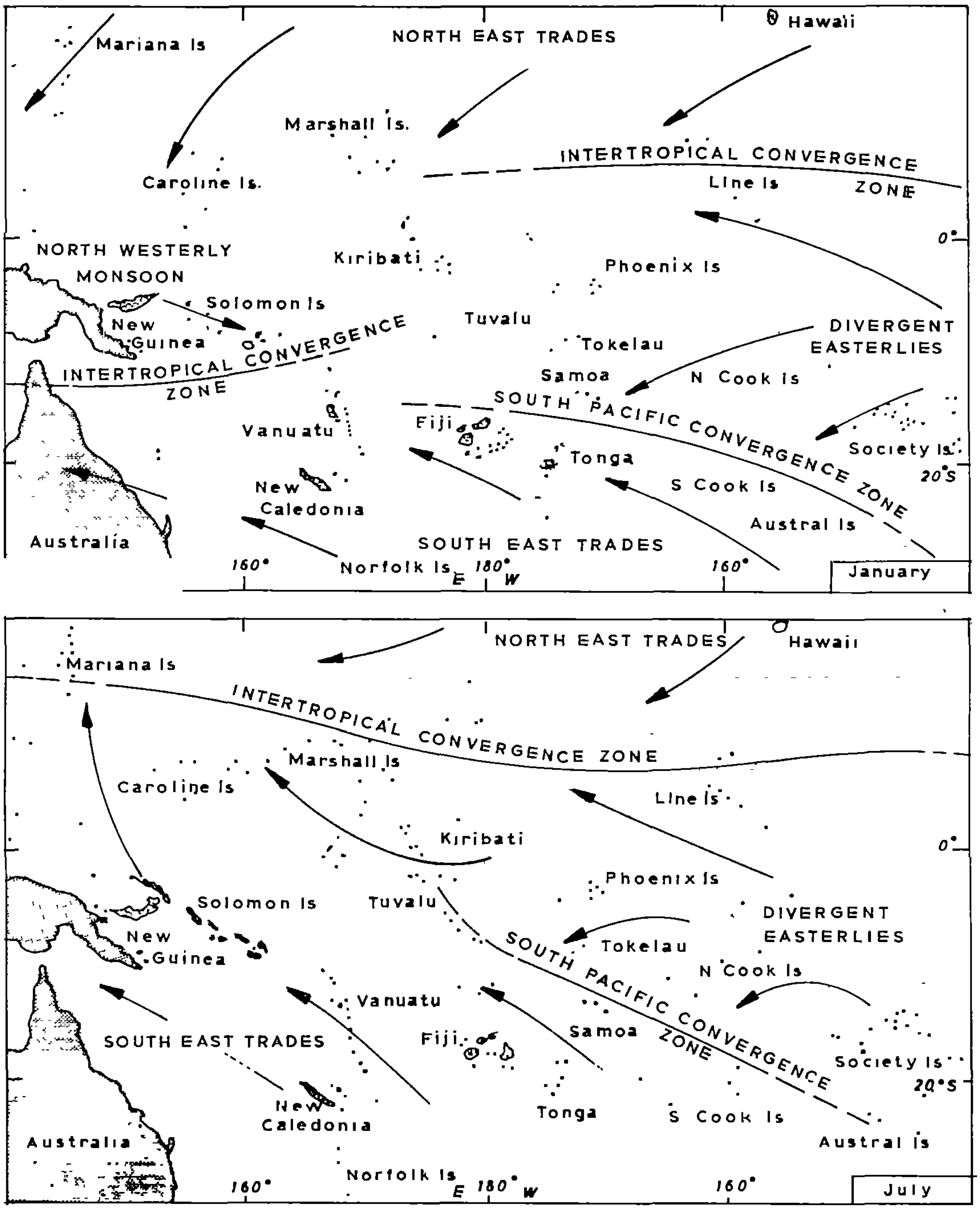

Figure 2. Circulation over the Pacific Islands (source New Zealand Meteorological Service).

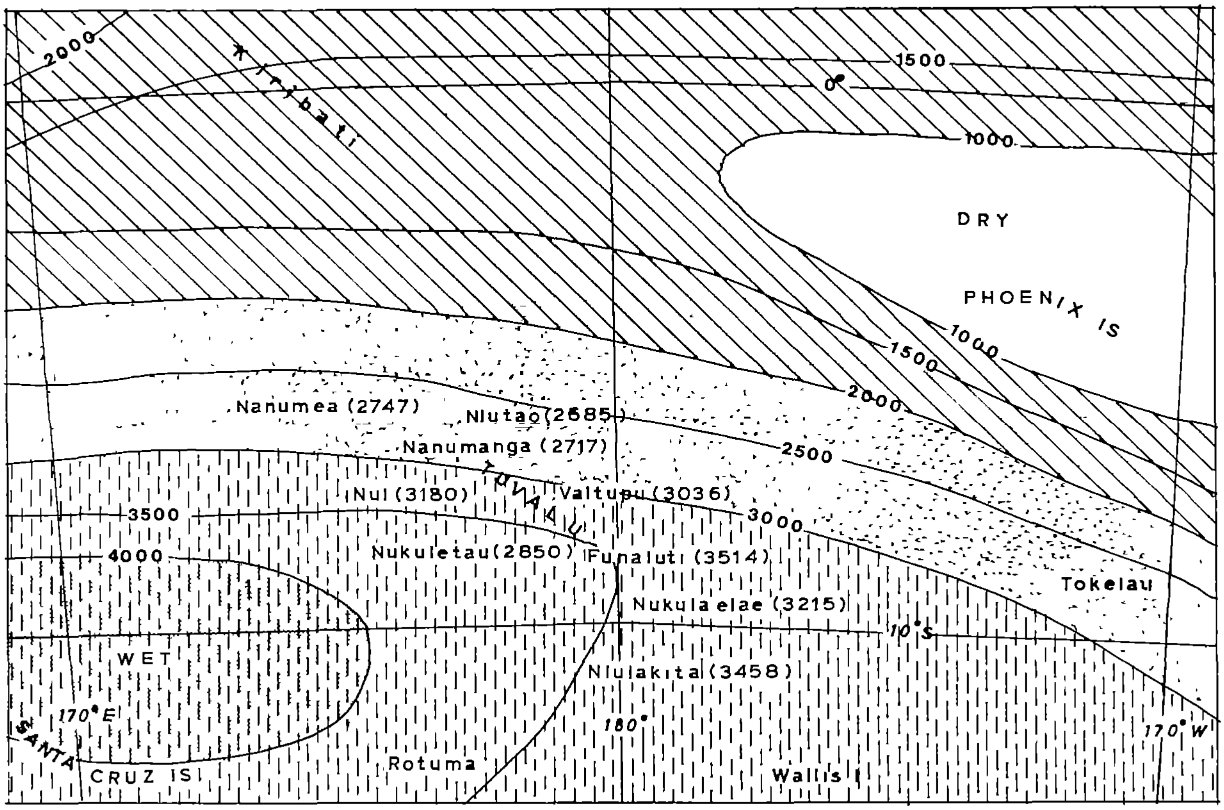

Figure 3. Mean annual rainfall in the vicinity of Tokelu, Tuvalu and Kiribati (source. New Zealand Meteorological Service).

train local counterparts. This paper draws on the experience gained in these projects and some previous NGO and UN supported activities in the region.

Many of the countries comprise groups of small coral islands that are remote from each other and in water resources terms have to be virtually independent. Their average annual rainfall varies from about 800mm to more than 3000mm. The size of an island, the permeability of the coral/sand/soil and the rainfall are important factors in determining the possible availability of ground water in the form of a lens.

DESIGN SIZING

This is dependent on the amount and variability of rainfall, the roof area, and the consumption. Generally values for consumption and roof area are selected based on local norms and the rainfall figures analysed. Monthly figures can be used but it is more accurate if daily figures are used, with an appropriate computer programme. Such programmes can produce a series of graphs relating roof area to volume of storage for any given rainfall record, daily or monthly demand and reliability (or percentage of time that the full demand can be met). Thus knowing the roof area of a building and the expected consumption it is relatively easy to determine tank sizes for different frequencies of failure, say one in two (50%) to one in twenty (5%) or even more.

It is usually uneconomic to consider trying to supply normal consumption for a period of failure less than one out of five (20% failure). Thereafter rationing would be necessary. In Tuvalu the policy is to provide household tanks to cater for periods of low rainfall lasting for up to 2 months and occurring at a frequency of 1 in 5 years and community cisterns to cater for the longer term, i.e. in length of time or infrequency of occurrence.

To illustrate the effect that rainfall patterns have on storage requirements, calculations were made for a roof area of $100m^2$ and a daily consumption by the household of 300 litres assuming 80% reliability. Thus:

- Funafuti at 8° 30′ south of the equator requires storage of $8.4m^3$;
- Nanumea at 5° 10′ south of the equator requires storage of $15.9m^3$;
- Tarawa at 1° 30′ north of the equator requires storage of $44.1m^3$.

Basically these results are due to the longer and more severe droughts that have been experienced as one reviews data going from islands favourably situated *vis a vis* the tradewinds and the tropical convergence zone and moves north to islands affected by the equatorial doldrum belt.

Some countries which have relatively reliable supplies of ground water, e.g. Kiribati, are now recognizing that the construction of rainwater catchment systems by using and storing the immediate rainfall can save their ground water resource until it really is needed during long dry spells and/or droughts. In such a case the tanks can be designed to cater for average rainfall with storage of about 1 month's normal consumption.

ACTUAL SIZING

Often the designed size of tank cannot be provided either because:

- It is too expensive;
- The roof catchment area is too small; and/or
- There is not enough space on which to build it.

In Tuvalu the roof area of houses ranges from about $50m^2$ to $120m^2$ or more. Family size ranges from two to ten or more with an average of about six. Due to social customs of hospitality the actual family size can vary rapidly. Many of the smaller houses are constructed of local materials and particularly *pandanus* thatched roofs. In such cases the runoff was not being used; therefore, there was an NGO project to provide kitchen catchments with small metal roofs of $8\text{-}12m^2$ and with 4400 litres capacity ferrocement tanks. This project was designed to provide 10 l/person/day of drinking water. However, once provided the requirements for water increased and currently a UNCDF/UNDP assisted project is providing about 1550 household ferrocement tanks, giving a total volume of $11{,}000m^3$, and $2500m^3$ of community storage together with associated gutters, downpipes and some roofing sheets, at material cost of US$1.3 million. The bulk of the household tanks are $9m^3$ and $12m^3$ capacity based on 30 and 40 days consumption of 300 l/day (six people using 50 litres each). The community cisterns were based on a standard size of $200m^3$ and built adjacent to meeting halls (*maneapas*), churches and schools which had the necessary capacity and quality of roof.

COSTS

For the Tuvalu project described above the percentage costs of imported materials and equipment, technical assistance, etc. is as follows:

-	Imported materials and equipment (UNCDF)	56%
-	Technical assistance (UNDP/UNDESD)	18%
-	Local materials and labour	8%
-	Government contribution	18%
-	Total	100%

The Government contribution includes communications, transport and salaries (as well as some paid labour for larger cisterns).

Fibreglass water tanks are produced in Tonga (as well as Australia and New Zealand). One of the drawbacks to greater use of such tanks is the relatively high cost of shipping; however, this can be offset if a sufficient quantity of nested type tanks is ordered and shipped together. The cost FOB Tonga is as follows:

-	3000 litres	US$ 500
-	5000 litres	US$ 900
-	10000 litres	US$1600

It is possible to obtain fibreglass panels and kits for assembling at the site; however, many of these have metal fittings which are not adequately corrosion proof for use on small tropical islands. This problem of corrosion of fittings also plagues prefabricated steel and wooden tanks when assembled on the islands.

High density black polyethylene (HDPE) is used for tanks in the food processing and chemical industries in Australia and New Zealand (some with ultraviolet protection are also made in medium density polyethylene which is not as durable and tough as HDPE but only about half the price). Prices for HDPE supplied FOB Australia are as follows:

-	5000 litres	US$1750
-	9000 litres	US$2420
-	17000 litres	US$5140

Once again shipping prices make these too expensive for use as water tanks; however, when cut in panels they could make excellent re-usable moulds for ferrocement tanks.

SOCIAL ATTITUDES

When the project for Tuvalu was being considered it was proposed initially that it should concentrate on providing community storage of a greater volume and a much smaller number of household tanks. During the consultations it was recognized that ferrocement tanks were much cheaper than the cisterns (about US$50/m^3 for ferrocement tank storage, versus concrete cisterns ranging from US$150 to US$250/m^3). Therefore it was decided to increase the number of ferrocement tanks and decrease the number of concrete cisterns.

The householders valued having the benefit of water under their control without having to walk to the nearest cistern for their water which might be rationed or not readily available when required. For the cisterns such benefits were obviously much less; nevertheless, some of them have strong flat roofs which can be used for other purposes (the larger ones are underground and the roof area can be used for various sports).

It should be noted that the beneficiaries were not being paid and had to provide local materials as well. The responsibility for completing the household tank was that of the beneficiary whilst for the cisterns the responsibility rested with the appropriate Island Council. The people on each island are generally organized into two groups for work on such projects. These groups work somewhat independently of each other and this led to the need to duplicate equipment, concrete mixers, formwork, etc.

Each type of project affects how the community is involved and it is also necessary to ensure that all community activities are taken into account when planning a project. Where aid is involved the people may be reticent to mention some potentially conflicting obligations and responsibilities requiring their efforts and time (i.e. they may agree in the hopes of being able to juggle the responsibilities and schedules and later they and the projects run into difficulties).

However, on most of the nine islands in Tuvalu the householders were keen to build their tanks. Once imported materials and plant were provided on site they worked quickly and with the minimum of supervision. Ferrocement tanks had been built since the early 1980s and the general method was well known. Supervision concentrated on obtaining a good rich mortar mix (a 1:2 cement to sand ratio). Furthermore, a liquid waterproofing additive was also used in order to reduce permeability of the finished mortar and to increase workability while maintaining a low water to cement ratio. Elsewhere in the region ferrocement tanks have failed due, it is believed, to mortar that is too lean (i.e. lack of cement); in this case gauge boxes were used to provide consistent volumes.

For the community tanks, availability of labour was a difficulty. Often there was not enough and occasionally too many. With unpaid labour, not everyone is motivated and this can give rise to difficulties. In such cases appeals had to be made to the Council or the leaders of the community. In one case the latter, who were keeping a check of progress, became dissatisfied and took appropriate action to the ultimate benefit of the project.

TRAINING

Prior to construction a workshop was held for those who were to organize the tank building. This was to discuss the method for household tanks and also build some. In addition training booklets were prepared on ferrocement tanks, roofing and plumbing techniques and translated. Copies of these booklets, with spares, were provided to the work supervisors on the islands. There is no doubt that translation of technical instructions/information into the appropriate local language is a great benefit. In this instance the initial translation was done by the local foreman. It should be noted that there is a WASH publication (Technical Report No. 27) on rainwater catchments which proved to be excellent.

MATERIALS

For roofing the local thatch materials affect the taste of the water harvested and thus are not generally acceptable to the people for roof catchments. Due to the corrosive conditions on small atolls, roofing is normally specified to have zinc/alume coating (i.e. mild steel covered with an amalgam of zinc and aluminium) or aluminium. It is also necessary to have adequate facia boards to which guttering can be attached.

Gutters and downpipes are normally PVC with ultraviolet protection - although metal ones are not unknown. Various models and dimensions are available from Australia, New

Zealand and UK. In the case of Tuvalu the Australian standard version was preferred due to its capacity (large enough to minimize overflow and spillage) and its availability in the region.

Household tanks have been built of various materials with different shapes and sizes:

- Ferrocement cylindrical, cubic and spherical;
- Reinforced concrete block walls with reinforced concrete floor and walls;
- Fibreglass;
- Corrugated steel with plastic liner.

Ferrocement is normally the cheapest. For aid projects it has the substantial benefit of contributing to the local component by the provision of more local materials - sand and aggregate and more labour for building. It is a tried and simple technique in the region and elsewhere (see Table 1 for quantities).

Within the region, due to the scattered nature of the islands, the immense distances involved, limited transportation and communications, providing the materials and plant at the right time and within budget can be difficult. Planning is very important and often based on needs for 6 months or more in the future. The possibly limited volume of materials and distance from supplier to customer often mean that prices are high, e.g. cement from Fiji costs US$130-US$155/tonne CIF delivered to Tuvalu 1000km away, and US$175/tonne CIF to Kiribati 2000km away. A roll of chicken wire mesh 90m^2 from Australia costs US$85 delivered to Tuvalu, and US$100 delivered to Kiribati. If a ship is missed there is a delay of 3 months. High prices will continue to affect such countries unless and until communications and shipping are improved and made more economical.

WOMEN AND COMMUNITY PARTICIPATION

The women in particular stand to benefit from the provision of house tanks as they had to seek water if it was not at the house. As a result the time saved can be used for other purposes, so they have been strong advocates of such projects. The impact on the whole community is substantial. Water is more available than before. Most families have direct control of the bulk of their supply and can ration it if necessary. Often the head of the household will directly supervise workers, who may consist of young male relatives. In some islands youth groups were organized to work from start to finish. Traditionally in the region families organize support, including the provision of food and lodging, for a visiting foreman and skilled supervisors.

CONCLUSION/LESSONS LEARNED

1. Rainwater catchment is important on low lying coral atolls where all available freshwater needs to be conserved, managed and protected.
2. Where rainfall is relatively reliable and abundant relatively small systems can yield good supplies most of the time at reasonable cost to householders and with some oversight by the Government.
3. On larger islands and coral atolls it is advisable to supply some of the demand from rainwater catchment systems in order to avoid overpumping of freshwater lenses which would result in saltwater intrusion.

Table 1. Quantities and time estimates for ferrocement tanks.

Nominal volume (m^3)	*12.0*	*8.4*	*9.0*	*5 4*
Nominal internal diameter (m)	2.50	2.50	2.50	2.50
Nominal external height (m)	2.60	1.90	2.00	1.30
Nominal base/wall thickness (m)	0.05	0.05	0.05	0 05
Main base thickness (m)	0.10	0.10	0 10	0.10
Main base length of side (m)	2 90	2.90	2.90	2.90
Mortar (1:2) for tank (m^3)	1.57	1.27	1.33	1.03
Concrete (1:2:4) for base (m^3)	0.84	0.84	0.84	0 84
Sand moist (m^3)	2.64	2.24	2.32	1.93
Aggregate (m^3)	0.78	0.78	0.78	0.78
Cement (tonne)	1.45	1.25	1.30	1 05
Waterproofer (litres)	14.3	11.6	12.1	9 4
Length of 4 mm wire (m)	327	245	262	196
Length of tie wire (m)	18	13	14	10
Area of chicken wire (m^2)	52.5	44.8	49.1	36.8
Area of F62 mesh (m^2)	8.7	8.7	8.7	8.7
20mm pipe (m)	2	2	2	1
20mm tap adaptor (no.)	1	1	1	1
20mm tap (no.)	1	1	1	3
20mm elbow (90° bend) (no.)	3	3	3	3
Labour - craftsman (man-days)	4	3	3	3
Labour - unskilled (man-days)	11	10	10	8
Tractor and trailer (hours)	6	5	5	4
Concrete mixer (hours)	7	6	6	5
Vibrator (hours)	1	1	1	1

4. Logistics is a problem and a major cost to projects on small scattered islands; therefore, as much as possible materials should be purchased in bulk and stored. Infrequent and irregular shipping schedules mean that "just-in-time" supply is not an option. In sizeable projects it would be more economical to build store houses which would pay for themselves by achieving the economies of bulk procurement and shipping.
5. Ferrocement household tanks are cheaper to construct than reinforced concrete communal cisterns and result in more voluntary involvement. However, close-knit communities have often been very active and effective in building and expanding community systems at churches, social halls, etc.
6. More work is needed on reducing costs of larger cisterns. One possibility worth further investigation is the use of special mortar placing equipment to build large thin walled tanks. Another option is to work on underground storage with membrane or ferrocement liners and cover/roof suitable for any intended use of this space.
7. In Tuvalu rainwater catchment systems have become a proven method of providing water for household, community and other uses. Such systems place the responsibility for the management of the supply on the owner of the system. In times of drought emergency, the Government has made legal provision for water rationing and sharing of supplies, whether stored in household or community cisterns.
8. The issue of appearance/aesthetics deserves greater attention especially for aboveground storage. Some NGO projects have encouraged various finishes and decorations; however, most projects do not allow time and/or budget to test reactions and optimize acceptability and durability of the appearance and finish.

RAINWATER HARVESTING IN KENYA: STATE OF THE ART AND RELATED SOCIO-ECONOMIC ISSUES

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ABSTRACT

In response to the International Drinking Water Supply and Sanitation Decade (IDWSSD) 1981-90, the Government of Kenya asserted that provision of basic needs such as water for domestic use, livestock and agriculture, would be one of the major components of the country's economic development towards the year 2000.

Although rainwater harvesting (RWH) has proved to be a viable alternative source of water supply, the Kenyan Government so far has not formulated any policy guidelines to co-ordinate its practice and development. It is left to individuals, NGOs, and bilateral and multi-lateral organizations who are dealing with rural and community development.

This paper highlights state of the art rainwater harvesting in Kenya, particularly in arid and semi-arid lands (ASAL). The roles of the relevant government ministries, NGOs, bilateral and multi-lateral organizations in RWH in the selected ASAL, high rainfall areas and urban areas are outlined.

The paper also looks at the various ways of collecting and using rainwater and runoff in the sample areas, and socio-economic issues affecting the spread and the development of the technology.

The paper concludes by noting that there is need for the Government to formulate an integrated water resources management policy, giving RWH its rightful emphasis, as well as acting as the co-ordinator of all the key players in RWH. A number of recommendations are made regarding some of the aspects that require attention and immediate study if RWH is to become an important catalyst for socio-economic development in Kenya.

INTRODUCTION

An adequate water supply is one of the basic needs of life. However, it is lacking among many communities of the world; some of those are found in the arid and semi-arid parts of Kenya. These marginal lands, often characterized by low rainfall, have come under increasing pressure from human and animal populations; Government settlement policy has seen people settled in these arid and semi-arid areas. If both land and people are to survive in such areas, rainwater harvesting systems must be employed to maximize the use of the little rain that falls. The system to be adopted must be cheap, small scale and decentralized so that funds available for the purpose can be used to benefit a larger number of the unreached. Technologies must be such that construction and maintainence can be carried out by the local people themselves, in order to avoid the need for continued and expensive institutional support, and to ensure community involvement. Even small-scale irrigation systems can boost crop yields and have been fundamental in improving nutrition and health, among small-scale farmers (Institute for Rural Water, 1982).

The present level of water system coverage in Kenya varies widely from as low as 14% in North Eastern Province to 20% in Central Province, with an average of only 15%, for rural coverage. The unserved population was estimated at the end of 1986 to be 14 millions (Cullis, 1985), which suggests that serious efforts must be made to alleviate this problem. Lately the general concensus is that more attention should be devoted to the use of rainwater resources, the potential of which has not been exploited in Kenya. Although water harvesting is a well-known technology in India, Sudan, Egypt and the Middle East, very little research on the potential of runoff water for farming systems has been done.

In sub-Saharan Africa, where severe drought and food shortages are frequent, water harvesting is still not seen as an adequate solution. Most governments and NGOs have tried to encourage the inhabitants of such regions to engage in rainwater harvesting by providing financial and technical assistance, especially since the rate of construction of improved water supply systems is below the target set in the International Drinking Water Supply and Sanitation Decade. Many of the schemes that have been completed are not in satisfactory operation; various reasons for this have been given, for example, a lack of sufficient funding and trained personnel to operate and maintain water and sanitation systems (Nation, 1988; Pearson *et al.*, 1979). It has also been suggested that to make a lasting impact on the urgent needs of the community, the water supply strategy must be based on a sustainable and replicable programme, and must take account of the pace at which resource constraints can be overcome (Helwig, 1973).

A successful community water supply programme involves a combination of hardware and software technology, and institutional and organizational support elements, matched in such a way that the people to benefit from the improved supply can afford the cost of operating and maintaining it, and have the skills, spare parts, materials and tools available to make it sustainable. The choice of technology, therefore must match the community resources available, for the up-keep of the system. Various water projects in Kenya have employed borrowed water harvesting technologies, without reference to a study on the most appropriate technology for the community in question. The key requirement for an appropriate solution is that it should be selected in the light of local circumstances, with particular attention given to the human resources, the socio-cultural set-up, and the financial resources available for operation and maintenance. The type of technology chosen should solve the water shortage problem reliably and economically for many years under local conditions rather than one that is copied directly from a different situation. It has been shown Jenkins *et al*, 1973 that the targets of the IDWSSD cannot be achieved unless there is a reorientation from expensive methods, towards appropriate low-cost techniques and a diversified approach to water supply systems for rural areas. Pearson *et al*, (1979) remarked that the most suitable water supply system is that developed with the involvement of the local people, thus creating a sense of participation and ownership within the community. Similarly, Cullis (1985) noted that efforts to introduce rainwater harvesting technology to the Turkana people in Kenya were not fully realized due to a lack of understanding of the social structure within which the technology was to be implemented and maintained, and also due to the lack of communication between the experts and the Turkana people on the type of technology they presented *vis-a-vis* their traditional methods. This emphasizes further the need for prior understanding of the people's traditions and attitudes; their economic capability and the level of acceptability of the various new technologies before significant decisions on the technology to be used are made. Such an awareness would lead to improvement in the local water technologies, and the development of appropriate water facilities which are easily maintained at affordable costs (Pigot *et al.*, 1982).

Although Kenya, as a UN member state has pledged to achieve the objectives set by IDWSSD, the reality is that only a few areas have benefited so far. The situation has been aggravated by lack of funds, lack of qualified personnel to start and man water projects adequately, and poor leadership within those water projects established. It is, therefore, necessary that the reasons why rainwater harvesting has not succeeded as well as expected and why of RWH has not been widely replicated are sought, in order to assist planners and community development officials in alleviating the water problems of Kenya. It is also imperative that an assessment of the socio-economic issues of rainwater harvesting for the general Kenyan population is carried out. This information is essential in the identification of new strategies to bring about greater local community participation and the crystallization of ideas related to rainwater harvesting systems. It is also necessary for the conceptualization of viable rainwater harvesting projects initiated by the local people to meet environmental protection, domestic, livestock and crop water needs in their localities.

This paper reports some results from on-going research which is examining existing rainwater harvesting practices, and the factors that have hindered the acceptance and implementation of new rainwater harvesting technologies in Kenya. The aim is to explore the cultural, economic, social, legislative and institutional factors that impede or promote the spread of these technologies, as well as the success of some on-going water harvesting projects.

Study Methodology

The study documented various RWH activities which include projects, research and related training going on in Kenya. The first three months were used to collect any recorded information on RWH in Kenya. Target groups included:

- Government ministries involved directly or indirectly with RWH, e.g. Ministry of Land Reclamation, Regional and Water Development, Ministry of Health, Ministry of Agriculture, Livestock and Marketing;
- Multilateral and bilateral agencies, e.g. UNICEF, SIDA, GTZ, IDRC and CIDA;
- NGOs, e.g. AMREF, Catholic diocese, Protestant churches, Islam and Aga Khan Foundation, Care Kenya, Save the Children Canada, Kengo, Action Aid.

In order to obtain information on socio-cultural aspects of RWH, two target groups were selected: a location in an area without land ownership problems, with a settled way of life, and an area with a pastrolist way of life, to provide information important for future development.

Some of the selected groups were used initially for a pilot study to improve the research instrument, the final version of which was used for the main study. Rainfall data for each study area was also collected, for use in the correlational analysis with rainwater harvesting practices.

The survey method was chosen to collect data for this study because of its wide applicability in social sciences. It also has the advantages of requring a relatively short time, and being inexpensive (Kincaid, 1981). The survey then, comprised of a structured interview with a proportion of the members of the selected group, as well as the ESAs operational in the area. The proportion depended on the size of the group, the role of the members in the group and the organizational structure of the community.

The researcher, with the help of assistants, carried out the interviews throughout the area of study. The responses to the questions were recorded for further analysis. To ensure the availability of the required respondents, letters were sent to local administrators (e.g. Chief) of the area, detailing the time of the visit and who would be seen. The collected data were later analysed by qualitative and quantitative methods to help in the interpretation of the results, and so provide answers to the stated aims of the research, i.e. to reveal some of the factors associated with rainwater harvesting practices.

RESULTS

The survey set out to establish the state of the art of rainwater harvesting in Kenya, particularly in ASAL, and the related socio-economic issues affecting the spread and the development of the technology. Only a summary of the results of the main study are reported. First there is a brief report of the results and an analysis of who is dealing with RWH in the area of study, followed by a summary of some of results and an analysis of the type of RWH technology observed in the area. Finally, some of the results and an analysis of the socio-economic issues affecting the spread and development of RWH technologies in the study areas are presented.

Actors in RWH in Kenya

Analysis of documents on RWH and the interviews with inhabitants of the study area, showed that a number of government ministries, NGOs, bilateral and multilateral agencies are involved, in one way or another, in rainwater harvesting. Their involvement was found to be either direct, or indirect through partnerships with other bilateral and multilateral agencies, within a particular area. The participation of the Government has not been very marked since its emphasis has been mainly on providing piped water and building dams rather than harvesting rainwater. A number of the bilateral and multilateral agencies were found to be heavily involved in rainwater harvesting activities in various parts of Kenya; these were SIDA, FINIDA, DANIDA, NORAD, ODA, JICA, USAID, CIDA, BELG, GTZ, SWCB, IDRC. The multilateral agencies we found to be active in the areas studied were: World Bank, UNICEF, UNDP, FAO and HABITAT. In some of the study areas, of a number of Kenya government ministries and departments had been involved in the promotion and development of rainwater catchment systems. The Ministry of Agriculture is leading with their soil and water conservation programmes in Machakos, Kitui and Turkana districts. Rainwater harvesting activities in these districts are mainly for food production through management of runoff. The Ministry of Health, through the construction of water jars (a programme largely funded by SIDA Sweden, and under the district public health department) has been actively involved in Nakuru, Meru and Laikipia districts. The Ministry of Land Reclamation, Regional and Water Development, in addition to implementing macro-projects, have funded rainwater projects with donors such as GTZ i.e. Kilifi Water and Sanitation Project (KIWASAP). This project promotes roof catchment and ferrocement tanks. In ASAL areas a large number of dams have been constructed, e.g. in Laikipia, Wajir, Mandera, Isiolo, Baringo to provide water for livestock etc.

In the 24 ASAL districts a number of programmes were found to have been started by the Dutch, e.g. in Elgeyo Marakwet, Kajiado and Laikipia. The Embu, Meru and Isiolo (EMI) rainwater harvesting programme is funded by Overseas Development Administration (ODA).

Other multilateral agencies were found to be supporting government departments or NGOs, or working in collaboration with more than one agency. UNICEF has played a major role in this endevour and is supporting rainwater projects in Baringo and Kitui especially. UNICEF originally promoted a 50-80m^3 hemispherical ferrocement tank through their village technology unit. CPK, working in Laikipia, has built over 500 ground water tanks of 80-100m^3 using various lining techniques: i.e. stone rubble and ferrocement for tanks on blackcotton soil; and ferrocement with only chicken wire where the soils are impermeable having hard murram. These tanks are the most cost effective options per gallon.

RWH technologies and their spread

Visits to the various study areas revealed a number of RWH technologies that are currently in use. Table 1 shows the technologies used in different areas.
Table 1 indicates that RWH technologies are common in rural ASAL and rural high rainfall areas but very little use is made of them in urban areas, except in peri-urban areas. Another observation was that there was limited use of runoff farming systems in ASAL, except for isolated trials in Turkana, Isiolo and Laikipia.

Table 1. Rainwater harvesting technologies.

Technology	*Rural ASAL*	*Rural high rainfall*	*Urban*
Roof top catchment			
Standing tanks	Samburu	Kiambu	-
	Laikipia	Nyeri	-
Underground tanks	Marsabit	Nyandarua	-
	Baringo	Murang'a	-
Mobile tanks	Kitui	Kirinyaga	-
	Machakos	Kisii	-
Institutional system	-	Meru	-
Surface catchments			
Small dams/pans	Marsabit Laikipia Samburu	Kiambu Nyandarua	-
Sub-surface dams	Kitui Machakos	-	-
Ground tanks	Laikipia Kitui	-	-
Rock catchments	Kitui Laikipia	-	-
Runoff farming systems			
Internal catchment (micro-catchment)	Turkana Isiolo Laikipia	-	-
External catchment (spate diversion)	Turkana Isiolo	-	-

Table 2 shows that the use of plastics among subsistence farmers to control evaporation from the soil surface was not common in ASAL. It was expected that practices to reduce the loss of water through seepage in agriculture would be common in ASAL, but this was not the case. This may be attributed to lack of awareness or economic constraints in the area.

Table 2. Rainwater conservation technologies.

Technology	*Rural ASAL*	*Rural high rainfall*	*Urban*
Water conservation			
Ferrocement	Kitui Machakos	Nyandarua, Kisii	-
	Laikipia Baringo		
Galvanized steel	Laikipia Machakos	Meru	-
Grass/Papyrus	Laikipia		
Polythene/Chicken wire	-	-	-
Concrete roofs	-	Embu Kirinyaga	-
		Kiambu Nyeri Nyandarua	
Control from soil surface - plastics			
Control transpiration Ferrocement	Laikipia Machakos	Kirinyaga Nyeri	-
	Kitui Marsabit	Kiambu Meru	
		Nyandarua Embu	
Plastics			
Storing water	Laikipia	-	-
Agriculture	-	-	-

Socio-economic issues related to RWH

A number of socio-economic issues related to the development and spread of RWH technologies were raised by respondents and deduced from observations made during field visits. The major ones related to technology selection; the mode of capacity building of the particular target group; finance, and management of the available resources; and the level and extent of community participation.

The study revealed that where the choice of technology was related only to the socio-economic status of the target group without due consideration of the engineering performance of the materials (i.e. adobe block tanks in Nakuru, Nyandarua and Siaya districts, and Gala tanks in South Nyanza, Siaya, Kiambu), the technology did not last. Similarly, the technology did not last where it had not been matched with the lifestyle of the target group e.g. in Turkana and Isiolo districts where the inhabitants are pastoralists. This may have been due to lack of commitment or the lack of technical and managerial skills amongst the beneficiaries. It was observed that where the technology chosen was beyond the economic and institutional capacities of the target group, its sustainability and replicability could not be guaranteed.

CONCLUSIONS

The study has shown that of late RWH technology has spread considerably except for urban areas. The biggest increase has been in ASAL followed by high rainfall rural and peri-urban areas of Kenya. The spread of the technology in these last two areas is attributed to:

1. The collapse of a number of piped water schemes, for example in Murang'a, Nyeri, Siaya and Nyandarua.
2. Change in land use patterns due to increased population, resulting in pollution of river sources, for example, Kabare Institute in Kirinyaga and Kiharu Division of Murang'a District.
3. Increased economic and population pressure on urban water schemes, resulting in little or no supply of water to peri-urban areas e.g. areas, around Nairobi, Kisumu and Mombasa, and also areas around smaller towns.

Coverage would have been better countrywide, were it not for the country's poor economic performance in the 1990s and the escalation in the price of building materials. This might call for more external support to subsidize the cost of building rainwater catchment systems for sustainable development in Kenya.

Finally, the study has shown that there are very many organizations and government departments involved in the promotion and development of RWH in various parts of Kenya. However, there has not been adequate collaboration, co-ordination or co-operation among the actors in the sector. This may be due to lack of a clear, detailed national water policy that would define roles, responsibilities and relationships among the actors.

RECOMMENDATIONS

1. Since there is no relevant and recent water law, or policy governing utilization of rainwater for economic growth, there is a need, for a national water policy and a new water law to define operational guidelines, co-ordination, collaboration, and co-operation of the key actors in rainwater harvesting in Kenya.

2. A co-ordinated effort to collect and document all the rainwater harvesting reports is necessary as well as on-going research and training, to facilitate the creation of a data-base on rainwater catchment systems in Kenya.
3. Rainwater catchment technologies that are socially acceptable and not too dependent on external resources (skills and capital) should be encouraged in order to ensure local involvement for sustainability of the particular technology.

REFERENCES

Cullis, A.D. (1985). Personal communication.

Helwig, D.H.R. (1973). Survey of Rain Runoff Harvesting. *South African Jl of Science*, **69**, 77-78.

Institute for Rural Water (1982) *Evaluating Rainfall Catchment.* USAID Water for the World, Technical Notes, RWS 1.

Jenkins, D.F. *et al.* (1973). *Feasibility of Rainwater Collection Systems in California*, p.93. Contribution No. 173, California Water Resources Centre, University of California.

Government of Kenya. *Economic Management for Renewed Growth.* Session Paper No. 1.

Kincaid, T.C. (1981). Customer Information Brochure. Surface Water Treatment Co. Columbus, Ohio.

Nation, (1988). *Daily Nation*, 14th June, p. 14. Nairobi, Kenya.

Pearson, F. *et al.* (1979). Storage Requirement for Domestic Rainwater Collection Systems in California. *Proc. AWWA Conf.*, Part 2, pp. 671-680. San Francisco.

Pigot, T.L. *et al.* (1982). Application of Gould Matrix Technique to Roof Water Storage. *Proc. Conf.* on *Rainwater Cistern Systems Conference*, pp. 144-150, Honolulu.

DISCUSSIONS

Dr Jessica Salas commented that the authors had repeatedly emphasized the problem of affordability, but she questioned whether affordability should be an issue in water supply for poverty-stricken areas. She suggested that it should be a basic service to be provided by the government.

In reply **Mr Mbugua** pointed out that very few countries have included rainwater harvesting in their national water policies, though Thailand is reported to have a policy that funds rainwater harvesting through subsidies. The question of affordability and subsidy depends on individual governments.

AN OVERVIEW OF RAINWATER HARVESTING IN KITUI, KENYA

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ABSTRACT

The paper examines various methods of rainwater harvesting in Kitui District, Kenya. The projects are community-based small-scale water programmes. Many NGOs are currently involved in rainwater harvesting in the district, they include: Danida, World Vision International, Actionaid and Diocese of Kitui among others. This paper is based on the activities carried out by the Diocese of Kitui, which has been involved in community development programmes since 1970. They have been conducted effectively through women's groups, self-help groups and parish leadership groups. The objective is to provide clean water nearer to the communities, thus reducing the time spent in fetching water from distant sources. This allows women to concentrate on other activities such as child health care, farming or entrepreneurship.

TECHNOLOGICAL AND IMPLEMENTATION PROBLEMS

The operation, maintenance and training aspects of completed and on-going projects have been neglected, while public awareness and participation of the communities involved is often inadequate.

The rate of evaporation is generally high, hence many reservoirs dry up when the rains cease. Systems of drawing water, for example pumps, rely on imported spare parts which are locally unavailable or expensive. There are cases where the agency or organization involved installs them without passing on the technological and maintenance know-how to the beneficiaries.

To overcome this, the Dioceses of Kitui has developed a direct action pump that is made of locally available parts/material and is easy to maintain. It has a limitation in that it can only draw water effectively down to a depth of 12 metres.

Most of the rural people are below the UN poverty line thus their contribution towards the management of the project before and after completion is often inadequate, - for example the purchase of spare parts or rehabilitation costs.

Contamination of surface water reservoirs by animals and decomposing vegetation is high. Reservoirs are ideal breeding-places for disease-bearing organisms such as mosquitoes and snails. Hygiene and water harvesting are sometimes treated independently, while they are infact, part and parcel of water supply.

Some of the artisans are not serious about their work, leading to poor wormanship. The artisans operate in remote and bandit-infested areas which does not augur well for morale.

Figure 1. The location of Kitui district.

SOCIO-ECONOMIC ASPECTS

The management capability of the community is under-utilized; involvement is mostly confined to unskilled "free" labour during construction and supplying local materials. There has been limited involvement of communities in choosing the appropriate technologies and design, selecting and supporting community members to be trained, organizing effective financing and maintenance.

Water harvesting systems demand a high and sustained level of community involvement in management, and are labour-intensive during construction. Catchments and reservoirs need frequent cleaning and proper care. Such high inputs may not be possible as the members of the communities are engaged in other activities.

Since there is a risk of social conflict between and within groups, a high level of community organization is vital. Users have to be disciplined and sensible during dry seasons to ensure equal benefits are received by all. To ensure the maximum benefit from these sources it is important that the water is used only for drinking and washing.

COMMUNITY PARTICIPATION

The Diocese of Kitui water programme involves the community in the process of identifying a project, discussing problems concerning their own projects, planning solutions to arising problems, and operation and maintenance strategies. The group is involved fully in the construction under the supervision of a qualified artisan and a technician.

The groups are assisted to strengthen their management skills which enable them to sustain their project in the long-run. The projects are implemented by the Diocese in collaboration with organized groups which have to satisfy several conditions:

- Group should have 10-30 members over a period of 6 months.
- The group must participate in organized training which analyses community needs and ways of group action to respond to them.
- The group should be able to show concrete evidence of its project work.
- The group must be prepared to participate in committee decisions at grass-roots or Diocesan council. They should be actively involved in all the stages of identification, implementation and maintenance of the project.
- The group must have a viable method of finance or labour contribution for the project they are putting forward.
- The group contributes 10% or 20% towards the cost of cement depending on the type of project, i.e. 10% for rock catchment and 20% for lined wells. They should have an account for maintenance of the project.
- The group takes care of the artisan's subsistence and accommodation.
- All locally-available material needed for construction such as sand, stones and aggregate must be supplied by the group.

Other relevant conditions will be worked out as the project implementation gathers momentum. After the group has accepted the conditions they sign an agreement at the parish level. The technical aspects and discussions are undertaken with the assistance of an area co-ordinator, and the technical staff who frequently meet the group on site.

ENVIRONMENTAL CONSIDERATIONS

Construction of a small reservoir has less of an adverse impact on the ecology of an area due to the limited scale of both the project and water use.

Care should be taken to ensure that construction of the reservoir does not upset the balance between the quantity of water available and existing users. Obstructing a river by a dam may interfere with the water supply of downstream users.

Overgrazing by animals using the water points can cause serious erosion due to the fragile soils involved.

RECOMMENDATIONS

Women have to be fully involved in decision-making, implementation and maintenance; they need to understand the reasons for the technology used.

Households should be encouraged and, if necessary, assisted to own rainwater harvesting systems. The assistance could be in the form of a subsidy; this would put less pressure on communal sources. Professionals and technicians should sympathetically find out what the community is doing, and then assist them to do it better.

NGOs working in the country should collaborate with each other to avoid duplication or over-concentration in one area. They should share ideas and effective technologies.

Donor agencies should be involved in various community animation programmes to promote a high sense of responsibility and self-reliance.

Water points should be fenced and properly managed. Vegetation inside reservoirs should be cleared before the reservoir is impounded.

Groups should compile an inventory to assess how successful they are in water harvesting projects, what impact they have had on their lives in real terms, and where and how these could be strengthened.

More research should be carried out to improve and strengthen existing methods; and identify new methods, to ensure effective conservation of water.

REFERENCES

KBWDP (1992). Guidelines for the Design, Construction and Rehabilitation of Small Dams and Pans in Kenya. Kenya-Belgium Water Development Programme. *Water Harvesting in Five African Countries*. International Red Cross

COST EFFECTIVENESS OF RAINWATER CISTERN SYSTEMS AND ITS APPROPRIATENESS IN RURAL SRI LANKA

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ABSTRACT

"Water for all by the year 2000" is a popular slogan in Sri Lanka. The International Water Supply and Sanitation Decade target of supplying potable water for 100% of the urban population and 15% of the rural population is difficult to achieve. However, to accelerate accomplishment of the year 2000 goal, the Government of Sri Lanka has embarked on an ambitious programme to provide potable water through donor assistance.

One such programme embarked upon was carried out to provide piped water to an irrigation settlement scheme in a remote part of southern Sri Lanka. The programme was funded by the ADB and provided potable water to 4200 families in the settlement scheme. The source of this water supply is a major reservoir dam built on a perennial river. The programme provided water through one stand post for every 10-12 families. After one year of operation, the programme was faced with the problem of low water yields in the storage reservoir and vandalism of the stand posts, leaving the families without any drinking water source. The funding agency had to rehabilitate the broken stand posts in order to revive the programme. The donor in this case has spent Rs. 38 million (US $ 0.90 million) to date.

This is a classic case where a large sum of donor assistance has been used to develop inappropriate social infrastructure without community participation. If rainwater cisterns had been developed for each household at a very liberal estimate of Rs. 10,000 (US$ 217), the Government of Sri Lanka would have saved 4 million (US$ 91,000). Developing individual rainwater cisterns would also have instilled a sense of ownership and eliminated the need to rehabilitate the programme so soon after implementation.

This paper also discusses the social and economic benefits of rainwater cisterns as a sustainable source, against traditional piped water supply systems. Rainwater is also identified as the cheapest and the most sustainable source of drinking water for the rural poor in the dry zone of Sri Lanka.

INTRODUCTION

Sri Lanka is an island in the Indian Ocean, situated off the southern tip of India. The land area is approximately 65,000km^2. The island is pear shaped with a mountain range in the south-central part of the country; elevation ranges from 900m to 1200m. The rest of the island is flat. Sri Lanka is a tropical country with little seasonal climatic variation. The mean monthly temperature varies from 26°C to 28°C. The country can be divided into two distinct climatic zones.

The wet zone covers one-third of the country and receives an average annual rainfall of 2400mm. The dry zone covers two-thirds of the country and receives an average rainfall of 1400mm.

In Sri Lanka, the International Water Supply and Sanitation Decade declared in 1980 officially ends in 1995. The International Decade was extended for another 5 years due to the civil disturbance that prevailed towards the end of 1980s; work had been abandoned in many parts of the country due to the unsafe situation. Sri Lanka had set a goal of providing good quality potable water for most of her population through piped water systems, tube wells and protected wells. The Decade had targeted 100% of the urban population and 15% of the rural population to be served with piped water, whereas 85% of the rural sector was expected to be provided with protected well water. To achieve the goal of "water for all by the year 2000", the state will have to secure large amounts of funds, and make efforts to upgrade the operation and maintenance capability of the National Water Supply and Drainage Board (NWSDB). There was more than a ten-fold increase in water supply and sanitation investments from the 1970s to the late 1980s. With these efforts and increased investments, an improvement in the present situation, especially in the rural areas, is to be hoped for.

During the past decade, many water supply projects involving local and foreign NGOs were undertaken to supply potable water to the rural areas. However, the projects concentrated on only three options: the most popular was piped water, followed by tube wells, then open dug wells. Most of the funds were spent on the first option which was considered then to be the most appropriate source of domestic water. Many of the projects, while attempting to provide good and efficient supply of water, ignored community participation; the results of this oversight were immediately evident in some projects.

Since 1989, all annual water supply plans have emphasized the importance of participation in providing a cost-effective, affordable and sustainable water supply source.

THE NEGLECTED SOURCE OF WATER SUPPLY

Most water supply projects were so obsessed with the three sources of water supply mentioned before that they neglected another source, which could prove more sustainable than the others. Sri Lanka should emphasize rainwater collection for domestic use; this is the neglected source that has great potential for sustainability.

In the late 1950s and early 1960s rainwater collection from roof catchments was a principal source of drinking water in many government quarters in the dry zone. With the introduction of piped water, these rainwater cisterns were discarded. At present about 9% of the population uses rainwater catchment from various sources; however, they do not depend only on rainwater for their domestic needs. They use ground water as the main source of drinking water, but during the dry seasons when ground water sources run dry they use collected rainwater. In the deep south of Sri Lanka, where there is a severe drinking water shortage from April to August, most people with tile roofs collect rainwater during the rainy season. The water is collected in open concrete tanks constructed under the main gutters; the tanks are approximately $25ft^3$. People also use tarpaulin sheets, royal palm leaves, funnels placed at the convergence of two roofs, and coconut leaves tied to jak (*Artrocapus nobelis*) tree trunks, to collect rainwater for use during dry periods. Most rainwater collected in rural areas is used to supplement the principal drinking water source. In urban areas some people also adopt their own systems of rainwater collections to supplement periods of water shortage. A good example the suburban areas of Colombo (the capital of Sri Lanka) where piped water is restricted to a few hours a day. Some enterprising residents have constructed underground tanks to collect rainwater from roof catchments and then pump it to overhead tanks for domestic use. This system is very successful and proves to be a reliable source of water. Colombo is situated in the wet zone with a good distribution of rainfall throughout the year, which also contributes to the success of these systems.

PRESENT SOURCE OF DOMESTIC WATER

Like many other developing countries, Sri Lanka has two main types of domestic water supply. Piped water is restricted mostly to urban areas, while protected well water is used as the principal source in the rural areas. The percentage of protected wells outside the premises is the same as protected well within the premises for the entire country, but in the rural areas the percentage of wells outside the premises is higher (Table 1). The unprotected/unspecified sources contribute about 35% in the rural areas and almost 25% country-wide.

Table 1. Percentage of water service use in Sri Lanka.

Water service	*Urban*	*Rural*	*Estate*	*Total*
Piped supply within premises	37.6	3.2	-	13.3
Piped supply outside premises	25.1	4 7	54	8 8
Protected well within premises	10 3	24.1	22	27 6
Protected well outside premises	15 0	33.0	-	26 0
Unprotected/unspecified source	12.0	36 0	24	24 3

The Government of Sri Lanka has tried various ways to provide good quality potable water to the population served by the last category in Table 1. Despite generous donor assistance and NGO support, almost 25% of the present Sri Lankan population still depends on unprotected/unspecified sources of drinking water - the major cause of most common water-borne diseases. Even in urban areas only 62% of the population is served by piped water, leaving 38% yet to achieve the Decade target by 1995.

CONSTRAINTS

At the end of the first 10 years (1990), with considerable capital and human resources invested, achievements of the Decade targets were disappointing. Out of the 3,885,000 people served by piped water, 50% of the urban residents were not satisfied with the service, while in the rural areas the proportion was only 19%. Tube wells are the main rural water source; about 64% of people using this source were not satisfied with the service (Ministry of Finance and Planning). There were several reasons: most of the programmes were implemented without community participation; the main administration agency (NWSDB) is severely handicapped by lack of capacity to implement and manage such a large programme island-wide. Furthermore, the insufficient funding and the high operational cost of NWSDB (personnel and electricity costs add up to more than 65%) have greatly restricted the implementation of the programme.

The NWSDB proposed to overcome these difficulties by privatizing its operation and maintenance activities through a limited liability company. However, this has still not been approved due to political and social pressure.

INVESTMENT

As mentioned earlier, investment in water supply has increased over ten-fold since the 1970s. However, if potable water is to be provided for all by the year 2000, Sri Lanka will have to invest 25 times more than at present. The estimated population to be served by the year 2000 is 135 million and the investment required is in the range of Rs. 25,130 million (US$ 546 million). This works out to a *per capita* cost of Rs. 1864, which is very high considering the percentage of dissatisfaction both in the urban and rural areas. Of the above total investment, 47% is for the urban sector and 59% for the rural areas.

Water supply scheme in Kirindi Oya Irrigation Settlement Project

The best example of a donor-funded rural water supply scheme is this irrigation settlement project in the southern part of Sri Lanka. The donors funded Rs. 46 million (US$ 1 million) to provide piped water to 4200 families, with 10-12 families per stand post. Three years after implementation, the donors are faced with the problem of broken stand posts, lack of water in the feeder reservoir in the dry season and inequitable distribution due to political pressure, all of which has created problems for the sustainability of the project. During the last dry season, the old settlement area (outside the 4200 families) obtained one water rotation from the dead storage of the reservoir, through political pressure. This reduced the dead storage by one-third, affecting the domestic water supply of the new settlement because a lot of sediment was pumped into the water filtration system, which had to be replaced at an estimated cost of Rs. 100,000 (US$ 2173).

ALTERNATIVE

With such high investment, unpredictability and instability, the Government of Sri Lanka needs to look for long-term sustainable, cost-effective systems of water supply. There are many places in the rural areas where rainwater catchment systems (RWCS) would be more appropriate than a piped water supply; one such location is the Kirindi Oya irrigation settlement. With a high degree of dissatisfaction due to social, political and technical problems, especially in drought years, a community sustainable rainwater catchment system would have been more appropriate. At a liberal estimate of Rs. 10,000 (US$ 217) per cistern of 3.5 m^3 capacity, the total cost of providing a cistern to each family would amount to only Rs. 42 million (US$ 0.91 million) which means a saving of Rs. 4 million (US$ 0.089 million). This calculation is based on the assumption that the project would be funded by a donor. But many rainwater catchment projects are community based and constructed on a self-help basis; the cost of projects is reduced through community participation.

This does not mean that rainwater catchment can replace other sources of domestic water in the rural areas, but much of Sri Lanka receives enough rainfall during the year to establish rainwater catchment systems. What is lacking is community acceptance and participation. An irrigation settlement project is one of the easiest places to enlist community participation. From the start, all agricultural activities require a participatory approach, so an institutional arrangement is already in place to implement a participatory RWCS programme.

RWCS is, of course, costly if one considers the per unit cost for each family. However, in the long run, when considering the drawbacks of other domestic water supply systems, RWCS can be a more sustainable alternative. In the Kirindi Oya irrigation settlement, the donors had to supply additional funds to rehabilitate the programme after the stand posts were damaged. This type of damage will not occur for individually owned RWCS units. The operational and management expenses of RWCS are negligible compared to other water supply systems. In rural Sri Lanka, surface water is primarily used for irrigated agriculture. Since 1989, even ground water, which was not used for agriculture before, is in great demand for irrigation (through agricultural wells), so an unlimited supply from either source in the future is questionable. Therefore, alternative sustainable sources are urgently needed to provide domestic water in the rural areas. RWCS could be the ideal alternative both on the small scale, as in the case of the Kirindi Oya irrigation settlement, or on the large scale, with potential for implementation throughout the country. The assistance of NGOs could be sought to establish self-help schemes on the large scale.

In 1985, IDRC proposed three locations in Sri Lanka for RWCS pilot projects, to be undertaken with the assistance of Sarvodaya (the largest single NGO in Sri Lanka, with over 4000 villages in its network), which would establish self-help schemes to implement 50 rainwater catchment cisterns. Unfortunately, this proposal was never followed through.

CONCLUSION

If Sri Lanka is to provide potable water to all by the year 2000, it will have to make use of natural precipitation through rainwater catchment systems, and enlist full community participation. As the demand for surface and ground water increases with intensified agriculture, the availability of these two traditional sources for domestic water will decrease. This will exert pressure to make use of the only untapped available water source. The technical feasibility of RWCS has already been proved. International and national donor agencies should consider this vast resource to supplement their on-going water supply programmes, if they intend to achieve the target by the year 2000.

REFERENCES

Appan, A. (1985). Preliminary Investigations for Establishing Roof Water Monitoring Stations in South East Asia. Proposal prepared for IDRC.

Intermediate Technology Development Group. (1992). Assessment of the Application of Appropriate Technologies in the Improvement of Rural Water Supply in Sri Lanka - Some Proposals.

Ministry of Finance and Planning. *Public Investment Programmes* 1988-1992, 1989-1993, 1991-1995. National Planning Division, Colombo.

RAINWATER COLLECTION PRACTICES IN BANGLADESH

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ABSTRACT

Some villages in the police district of Dacope in the Sundarban area were surveyed to find out the present practices of storage for rainwater. It was found that people in this area are interested in storing rainwater during the dry periods and have practiced it for a long time. The roofs of domestic houses are used for the collection of rainwater and gutters are made of different locally available materials. Normally big earthenware jars of 100-500 litres capacity are used for storage to supply water for the long (3-4 months) dry season. Wealthy families (about 4%) in the area buy 10-30 big jars for storing water. Rainwater is mainly used for drinking and cooking purposes.

Gutters made of bamboo, the bark of banana trees and palm wood, galvanized sheets (20 gauge), are used to divert roof water into the collector. A small pitcher (15-20 l) called *kalshi*, is used to fetch water from nearby water sources. Roofs are mostly made of paddy straw or corrugated iron sheets. The cost of the gutters varies from Tk.50 to Tk.300 and the average cost of roofs varies from Tk.500 to more than Tk.10,000 (US# 1 = Tk.38). Forest and hilly areas are the best potential places for harvesting rainwater; people there also use rainwater from ditches. Bangladesh has 14,000km^2 forest, 18,079km^2 of hilly areas and 5890km^2 is coastal area. Normally women are engaged in collecting and harvesting rainwater.

INTRODUCTION

The scarcity of safe drinking water in some areas of Bangladesh - coastal, hilly, and forest areas - is very acute around the year and the problem becomes serious during the dry season (September to March). Water, though available during the rainy season, is not drinkable due to mixing with domestic and other wastes from the densely populated villages. Surface water in coastal regions has a severe salinity problem (Hussain, Ziauddin and Ali, 1988).

Therefore a study was undertaken in the areas mentioned above to identify storage systems, people's interest, type of gutters, the state of roofs and economic conditions (Hussain and Ziauddin, 1992).

As the duration of rainfall is limited to the months of April to August each year, storage facilities should be available to provide safe drinking water to solve the acute problem in dry seasons. Rainwater can easily be harvested, stored and treated for use, in different countries (Pacey and Cullis, 1986). Bangladesh has 14,000km^2 of forest, 18,079km^2 of hilly areas and 5,890km^2 of coastal area potentially available, according to the BBS report (1987).

FIELD SURVEY

Field surveys were conducted in Sundarban coastal area, Sylhet hilly area and Bhawal forest area with the following results.

Storage practice

In Sundarban area people store rainwater in a small pitcher for short periods. The wealthy store water in many big earthenware jars for 3-4 months. In the hilly area people do not use rainwater directly, but they do use rainwater from a small canal at the foot of the hills. In the forest area, people use rainwater from ditches.

Roof condition

The general state of the roofs of houses is very poor.

Table 1. The state of roofs condition in selected areas.

Location	*C.I. sheet roof*	*Thatched roof*	*Area (m^2)*
Sundarban (20 families)	10%	90%	25 - 40
Hilly (20 families)	5%	95%	20 - 32
Forest (20 families)	-	100%	15 - 24

The average family size in the areas is about 6.1, which is higher than the average family size of 5.82 for Bangladesh as a whole (BBS, 1987). Most houses have thatched roofs and only a very small number use corrugated iron sheets.

Gutters and their cost

Different types of gutters are used in Sundarban area such as bamboo, palm, bark of banana tree, wooden, and galvanized iron sheet. During the survey period the following information was obtained:

Table 2. Cost of gutters in the survey areas (Tk).

Gutter material	*Material cost*	*Manufacturing cost*	*Total cost*	*Useable life*
Bamboo	40	self	40	3-4 months
Palm tree	230	50	280	More than 5 years
Bark of banana tree	-	-	-	1-5 days
Wooden	100	50	100	2-3 years
G.I. sheet	150	80	230	4-5 years

Gutters of bamboo and bark of banana trees are used by the very poor people and their life is very short. Palm tree, wooden and G.I. sheet gutters are used by the villagers who have a good income and land or property. A gutter from a palm tree is very strong but costly for the villagers, and only 2-10% of people have access to it. G.I. sheet gutters are rarely found and they need technical know-how to make. Wooden gutters are available for well-to-do farmers, and are made by the villager carpenter.

Collectors and their cost

Normally the village people use *motka* (earthenware jars) of different sizes and a pitcher (*kalshi*). A pitcher is used to fetch water from an outside source. Landless people are unable to buy earthenware jars and they cannot store water.

Table 3. Cost of different types of rainwater storage structures.

Type of collector	*Total cost (Tk)*	*Capacity (litres)*
Earthenware jars		
1	100	100
2	200	150
3	300	250
4	500	500
Pitcher	25	10
Tub (plastic)	80	20

The life of an individual item depends on the nature of use; if safely used they can last for many years.

Maintenance

Due to lack of maintenance and careless use, sometimes the water in the earthenware jar becomes contaminated with toads/frogs, mosquitoes, cockroaches or rats. The jar should be kept covered at all times either with a lid or polyethylene sheet. Periodic cleaning is necessary, but rarely practised.

Training

Most of the villagers are uneducated. They don't know when or how to collect water, how to store it or how to use the stored water. Therefore, a proper training programme should be launched to educate them in water collection and storage. There is no problem with collecting water from a corrugated iron roof, but water from thatched roofs is contaminated with straw and discoloured.

Water quality control practices

Drinking water quality control was not very common in Bangladesh as a whole. Only a very few village people tried to maintain quality of water due to the fear of water-borne diseases. Biological, chemical, filtration and sedimentation were some of the methods of water quality control practised.

Biological control
A special kind of fish known locally as *Koi, Sing* or *Magur* was allowed to grow in the stored water which ate the larva of mosquitoes and other insects. On the other hand, the fishes discharged their own excreta into the water which caused deterioration in the quality of the drinking water.

Chemical treatments
Lime or alum is used to purify water. A few households in the area developed a technique to maintain the quality of stored water by treating it with about 25g/200 litre of burnt snail shell.

Filtration
Several types of filter elements such as a piece of cloth or mosquito netting were used to filter water. In hilly and forest areas a sand filter unit was used to filter rainwater before it was consumed. Pond water was also sometimes filtered to separate suspended particles before drinking. Sedimentation or boiling were also practised before river or canal water was consumed.

Cost of different sources of water

Table 4 shows a cost comparison of different types of water sources in Sundarban area. The cost was calculated on the basis of a consumption rate of 3 litres/person/day for a family of seven members. The cost of drinking water storage facilities, labour cost for collection, repair and maintenance cost and installation cost, whenever appropriate were also considered. Tax and insurance costs were not included in the computation because these were not practised locally. The straight line method was used in cost computation. Results indicated that a better quality of drinking water is supplied either by rainwater catchment or the DPHE-UNICEF sand filter method. Table 4 shows that rainwater catchment was found to be more economic than the DPHE-UNICEF sand filter system.

SOCIAL ASPECTS OF RAINWATER USE

1. Some houses use rainwater for cooking because they find it easy to boil food grains and it takes less time to cook vegetables and pulses. Rainwater is very popular for the preparation of tea. Villagers also reported that food cooked in rainwater tastes better.
2. During the rainy season roads become muddy; this hinders villagers going outside the house to fetch drinking water and they prefer to collect and drink rainwater from roof catchment.
3. Some village people are physically resistant to disease organisms usually present in pond, river or canal water. Thus, it was hard to convince them of the difference between pure and impure water. However, some villagers did realize the benefit of drinking good quality water.
4. About 75% of rainwater consumers wanted to build better and larger rainwater storage units for private use. Most people assumed that it is the responsibility of government to provide

Table 4. Comparative cost of different types of water.

Type of water source	*Average water cost (Tk./litre)*
Pond	0.254
River	0.045
Canal/ditch	0.045
Rainwater	
Roof discharge	0.290
Open sky catchment	0.300
Hand tube well	0 285
DPHE-UNICEF sand filter system	0.321

pure drinking water to the villagers. Only a limited number of households wanted to get a bank loan with a very low interest rate to establish a drinking water storage facility.

5. Seasonal variation had a significant effect on consumption of various sources of drinking water. About 35.5% households had been drinking rainwater in the rainy season but in the dry season the figure fell to 2.4%, which means that only 2.4% of households had been drinking rainwater throughout the year. This was due to non-availability of rainwater in the dry season and lack of proper storage facilities.
6. It was observed that women in the village had a significant role in the collection of drinking water. Society assumed that collection of drinking water was a woman's job. Sometimes women went to distant places to fetch drinking water with a pitcher on their heads.

RECOMMENDATIONS

1. This study was conducted in limited areas. A more extensive study might be undertaken to train people in hilly and forest areas in the collection of rainwater and development of storage structures.
2. People in the study areas showed an interest in using rainwater but lacked facilities. For poor farmers, low cost rainwater storage facilities could solve the drinking water problem in the area.
3. People who have thatched roofs could use a polythene sheet on the roof for the collection of safe rainwater; or a clean tarpaulin as a rainwater collector.
4. Family members should be trained to maintain the quality of stored water.
5. No significant lack of interest was found regarding rain water use. The consumption of rainwater will be socially and culturally accepted.
6. Normally rainwater does not have any minerals essential for the human body. These should be added to the rainwater from time-to-time.

REFERENCES

Bangladesh Bureau of Statistics (1987). *Statistical Year Book of Bangladesh.* Government of Peoples Republic of Bangladesh.

Hussain, M.D., **Ziauddin, A.T.M.** and **Ali, M.R.** (1988). *Rainwater Use in Bangladesh - A Case Study in Dacope Upazila.* Research report No. 8, Department of Farm Power and Machinery. Bangladesh Agricultural University.

Hussain, M.D. and **Ziauddin, A.T.M.** (1992). Rainwater Harvesting and Storage Techniques from Bangladesh. *Water Lines*, **10**, (3). London.

Pacey, A. and **Cullis, A.** (1986). *Rain Water Harvesting*. Intermediate Technology Publication. 9 King Street, London.

A COMMUNITY APPROACH TO BUILDING RAINWATER CISTERNS

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ABSTRACT

When developing community water and sanitation programmes there is a tendency for agencies to concentrate on design and building, whilst local initiatives to implement traditional or new methods may not achieve quality and value. The challenge is to make agencies more sympathetic to the community and the community more receptive to good design and building methods.

In the Diocese of Nakuru there are relics of agency programmes and unsatisfactory community designed and built cisterns. The paper discusses how the Diocese has overcome the inherent problems that beset agencies, by successfully combining local skills, tradition, and initiative with proven rainwater cistern systems.

As part of the comprehensive development programme the Diocese trains both traditional community groups and self-employed builders to achieve a sustainable high quality water supply.

INTRODUCTION

Kenya has received aid to fund low-cost technologies from various donors, who have their own philosophies, objectives and ways of working within the country. Some run their own programmes, some fund government-run programmes, and others put money into local NGOs and churches. Due to the proliferation of funding organizations and methods of funding there are different approaches and technologies being practised in Kenya.

The number of donor agencies who have funded rainwater harvesting projects is also large. Many donors and recipient organizations have their own fixed ideas on rainwater harvesting. Due to the rush for results, many mistakes have been repeated and no collective knowledge, experience and research has been built up.

The vast majority of externally funded rainwater harvesting projects have employed people directly to build the cisterns, e.g. the KIDP sponsored project in Kitui (Gould, 1991), or employed the recipients to build bunds for themselves, e.g. the Turkana Rehabilitation Project (Cullis and Pacey, 1992). This had led to few cisterns being built by the community with their own finances after the projects have finished.

European settlers in Kenya often built or made rainwater cisterns to supply water for their own domestic uses. Many of these rainwater cisterns were made of corrugated iron sheets with a capacity of $5m^3$. Local Kenyans were taught to make these cisterns by the settlers and the skills were passed on, so that as a result corrugated iron cisterns are widely made and used by Kenyans in both cities and the countryside. As these iron cisterns have a number of disadvantages (which will be considered later), more enterprising individuals and community groups started to build permanent cisterns made from a variety of materials like stone, brick and concrete. Often people built to their own design and used ideas obtained from cisterns seen elsewhere. Surprisingly, only a few of these cisterns have collapsed although many lack features which keep the water clean. Obviously there is the ability to build cisterns and an appreciation of their advantages already in the community.

The CPK diocese of Nakuru Community Development Programme

The Diocese of Nakuru started a development programme during the 1984 drought which has grown to cover approximately 16,000km^2. The average rainfall within the programme area is between 500mm and 1200mm; the communities are predominantly settled agriculturalists owning farms ranging in size between 0.5 and 4 hectares.

To help communities improve all aspects of their life the programme has extensionists specialized in health, agriculture, and water development (called technical trainers). On a smallholding all these disciplines are interdependent and play an important role in the improvement of a household.

The water section of the development programme maintains an open mind in selecting which water source is the most appropriate to develop in a particular area. A number of considerations must be taken into account: the wealth of the community, the official and unofficial organization within the community, what the community perceives their needs are, and how they think they can fulfil them. A number of technologies have been developed within the programme area: boreholes, hand-dug wells, springs, dams and rainwater cisterns. Any water development is always accompanied by teaching, and building improved sanitation facilities.

Due to the depth and variations of ground water, the cost of its development, and the problems of reliability and maintenance of pumps, borehole and hand-dug wells are rarely an option; springs and dams are restricted to particular areas which have a suitable geography. Thus rainwater cisterns are often the most attractive option.

The programme has had a problem with the variety of designs within its area. It would be impractical to train the programme's technical trainers on all the designs and this is confusing to the community; therefore it was decided to concentrate on seven designs (in Table 1). These designs are either locally developed and proven designs, or adopted and adapted designs of other agencies like the UNICEF Kenya ferrocement cistern.

Table 1. Tank types recommended by the programme

Tank type	*Size (m^3)*	*Roof*	*Cost of tank*		*Cost of roof*	
			Kshs	*US$*	*Kshs*	*US$*
Masonry	14	Ferro-cement	15,000	215	7,000	100
Masonry	20	Ferro-cement	30,000	428	8,000	114
Sub-surface hemispherical (chicken wire/ cement)	90	Ferro-cement	18,000	257	20,000	286
Sub-surface hemispherical (rough stones/cement)	90	Live	18,000	257	2,000	28
Ferrocement	20	Ferro-cement	20,000	286	10,000	143
Water jar	2	N/A	7,000	100	N/A	N/A

US# 1 = Kshs 70 (Interbank rate, April 1993).

The reason for the exclusion of the prefabricated corrugated iron cistern mentioned earlier, is that at Kshs 12,000 ($ 170) and with a life span of 2-5 years, they are an expensive investment in the long term. In keeping with the programme's flexible approach, communities who have no safe water and want a stop-gap may be encouraged to buy corrugated iron cisterns.

The programme has always had a strong emphasis on training. The philosophy is to educate the community about the different options they have and then to train them to carry out whatever they decide. The programme does not have to give financial support or material help-just knowledge; as a result if the programme withdrew suddenly no harm would be done and the community could continue with the knowledge already imparted.

DESIGN

The cost of a cistern can be minimized by using the cheapest and most readily available local material. Throughout large areas of the Rift Valley stone is quarried and as a result it is not expensive and requires little transport. Where stone is not readily available other building materials such as rubble stones or ferrocement may be cheaper. Thus the programme is flexible enough to be able to advise the community how to build with a range of materials.

An illustration of how the programme has adapted with changing economic circumstances is the *adobe* cistern. Between 1984 and 1989, the programme encouraged and taught how *adobe* blocks (sun dried earth blocks) are made, and how to use them to build $14m^3$ round standing cisterns. These were, at the time the cheapest cistern which could be built as the materials which had to be bought were mainly limited to chicken wire and cement. Then followed several large increases in the price of chicken wire and it became cheaper to buy, transport and build stone cisterns rather than buy chicken wire.

Agencies prefer to have one design which can be replicated throughout its area of operation, which allows for simpler training, easier supply of materials, and standard procedures. The design does not use local materials, and is nearly always built using ferrocement or concrete.

The rigid agency approach has led to a situation in an area called Roda,just outside Nakuru town, where a community-based project is building stone cisterns as there are quarries for both stone and sand in the vicinity. However an agency has started a ferrocement cistern building project. The ferrocement cisterns cost three times as much to build as stone, for the same volume (Mbugua, 1991), so the agency is having to pay nearly all the material costs as an incentive. The people who have the ferrocement cisterns freely admit that they would have built a stone cistern if the agency had not given such a large incentive. This approach is giving neither value for money for the agency; nor encouraging the community to become self-sufficient.

The programme's technical trainers can use the chart shown in Figure 1, knowledge of successful cistern sizes in the immediate area, and whether the cistern will be used for irrigation, watering cows, domestic purposes, etc. to suggest a suitable cistern size. As a result the programme has four standard cistern sizes (see Table 1) ranging between $2m^3$ and $90m^3$. To improve and develop the designs to enable the stored water to meet WHO guidelines (WHO, 1985) the programme has a small mobile water testing laboratory. It has often been observed that groups who start building $14m^3$ cisterns will soon move on to building $20m^3$ cistens as they appreciate the benefits that a good water supply brings. Increasing the volume of cisterns can lead to disaster, as the need to increase the strength and reinforcement is not always appreciated by the builder. It is therefore important for the technical trainer to be there to advise.

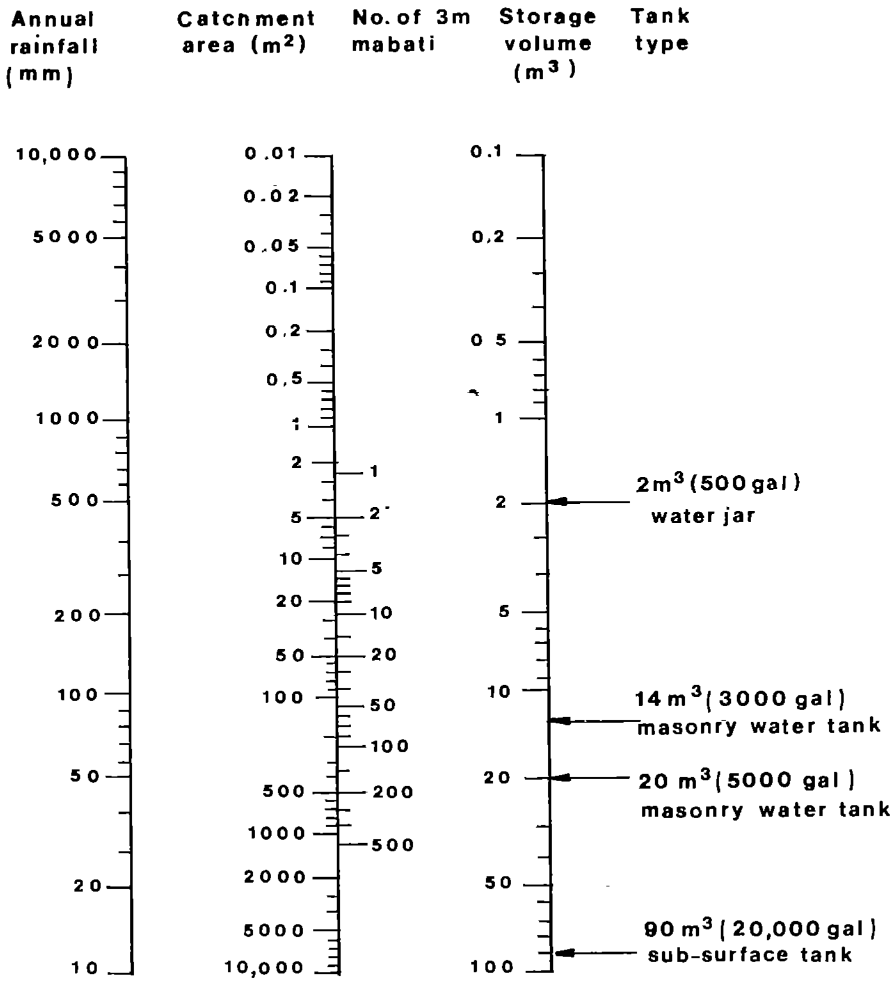

Figure 1. Chart to determine the size of the tank. (adapted from Fok, 1989).

In the dry (700mm) northern area of the programme which has an erratic rainfall pattern, cisterns were required to collect road runoff to be used for irrigation. A $90m^3$ sub-surface hemispherical design was developed which is lined with chicken wire and cement or rough stones, depending on the soil's clay content.

The programme stresses that to keep water from being contaminated a good roof is required. Various types of roof can be seen in the programme area, but the one which the programme now recommends is the ferrocement roof. These roofs are expensive, often costing as much as the cistern itself, but the advantage is that the cistern is totally sealed. Corrugated iron roofs are common but they are almost impossible to seal. The authors have seen dead lizards, insects and other creatures in "sealed" corrugated-iron roofed cisterns. The ferrocement roof if built according to the UNICEF Kenya method, which has been adapted to fit masonry, and even sub-surface hemispherical cisterns. If the cistern is not going to be used for domestic purposes a roof frame to support plants is suggested, to provide shade and thus reduce evaporation loss. However mosquitoes can breed and pollution from the wind and small animals can occur.

It is important that the water collection method is adequate. A locally devised anti-splash system (Nissen-Petersen and Lee, 1990) is advised, together with a first flush arrangement.

Finally the outlet must go through the foundation slab of any standing cistern. Those which have the outlet going through the wall invariably leak due to the tap being hit; this causes the seal between outlet pipe and cistern wall to be broken. If the outlet pipe goes through the foundations it is many times stronger and is protected from damage. With sub-surface cisterns a water pump is required. The programme recommends the locally manufactured Rower pump, which has proved very popular in the communities and costs only Kshs 2100 (US$ 30), (Cumberlege, 1993).

THE COMMUNITY

The programme only works with community groups which have formed under their own initiative. If there is no group in an area the technical trainer may encourage them to form one by explaining the benefits on occasions when the community meets, like at church or chief's *barazas* (meetings).

The community group is a traditional method of mutual aid especially amongst women, and since independence it has been encouraged by the Government. These groups have a membership of between 12 and 70 and are both single-sex and mixed, although about 90% are all women; they meet at regular intervals usually once a week. Members contribute an agreed amount of money monthly to a central pool to purchase materials to build a member a rainwater cistern. The groups have a wide range of self-devised rules and regulations, for example, fines for being late to a meeting. The way the members choose who will get the next cistern varies considerably; sometimes a lottery is drawn, other times people with a disability are preferred.

The group will always try and reduce its costs one way is to do all the unskilled labour itself. When the group meets tasks like digging out the foundations, mixing cement and carrying materials are all done by the members. In addition the members will supply materials such as sand and aggregate, where they are locally available.

The concept of clean potable water is not understood. Communities often say clean water is clear water, i.e. with a low turbidity. As a result roofs are not felt to be a must. Other aspects of cisterns are not fully appreciated, such as the need to clean the cistern annually to maintain water quality.

The community requires an accessible clean supply of water, particularly during the planting season as this is the most labour-intensive time of the year. Planting takes place when the first rains come, so cisterns are replenishing. If the cistern runs dry in the dry season it is not as critical as there is not so much work to be done on the land (Pacey and Cullis, 1986). However it does not take long for families to learn how to ration their water. After a couple of years, families tend to purchase or build further cisterns to reduce the likelihood of running out of water.

It is important for the programme's technical trainers to tread carefully when first dealing with a group. They must first gain their trust and understand their politics. Through teaching and training they encourage groups to start building cisterns. In some instances it has taken up to 3 years from first meeting a group until the first cistern has been built.

The technical trainers meet the group approximately once a month. They suggest suitable cistern sizes and design, recommend self-employed builders called Masons *(fundis)* in the area who have a good track record, teach the importance of roofs, good gutters, first flush systems, improved latrines etc. They will explain how the design the community has chosen ought to be built and the materials required. Thus the community has the knowledge to check the *fundi* and thus feel more in control. In one instance a *fundi* persuaded a group to use fewer bags of cement than the technical trainer had recommended. The cistern soon cracked and started leaking, resulting in its demolition, the sacking of the *fundi*, increased trust in the technical trainer.

Due to the immediate demand for cisterns by all the members and the perceived unimportance of roofs, often a cistern is built for every member before any roofs are put on. Therefore technical trainers encourage every member of the group, after completing a cistern, to put a roof on it. If the programme insisted on a roof at the beginning it might alienate itself from the group.

Another very successful method of training the community is a called "training by exposure". In areas where there are no cisterns the programme will build a cistern at the church and at the school; people are then exposed to the cisterns and their benefits. Another example is the policy of taking some members from a new group to see members of another established group. Once the visitors see other people in a similar situation to themselves, building cisterns, the visitors return with great zeal to do it themselves. These trips have proved to be simple, cheap and an effective way to train and encourage. The programme has never felt the need for a demonstration centre.

It is not good enough to just train the community, due to the reliance placed on *fundis* they too must be trained. The *fundis* have a wide range of official training and education, as well as varied experience. When a technical trainer visits a group he will talk to the *fundi* and explain any design errors he is making and alterations in building method required. The programme will attach an unexperienced *fundi* in building a particular cistern design with one who is building that type of cistern. Finally residential courses have been held which teach the *fundis* the reasoning behind the designs. Together with the programme, they can then help persuade groups to put proper gutters on houses and roofs on cisterns. The courses also introduce *fundis* to new technologies and ideas.

Two examples of the programme's success follow. In Ng'arua, which is 70km north of Nakuru and has an erratic rainfall (700mm average), two groups of 50 and 40 members have been building sub-surface hemispherical cisterns since 1985. Only recently with the completion of most tanks and the introduction of a cheap pump have the benefits of the cisterns become apparent. Over the last year 10 new groups have started building 16 tanks without the programme's direct involvement.

The second example (Ndegwa, 1991) is a community at Pwani 15km west of Nakuru town where the first group started to build standing $14m^3$ cisterns in 1987. In May 1991 at least 700 cisterns had been completed in the area. The programme is in contact with 17 groups who have completed 616 cisterns; by May 1993, the number of groups in the area had increased to 53.

CONCLUSION

An approach to developing rainwater cisterns in an area which puts the community first has much better long-term success than the typical agency approach. The community approach takes a lot longer and thus requires patience by donors and high motivation and good communication skills by local staff.

The technical side of the rainwater cisterns building programme is important but has been over-emphasized in the past. The design must be flexible, cheap and as simple as possible to build.

Around Nakuru, the area is being settled by households who can afford a cistern over a 3-5 year period; the programme had to put relatively little money into building cisterns. This comparative wealth has led to cisterns being built by groups who are not in contact with the programme, but the idea and design have come from groups who are, so snowballing occurs. It must be accepted that this low aid approach will enable a maximum of about 80% of the community to build cisterns.

With the knowledge and skills left in the community by the programme, rainwater cisterns will be the safest, most cost-effective and most popular source of domestic water long after the programme finishes.

REFERENCES

Cullis, A. and **Pacey, A.** (1992). *A Development Dialogue: Rainwater Harvesting in Turkana*, IT Publications, London.

Cumberlege, O. (1993). Making Every Drop Count. *Waterlines*, **11**, (3), 23-26, IT Publications London.

Fok, Y.S. (1989). International Drinking Water Supply and Sanitation Decade and the Progress of Rainwater Cistern Systems. *Proc. Fourth Int. Conf. on Rainwater cistern systems*, Manila, Philippines, 2-4 August, A1-1-16.

Gould, J. (1991). Rainwater Catchment Systems for Household Water Supply. *Environmental Sanitation Reviews*, No. 32. Environmental Sanitation Information Centre, Thailand.

Mbugua. J. (1991). The Diocese of Nakuru Rainwater Harvesting Project. *Proc 1st Nat Workshop on Rainwater Harvesting*, p.24. CPK Diocese of Nakuru.

Ndegwa, J. (1991). The Pwani Community Rainwater Catchment Project - a Case Study. *Proc 1st Nat Workshop on Rainwater Harvesting*, p. 66. CPK Diocese of Nakuru.

Nissen-Petersen, E and **Lee, M.** (1990). Water Tanks with Guttering and Hand-pump. Manual No. 1, *Harvesting Rainwater in Semi-arid Africa*. Nairobi.

Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas*. IT Publications, London.

WHO (1985). *Guidelines for Drinking Water Quality*, vol. 1, *Recommendations*. World Health Organisation, Geneva.

COMMUNITY PARTICIPATION IN RAINWATER CISTERN SYSTEMS

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ABSTRACT

It is a long time since international aid agencies and government organizations in developing countries realized the importance of community participation in every water project. In spite of this, important issues such as how to motivate communities, and what contributions and responsibilities they should assume, remain only partially solved.

Significant progress has been made in rainwater catchment systems "hardware", namely the development of low cost appropriate tank designs and construction techniques. But the "software" aspects of rainwater catchment implementation have not been well documented.

This paper looks at various approaches to Community participation, which is an effective means of delivering basic services, because of its principle of collective planning, involvement and participation. It also focuses on methods of overcoming constraints by conducting preliminary surveys, promoting awareness of, and interest in rainwater cisterns, setting up organizational frameworks and identifying skills and resources at grassroots level.

INTRODUCTION

The renewed interest in rainwater collection technologies during the last decade has resulted in a rapid growth in the literature on this topic. However, up to now, the majority of articles have been concerned with what we term the "hardware" aspects of rainwater catchment systems, namely their construction and design, which are, of course, extremely important.

But there is a growing awareness that technical information alone is not enough for a successful implementation programme. Unlike the "hardware", which can often be easily modified and replicated anywhere, the "software" aspects of successful rainwater catchment implementation strategies are difficult to replicate in different communities. Thus community participation should be the entry point of any community-based project. In promoting community participation the promoter must help as many community members as possible to be actively involved in all parts of planning, carrying out and evaluating the actions it takes to solve its problems.

The promoter helps the community:

- To organize itself so as many people as possible can participate;
- To train its members to participate; and
- To make it easier for its members to participate.

PARTICIPATION

Participation in rainwater catchment systems is generally in the form of cash, provision of labour, community inputs of locally available resources, decision-making in planning and implementation, and anything agreed to by the community and the external agent during the project planning stage. They depend on various factors including the socio-economic status of a community, past experience, comparative benefits, initiative of the external agent, the location of the project, war, the culture and religion of the people, local values and preferences, the influence of both formal and informal leaders, and the community's priority needs.

Training

To promote a rainwater catchment programme through community participation, training is very important. Some of the issues to be addressed include: good organization, logistic preparation and support. There should be close contact between the training team and the community throughout the programme, and the training should not be so long as to run the risk of participants losing their enthusiasm and interest. The construction work should start as early as possible in order to have some spare time towards the end of training. A manual compiled by the participants is recommended as it serves as a starting point, and the participants are proud of their work.

Guidelines to successful rainwater catchment systems

Most rainwater projects begin in a small way and grow slowly, developing into bigger systems by changing designs, and implementation strategies.

Projects which involve the community from the outset in planning, implementing and maintaining the system have a greater chance of being sustainable; than those that are predominantly by local people have a far higher success rate than those set up and run by oursiders. Experience has shown that the project will be successful where there is a real "felt need" for water. Projects where the idea of contributing funds is not new to the community have a much better record of success than those supported entirely from external sources.

FAILURE OF COMMUNITY-BASED PROJECTS

Some of the obstacles and constraints encoutered include:

- Reluctance of governments and international funding bodies to support small-scale scattered projects at the grass roots;
- Social feasibility;
- Biased implementation procedure;
- Failure of the external agent to provide adequate information and skills;
- Wrong technologies being beyond the capacity of a community to operate and maintain;
- Security situation of the country;
- Lack of an integrated approach in project implementation;
- Political and leadership changes.

CONCLUSION

Although the international climate has become unfavourable for small-scale rural initiatives, including rainwater catchment systems, the latter can make a positive impact if an appropriate approach is adopted. Successful widespread implementation in any region depends on the following conditions:

- Hydrological suitability;
- The design should be simple and affordable;
- There should be a real felt need in the project area;
- A successful assessment of technical, economic and social feasibility;
- Effective management training, and sufficient financial support to ensure tank construction can proceed without any problems;
- From the beginning people should be helped to develop the skills that they need to act independently, and not to depend on outside agents;
- Starting with the first meeting, community members should understand that the project team is there to help them carry out a project, not to do it for them.

The first two of these conditions are physical factors relating to the "hardware" of the rainwater collection system, the rest can be described as "software" factors. From experience these may not be obvious but are just as important in determining the success of any project. It is therefore, imperative that policy makers, planners and implementers give as much of their attention to the "software" side of rainwater catchment implementation as to its "hardware".

REFERENCES

(1989). *Proc Fourth Int. Conf on Rainwater Cistern Systems.* Manila, Philippines

Wash Technical, Report No. 33. (1988). *A Workshop Design for Community Participation.* Vol.I, Starting Work with Communities.

Wash Technical Report, No. 33. (1988). *A Workshop Design for Community Participation.* Vol.II, Planning and Implementing Sustainable Projects.

Watt S.B. (1987). *Ferrocement Water Tanks and Their Construction.* IT. Publications, London.

THE ROLE OF RURAL WOMEN IN THE DEVELOPMENT AND SUSTAINABILITY OF RAINWATER CATCHMENT SYSTEMS

Jackson Thoya

ABSTRACT

It is a recognized fact that most countries of the developing world face diverse constraints in trying to supply adequate clean piped water to rural communities. It may be not only economical - but also necessary - to establish self-help community-based rainwater catchment projects. However, such projects are not easy to initiate and manage. Many rural programmes in different geographical zones have floundered; several reasons can be advanced to account for their failure.

Accepting, then that community-based projects are essential, and more feasible, we base the discussion on the key roles of rural women in the development and sustainability of rainwater catchment systems. Considering that rural women probably form more than 50% of the rural population due to higher male out-migration and mortality rates, it logically follows that women are the key actors. This is underlined when we consider that water is of particular importance to women (especially rural women) since they are the sole providers of water for domestic usage.

The need and importance of involving women in rural water projects is stressed, especially the significant roles which women can and should play in the implementation and general sustainability of such projects. This, together with the realization that initiating water projects which are compatible with the people's culture and gender roles, and which draw on local resources - human and financial - is a sure way of achieving sustainability. So, meaningful sustainability of most rural projects - water included - is only possible when women, as the key actors, are identified as the target group.

INTRODUCTION

From early civilization people have settled close to water sources because water is essential for survival. However, the water may be contaminated or unreliable, or not available at all, particularly for rural communities in the developing world. In spite of this, it has not been environmentally, economically or technically feasible to develop safe and reliable water systems in most rural areas. Serious constraints stand in the way of efforts to expand and sustain water supply systems which include: organizational, financial, environmental, administrative, technical and lack of community participation; the size of the task, in itself, constitutes an enormous obstacle.

Considering all these difficulties, the need to initiate and sustain self-help water catchment systems becomes evident. This paper, therefore underscores the importance of rainwater harvesting, which could go a long way towards providing much needed clean water mainly for domestic usage, - particularly in rural areas - and the role the women could play.

Rainwater harvesting and storage - which has attracted considerable attention in recent years - is almost 4000 years old (NAS, 1981; Omwenga 1984) and in some tropical regions rainwater continues to provide the only source of domestic water supply. But for rainwater harvesting systems to be of long-term significance, storage must be an integral part of the project because rainfall is seasonal almost everywhere, and inadequate storage facilities render the system useless in drought seasons. It is generally agreed that the conservation of rainwater represents the most practical and economical source of new water supply.

WOMEN AND DEVELOPMENT

Including gender issues in this paper is a consequence of the realization of the critical importance of the development and management of improved water resources on women - and children. In "traditional" African communities, fetching water is one of the many duties relegated to women, and sometimes children. Hence, since women are more directly affected by the hardships of fetching water, men and women quite often view the benefits of rainwater harvesting and storage differently (Pacey and Cullis, 1986).

It is, however, crucial to point out that the benefits of rainwater harvesting are by no means confined to women and children. An adequate supply of safe water is a prerequisite for significant socio-economic development of a community because water supply projects support multi-sectoral developments, i.e. in health, land use, food production, employment and education (UNDP, 1990; UN Water Conference, 1977; IRC, (1981). Hence, any improved water supply will have a wide-ranging impact on the lives of the people.

It can thus be argued that the development of various sectors of a community's economy are dependent on an adequate water supply (Falkenmark, 1982). The accrued benefits of water availability include reduced morbidity and mortality due to a reduction in waterborne and water-related diseases; the release of women and children from the task of fetching water from afar leads to time and energy savings which, provided that the time and energy gained are economically utilized (in agricultural management, small home industries or child care), will result in higher productivity and income, and in turn will bring about development.

Whereas an adequate safe water supply contributes to the well- being of all community members, its absence may greatly hinder development. For instance, lack of water contributes to an increase in waterborne and water-related diseases. This may result in ill health of the labour force and thus seriously affect their productivity in all sectors of development.

Having noted that rural women are the water providers, and bearing in mind the accrued benefits, of an adequate safe water supply it could be said that there is a special relationship between women and water. So the provision of clean and accessible water to rural communities could revolutionize women's roles by fundamentally altering the existing gender division of labour. With this realization, we stress the need to consider the socio-cultural and structural aspects of the communities - including the distribution of socio-economic power and prestige at the local level - in which any water harvesting project is initiated (Ndege, 1992; Gitau, 1992; Kandawire, 1981; Matango and Mayerle, 1971).

The above line of thought underscores the importance of community participation in the planning, construction, maintenance and evaluation of any water harvesting system (Morgan, 1990; Haile, 1981). In fact community participation is the indispensable social component of any rural water supply programme. It ensures the success of the programme by fostering a sense of responsibility and ownership (Getechah, 1981; McCommon *et al.*, 1990). However, the enhancement of the capacity of local communities to assume a leading role in the planning, construction, financing and management of new water harvesting systems cannot be attained without the inclusion of women. This is partly because women are more directly affected by water issues, as stated earlier, and partly because in most rural parts of Africa, women form the majority. Hence, real and sustainable progress is only possible when women are properly recognized as an essential target group of the rural population.

The success of rainwater harvesting systems - might be a function of, among other things, the extent to which the project team is able to mobilize women and to fit in with the people's culture and gender division of labour. The mobilization process ensures an increase in community awareness, as studies in Kenya have revealed (Getechah, 1981), which contributes to achieving the success and sustainability of water harvesting systems. The type of water harvesting project, its degree of technological sophistication, implementation and management ought to conform to the cultural norms, the technical ability of community members, and the availability of skilled workers (or those who could be trained) for the successful execution and management of the project. The focus should be on women, the main beneficiaries; not only is their labour a crucial prerequisite for project implementation and sustainability, but they can also offer capital and be trained to service the project.

We must point out that technical experts have time and again failed to consider the needs of women as relevant issues in implementing water harvesting systems (UN Water Conference, 1977); this is absurd. Although the "complexities of the political, financial and technical problems involved in rural water supply are so overwhelming", and may thus overshadow women's needs, "identifying and defining the needs of rural women would clarify many development problems and provide a valuable index for measuring progress achieved in rural development" (p.791).

The inclusion of women, and their needs, in rainwater harvesting systems, which should entail their involvement in the actual planning, construction and maintenance of the system, could be a catalyst for multi-sectoral development as stated earlier and for the integration of women in wider development sectors. The integration could relieve women from traditional tasks without undermining their social status.

In the field of development of rainwater catchment systems, particularly for domestic use, and their sustainability, the roles that women can and ought to play are diverse; they range from the planning process, through the financing, construction, operation and maintenance, to evaluation. This will come about when the women's needs are emphasized, and the project draws on local resources, both human and financial. One of the essentials is the selection of appropriate technology which is simple and reliable, uses cheap and available materials and sources of energy, meets human needs, which will reduce the burden of carrying water which falls on women and children (Harlaut, 1971; World Bank, 1980, 1982).

The technical aspect is of paramount importance and needs to be emphasized (Wanyonyi, 1993). Quite often people - women in particular - are not consulted on matters of design, construction, use and maintenance of water facilities. Problems may be encountered when the technology utilized is not compatible with local conditions and the situation of women or the community as a whole. This may make the difference between achieving or not achieving success and sustainability of water systems.

CONCLUSION

The paper has touched on the crucial significance of water not only for survival but in supporting all sectors of development. It recognizes water as a "female domain" in most parts of rural

Africa. Since there is a link between the needs of women and water issues. Realising this is the reason for discussing the development of rainwater catchment systems and the roles that women can play.

We have emphasized the need to target women, as the main beneficiaries, in order to successfully involve the community in rural water harvesting systems. They should be brought into the whole decision making process, from planning, construction, operation, maintenance to evaluation of rainwater harvesting systems. It is through the effective participation of rural women that overall performance can be improved and sustained.

However, this requires gender-sensitive strategies and the compatibility of rainwater programmes with the technical, socio-cultural and structural characteristics of the community. The success and sustainability of community water project depends, not least, upon the reliance on local initiative; involvement of the community, women included; placing responsibility for the project on those who are to benefit most; giving attention to socio-political and technical factors; the installation of well- designed maintenance schemes, in accord with local conditions which rely on the community and its assumption of long-term responsibility for the water supply system (Glennie, 1983).

RECOMMENDATIONS

1. The development of any community water system - be it rainwater catchment or otherwise - should be implemented with a clear understanding of the needs of women, gender issues, and the socio-cultural, economic and structural aspects of the community to ensure compatibility, which is necessary for the success of the system.
2. The effective participation of women, the main beneficiaries of water harvesting systems, in the planning, designing, construction and overall sustainability of water systems is essential. This means women should be trained in the technical and managerial aspects of water harvesting systems.
3. The provision of water to rural communities should not only aim to relieve women of their traditional task. It should also aim to modernize their role in rural water supply by reducing the hardships while preserving the social status.
4. Rural rainwater harvesting systems which are gender sensitive should be the focal point of integrated rural development projects and thus accelerate women's integration in the overall development process.
5. Since women are the major water providers, it is crucial that research in basic and applied water technology should take account of women's needs and conditions. Water technology, which is appropriate to women's needs would ensure their active participation in rural water harvesting systems.

These recommendations, among others, could greatly improve the sustainability of rainwater harvesting systems in most communities, especially in rural areas.

REFERENCES

Falkenmark, M., Ed, (1982). Rural Water Supply and Health; The Need for a New Strategy. Scandinavian Institute of African Studies, Sweden.

Getechah, W., (1981). The Role of Women in Rural Water Development in Kenya. *Rural Water Supply in Developing Countries.* Proc. of an IDRC Workshop on training held in Zomba, Malawi. CIDA, Ottawa.

Gitau, G.N. (1992). The Role of Women as Participants and Beneficiaries of Rainfed Water Systems in Rural Kenya. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems in Kenya.* Nairobi.
Glennie, C. (1983). Village Water Supply in the Decade: Lessons from Field Experience. John Wiley and Sons, Chichester.
Haile, T. (1981). Community Participation in Rural Water Supply Development. *Rural Water Supply in Developing Countries.* Proc. of an IDRC Workshop on training held in Zomba, Malawi, CIDA, Ottawa.
Harlaut, A. (1971). Basic Considerations for the Design of Rural Water Supplies. *Proc. Conf on Rural Water Supply in East Africa.*
IRC (1981). *Small Community Water Supplies: Technology of Small Water Supply Systems in Developing Countries. International Reference Centre for Community Water Supply and Sanitation.* The Hague, Netherlands.
Kandawire, J.A.K. (1981). A Sociological Approach to Water Development. *Rural Water Supply in Developing Countries.* Proc. of an IDRC Workshop on training held in Zomba, Malawi. CIDA, Ottawa.
Matango, R.R. and **Mayerle, D.** (1971). Some Problems of Water Resource Development in Developing Countries. *Proc. Conf. on Rural Water Supply in East Africa*
McCommon, C. *et al.* (1990). *Community Management of Rural Water Supply and Sanitation Services* The World Bank, Washington.
Morgan, P. (1990). *Rural Water Supplies and Sanitation.* A text from Zimbabwe's Blair Research Laboratory. Macmillian, London.
NAS, (1981). More Water for Arid Lands: Promising Technologies and Research Opportunities. National Academy of Science, Washington DC.
Ndege, M.M. (1992). Rainwater Harvesting in Kenya - The State of the Art. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems in Kenya.* Nairobi.
Omwenga, J.M. (1984). Rainwater Harvesting for Domestic Water Supply in Kisii, Kenya. M.Sc. Thesis, Tampere University of Technology, Finland.
Pacey, A. and **Cullis, A.** (1986). *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas.* Intermediate Technology Publications, London.
UNDP (1990). International Drinking Water Supply and Sanitation Decade, Case History No. 6, New York.
UN Water Conference (1977). Water Development and Management: *Proc. UN Water Conference,* Argentina, *part 2* Argentina, Pergamon Press, Oxford.
Wanyonyi, J.M. (1993). Appropriate Techniques in Rainwater Harvesting. *Proc 2nd Nat Conf. on Rainwater Catchment Systems in Kenya,* Nairobi.
World Bank (1980). Guidelines on Planning and Management of Rural Water Supplies in Developing Countries. Appropriate Technology, **7**. (3), 17-20.
World Bank (1982). Women's Self-help Efforts for Water Supply in Kenya. *Appropriate Technology,* **9**, (3), 19-21.

DISCUSSION

Dr Jessica Salas questioned the author's argument that water is a project for women because traditionally it is the women's role to fetch water for domestic use. She pointed out that one of the reasons why women cannot pursue opportunities for development is because they are bound by culturally and traditionally prescribed roles. She suggested that there should be an integration of gender in rainwater projects which would gradually change the prescribed roles.

THE ABILITY OF RURAL WOMEN IN TANZANIA TO PAY FOR RAINWATER HARVESTING

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ABSTRACT

Through a grass-roots local NGO a district-wide rainwater harvesting project was established in Karagwe, Tanzania during 1991. The aim was to set up approximately four village production centres each year, where local masons, male and female, would be trained to construct cement water jars of 1200 litre capacity, built around a formwork of a sand-filled sack. The jars were to be sold at cost price to the residents of the immediate village area. The feasibility study carried out through three local women's groups showed an ability to pay, a sufficient annual rainfall (1000mm) and a suitability and acceptance of roof-top rainwater harvesting for the project to proceed. The production centre was setup as a pilot project, and 60 jars were made in the first year. Sales were lower than expected, and a cost-sharing scheme was promoted to aid sales. The general lack of trust between villagers, and the reluctance of the rural women to realize their potential as money earners has been a drain on the project's success. An evaluation of the willingness-to-pay of the rural women identified the areas where motivation and support was needed in order that the women themselves might realize their potential and bring about improvements in water supply.

INTRODUCTION

It is widely understood that water collection is women's work. Women in East Africa are seldom in a position to reduce this burden by improving their water supply. This is because traditionally the men raise and control the family income, and water supply lies low on an average man's list of expense priorities. In many areas women are changing these traditions by raising cash through their own efforts in order to pay for water supply improvements. This paper describes a rural rainwater harvesting project in Tanzania where women are encouraged to pay for it. It focuses on the socio-cultural aspects of the project.

Tanzania has a population of 27.4 million (1992 figure), over 80% of whom live in rural communities. For these people the hand hoe is the common farming implement; mechanization and even animal traction are limited to a few areas. Communications within Tanzania are poor: the state of rural roads is probably the principal factor preventing rural development.

Water policies and masterplans have been in existence in Tanzania for several years. Yet the implementation of these policies has proved difficult, due to the lack of available funds and the dependence on costly technologies. As a result the percentage coverage for rural water supply remained stagnant at that 46% throughout the 1980's, in spite of substantial donor inputs to water projects (Ministry, 1989). It is fair to say that of 46% coverage, many systems lie "dead" or dormant, due to mis-use, mis-management or lack of spare parts. This means that over 54% of the rural community either consume water from polluted sources, and/or waste a lot of valuable productive time in water collection. This time is spent largely by women, so that women are prevented from developing their productive resources.

RAINWATER HARVESTING IN TANZANIA

In much of Tanzania, including the large central arid zone south of Lake Victoria, the annual rainfall is less than 800 mm, and it falls in one short rainy season alone. Here rainwater harvesting is only feasible where very large tanks can be afforded. On the individual level rainwater harvesting (RWH) is not an appropriate option. However, north and south of the arid zone in Tanzania there are areas of higher rainfall, of more temperate climate, and noticeably of more rugged terrain. Consequently these areas lend themselves better to crop farming, and they are inhabited principally by fully sedentary communities. Building long-lasting houses is a priority for such people. It is here, in the peripheral rural areas of Tanzania, where iron sheet roofing is common, and RWH from roof catchments has the potential to be broadly adopted.

KARAGWE DISTRICT

Kagera Region is one such area, lying between the west shore of Lake Victoria, and the borders of the Republic of Uganda and of Rwanda. It enjoys two rainy seasons, of 3 months and 4 months each. The project described lies in Karagwe, one of Kagera's five districts. Karagwe District has an average annual rainfall of 1000mm. The people are predominantly farmers growing beans and coffee for cash. Bananas, beans and maize are the staple food crops.

An important aspect of Karagwe District is its topography and drainage. Precipitation, or rainwater, sinks rapidly through the fractured ancient rock, leaving little surface water, to form a deep ground-water table. That surface water is found deep in the valley bottoms. Ironically it is the ridge tops rather than the valley bottoms which are inhabited. As a result natural water sources are many hours walk from the inhabited ridge tops. RWH is therefore, the only widely available option for household water supply in Karagwe District.

KARADEA

One of the organizations which is promoting and supporting development in Karagwe is Karagwe Development Association, or KARADEA. KARADEA is a self-help grass-roots organization, working on ten integrated development issues; it is focussed on raising the status of rural women, and is responsible for the management of the project described here.

FEASIBILITY STUDY FOR KARADEA'S RAINWATER HARVESTING PROJECT

After a basic assessment of water sources, and of available catchments it was established that RWH is the most appropriate and cost-effective method of widespread water supply in Karagwe District. It was necessary to design a project which would fit in with KARADEA's ethos (namely low budget, using self-help), which would be acceptable to the target group. A feasibility study was designed to assess the ability of the target group to pay for RWH, and just as importantly, to assess the willingness to pay. This would determine the scale of the RWH design, and the expense which could be incurred; whether large ferrocement tanks, or sub-surface community tanks, or household jars. KARADEA's approach is to use its widespread members as facilitators in the designing of projects, producing "projects for people". This avoids the unnecessary expenses incurred by inappropriate projects designed by bureaucrats who are distanced from the target group. The feasibility study was begun in Bisheshe, a village where there was both a high concentration of KARADEA members (7% of the 900 subscribing members), and had a severe problem of water supply. Bisheshe is located 20km south of the district town of Kayanga. With the help and co-operation of the active KARADEA women's development group a carefully compiled questionnaire was distributed to 40 women, who in turn were to visit ten houses each, thus reaching almost 50% of the women in the village. The aim of the questionnaire was to assess water usage, roof catchment area and general attitudes to rainwater as a potential source of water.

RESULTS OF THE QUESTIONNAIRE

The following information was recovered from the 305 households surveyed, being 47% of the total households in the village.

1. An average of seven people were living in each household, with an average household water demand of 100 litres, or five buckets, per day.
2. The average distance to the existing water source (a saline water hole) was 1.5km, thus a total of 15km was covered daily for water collection alone.
3. Of the 305 houses surveyed, 191 had iron roofing, that is 63% of the village. Of these 12% were already using a RWH system.
4. On average each roof was made of 36 iron sheets, giving a total catchment area of $90m^2$. Using the annual rainfall of 1000mm the maximum total annual collection would be 90,000 litres, ($90m^3$), which is an average of 12.5 buckets per day.
5. More than half of those with iron roofs thought that total roof catchment could provide sufficient water: 85% of all surveyed were "ready to engage in rainwater harvesting".

ABILITY TO PAY

This is a measure of the appropriateness and sustainability of development activity. It compares the expense required of the target group to its ability to pay for it. The feasibility study identified a positive "ability to pay" by the following means:

1. Abundant cash crops of coffee and beans, there being two harvests a year;
2. 60% of households surveyed were keeping a number of goats and chickens, which could be sold to raise cash;
3. Many women were growing vegetables for sale; particularly those KARADEA members who had obtained a soft loan from the improved nutrition project. One woman raised Tsh 50,000 from a $10m^2$ plot (Tsh 500 is approximately one US dollar).
4. Frequent preparation by women of the "local brew", creating regular, small monthly cash incomes, of around Tsh 5,000.
5. Cattle keeping - the sale of only one cow would generate enough to build a small tank, and to erect gutters.

WILLINGNESS TO PAY

This is another measure of the appropriateness of the project. It compares the expense required from the target group with their willingness to pay for it. Similarly it is an indirect measure of the actual problem with the percieved problem of the target group. It must be appreciated that "willingness to pay" before payment is required is often greater than the willingness to pay at the time at which a payment is required. The feasibility study made an attempt to assess the willingness of the Bisheshe villagers to pay for water supply improvements. Through the questionnaire each household was asked to estimate how much cash raised monthly by various means might remain after household espenses were extracted: 90% estimated less than Tsh 500 per month, 5% estimated between Tsh 500 and Tsh 1,000; the remaining 5% between Tsh 1,000 and Tsh 2,000 (2-4 US$).

To summarize, the feasibility study provided the following information:

1. Sufficient rainfall patterns
2. Lack of alternative water sources for low cost improvements
3. Sufficient existing catchment surfaces (roof catchment) for RWH
4. A percieved problem of water supply
5. A potential for raising sufficient cash - at least Tsh 70,000 per year (US$ 150) from farming and local brew alone.
6. Very little willingness to make cash available for water requirements.

The first five points suggested that a project to train local masons to build and promote RWH water using large ferrocement tanks of over $20m^3$ would be both desirable and appropriate. However the last point indicates that very little cash would willingly be made available for RWH. Most households estimated less than Tsh 500 a month, in which case, without enormous credit or subsidy, not even the gutters for such a RWH scheme would be affordable, let alone the tanks themselves. Since KARADEA, a low cost grass-roots NGO with limited funding, was not in a position to provide such a subsidy, an alternative low-cost design of RWH system was needed.

THE PROJECT

A cement water jar design was followed, similar to the successful Thai Jumbo Jar, which Arnold Pacey cites as the water tank of lowest unit cost. An existing project of such rain jars of Karagwe District had received a positive response from the community, and this was evidence of its appropriateness, however, it was limited to small areas of the district. The jar is $1.2m^3$ capacity and made around a formwork of a sand-filled sack. It is fitted with a tap, and a cement cover. The jar is constructed over 2 days, and then filled with water and left to cure for 1 month. The mortar mixture is 2:3 cement to sand, and no ferro-reinforcement is used. The cost was Tsh 12,000 (approximately US$ 30, at 1991 prices).

In Bisheshe six village meetings were held for broad discussion and planning of the project. A water council and water committee were formed with village members, half of whom were women. Two men and two women from within the village were selected by the committee to be trained to construct the jars. A production unit, or workshop, was established in July 1991, 4 months after the beginning of the feasibility study. Training was completed in 4 weeks and production of jars followed without interruption.

EVALUATION

An evaluation of the design and the sales was carried out after 30 jars had been made. Technically the construction method was quickly and easily understood. The *fundis*, or masons worked well together; the principals of cement usage had been emphasized during training. A few problems were encountered and improvements made:

1. There was a problem with the quality of the local sand. The first three jars showed signs of cracking before the curing period of 30 days was over. The sand was changed for a better quality sand - cleaner and coarser - and there were no subsequent problems with cracking.
2. Some jars sustained damage during transportation by lorry. It became necessary to seat the jar on a deep layer of loose sand during transit, and to keep distances to a minimum.
3. Improvements were made to the cement cover. Whereas previously the cover had to be removed to allow runoff to enter the jar, by inserting a piece of mosquito wire into the cover it could be left *in situ* throughout the seasons, whilst acting as a rough screen for runoff.
4. Improvements were made to the curing process by replacing the hessian covering with large polythene sheets; silage bags were ideal for the job.
5. Water theft by neighbours was common in the village. To increase the security of the rainwater, lockable taps were fitted. Unfortunately those available in Tanzania are of poor quality and tended to break.

EVALUATION OF PRODUCTION VERSUS SALES

The team could make a maximum of ten jars a month, or 110 a year, assuming a constant supply of materials. However the production rate exceeded the rate of sales, and consequently some jars sat idle for months in the workshop. To prevent this the jars were made strictly to order, each order being accompanied by a 10% advance payment.

Disappointingly only 60 jars were sold in the first 12 months. Of these only 20 were bought by the Bisheshe villagers. The other 40 were bought predominantly by higher income Karagwe inhabitants, who had access to personal transportation for the jar. Evaluation of the low rate of sales identified the following three factors:

1. A severe drop in the coffee price in 1991 and 1992, disasterously reducing the major source of cash in the villages,
2. Delayed rains, resulting in a lack of motivation for investment in water sources depending on rainwater.
3. The reluctance of women to raise cash to buy a jar; and the reluctance of the male community to recognize water as a worthwhile expense.

Action following evaluation

Through village meetings the men and women were encouraged to support each other in raising the money required to buy a rainwater jar. Of the villagers surveyed, 60% were keeping small livestock, often owning more than 12 goats, or 20 chickens. The sale of three goats would cover the cost of a jar. Sales were boosted in this way, although in general the sale of livestock was met with reluctance.

COST SHARING

In a further effort to support the target group, and to boost jar sales, a round-fund scheme was promoted. The aim was for a group of households to contribute the total cost of one jar, which would be installed at the first house. A second jar would be purchased and installed after the second contribution, and so on, until each house in the group had acquired a jar.

This scheme also again met with scepticism; it was only adopted by one pair of women. The reason for its unpopularity was a lack of trust between the villagers, even between friends and neighbours.

CREDIT SYSTEMS

Credit systems are widely dismissed by donors, following a number of schemes which have failed to collect the repayments. However KARADEA has been managing an effective credit system for small loans of less than Tsh 20,000 for 200 women members over the last 4 years. Within this structure, those women in Bisheshe who were holding a loan were given an extra year's extension on the purchase of a jar. Sales were increased by 10%. The credit system will be expanded further to aid the distribution of water jars in Karagwe District, where half the cost of the jar is given on credit.

CONCLUSION

Cement water jars are a viable and popular aid for rainwater harvesting in Karagwe District and other rural areas with similar climatic and economic conditions. In spite of their limited capacity, the jars can supply water over the 6-7 months of rain, the season when most time is required for agricultural activities.

The women in Bisheshe have the means and ability to raise sufficient income to pay for such low cost water improvements as rainwater jars. The sale of goats, chickens, vegetables and local beer, together with cash crop incomes, should be sufficient to cover both household expenses and rainwater harvesting.

Despite such a positive ability to pay, the village women were reluctant to raise funds for it. Income generation remained a man's prerogative. Accordingly water remained low on the list of priorities for expenditure when the cash-crop payments were collected.

More effort is required in the future to raise the status of women, so that they might realize their potential for income generation, and in so doing become willing to pay for water and health improvements.

REFERENCES

Ministry of Water (1989). Evaluation of International Water Supply Decade Performance in Tanzania. *Proc. of a Report Presented at the 11th Annual Water Engineers Conference.* Mwanza, Tanzania.

Mayo, A.W. (1991). Experience in Rainwater Harvesting in Tanzania. *Proc of the 5th Int. Conf. on Rainwater Catchment Systems*, Taiwan.

Pacey, A and **Cullis, A** (1986). Rainwater Harvesting. Intermediate Technology Publications.

WATER QUALITY

OVERVIEW OF QUALITY ISSUES RELATED TO RAINWATER HARVESTING

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Although rainwater harvesting is widespread in many parts of the world, estimates of the actual quantities involved and its quality are issues that are given relatively little importance. This should not be the case especially if this water is to be included in integrated water resources management.

The harvesting of rainwater can either be directly from the atmosphere - in which case the quality is influenced by the atmospheric conditions, or via runoff in which case the quality becomes a major issue of concern and quality parameters like pH, COD, BOD^5, SS, Nitrates, etc. need to be investigated in depth before the water is put to human use. Several papers touching on quality of harvested water are presented.

Cistern tanks being an essential component of water collection are reviewed for their quality issues. The concentration of faecal indicator bacteria is presented and compared with WHO guidelines. The quality of the water in cisterns in relation to design and maintenance of the water is presented. Tests to establish improvement in quality of cistern water tanks, using various methods, are evaluated (total bacteria, total coliform, faecal coliform, hydrogen sulphide, conductivity, turbidity, pH and phosphates). Results presented are not conclusive although those available argue that this water does not meet USEPA standards, which may be rather stringent for most developing countries.

The question of acid rain caused by hydrogen sulphide from various sources: leached lead from roofing materials, nails, painted tanks, etc. is presented in another paper. The paper emphasizes the need to guard against these in new constructions as they are a major source of such contamination in harvested rainwater as is the case in Hawaii city.

Methods of eliminating possible contamination by organic pathogens is presented in another paper. It is argued that chlorination, the usual remedy, has certain drawbacks: it is expensive, not readily available, requires trained personnel (not available in rural areas), is poisonous in high concentrations and produces carcinogenic compounds, adds an unpleasant taste and stimulates corrosion of metal and concrete. Ultraviolet radiation has been tried, and when used under the right conditions of exposure and intensity is found to be an effective disinfecting agent. It also does not produce side-effects as chlorine does. Its major drawback is that it does not guard against subsequent re-infection due to careless handling - a common occurrence in rural communities. In Thailand, solar radiation has been tried for disinfecting drinking water at laboratory level; this paper describes the design and testing of the prototype unit under actual field conditions.

There is a paper which examines rainwater specifically for pathogens originating from animals and which may be associated with disease in humans - causing diarrhoea. The research involved the collection of samples from 12 different private and public cisterns and their evaluation. The results reveal that there is a significantly low level of risk from this water compared to surface water, commonly used for drinking.

Another paper argues the case for worldwide quality standards to be set for cistern water, as opposed to using standard drinking-water standards. The paper proposes some minimum criteria for safe drinking-water from cisterns. What is not clear, however, is if the proposed cistern standards will be radically different from existing drinking-water standards.

Finally, the paper on rainwater as a wasted resource argues that large volumes of runoff go to waste in most towns. In a case study of Nairobi - where tests for both quantity and quality were carried out - the results were compared for quality with WHO guidelines for both domestic and industrial needs. The results indicate that except for a few quality parameters, the quality of this wasted resource is acceptable as an alternative source of water for industrial - and with nominal treatment - for domestic use.

QUANTITY AND QUALITY OF RUNOFF IN NAIROBI: THE WASTED RESOURCE

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ABSTRACT

Rainwater harvesting, an ancient art, is not practised in Nairobi although water shortages and high water costs are the order of the day. In Nairobi there is an enormous amount of water from rainfall which goes to waste, which not only causes structural damage to property and roads but has been known to cause deaths.

This paper reports on a study to investigate the volume of storm runoff generated from selected streets in Nairobi from a series of consecutive storms. The quality of the water was also ascertained and the characteristics were compared with guidelines for domestic and industrial needs.

The conclusion reached from this study is that the volume of runoff from the selected streets is substantial and that its quality, as indicated by the various parameters which were measured, is acceptable as an alternative source of water for industrial and, with nominal treatment, even domestic needs.

INTRODUCTION

Rainwater harvesting has predominantly been used in arid and semi- arid areas (ASALs) and in rural areas, not only in Kenya but in many parts of the world. This has meant that most research has concentrated on those areas rather than on urban areas.

Rainwater harvesting, has great potential in urban areas because of the high percentage of impervious surfaces producing large volumes of water which, if properly harnessed, can be used to supplement other conventional sources of urban water supply. This practice should be encouraged given that one of the most widespread and directly accessible sources of water is rainfall.

Tebbutt (1983) estimated that about 23% of urban populations in developing countries have no access to a safe water supply, and are continually exposed to various diseases which could be eradicated if there was adequate water. The population of Nairobi is increasing rapidly (due to both the high birthrate and rural to urban migration) and outstripping the capacity of conventional water sources. Therefore greater attention should be focused on integrating rainwater catchment systems to provide water, not only for domestic, but also for industrial use.

While much publicity is given to water shortages in many parts of the city and to the high cost of providing water due to distant sources, the harnessing or rainwater, both directly and from runoff, remains an elusive dream. This paper examines in depth the volume of water wasted as a result of this neglect and reports on its quality - physical, chemical and bacteriological - to determine its suitability to supplement existing conventional sources of water.

TYPICAL CHARACTERISTICS OF DOMESTIC WATER

The characteristics of various sources of water are presented in Table 1. In the case of potable water it is common practice to assess its quality in relation to specified guidelines or standards. Most third-world countries rely on WHO standards. In most cases, rainwater in its natural state has been found to be suitable for domestic use without any form of treatment (Beekalaze, 1992).

Table 1. Characteristics of various sources of water

	Upland catchment	*Lowland river*	*Aquifer chalk*
pH	6.0	7.5	7.2
Total solids (mg/l)	50	400	300
Conductivity (μs/cm)	45	700	600
Chlorides (mg/l)	10	50	25
Total alkalinity (mg/l)	20	175	110
Total hardness (mg/l)	10	200	200
Colour (Hazens) (mg/l)	70	40	5
Turbidity (mg/l)	5	50	5
Ammonia Nitrogen (mg/l)	0.05	0.5	0 05
Nitrate (NO_3)(mg/l)	0.1	2.0	0.5
Dissolved oxygen (% saturation)	100	75	2
BOD_5	2	4	2
Coliform MPN/100ml	20	20000	5

Source: Tebutt, (1983)

Ironically, the purity of rainwater has sometimes been cited by critics as a possible drawback to its use as a drinking water source since a balanced human diet requires small quantities of dissolved trace minerals which are largely absent in rainwater but present in other sources. This should not be a major handicap as such minerals can be added if desired.

Some quality parameters of rainwater from roof catchment in Nairobi are given alongside those for a river and standards set by WHO (Table 2).

THE STUDY AREA

Nairobi, the capital city of Kenya is estimated to have a population of about 1.5 million people (Otieno, 1992). The population has doubled over the last 10 years due to natural increase as well as rural to urban migration in search of gainful employment. Such a high increase (about

Table 2. Comparison of rainwater from roof catchment with river water and WHO standards

	Rainwater	*River water*	*WHO limits*
pH	8	6.75	6.75
Turbidity (mg/l)	0.8	2.0	300
Total Hardness as $CaCo_3$ (mg/l)	60	N.A	15
Total Alkalinity as $CaCo_3$ (mg/l)	38	9.00	400
Iron (Fe^{3+}) (mg/l)	0.50	0.90	0.30
Calcium (Ca^{2+})(mg/l)	1 20	0.80	75.0
Magnesium (Mg^{2+}) (mg/l)	0 50	0.50	30.0
Chloride (mg/l)	8.80	6.90	250
Sulphate (SO_4) (mg/l)	1.50	3.30	250
Silica (mg/l)	0.50	7.00	50
Total dissolved solids (Mg/l)	94	82.00	250

5% p.a), is putting pressure on the infrastructure, including water supply, health, and transport, and jeopardizing their maintenance. The extent of the built-up area has increased three-fold from 1976 to 1986 (Krhoda, 1991), resulting in an increase in impervious surfaces, which are ideal for rainwater harvesting. It is estimated that as much as 60% of the surface of Nairobi is impervious, and suitable for runoff harvesting (Otieno, 1992).

RAINFALL PATTERN

Nairobi experiences high rainfall, with the long rains from mid-March to the end of May, and the short rains between October and December. Some rain has, however, been recorded during the dry months of January and February. This pattern is disrupted frequently and is only a guide.

The failure to utilize this rainfall as an alternative source of water supply is to waste a valuable resource. Assuming, for example, that about 30% of annual precipitation is wasted through unavoidable means, (e.g evaporation, evapotranspiration etc.) then 70% of the rainfall is wasted as runoff into rivers. Indeed this runoff volume constitutes a great resource which occasionally results into floods which are on record as having caused loss of lives, destruction of roads which are costly to repair, and structural failure of building foundations among others.

Furthermore, floods result in stagnant pools of water which are breeding grounds for pathogenic organisms and are home for many mosquitoes which cause malaria. Therefore the wasted rainwater is responsible for socio-economic, ecological and hydrogeotechnical problems.

QUANTITY OF RAINWATER

Because of the high percentage of impervious surface area in Nairobi, theoretically, there could be a substantial volume of rainwater harvested. If rainwater harvesting was encouraged, this water could supplement existing conventional sources of water supply.

It has been proved that under proper design, construction, operation and maintenance, rainwater harvesting systems can provide palatable, cheap and substantial water for domestic use (Bo, 1992).

A model of components of rainwater harvesting systems has been proposed (Fig. 1) in which the main sources of the catchment consist of the ground, roads, paved surfaces and roofs. Apart from catchment, other components of the model include transportation, purification and storage.

Rainfall

Catchment (ground, roads, paved surfaces, roofs)

Transportation (ditches, gutters)

Purification (sedimentation, coagulation, filtration and disinfection)

Storage (water tanks)

Figure 1. Components of rainwater harvesting systems.

In runoff harvesting, purification and storage are two components that require careful planning. Usually runoff water will require some purification before it becomes suitable for human consumption. After the water is harvested there needs to be storage, from where the water can be supplied to consumers. It is this storage which presents the greatest challenge to scientists at the moment.

The expected volumes for ground and roof catchments in Nairobi are presented here.

Ground catchments

The advantage of this mode of harvesting is that it can take place over a large area. If we divide Nairobi into many micro-catchments, each of 100m x 100m, and if it is assumed that only 60% of the rainfall is harvested (urban paved areas), then the amount of water that can be collected on an annual basis may be estimated from formula (1).

Volume = area x factor(coefficient) x annual rainfall ....(1)

Assuming that the rainfall in the area is 1000 mm, then using equation (1), the volume of water harvested by one micro-catchment would be:

$$\text{Volume} = 100 \times 100 \times 0.30 \times 0.60 \times \frac{1000}{1000}\ \text{m}^3/\text{year}$$

$$= 1800\text{m}^3/\text{year}$$

$$= 4930\ \text{l/day on average.}$$

Assuming that each person requires 200 l/per day, this micro-catchment would adequately support 25 persons.

Roof catchments

This is the easiest and therefore most commonly used form of rainwater harvesting. It continues to be widely used in the rural areas of Kenya especially in homes where there is no piped water. Unfortunately, its use in urban areas remains insignificant.

For this method to be accepted in urban areas where there is a severe water shortage, it may be necessary for the authorities to mandate it by law so that, especially in towns where rainfall is plentiful, every new building is required to have a rainwater collecting system including a cistern to store the runoff from the roof. The tanks could be built underground and form an integral part of the basement of the building.

The quantity of rainwater that can be collected through roof catchment can be determined by the effective area of the roof and the local annual rainfall. The volume can be calculated using formula (2).

Volume = area x factor (coefficient) x annual rainfall ....(2)

For most corrugated roofs, a coefficient of 0.8 is assumed (allowing for 20% losses). Thus for a house of effective roof size 10 m x 5 m, situated in a zone of about 1000 mm rainfall per annum, the volume of water collected would be:

$$\text{Volume} = 5 \times 10 \times \frac{1000}{1000} \times 0.8 = 40\ m^3/\text{year}$$

$$= 109\ \text{l/day}.$$

Therefore, even such a small roof would provide just about adequate water for one person per annum in an area with annual rainfall of 1000 mm. This would be a major supplement to existing supplies in urban areas.

Storage of rainwater

The biggest challenge of rainwater harvesting is to store adequate volumes of water to run through the dry periods. In normal circumstances, in Nairobi, there is a long dry spell lasting 3 months. If rainwater harvesting is to become popular, it must meet the needs of those it serves throughout the dry season. Thus for the small catchment of 10m x 5m, assuming 3 months dry period, the minimum size of tank required to store water for 90 days at 109 l/day is 9810 litres (9.81 m^3). Obviously, for a larger catchment, a larger tank would be necessary.

QUALITY OF RAINWATER

To investigate the quality of rainwater, it was decided to examine both rainwater harvested from roofs and that resulting from runoff. The intention was to establish the quality of these two sources of water as they are considered to be a major resource which currently goes to waste.

It has been reported (Michaelides, 1989; Otieno, 1992) that initial rainwater, i.e. the first flush, is usually of poor quality. Thus, in all cases, the initial flush was collected and tested to confirm this fear.

To test runoff, samples were taken every 10 minutes for the first 30 minutes and then at 30-minute intervals for the duration of the storm, or for 2 hours, whichever was the longer. The results are presented in Table 3.

Physical and chemical analyses were performed on rainwater from the roofs and gutters, together with that in storage containers, both outdoor and indoor; the results are presented in

Table 4. Bacteriological tests were also performed on a number of these sources of rainwater, the results are presented in Table 5.

Table 3. Runoff quality in some streets of Nairobi.

Station	Time (mins)	pH	COD	BOD_5	SS	Nitrates as NO_3
Uhuru Highway 1	10	5 0	90	30	240	60
	20	5 8	60	20	210	40
	30	7 1	40	13	120	20
	60	7.2	20	7	100	10
	90	7 0	10	3	60	10
	120	7 0	5	2	38	5
Uhuru Highway 2	10	4 8	82	29	200	50
	20	5.7	61	22	210	40
	30	6.8	34	12	200	20
	60	6 9	30	11	80	10
	90	7 0	32	11	40	5
	120	7 0	5	2	30	5
Kijabe Street 1	10	6 0	60	21	140	20
	20	6 4	50	18	120	20
	30	6 8	31	11	100	10
	60	7.0	30	11	60	10
	90	7 0	10	4	30	5
	120	7 0	10	4	30	5
Kijabe Street 2	10	5 8	60	18	120	30
	20	6.1	40	12	80	25
	30	6 6	30	9	40	20
	60	6 9	10	3	30	20
	90	7.2	5	2	30	10
	120	7 1	5	2	20	5
University Way 1	10	5.8	50	16	130	40
	20	6.4	40	13	120	40
	30	6.6	30	10	100	30
	60	6.9	10	3	70	20
	90	7 0	5	2	60	20
	120	7 2	5	2	30	5
University Way 2	10	5 8	48	12	140	38
	20	6 3	42	10	130	40
	30	6 8	30	7	100	30
	60	6.8	30	7	60	20
	90	7 1	10	3	40	10
	120	7 2	5	1	30	10
Koinange Street 1	10	6 2	40	16	80	30
	20	6.8	10	4	88	10
	30	6 8	10	4	60	10
	60	7.2	5	2	30	10
	90	7 2	5	2	30	5
	120	7.1	5	2	30	5
	20	6.3	10	3	90	30
	30	6.8	10	3	60	20
	60	6 9	5	2	30	5
	90	7 2	5	2	30	5
	120	7.2	5	2	20	5

Table 4. Physical and chemical parameters of rainwater runoff.

Parameter	*Value*
pH	8
Turbidity (NTU)	0.8
Colour (Hazens)	4
Total alkalinity as $CaCo^3$ (mg/l)	38
Chloride (mg/l)	8 8
Sulphate (mg/l)	2.4
Total hardness as $CaCo^3$ (mg/l)	60
Total iron (mg/l)	0.50
Electrical conductivity (µs/cm) at 25°C	125
Total dissolved solids (mg/l)	94

Table 5. Generalized effluent discharge standards in Kenya.

Constituent	
pH	6.5 - 8.5
BOD_5	20 mg/l
COD	50 mg/l
SS	30 mg/l
Nitrates	30 mg/l
Sulphides	2 mg/l

Results of quality analysis

Results of runoff quality (Table 3) clearly indicate that for most parameters, the values decrease with time of runoff sampling, an indication that the initial flush clears most of the contaminants from the surface, leaving the rest of the runoff fairly clear and of comparable quality with lowland river water (see Table 1).

Although the samples were taken away from heavily industrialized areas of Nairobi, it is still possible that the wet washout of heavy metals and sulphurous compounds in the air could have had an effect on the quality of collected rainwater, which would account for the initial low pH values. Indeed, if rainwater harvesting were to be commercialized, the low pH would be a worrying phenomenon because of its tendency to corrode appliances.

These results further indicate that the BOD_5 loading of samples taken from Uhuru Highway and Kijabe Street were higher than those taken from other streets. This could be attributed to the busy state of these roads, making them more like an industrial environment. Runoff quality is also considerably impaired because of increased erosion probably caused by heavy construction activities on Uhuru Highway; samples taken there show a high value for suspended solids.

Comparing the results in Table 3 with generalized effluent standards for discharge into water sources (Table 5), it is clear that except for a few samples along Uhuru Highway which gave BOD_5 of 30, 29 and 22 mg/l, the runoff would be of better quality than some of the effluent in terms of BOD_5. This trend is the same for other parameters except for initial flush samples taken from Kijabe Street.

Results of bacteriological analysis

The bacteriological quality of rainwater samples collected from the roofs of buildings and from storage containers (outdoor and indoor) was evaluated to identify sources of contamination, which can be classified as being one or more of the following:

- Washout of atmospheric pollutants during rainfall;
- Fallout of atmospheric pollutants during dry period;
- Particulate matter from natural weathering or decay of roof materials and bird faeces deposited on the roof;
- Contamination of storage containers either before, during or after water collection.

The source of bacteriological contamination in the water samples was investigated by employing the ratio of faecal coliform to faecal streptococci (FC : FS) technique (Table 6).

From an analysis of the results in Table 6, about 40%, 50% and 75% of the samples collected from the roofs, outdoor storage and indoor storage respectively, failed to meet drinking-water quality standard (WHO, 1971). Furthermore, about 80% of samples collected from roofs and gutters had FC : FS ratios less than 1 - indicating animal contamination. Of the samples collected from indoor storage 40% had FC : FS ratios of less than 1 and 50% had ratios greater than 4, indicating both animal and human contamination (Wirojanagud, 1992).

From the bacteriological analysis presented, it was evident that the human contamination observed probably occurred through insanitary practices during the handling of and usage from indoor containers. If this source of contamination could be eliminated, then rainwater quality in Nairobi would be of acceptable standard for human consumption in terms of bacteriological contamination.

Table 6. Bacteriological quality of rainwater from selected rainwater sources.

Source	*No of samples*	*Met standard*	*Did not meet standard*	*FC . FS*			
				> 4	> 2	1 - 2	< 1
Roof and gutter	100	60	40	9	4	7	80
Outdoor storage	60	30	30	6	3	3	48
Indoor storage	30	7	23	15	2	1	12

CONCLUSIONS

Rainwater, although not harvested on a significant scale in urban areas of Kenya, is a viable source of water as far as physical, chemical and bacteriological criteria are concerned.

Contamination of rainwater mostly takes place during collection and handling. If, these aspects are carefully regulated, and flushing systems installed to ensure the polluted initial flush is not collected by the containers, the quality of rainwater collected in Nairobi is suitable for human needs. If necessary, simple treatment methods, e.g. disinfection could be used to make the rainwater relatively safe for human consumption.

The major challenge to effective use of runoff is how to collect and store this water. The matter of the exact nature of how and where the floodwaters can be harnessed reqiures further research.

The volume of water currently wasted as runoff, given its quality and the persistent shortages of water in parts of Nairobi, combined with the high cost of conventional sources, makes a case for runoff harvesting to supplement conventional sources of water for this city.

REFERENCES

Beekalaze, C.M. (1992). Rainwater Utilization and Water Quality. *Proc. Regional Conf of the Int Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Bo, Ling (1992). Direct Use of Rainwater for Domestic Use. *Proc. Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyoto, Japan.

Klein, B. and **Bullerman, M.** (1989). Qualitative Aspects of Rainwater Use in one Federal Republic of Germany. *Proc. 4th Int. Conf on Rainwater Cistern Systems.* Manila, Philippines.

Krhoda, G.O. (1991). Urban Development and Stormwater. *Proc. 17th WEDC Conf. on Infrastructure, Environment, Water and People.*
Michaelides, G. (1989). Investigation into the Quality of Roof Harvested Rainwater for Domestic Use in Developing Countries. *Proc. 4th Int Conf. on Rainwater Cistern Systems.* Manila, Philippines.
Ndiritu, J.G. and **Otieno, F.A.O.** (1991). Water Quality Monitoring in Kenya. *Proc. 17th WEDC Conf. on Infrastructure, Environment, Water and People.*
Otieno, F.A.O. (1991). Assessment of Pollution Status of Nairobi River: An Overview. *Proc Seminar on Water, Health and the Environment.* Nairobi, Kenya
Otieno F.A.O. (1992). Quality of Urban Runoff in Nairobi. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems in Kenya,* pp. 143 - 151. Nairobi, Kenya.
Pacey, A. and **Cullis, A.** (1989). *Rainwater Harvesting. The collection of Rainwater and Runoff in Rural Areas.* ITDG, Bristol, UK.
Tebbutt, T.H.Y. (1983). *Principles of Water Quality Control, 3rd edn.* Pergamon Press, Oxford.
WHO (1971). *Drinking Water Standards.* Geneva.
Wirojanagud, W. (1992). Rainwater Contamination and Control. *Proc. Regional Conf of the Int Rainwater Catchment Systems Assoc..* Kyoto. Japan.

DISCUSSION

Oliver Cumberlege commented that this research was very interesting as it was similar to that done at Khon Khan University, Thailand. It is a fact that faecal coliform and faecal streptococci die at a different rate while being stored in a tank. Therefore the FC:FS ratio may have been inaccurate by the time the water in the household containers was tested.

Mr Otieno said that previously there had been no method of isolating the source of contamination and it was a microbiologist, who had suggested the FC:FS ratio. He also said that it had been learnt recently that most of the faecal coliform and faecal streptococci will die quite fast, thereby giving false results. This was not obvious from the research results. However, the researchers are aware of the setback and will seek further professional advice.

Dr O. Ogembi asked what was the explanation for the rather high pH from the rainwater recorded. In response **Dr Otieno** said this could be attributed to the decayed matter found on most roof surfaces.

E.K. Bagarukayo said that before a storm the wind is normally very strong. He asked if it was possible that the wind would blow away the dirt and debris before the storm. In reply **Dr Otieno** stated that there was no evidence of strong winds being able to clean the surface or even being a regular occurrence before a storm. If this was the case, then it was not evident from the results of this study.

WATER QUALITY STANDARDS FOR RAINWATER CISTERN SYSTEMS

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ABSTRACT

Based on the recommendations of a technical group, water quality standards are suggested for rainwater cistern systems. Three classes of water have been defined, based on faecal coliform content of cistern water. Chlorination, and if resources permit, the use of ultraviolet light are recommended to disinfect water supplies for drinking purposes.

INTRODUCTION

Cisterns are used to collect rainwater in many parts of the world such as the Caribbean Islands, Hawaii, Southeast Asia, Africa, Australia and in some parts of North and South America. Lye (1992) estimated more than 200,000 individual rainwater catchment systems to be currently in use in the USA. Cisterns can range in size from less than 100 litres to more than 100,000 litres, depending upon the runoff generated and the materials used for construction. As cistern water use increases around the world, it is necessary to pay attention to the quality of water that is collected in cisterns for drinking purposes and domestic use.

Cistern water quality is a function of the environment, roof and cistern materials, maintenance, and disinfection. This can be expressed as:

$$Q_{cw} = f(E, R, C, M, D)$$

where

Q_{cw} = Quality of cistern water
E = Environment (rainfall, overhanging plant cover, etc.)
R = Roof material
C = Cistern material
M = Maintenance (physical, mechanical etc.), and
D = Disinfection (chemical).

Cistern water quality can also be expressed as:

$$Q_{cw} = f(P_c, C_c, B_c)$$

where

Q_{cw} = Quality of cistern water
P_c = Physical contamination
C_c = Chemical contamination, and
B_c = Bacteriological contamination.

It may be seen from the above that cistern water quality is subject to many environmental factors, and any standards developed for cistern water quality should be based on the fact that contamination can occur from diverse sources.

CISTERN WATER QUALITY STANDARDS

A technical meeting was organized recently at the Water Resources Research Institute, University of the Virgin Islands where Dr Roger Fujioka from the University of Hawaii, Dr Denis Lye from the University of Northern Kentucky and Dr Hari Krishna from the University of the Virgin Islands participated. The group discussed the subject of developing suitable water quality standards for cisterns (rainwater catchment systems). The recommendations of the group were as follows.

1. Water quality standards for cisterns should be based on the recognition that many environmental factors can and do affect the water that is collected.
2. Water quality standards to be set for rainwater cisterns should be those that can be achieved in real life, rather than the ideal.
3. The conditions for cisterns in tropical regions, particularly in developing countries, are far different from temperate regions so the water quality standards should be less stringent for them as opposed to developed countries.
4. Traditional total coliform indicators may not be adequate or appropriate to define the quality of rainwater systems.
5. Faecal coliforms may be considered as more appropriate indicators of cistern water quality.
6. Three classes of water are proposed at this time for cisterns which collect rainwater from rooftops.
   Class I:0 faecal coliforms/100 ml
   Class II:1-10 faecal coliforms/100 ml
   Class III: > 10 faecal coliforms/100 ml.

Class I would be the highest quality water, followed by class II and class III. While class I would be the ideal, it may not always be attainable; class II water would be of marginal quality, while class III would be unacceptable for drinking purposes.

As research progresses, it might become necessary to include other indicators to more fully define acceptable quality for drinking water.

SIMPLE TECHNIQUES FOR DISINFECTION AND TESTING

The water to be used for drinking may be disinfected using small amounts of chlorine. For example, household bleach, containing the active ingredient sodium hypochlorite, has been recommended for disinfection, at the rate of 1ml/25 litres of water in the Virgin Islands (Krishna, 1991). Where resources and technology permit, filters could be used along with ultraviolet (UV) light to disinfect drinking water (Rijal and Fujioka, 1992). One UV unit could be used to provide drinking-water supplies for several different users, if necessary. Simple inexpensive presence/absence tests for faecal coliforms, or hydrogen sulphide tests (Manja, Maurya and Rao, 1982) could be conducted in areas where fully-equipped laboratories are not available.

ACKNOWLEDGEMENT

Sincere appreciation is extended to Dr Dennis Lye, University of Northern Kentucky, and Dr Roger Fujioka, University of Hawaii for participating in the technical meeting at the University of the Virgin Islands, to discuss water quality standards for rainwater cistern systems. The comments they provided on the draft recommendations are gratefully acknowledged.

REFERENCES

Krisha, J.H. (1991). Improving cistern water quality. *Proc. 5th Int. Conf. on Rainwater Cistern Systems.*, Keelung, Taiwan.
Lye, D.J. (1992). *Legionella* and *Amoeba* found in cistern systems. *Proc. Regional Conf. of the Int. Rainwater Cistern Systems Assoc.* Kyoto, Japan.
Manja, K.S., Maurya, M.S. and **Rao, K.M.** (1982). A Simple Field Test for Detection of Faecal Pollution in Drinking Water. *Bull. World Health Organization,* **60**(5), 797 - 801.
Rijal, G. and **Fujioka, R.S.** (1992). Effects of UV and Bacterial Tests on Cistern Waters. *Proc Regional Conf. of the Int. Rainwater Cistern Systems Assoc. Kyoto, Japan.*

DISCUSSION

S. Burgess asked why it was recommended that cistern water quality standards should be based on faecal coliform count rather than total coliform count.

Prof Appan responded that total coliform count need not necessarily originate from animal or human wastes only. However, faecal coliform presence indicates that the water has been contaminated with wastes from animals or humans. Hence most water authorities insist on a faecal coliform count of < 1 for drinking purposes. He further noted that both tests were only indicative of potential pathogenic contamination and hence the stringent standards for faecal coliform count.

It was asked why there should be different water quality standards for tropical countries and temperate (advanced) countries. **Roger Fujioka** responded that, studies conducted in tropical Islands such as Hawaii, Gua, Puerto Rico and Virgin Islands showed sources of environmental pollution from bacteria such as faecal coliform. Environmental sources of faecal indicator bacteria include soil, water and plants which have not recently been contaminated with faecal material. WHO and EPA use faecal indicator bacteria to set water quality standards and this does not take account of the tropical situation of environmental pollution. These faecal indicator bacteria do not cause disease but only indicate that water may be contaminated.

Jessica Salas commented that she had learned from one of the papers presented that water potability is relative. Since immunity and sanitation practices in various areas vary, she wanted to know whether the author agreed with this. The author stated that he was in agreement with this opinion.

Jessica Salas then enquired how the International Rainwater Catchment Systems Association would deal with policy recommendations to the department of health of the government on guidelines for community use. She wondered whether these recommendations would be relative to health and sanitation practices in the area. The author responded that immunity and sanitation practices certainly varied from area to area and guidelines and recommendations as well as standards for the use of rainwater, or any source of water in order to prevent harmful health effects, should consider the entire situation namely:

1. If the water is not enough (quantity) one cannot expect to maintain satisfactory sanitary services. Under these conditions it is innappropriate to set water quality standards. Efforts should be directed at obtaining more and cleaner water and educate people to improve sanitary practices.
2. Once there is enough water available and the water source is reasonably clean, recommendations, guidelines and water quality standards should be implemented. These guidelines should be specific for a given condition (area) using international WHO and national (USEPA) standards only as guidelines and references.

Mr Muna stated that the table showing roofing materials used in Hawaii did not include asbestos. Asbestos is used in some countries for making roofs. What was the reason for not using these materials in Hawaii? Was this because this material was a health hazard? The author responded that the most commonly used roofing materials in Hawaii are the following: 1. wood (red wood); 2. rock (as gravel); 3. tile; 4. corrugated iron; 5. paper shingles (which contain asbestos. They are less common because they do not last as long as other materials); 6. aluminium/copper are also used.

Asbestos is used most extensively indoors in ceilings and walls. Decay of asbestos materials indoors results in aerosal breathing and is most dangerous for health. However there is no evidence that drinking low levels of asbestos will cause any health problems, but it would be prudent not to use asbestos materials in rain water catchments if possible.

GUIDELINES AND MICROBIAL STANDARDS FOR CISTERN WATERS

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ABSTRACT

Despite the availability of information on how best to design, build and maintain rainwater cistern systems to ensure adequate water quality, few systems follow these guidelines. Studies in Hawaii and elsewhere reveal that most cistern owners have not heard of foul-flush devices, do not clean their water collection systems/reservoir tanks at regular intervals, many do not use filters and most do not disinfect their waters. As a result of these practices, most cistern waters do not meet the USEPA bacteriological standards for drinking water. The poor quality of cistern waters in Hawaii is not due to insufficient education of the owners, poor sanitary conditions nor to the use of makeshift materials to construct their cistern systems. Worldwide, the quality of most cistern water has not been determined, as such systems are regarded as private and many countries do not require the monitoring of cistern water quality. However, the available information indicates that the quality of most cistern waters cannot meet microbial standards. Implementation of guidelines for cistern systems will improve water quality but waters may never consistently meet USEPA drinking-water standards. By sanitary survey, most cistern waters can be determined to be free of contamination from human faecal wastes and the risks associated with non-human sources of indicator bacteria should be less than that of a water containing indicators of human origin. Under these conditions, a realistic microbial standard for cistern water of 10 faecal coliforms/100ml is proposed.

INTRODUCTION

Clean and safe water piped to homes by a reliable supplier and available at the turn of a tap is taken for granted by most people. For some households, the most feasible way to obtain water for household use is by a catchment system which essentially collects rainwater from roofs of structures and transports the water via gutters and pipes into a reservoir tank or cistern for future use. Most of these cistern systems are built in areas where piped water is not supplied by a water supplier. Generally, this is because the place of residence is too far away from a water supplier, or in areas where the cost of piping is uneconomical due to low density of people, or where the cost of pumping water is prohibitive such as higher elevations.

Since a rainwater catchment system for home use is classified as an individual system, there are no public health regulations with regard to building or maintaining these systems and for testing the quality of the product water. The absence of regulations results in great variations in the building of catchment systems and no incentives for proper maintenance or testing of the product water. As a result, the quality of water in these private cisterns is usually not known and can be expected to vary considerably from system to system. A second part of the problem is that properly written guidelines for the building of cisterns are not available to the people who require that cisterns be built. As a result, cistern users do not get enough information on the best ways to build and maintain rainwater catchment systems and are not informed of the anticipated problems of the cistern systems.

The objective of this study is to compare the guidelines for the design, construction and maintenance of rainwater catchment systems with the realities of rainwater cisterns used for individual homes. The study focuses on cistern systems used in tropical environments and examines the microbiological quality of cistern waters as compared to World Health Organization (WHO, 1984) and United States Environmental Protection Agency (USEPA, 1984) drinking-water standards which essentially state that drinking water should contain less than 1 coliform/100 ml.

DISCUSSION

Published guidelines and recommendations on the construction and maintenance of rainwater cisterns are available (Michaelides and Young, 1983; State of California, 1981). Some of these guidelines are reviewed, together with the realities of meeting them.

Guideline one

Roofs of structures should be of a smooth material to prevent entrapment of contaminants on the roof. Rainwater flowing off smooth roofs will carry less contaminants into cisterns.

The reality
Home-owners generally build houses to suit their needs, and the roofing material used is usually not determined by their need for a rainwater catchment system. In many catchment areas, roofs of houses vary in the material used (Fujioka and Chinn, 1987). However, in small tropical islands where materials are difficult to obtain, corrugated iron, a smooth surface material, is often used.

Guideline two

Prevent trees from overhanging the house. Establish a programme of cleaning out gutters and washing the roof.

The reality
Many homes are near trees which overhang the roof. These trees drop their leaves onto the roof and into the gutters. Most home-owners do not clean out the leaves from gutters at regular intervals and fewer subscribe to a regimen of periodically washing the entire roof. Besides leaves, trees are home to birds, lizards and many insects which contaminate the roof and gutters with their faecal droppings. Whatever contaminates the roof will contaminate the cistern reservoir.

Guideline three

Use roof washers or foul-flush devices.

The reality
This recommendation is made in most published guidelines since it is well known that the first rainfall will transport most of the contaminants on the roof and in the gutters to the cistern. There are two types of foul-flush devices to prevent the initial flow of rainwater from entering the cistern. The first is a mechanical two-way valve which requires someone to mechanically turn the valve to waste the initial flow of rainwater and to mechanically turn the valve to direct the cleaner water into the cistern. This design is not reliable since someone will need to be there to turn the valve when it first rains. The second is an automatic foul-flush device which automatically collects and discards a set volume of water before water is allowed to flow into the cistern. Since this an automated system, it should be used in all cistern systems. However, most cistern users have not heard of foul-flush devices and very few of these foul-flush devices are in actual use.

Guideline four

Water from the roof should be screened and filtered before it reaches the cistern.

The reality
Screens are often used but these retain only large contaminants such as leaves. Smaller particles which contain microbial and chemical contaminants pass through these screens. Smaller pore size filters to retain microbial and chemical contaminants are not usually used since they tend to retard the flow of rainwater into the cistern and require frequent cleaning.

Guideline five

Cisterns should be sealed to keep out sunlight and contaminants such as insects (mosquitoes), reptiles (lizards) and animals (birds) from entering them.

The reality
This guideline is not consistently followed because it is easier to build systems which are not sealed. Cisterns which allow sunlight to enter often experience problems with algal growth. Some cisterns prevent sunlight from entering but are open to the outside and allows insects, lizards and small animals (birds) to enter and to contaminate the cistern.

Guideline six

Cisterns should be periodically cleaned.

The reality
Many cisterns are built to hold large volumes of water to ensure availability of water during dry periods. The larger the cistern the more difficult it is to clean and waters in these tanks are considered too valuable to discard. Cleaning requires draining the water and the need for more water to rinse the cistern. Many households use a single tank and cannot afford to drain their tanks. As a result, large cisterns are not cleaned as often as is required to maintain the quality of the water (Fujioka and Chinn, 1987; Lye, 1987).

Guideline seven

Water in the cistern should be periodically disinfected.

The reality
Most cistern owners do not disinfect their cisterns for two reasons. First, the procedure for properly disinfecting a cistern is difficult because the effective disinfecting dose of the disinfectant is dependent not only on the volume of water but also on the quality of the water and the ability to mix the disinfectant in the water properly. Actual attempts at disinfecting cisterns by adding liquid or solid forms of chlorine have not resulted in long-term improvement of water quality and often result in poor tasting water. Cistern owners do not like the taste of chlorine.

Guideline eight

Cistern waters should be monitored for drinking-water quality and evaluated against the drinking-water standard.

The reality
Since there are no requirements to monitor the quality of cistern waters, many owners have not had their water tested and the quality of water in most cisterns is not known. However, based on the results of limited studies (Dillaha and Zolan, 1983; Fujioka and Chinn, 1987; Lye, 1987; Ruskin and Callender, 1988) it is clear that cistern waters contain high levels of total coliform, faecal coliform and total heterotrophic bacteria and cannot meet drinking water standards established by WHO and USEPA.

CONCLUSION

The purpose of rainwater catchment systems is to collect rainwater which flows over the surface of the roof, through gutters and piping to be stored in a reservoir tank or cistern. Contaminants on the roof and in the gutters will be carried by the water into the cistern. It is not surprising that water in cisterns contains high concentrates of total coliform and faecal coliform bacteria, exceeding WHO and USEPA drinking-water standards. Moreover, the very high concentrations of total heterotrophic bacteria in cistern waters also provide evidence that cistern water is of poor quality and contains excessive concentrations of nutrients.

Every effort should be made to obtain cistern waters which are clean and uncontaminated. The first step towards this goal is to disseminate information to cistern users in the form of guidelines for the proper building and maintenance of rainwater catchment systems. Moreover, there will be need for a programme to monitor the quality of cistern waters, so that cistern users become aware of the quality of their water and the steps they can take to improve its quality. However, cistern waters will most likely be contaminated with some coliform bacteria. It is therefore recommended that cistern waters be disinfected before drinking. A practical approach is to designate one pipe in the household to be used for drinking purposes and to only disinfect water which is to be used for drinking rather than to attempt to disinfect all the water in the cistern. Since boiling water requires no additional equipment this is the most practical solution. The use of chlorine or other kinds of disinfectants which require good dosage and mixing will often result in unacceptable taste due to disinfection, as well as the formation of carcinogenic by-products. Thus, caution should be practised in chlorination of cistern water. Today, economical ultraviolet light disinfection systems are available and can effectively disinfect water flowing from a single tap without adding taste or the formation of carcinogenic by-products. Thus, this is a practical solution in affluent communities.

It must be recognized that rainwater catchment systems provide a necessary source of water for a significant number of people. Moreover, it is unrealistic to believe that the quality of cistern waters collected from individual homes will ever reach the quality of municipal water supply. Thus, drinking-water standards established for municipal drinking-water supply should not be applied to cistern waters. WHO (1984) recognized this and modified drinking-water standards to 10 coliform/100ml for unpiped systems such as cistern waters.

A realistic decision should be made with regard to establishing a water quality standard specific for cistern waters under defined conditions. One defined condition is for rainwater catchment systems from individual homes in tropical areas of the world. It should be recognized that in tropical countries there are environmental sources (e.g. soil) of total and faecal coliform bacteria (Hardina and Fujioka, 1991), so the presence of coliform bacteria in water does not necessarily mean that the water is contaminated with faecal matter. Cistern waters in tropical areas also contain high concentrations of heterotrophic bacteria which are known to interfere with total coliform assay, so the total coliform test is not dependable in this situation. Other factors should be considered: for example, it is reasonable to conclude that faecal contamination on the roof will not be from humans or larger animals, the sources of most pathogens for humans. The absence of human faecal contamination will ensure that the cistern water will not contain human viruses, one of the major causes of water-borne diseases. The absence of faecal contamination from larger animals also reduces the possibility of protozoan water-borne pathogens such as *Giardia* and *Cryptosporidium*. Some bacterial pathogens such as *Salmonella* species have been reported in lizards and birds. However, it is well known that the infectious dose of most *Salmonella* species is very high (>1000). Finally, the risk of drinking water from cisterns is still primarily to those who live in that household, and for many households, catchment systems provide the only practical means of obtaining water. Taken together, these results indicate that in tropical areas of the world a realistic and practical standard for cistern waters for individual catchment systems can be set at no more than 10 faecal coliform/100 ml.

REFERENCES

Dillaha, T.T. and **Zolan, W.J.** (1983). An Investigation of the Water Quality of Rooftop Rainwater Catchment Systems in Micronesia. *Technical Report No 45* Water and Energy Research Institute of the Western Pacific, University of Guam.

Fujioka, R.S. and **Chinn, R.D.** (1987). The Microbiological Quality of Cistern Waters in the Tantalus Area of Honolulu, Hawaii. *Proc. 3rd Int Conf on Rainwater Cistern System.* Khon Khaen, Thailand.

Hardina, C.M. and **Fujioka, R.S.** (1991). Soil: The Environmental Source of *Escherichia coli* and Enterococci in Hawaii's Streams. *Environmental Toxicology and Water Quality,* **6**, 185-195.

Lye, D.J. (1987). Bacteria Levels in Cistern Water Systems of Northern Kentucky. *Water Resources Bull.*, **23**, 1063-1068.

Michaelides, G. and **Young, R.J.** (1983). Design and Maintenance of Rainwater Harvesting Systems. *Water Resources Jl,* **139**, 35-42.

Ruskin, R.H and **Callender, P.S.** (1988). Maintenance of Cistern Water Quality and Quantity in the Virgin Islands. *Technical Report No. 30* Water Resources Research Centre, University of the Virgin Islands.

State of California (1981). Captured Rainfall: Small-scale Water Supply Systems. *Department of Water Resources Bulletin,* 213.

USEPA (1984). *Drinking Water Microbiology.* EPA 570/9-84-006. US Environmental Protection Agency, Washington, DC.

WHO (1984). *Guidelines for Drinking-water Quality*, Vol. 1, *Recommendations*. World Health Organization, Geneva, Switzerland, pp. 1-130.

DISCUSSIONS

J. Hari asked why there should be a different water quality standards for tropical countries and temperate (advanced countries). In reply **Roger Fujioka** said that the studies conducted in tropical islands such as Hawaii, Guam, Puerto Rico and Virgin Islands show environmental sources of faecal indicator bacteria such as total coliform and faecal coliform. Environmental sources of faecal indicator bacteria are soil and water or plants not recently contaminated with faecal material. These faecal indicator bacteria multiply in the environment. WHO and EPA use these indicator bacteria to set water quality standards but assume no significant environmental source of faecal indicator bacteria. These faecal indicator bacteria may not cause disease but indicate that water may be contaminated with feaces.

ASSESSMENT OF FOUR RAINWATER CATCHMENT DESIGNS ON CISTERN WATER QUALITY

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ABSTRACT

This paper reports on an experiment in which the same corrugated metal roof from a given building was used to collect rainwater, using four different collection designs into four identical 55 gallon plastic cistern tanks and to determine the comparative water quality (bacteria). The four variations in design were: a covered tank with screen device (Gutter Snipe); a covered tank with screen and foul flush diverter; a covered tank with screen and sand/gravel/charcoal filter; and an uncovered tank as a control. The drinking water quality of the four cisterns was evaluated by testing for concentrations of bacteria (total bacteria, total coliform, faecal coliform, and hydrogen sulphide producing bacteria), conductivity, turbidity, pH, and phosphates. The results indicated that tank 4 (sand/gravel/charcoal filter) demonstrated the lowest levels of indicator bacteria, ranging from 0 to 6 faecal coliforms per 100 ml (average of 1.3 CFU/100 ml), followed by tank 3 (foul flush) with a range of 0 - 168 CFU/100 ml (average of 17.8 CFU/100 ml), tank 2 (screen only) with a range of 0 - 388 CFU/100 ml (average of 51 CFU/100 ml), and finally tank 1 (uncovered), which ranged from 0 to 2.59 x 10^4 CFU/100 ml (average of 2430 CFU/100 ml). However, bacteria concentrations of at least one of the three faecal indicator bacteria (total coliform, faecal coliform, and hydrogen sulphide producing) were often recovered from these waters, indicating that the system designs were not able to meet US microbiological drinkingwater standards. All four systems were below the maximum turbidity level of 5 NTU established for individual sources. These cistern waters were also determined to have very high concentrations of total bacteria, always exceeding 500/ml, the minimum level at which interference with the recovery of total coliform bacteria have been reported. Faecal (44.5°C) and total (35.0°C) coliform results were compared with the hydrogen sulphide MPN method (room temp.). The hydrogen sulphide test correlated better with faecal coliform results as compared to total coliform results after a 24 hour incubation period.

INTRODUCTION

Rainwater collected from roofs and stored in cistern tanks is an essential source of drinking water in many countries throughout the world. Various rainwater catchment system designs exist that collect rainwater from roofs and store it in cisterns. Many studies focus on specific designs (e.g. use of diverters, filters, etc.) and their effects on cistern water quality (Michaelides, 1987; UN, 1989; Young and Sharpe, 1982). There is a lack of available information comparing different system designs to determine if, indeed, any significant differences exist between these designs and their effects on water quality. Although a "universal" rainwater catchment system design may not be feasible or practical, certain components are necessary for a rainwater catchment system. One problem with cistern water sources is the concentration of faecal indicator bacteria far in excess of the USEPA and WHO guidelines for drinking water (USEPA, 1985 a,b). The quality of the water in cistern tanks may be directly related to the design and maintenance of the rainwater roof catchment system.

The subject of this paper is to statistically compare four different rainwater catchment system designs to determine the effects of these designs on cistern water quality and whether these effects are significantly different. The four primary treatment designs selected represent the types of systems currently used throughout the world today.

MATERIALS AND METHODS

Study site and experimental design

A field experiment was conducted at the University of Hawaii Campus from July 1992 to February 1993. Rainwater was collected from the same corrugated metal roof from a given building using four different designs, into four identical 55 gallon plastic cisterns. The total roof dimensions are 30m long by 6m wide; however, only $9m^2$ of roof area was used to collect rainwater for each of the four catchment systems and the roof area was free of tree coverage. Two tanks each were positioned on the north and south sides of the building used to collect rainfall. The roofing material was corrugated metal. The gutter systems for all four systems were identical vinyl gutters developed by Snap-Seal. Each catchment system used a 10ft length of gutter connected to a $5cm^2$ plastic down-spout.

The four catchment system designs were :

1. Unmodified collection system and uncovered cistern (open tank).
2. Screening device (Gutter Snipe) and covered cistern.
3. Foul flush diverter and covered cistern.
4. Sand/charcoal/gravel filter and covered cistern.

Taps were placed 3.5 inches above the bottom of each tank. Overflow pipes were installed 3 inches below the rim of each tank. For the covered tanks, the overflow pipes were screened with a fine vinyl screen. The tanks were elevated 8 inches from the ground to prevent possible contamination from the ground surface.

System description

System 1 Unmodified collection system and uncovered cistern
Cistern 1 is open to the environment. This tank will represent a "worst case" or "no treatment" scenario for system comparison.

System 2 Screening device and covered system.
A sloped stainless steel (1mm space) screening device called the Gutter Snipe (developed by H.E. Finch, Inc. of Hilo, Hawaii) (Finch, 1992) was connected to the downpipe and set on top of the tank cover. This device allows water to flow to the cistern while solid matter slides down the screen and falls to the ground. The product specifications suggest that the Gutter Snipe not be placed lower than 60cm below the gutter, due to the excessive force of the water that would result. However, this arrangement was not possible due to the distance from the roof to the tank. To adjust for this discrepancy a 90 degree bend in the down-spout, approximately 60cm below the gutter, was installed to slow the water sufficiently so that the force of water would not be a problem.

System 3 Foul flush diverter system and covered cistern.
The diverter design selected for this experiment was that developed by Michealides (1987) with slight modifications. The dimensions of the diverter for this study were scaled down in size. The catchment area for this experiment (9 m^2) is approximately one-fourth the catchment area used by Michaelides. The diverter was constructed of plastic (PVC) piping following the design suggested by Michaelides. The first 0.01 inches (0.254mm) of rainfall is considered to be adequate to remove most of the dust and dirt from the surface of the catchment (Young and Sharp, 1982). Noting that volume = roof area ($9m^2$) x runoff coefficient (0.8) x rainfall, the volume required for this diverter design is approximately 2 litres. The volume of the diverter was expanded to capture 4 litres to assure that the majority of the dust and debris washed from the roof was captured in the diverter. The downpipe, leading from the gutter to the diverter, was modified. A square plastic downpipe (5cm x 5cm) connected the gutter to the diverter instead of the suggested 4-inch diameter downpipe. Michaelides' design places a coarse screen at the mouth of the down-spout. In this study the coarse screen was relocated to cover the entire 10ft gutter section. It was thought that the location of the coarse screen over the entire gutter would reduce the likelihood of the downpipe clogging, thereby minimizing overall cleaning and maintenance.

System 4. Filter system
A scaled-down model of a filter system as described by USAID (1984 a, b) was used for this study. Modifications to the filter system included substituting a 5 gallon plastic bucket for the cement box design. The cement box was too cumbersome to set on top of the tank. A 2inch diameter hole was cut in the bottom of the plastic bucket, and a fine screen was placed over the hole. The filter consisted of a 50mm thick layer of pea gravel as the bottom layer of the filter. A 50mm thick layer of crushed charcoal was placed on top of the layer of pea gravel. On top of the charcoal was a 50mm thick layer of sand, and on top of the sand was a 50mm thick layer of gravel. A fine screen was secured, with tie wire, over the top of the entire filter bucket. The USAID design recommended that a coarse screen for this system design was placed over the 10ft length of gutter. Placing the coarse screen over the gutter prevented large debris from entering the gutter and possibly clogging the downpipe and building up on the filter screen cover. Blockages could result in gutter overflow thereby losing water.

Collection and analysis of rainwater

Rainfall was measured daily throughout the course of the study using an all-weather rain gauge. The rain guage was located a distance of approximately 15ft away from the building used for rainwater collection. Water samples from each catchment tank were collected from the taps into clean, sterile, 1 litre polyethylene bottles. A water sample was also collected from the foul flush diverter apparatus. The taps were disinfected with isopropyl alcohol prior to collection of the water samples. The water was allowed to run for 2 minutes to rinse off the alcohol. Samples were transported to the laboratory in coolers and analysed within 1.5 hours of sampling. Samples were collected under varying weather conditions (i.e. periods of no rain; periods of continual rain; following heavy rains; following hurricane Iniki; and following a period of non-maintenance).

Chemical analysis

Turbidity was measured in nephelometric turbidity units (NTU) using the HACH Turbidimeter (Model 2100A) while reactive ortho-phosphate was measured in mg/litre using the HACH model DR/3000 spectrophotometer. Conductivity was measured in mmhos/cm (SI units are millisiemens per metre: 1 mS/m = 10 mmhos/cm) using the YSI Conductivity Bridge (Model 31A). pH was measured using the Orion Research microprocessor pH/millivolt meter 811. All measurements were conducted using standard methods (APHA, 1989).

Microbial analysis

Bacteria as Colony Farming Units (CFU/100ml) were enumerated by the membrane filtration method (APHA, 1989) using selective media to recover total coliform (mENDO agar @ 35°C for 24 hours), faecal coliform (mFC agar @ 44.5°C for 24 hours) and total heterotrophic bacteria (mHPC agar at 37°C for 48 hours). Water samples (25ml and 50ml) of appropriate dilutions were filtered through 0.45m filters (Gelman Sciences Inc., Ann Arbor, MI). These water samples were also analysed for hydrogen sulphide (H_2S) producing bacteria using the MPN Index/100 ml using Table 9221:III by the five tube most-probable number (MPN) technique methods (APHA, 1989). The tubes were incubated at room temperature (22 - 24°C) for 24 hours. The blackening of a paper strip in the hydrogen sulphide medium indicated a positive reaction (Manja, Maurya and Rao, 1982).

Statistical analysis

Physical and microbial results were analysed for statistical significance using One-way Analysis of Variance (ANOVA). Results were judged to be statistically significant only if the level of significance was 5% or less. Statistically significant results were further analysed using Tukey's multiple comparison test to determine which of the four primary treatment designs, if any, significantly differ from one another.

RESULTS AND DISCUSSION

Sixteen samples were collected over an 8-month period under various weather conditions. However, for some samples results were not available for all four systems and were not incorporated into the analysis. Sample sizes used for each water quality parameter analysed were tabulated. Analysis of cistern waters for conductivity, ortho-phosphate, pH, turbidity, total coliform, faecal coliform, and total heterotrophic bacteria are summarized in Table 1. System 4 (filter) results demonstrated dramatic differences in bacteria levels between those samples taken within 1 week of the installation of the filter, and those samples collected 1 month after the filter installation, so the data for cistern 4 was separated into two columns, A and B. Values in column A include in the analysis those samples taken immediately after the filter installation, and those in column B exclude those samples in the analysis.

The water quality regulations stipulate that drinking water be free of faecal contamination. The maximum contaminate level (MCL) for faecal indicator bacteria is therefore set at less than one total coliform bacteria per 100ml of water. In this study, water samples were analysed for faecal coliform, total coliform, total bacteria, conductivity, ortho-phosphate, pH, and turbidity. The results for each of the catchment system designs are given in Table 1.

Table 1. Analysis of cistern water samples from the unmodified screened, diverted and filtered systems

Assay	*Sample size*	*Tank 1 (control)*	*Tank 2 (screen)*	*Tank 3 (foul flush)*	*Tank 4 (filter) A*	*B*	*Among Tanks*[2]
Total coliform[1]	12	671.6	82.4	106.5	237 9	25.2	3 268*
Faecal coliform[1]	10	17.1	4 0	2.6	6.3	2.0	2 3481
Total bacteria[1]	12	5.26x10^6	3.94x10^6	7 64x10^6	7.56	1.82(x 10^6)	0.7686
Turbidity (NTU)	13	0.725	0.709	0.596	0.998	0.706	0.4486
Conductivity (mmhos/cm)	13	45.11	37.19	33 59	110.5	88 1	4 2609*
Ortho-phosphate (mg/l)	13	0.025	0.014	0.015	0.015	0.020	1.3635
pH	13	6.44	6.27	6 32	7.58	7.71	6.4251**

Note Values in geometric means

[1] Colony-forming units (CFU) per 100 ml.

[2] Test per differences among means.

* $p < 0.05$,

** $p < 0.005$.

System 1

Water from this cistern demonstrates the highest levels of indicator bacteria, ranging from 0 to 2.59×10^4 faecal coliforms per 100ml (geometric mean: 17.1 CFU/100ml), and total coliform bacteria levels ranging from 42 to 1.51×10^4 CFU/100ml (geometric mean: 671.6 CFU/100ml). Total bacteria levels exceeded 500 CFU/ml, ranging from 3.76×10^5 to > 1.20×10^8 CFU/ml (geometric mean: 5.26×10^6 CFU/ml).

Turbidity and conductivity results were well below the maximum contaminate levels (MCL) established for drinking water in the US (USEPA, 1985 a, b). Conductivity, which is the measurement of salts in the water, ranged from 12.77 to 136.16mmhos/cm (geometric mean: 45.11mmhos/cm), indicating that all four cistern waters were below the MCL of 250mg/l of chloride (490mmhos/cm). The conductivity of potable waters in the United States ranges generally from 50 to 1500mmhos/cm (5 - 150mS/m)(APHA, 1989). Clearly, the conductivity measured in the water of the unmodified and uncovered cistern is well within the potable water range. Turbidity ranged from 0.34 to 1.8 NTU (geometric mean: 0.725 NTU), and was below the recommended monthly MCL of 1.0 NTU level, and well below the 5.0 NTU limits established for non-community sources. Reactive ortho-phosphate concentrations ranged from 0.006 to 0.090mg/l (geometric mean: 0.025mg/l) as compared to water samples taken from Honolulu's municipal water supplier which ranged from < 0.003 to 0.015mg/l (Rijal and Fujioka, 1992). This result indicates that water in an unmodified and uncovered cistern may contain elevated concentrations of nutrients as compared to municipal water sources and reflects the fact that this water is contaminated by dirt and debris. The pH results ranged from 4.59 to 7.26 (geometric mean: 6.44) indicating that the water in system 1 tends to be acidic. The minimum and maximum allowable pH range for potability is 6.5 - 8.5 (USEPA, 1989).

System 2

This system represents the simplest modification of a collection system with an uncovered cistern. The results in Table 1 indicate that by covering the cistern and installing a simple, slanting screening device in the downpipe before the water reaches the cistern, coliform bacteria levels are reduced. Total coliform bacteria levels ranged from 28 to 558 CFU/100ml (geometric mean: 82.4 CFU/100ml), and faecal coliform bacteria ranged from 0 to 388 CFU/100ml (geometric mean: 4.0 CFU/100ml). Total bacteria levels exceeded 500 CFU/ml, ranging from 1.72×10^5 to 1.46×10^8 CFU/ml (geometric mean: 3.94×10^6 CFU/ml).

Turbidity results ranged from 0.47 to 1.5 NTU (geometric mean: 0.709 NTU). Conductivity measurements ranged from 8.43 to 107.46 mmhos/cm (geometric mean: 37.19 mmhos/cm). Both turbidity and conductivity measurements met drinking-water regulations. The water in system 2 exhibited the lowest pH value of the four systems compared. The values ranged from 4.94 to 7.42 (geometric mean: 6.27). Reactive ortho-phosphate concentrations ranged from 0.002 to 0.328 mg/l (geometric mean: 0.014mg/l). The presence of a screen and cover in the catchment system appears to lower the levels of ortho-phosphates as compared to the uncovered cistern; however, concentrations levels are, at times, elevated to levels that may promote increased bacterial growth.

System 3

In recent years, studies have focused on the inclusion of a foul flush diverter in a rainwater catchment system. The results indicate that the presence of a foul flush diverter does maintain lower coliform bacteria levels than the unmodified and uncovered cistern. Total coliform levels ranged from 0 to 4400 CFU/100ml (geometric mean = 106.5 CFU/100ml). Faecal coliform levels ranged from 0 to 168 CFU/100ml (geometric mean = 2.6 CFU/100ml). However, coliform bacteria levels did not appear to be different from the screening device and covered cistern collection system. In fact, total coliform levels were higher in system 3 than in system 2. Total bacteria levels exceeded 500 CFU/ml, ranging from 6.76×10^6 to 1.20×10^8 CFU/ml (geometric mean = 7.64×10^6 CFU/ml).

Turbidity and conductivity measurements were lowest for system 3. Turbidity levels ranged from 0.27 to 2.1 NTU (geometric mean: 0.596 NTU). Conductivity results ranged from 8.43 to 94.57mmhos/cm (geometric mean: 32.59mmhos/cm). The water in system 3 exhibited a low pH value, ranging from 4.59 to 7.61 (geometric mean: 6.32). Reactive ortho-phosphate concentrations ranged from 0.001 to 0.300mg/l (geometric mean: 0.015mg/l). The presence of a diverter and cover appears to lower the levels of ortho-phosphates as compared to the uncovered cistern; however, concentration levels can, at times, be elevated to higher levels.

System 4

Analysis of the results from system 4 indicates that a filter does have an effect, at least initially, on cistern water quality. It was observed that the bacteria levels were dramatically higher in those samples taken immediately after the installation of the filter than those samples taken 1 month after installation. Table 1 separates the results for system 4 into two columns, A and B. The values in column A include in the analysis those samples that immediately followed the filter installation. The values in column B exclude these samples from the analysis. After eliminating the effect of the filter, system 4 demonstrates the lowest total coliform level (geometric mean: 25.2 CFU/100ml; range of 0-196 CFU/100 ml) of the four systems compared. Faecal coliform levels ranged from 0 to 6 CFU/100ml (geometric mean; 2.0 CFU/100ml). Total bacteria levels ranged from 7.68×10^4 to 2.28×10^7 CFU/ml (geometric mean: 1.82×10^6 CFU/ml).

Turbidity levels ranged from 0.42 to 1.6 NTU (geometric mean: 0.706 NTU). Conductivity results were significantly higher than the other three systems. Results ranged from 52.76 to 146.15mmhos/cm (geometric mean: 88.1mmhos/cm). High conductivity readings have been attributed to the collection of dust and particulates by rainfall (Laquer, 1990). Since conductivity measurements are used to approximate total dissolved solids, it seems logical that the presence of additional dust and dirt particles, contributed by the filter components, would account for higher conductivity readings. The presence of the filter system effects cistern water pH. The resulting values for system 4 demonstrated significantly higher pH values than those recorded in the other three systems. pH values ranged from 7.37 to 8.59 (geometric mean: 7.71). System 4's pH values clearly lie within USEPA guidelines for potable waters. Reactive ortho-phosphate concentrations ranged from 0.007 to 0.189mg/l (geometric mean: 0.020mg/l). The presence of a filter and cover does not appear to lower the levels of ortho-phosphates any better than the other three systems in this study.

Hydrogen sulphide bacteria comparison

The hydrogen sulphide test is simple enough that cistern owners can run this test. The hydrogen sulphide assay, using the five tube MPN method, was run in parallel with the enumeration of faecal indicator bacteria, using the membrane filtration method, to determine a possible correlation between the two methods. Two comparisons were made for this analysis. First, the numbers derived from each test method were compared. In the second comparison, the hydrogen sulphide test was viewed as a presence/absence test. A persence or absence result from the hydrogen sulphide test was compared with the indicator bacteria levels derived by the membrane filtration method. The results indicated that faecal coliform counts correlated better (68%) with the hydrogen sulphide results at the 24 hour incubation period. However, total coliform counts correlated better with the hydrogen sulphide test (71%) at a 48 hour incubation period when the hydrogen sulphide test was compared as a presence/absence test. The comparison between the hydrogen sulphide results and the faecal and total coliform results did not correlate as closely as the results reported by Rijal and Fujioka (1992). Hydrogen sulphide producing bacteria are more likely to be found in cisterns that contain sediment build-up along the bottom of the cistern. The time period of this experiment did not allow for sediment to build up sufficiently in the cisterns.

STATISTICAL RESULTS AND CONCLUSIONS

Four rainwater catchment designs were analysed for significant differences on cistern water quality. Water samples for each tank were assayed for total coliform, faecal coliform, total bacteria, pH, turbidity, conductivity, ortho-phosphate, and pH. The results of this study indicate that the four rainwater catchment system designs analysed (unmodified and uncovered cistern; screening device and covered cistern; foul flush diverter and covered cistern; and sand/charcoal/gravel filter and covered cistern) do not differ significantly ($P > 0.05$) in their affect on faecal coliform bacteria levels, total heterotrophic bacteria levels, ortho-phosphate and turbidity measurements. The system containing the sand/charcoal/gravel filter significantly differed ($P < 0.05$) in conductivity and pH measurements from the unmodified, screened and diverted systems. The presence of a filter system appears to affect cistern water quality. Bacteria levels tended to be higher in those samples taken within a week after the installation of the filter. After eliminating these initial samples from the analysis, the filtered system did significantly differ ($P < 0.05$) from the unmodified and uncovered cistern in total coliform levels. However, bacteria concentrations of at least one of the three faecal indicator bacteria (total coliform, faecal coliform and hydrogen sulphide) were often recovered from these waters, indicating that these system designs would not meet US microbiological drinking-water standards. Fujioka, Chinn and Inserra (1991) suggested that a level of 10 faecal coliform CFU/100ml be instituted as a standard for rainwater catchment systems. Based on this proposed level, systems 2, 3 and 4 would meet this drinking-water standard.

The placement of the filter may be critical when designing the collection system. A filter placed on top of the cistern could not handle the water flow from a large catchment area following a heavy rainfall. Water may overflow at the filter site resulting in water loss. In areas where the collection of all rainfall is vital this system would not be appropriate. In this instance, to avoid possible water waste, the filter may be better located in the pipe leading from the tank to the house or tap.

Total bacteria levels in all four systems always exceeding the minimum 500/ml at which interference with the recovery of total coliforms have been reported (Geldreich, Allen and Taylor, 1978). It is possible that since high total bacteria levels were recovered, total coliform levels may actually be higher than the results indicate. Average total bacteria levels for all four systems are maintained at a level of 10^6 CFU/100 ml. This suggests that enough nutrients are within cistern waters, regardless of system design, to sustain a stable level of bacteria.

None of the four samples exceeded the 5.0 NTU limits established for non-community sources. Although not significantly different, those systems that incorporated at least a cover and some type of solid particle deterrent tended to maintain slightly better water quality than the unmodified collection system and uncovered cistern. Ortho-phosphate concentrations tended to be higher than concentrations in municipal water sources. A thin algal film covering the inside of the cistern walls attest to the fact that nutrient levels of these tanks are high.

Daily rainfall data was recorded between July 16, 1992 and February 28, 1993. No positive correlation appeared between rainfall density and bacteria levels. High bacteria counts occurred in different cistern water samples on different days over the course of the study.

REFERENCES

APHA, AWWA and **WPCF** (1989). *Standard Methods for the Enumeration of Water and Wastewater*, 17th edn. American Public Health Association, Washington DC.

Finch, H.E. (1992). Self-cleaning Screens for Catchment Systems. *Proc. Regional Conf. Int Rainwater Catchment Systems Association*, p. 250. Kyoto, Japan.
Fujioka, R.S., Chinn, R.D. and **Inserra, S.G.** (1991). *Proc. 5th Int Conf on Rainwater Catchment Systems*. p. 250. Keelung, Japan.
Geldreich, E.E., Allen, M.J. and **Taylor, R.H.** (1978). Interferences to Coliform Detection in Potable Water Supplies. C.W. Hendricks, ed. *Evaluation of the Microbiology Standards for Drinking Water*, EPA - 570/9-78-00C. Ed by C.W. Hendricks. USEPA, Washington, DC.
Laquer, F.C. (1990). An Intercomparison of Continuous Flow, and Automatically Segmenting Rainwater Collection Methods for Determining Precipitation Conductivity and pH. *Atmospheric Environment*, **24A**, (9) 2299-2306. Pergamon Press, Oxford.
Manja, K.S., Maurya, M.S. and **Rao, K.M.** (1982). A Sample Field Test for Detection of Faecal Pollution in Drinking Water. *Bull. World Health Organization*, **60**(5), 797-801.
Michaelides, G. (1987). Laboratory Experiments on Efficiency of Foul Flush Diversion Systems. *Proc 3rd Int. Conf on Rainwater Catchment Systems*. Khon Kaen, Thailand.
Rijal, G. and **Fujioka, R.** (1992). Effect of UV and Bacterial Tests on Cistern Waters. *Proc. Regional Conf of the Int. Rainwater Catchment Systems Assoc.* p. 492, Kyoto, Japan.
UN (1989). Water Resources Development in Asia and the Pacific: Dam Safety Evaluation and Monitoring, Water Tariffs and Rain-water Harvesting. *Water Resources Series*, No. 63. United Nations, New York.
USAID (1984a). Designing Roof Catchments, p. 97, *Technical Note No. RWS* 1.D.4.
USAID (1984b). Constructing, Operating and Maintaining Roof Catchments, p. 101. *Technical Note No. RWS* 1 C.4.
USEPA. (1985a). National Primary Drinking Water Regulations. *Fed Reg.* **50**, No. 219. US Environmental Protection Agency.
USEPA (1985b). National Secondary Drinking Water Regulations. *Fed. Reg* , **50**, No. 219, US Environmental Protection Agency.
USEPA (1989). National Secondary Drinking Water Regulations. *Fed. Reg.*, **54**, No. 97. US Environmental Protection Agency.
Young, E.S. Jr and **Sharpe, W.E.** (1982). Rainwater Cisterns Design, Construction and Water Treatment. Special Circular 277. College of Agriculture, Pennsylvania State University.

HYDROLOGY

HYDROLOGY OF RAINWATER CATCHMENT SYSTEMS

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Rainwater catchment systems are in principle analogous to the river basins or macrocatchments (area in thousands of km) drained by a major river. The runoff from such a macrocatchment is harvested by making a dam either for hydropower and/or water supply to meet various needs. Rainwater catchments are micro in size (say 10m to 1ha) and generally no drainage channel exists to drain the runoff other than some kind of artificial gutter or pipe. The catchments can take the form of a roof or a ground surface, suitably covered to generate more runoff, to be used for drinking, washing, stock watering, laundry, kitchen gardening etc. Such systems present one alternative for sustainance of rural folk in the vast semi-arid and arid environments worldwide.

Roof catchment systems are used for collecting runoff which is stored in tanks. The size and shape of the tanks and the roof areas vary considerably. Local designs for collection and storage have evolved from experience and largely they are not optimal. There have been some attempts to design systems based on principles which optimize the data on rainfall, water use and cost of roofing and tanks. Such attempts are confined to metal tanks and roofs, using weekly to annual data.

The design aspects relating to ground catchments are complex because of typical inherent hydrological problems. The hydrology of ground catchments is dominated by the absence of channels and pronounced overland flow, compounded by the presence of minute depressional storages and temporarily varying infiltration process. The other area which poses problems in experimentation is monitoring and accurate measurement of runoff rates, infiltration rates, and runoff volume trapped by surface puddles and hollows. The technology for monitoring and measuring flows from rivers is well developed but these techniques cannot be transposed to microcatchments simply because of scale problems.

Present practice in the design and analysis of ground catchment assumes the runoff coefficient to be entirely dependent on the material of the surface and constancy of infiltration rate. Conservative relationships are used for estimating runoff. Optimization attempts, similar to those for roof catchment systems, are practically non-existent.

Hydrological analysis for the design of the rainwater catchment systems is in its infancy. The following are basic issues that need to be resolved.

1. Identification of basic data for design. In particular the role of rainfall data should be specified in relation to the project benefits and the costs involved in collecting the data. It should be stressed that the data requirement should only be extended up to a daily basis, as such data is readily available. Suitable techniques should be evolved to transpose the rainfall information from the gauging sites to the sites where rainwater catchment systems are to be installed. The optimization analysis for roof catchment systems should be extended to a daily basis.

2. The criteria for designing rainwater catchment systems should be standardized using the reliability concepts based on probability analysis of the rainfall data. The central issue here is to decide the reliability level, i.e, 80%, 90%, or 95%, and the base of the data, i.e. weekly, monthly or annual totals, to which the above reliability criterion should be applied.
3. The variability of runoff coefficients in relation to the material, size and shape of catchments and rainfall characteristics needs to be studied intensively. The process of infiltration as influenced by cracking and crusting of soil surfaces also needs to be analysed and understood. There is need to prescribe a physically based infiltration model which should yield reliable infiltration rates by making use of the measurable properties of the soil. There is also a need to analyse and predict overland flow; a simple model involving the age-old Manning's formula and kinematic wave approximation might be a suitable choice. It is necessary to suitably account for losses in depressional elements and the evaporation process. The suitability of pan evaporimeter data needs to be examined; evaporation estimation should be based on minimal data, such as temperature alone.
4. The rigorous algorithms for design and operation of multipurpose reservoirs should be simplified greatly for the design and operation of cisterns in rainwater catchment systems. The algorithms, based on optimization concepts, should be simplified so as to be compatible with pocket calculators.
5. There is need to revisit the runoff plot experiments for a proper analysis and understanding of hydrological processes at micro level. Particular attention should be paid to the measurement of runoff rates in the order of fractions of a litre per second to a few litres per second using robust and methods such as flumes, weirs and tipping buckets, with minimal use of electronic gadgetry. Likewise some simple methods, other than cylinder infiltrometers, need to be devised for measurement of infiltration rates. Photogrammetric methods should be used to quantify the role of surface puddles and hollows. It must be stressed that accurate evaluation of infiltration rates is dependent on the correct quantification of water trapped in depressions.
6. Design procedures based on hydrological information should be laid out in the form of nomographs, slide rules or a small software package which could be run on a pocket calculator. The key element in the entire analysis is to preserve the simplicity and modest conservatism of design.

VALUE OF DAILY DATA FOR RAINWATER CATCHMENT

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ABSTRACT

As with all engineering systems, rainwater catchment (RWC) design requires a basic data set. This data set generally includes rainfall, target demand, and system size. Rainfall and demand data may be simple mean values, statistical distributions, or a time series, historical or synthetic. System size data may simply be catchment and cistern mean values, distributions, or a dynamic interrelation optimizing the two. Additional basic data may relate to gutter or pipe capacity, abstractions, water allocation and rationing. Different problems require different data.

Whatever data is employed, the data must be sufficiently precise for the purpose of the design. But as data acquisition may be costly, there is inefficiency in gathering more data than is needed. Thus every RWC design sould be initiated with a set of questions: "Should I acquire daily rainfall data? ... average roof size?... monthly demand data?..." There is a need to balance the costs of data with the benefits derivable from that data.

Using sensitivity analysis, the value of daily rainfall data is explored for a Northern New Mexico RWC system. The case study approach illustrates a non-rigorous methodology applicable in a wide variety of designs.

INTRODUCTION

Hegen (1987, 1991 and 1992) analysed RWC in Chama, New Mexico. For consistency, the same 7-year data set is used here. The earlier papers illustrated alternative perspectives of data presentation, the simplest being a histogram of daily rainfall depths.

Figure 1 shows the cumulative rainfall record reduced to an alternative series of wet and dry period durations. If measurable rain falls on each of *n* consecutive days, the series is a wet period of duration *n*. If no rainfall is recorded for *m* consecutive days, the series is a dry period of duration -*m*. (the negative sign is used for book-keeping purposes; it carries no mathematical significance). Approximately 20% of the dry periods are of 8 or more days in duration. Approximately 20% of the wet periods are of 4 or more days in length. The statistical distribution of the dry periods is clearly of concern in RWC performance prediction.

Figure 1 illustrates an analysis that could only be possible with a daily record of precipitation. The length of a dry period is not derivable from monthly totals. The ability to generate a figure such as this is, therefore, a benefit of having daily records. But daily data has a cost; someone must record the measurements. Does the value of the figure (and its related forms) exceed the costs associated with gathering the data? To pursue this question, simulation must be employed.

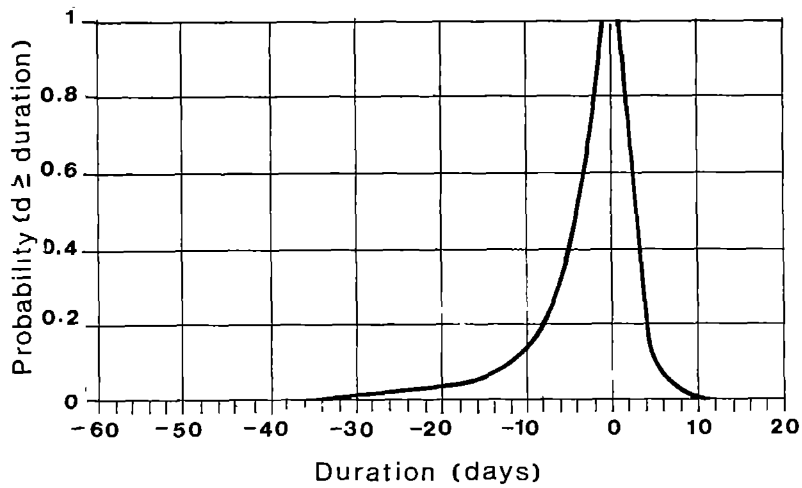

Figure 1 Cumulative distributions of wet and dry period durations.

SIMULATION

As suggested elsewhere, there is little justification for limiting RWC design to hand calculations. A rainfall time-series run through a RWC computer simulation provides far more information about system performance than what can be estimated from descriptive rainfall statistics.

Whether the time series is daily, weekly or monthly data, simulation is structurally the same. There are two fundamental operating rule algorithms for RWC utilization. The analyst must select the one most appropriate for a particular situation. The consumption before spill (Cbs) operating rule is:

$$C_i = \min \begin{cases} S_{i-1} + P_i \\ T \end{cases} \qquad \ldots. \quad (1)$$

$$Q_i = \max \begin{cases} S_{i-1} + P_i - V - C_i \\ 0 \end{cases} \qquad \ldots. \quad (2)$$

$$S_i = S_{i-1} + P_i - Q_i - C_i \qquad \ldots. \quad (3)$$

The spill before consumption (SbC) operating rule is

$$Q_i = \max \begin{cases} S_{i-1} + P_i - V \\ 0 \end{cases} \quad \ldots. \quad (4)$$

$$C_i = \min \begin{cases} S_{i-1} + P_i - Q_i \\ T \end{cases} \quad \ldots. \quad (5)$$

$$S_i = S_{i-1} + P_i - Q_i - C_i \quad \ldots. \quad (3)$$

where S_i is storage at the end of period i in (litres),

P_i is precipitation in period i (litres), the product of rainfall depth in period i and catchment area A,

V is cistern volume (litres),

Q_i is spill in period i in litres,

C_i is consumption in period i (litres)

T_i is target for period i (litres). A *per capita* basis is suggested to correct for household size.

Simulation quantifies how well a RWC satisfies the target demand. For simplicity in this paper, this measure is the number of periods in which the cistern is empty, i.e. $C_i = 0$. These instances will be called system failures. A more complex definition of failure might include a weight assigned when $0<C<T$. Simulation can tally these events as well.

DURATION OF MEAN RAINFALL

The time increments of equations (1) - (5) are arbitrary, but not inconsequential. The smaller the time step, the more accurate the simulated results. As a benchmark, the example data set has 2556 consecutive days with valid rainfall record. Running this daily data string through the SbC and CbS operating rules for an A of $10m^2$, a T of 15 litres/day and a V of 500 litres, there are 311 and 303 failures respectively. At this A, T and V the operating rule algorithm makes only a minor difference. The RWC system fails approximately 12% of the time. This benchmark is what would truly happen if the operating rule were used with the historical daily record.

What would be the consequence of using a 2-day mean rainfall at each time step? The rain gauge would need to be read only every other day, a data collection and processing savings. By averaging rainfall, there would be fewer predicted spills from the cistern, as an excessive rainfall one day would be averaged into the next day. Likewise there would be fewer predicted failures, as an actually dry day would appear to have some rainfall if an adjacent day had rain. The RWC would appear to work better (have fewer failures) in simulation than in reality. Simulating with the CbS algorithm, there are 277 failures, 26 more than by the daily data. The difference is the error: a 2-day mean model would miss 26 daily failures that 1 day modelling would have identified. Is the effort saved having to process rainfall data in groups of two, not individually, worth the consequences of underpredicting 26 failures in 2556 days? Grouping by two may be an acceptable choice in this case.

Likewise, rainfall can be grouped into 3-day means, weekly means, or any other convenient duration. The larger the duration, the more the averaging will make the simulated RWC erroneously appear to work better, but less effort will be required for data collection. (The extreme case would be averaging the entire data set. As long as the mean exceeds T, the system seems never to fail). In this case study, the data string was wrapped head to tail, as if the first record also followed the last record, allowing all results to be compared to the 2556 day benchmark. Moving means were used, rather than step changes at the end of each duration. Table 1 summarizes results. The benchmark case is shown in bold.

Table 1. Summary of RWC simulated failures (C=0).

Operating rule		*Area (m^2)*	*Volume (l)*	*Target (l/day)*	*Duration of mean (days)*					
SbC	*CbS*				*1*	2	*3*	*7*	*14*	*31*
X		10	500	15	311	283	260	168	76	28
	X	10	500	15	303	277	255	163	74	28
	X	9	500	15	383	357	322	216	105	32
	X	8	500	15	498	467	428	286	145	47
	X	10	450	15	333	302	277	181	83	31
	X	10	400	15	369	338	307	205	98	37
	X	10	500	16.5	396	363	336	229	109	38
	X	10	500	18	494	462	427	292	144	50

DISCUSSION

Table 1 shows the effect of operating rule algorithm choice and the sensitivity to 10% and 20% decreases in A and V and increases in T. Failures are more sensitive to A than to V. Most significant to this paper, Table 1 shows the consequence of using biweekly, or even monthly means. Simulation is roughly only 10% accurate (i.e. simulation catches only 10% of the failures) when monthly moving means are used in place of daily data. In short, monthly means are not good enough. Simulation is roughly 50% accurate if weekly averages are used in place of daily data. The data trade-off is reasonably consistent for all eight classes.

This case study is not sufficient to draw broad conclusions regarding daily *vs* weekly or monthly data. Rather, it illustrates the relative value of data for accurate modelling. If the cost of daily data is simply the cost of transcribing existing rainfall records into the computer, the errors from using weekly or monthly means seems to merit using the full daily data set. If only monthly data is available, the expense of securing a daily record must be weighed against the consequences of substantially underestimating the RWC failures.

There is, of course, no "correct" duration. Simulation is, however, a reasonably straightforward way to explore the sensitivity of RWC system performance to the time step. Understanding this relationship can lead to improved RWC design.

REFERENCES

Heggen, R.J. (1987). Rainwater Catchment Rationing. *Proc. 3rd Int Conf. on Rain Water Cistern Systems.* Khon Kaen, Thailand.
Heggen, R.J. (1991). Dynamic Programming of Rain Water Catchments. *Proc. 5th Int Conf on Rain Water Catchment Systems.* Taiwan.
Heggen, R.J. (1992). Risk and Critical Rainfall Events. *Global Water Use Under Limited Water Situation,* Vol. 2, Ed by I. Minami, IRSCA, Kyoto, Japan.

A PERSONAL NOTE

I have had interest in rainwater catchment (RWC) since the days I relied on it was as a novice engineer in Micronesia. The more I have subsequently pursued "big" problems in water resources engineering, the more I have discovered that the RWC problems presents many of the same analytic questions. There is commonality between watershed modelling and roof catchment. There is commonality between spillway hydraulic and gutter flow. There is commonality between reservoir operation and cistern use.

For watershed, spillway and operating rule analysis, there is a wealth of analytic techniques and ongoing engineering research. For RWC, there is a paucity of comparable scientific activity. RWC engineering is often at a technical level practised 50 years ago. Such disparity makes little sense. I suggest ten reasons why RWC inherently merits an improved level of analysis.

1. The millions of consumers who rely on RWC deserve well thought-out systems, not trial and error implementation.
2. The consequences of under design can be catastrophic.
3. The consequences of over design can impose undue costs of economically marginal communities.
4. RWCs are complex systems. A RWC based on back-of-envelope engineering is like a bridge beam selected by kicking the available stock of steel.
5. Data is obtainable. Every viable RWC project has at least a minimally literate person in the field with access to a tin can and ruler. Though the resulting rainfall data may be less than complete, it is an adequate start.
6. Mathematical modelling is an "appropriate technology" everywhere. Engineers in most nations are computationally competent. Consumers in no nation, rich or poor, comprehend the analytic basis for much of their infrastructure. The engineers in every society must.
7. Computers are likewise an "appropriate technology". RWC computations are not complex, but they can be lengthy. An 8086 machine in the provincial capital is enough to look at the data. Whether it takes 4 seconds or 40 minutes to get the output is inconsequential.
8. Good design respects, and should take advantage of social, cultural and economic constraints. Perceived conflict between such constraints and an engineered RWC system stems from the narrowest practice of engineering.

9. Good design sharpens both the skill and, perhaps what is more important the creativity of the analyst. The engineer becomes more observant.
10. Good design is fun. To make things that work is not the goal of engineering. To make things that work well is.

I have contributed a paper to each of the RWC international conferences stressing some aspects of improved design. I have not proposed any particular analysis to be the correct approach for other situations. I have simply suggested by example that more could, and should be done in engineering design.

This paper is another in my series. Don't concentrate on its technical merit; in that respect it is not major. Critique it instead for its theme. Data has a price. Data has a value. If the value exceeds the price, investment in data is worthwhile. If the price exceeds the value, investment in data is a net loss. This is the same for every RWC in the world. What data can be developed for what price? What data should be developed?

DISCUSSIONS

Mr Wafua wanted to know what simulation was used in the case study presented in this paper. **Mr Heggen** responded that the simulation used both the spill before consumption and the consume before spill rules. In the case study, the rules did not make a great difference for the objective. However, it had been noted from other studies that the consume before spill rule sometimes yielded a performance that was about 10% better than when the same data was run on the spill before consumption rule. The authors experience with real assistance indicated that users would run out into the rain and start drawing from the system. Thus the spill before consumption rule may be the more realistic.

Mr Burgess commented that the storage tank would "even out" the fluctuations caused by the mean when using average rainfall and demand data. The author responded that this was correct. However, the difficulty was that to even out large fluctuations the storage capacity had to be high. The objective of the design included a rational determination of this capacity. That is, balancing the cost of storage against the improvement in performance. The advantage of simulation with short time steps was that such modelling could demonstrate the sensitivity of storage (or any other parameter) to performance. Modelling with long time steps tended to mask the real behaviour which was being simulated.

RAIN-SUM: A CRITERION FOR DESIGN OF RAINWATER HARVESTING SYSTEMS

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ABSTRACT

One criterion for the design of a rainwater harvesting system is proposed, on the basis of the rain falling during a wet period lasting for several days. The total rainfall over the successive wet days is referred to as rain-sum and the rainfall lasting successive days as rain-run. For the design of a rainwater harvesting system, interest may lie in the longest rain-run which may result in the maximum rain-sum. This requires an analysis in the stochastic domain involving the interaction between rain-run and rain-sum, as rainfall is a stochastic process. The analysis paves the way for deriving the frequency (probability) distribution of the largest rain-sum which can be used to choose a design value for rainwater harvesting systems. The wet spells or rain-runs display persistence in their occurrence in the climatic environments of Kenya. The persistence behaviour was modelled by a Markov process. The rain-sums were modelled using the Weibull model of probability with its parameters derived from daily rainfall for short and long rainy seasons. The probabilities of largest rain-sums were computed and those corresponding to 80% and 50% probability levels were regarded as suitable design indices. These design indices appeared more realistic and optimal in relation to indices based on the probability analysis of annual and seasonal totals and the annual daily maximum rainfall.

INTRODUCTION

The practice of rainwater harvesting has been catching on in the water-starved regions of the world; the arid and semi-arid lands (ASAL) of Kenya are no exception. Several criteria are in vogue today for the hydrologic design of a rainwater harvesting system. One criterion which is simple and popular is based on annual rainfall totals which are analysed for frequency distribution, and a value corresponding to 80% reliability level is chosen; i.e. the annual rainfall value with the exceedance probability of 80% or non-exceedence probability of 20% is used for designing the system. Although an 80% reliability criterion sounds sensible, the analysis based on annual totals lacks a rationale. Because one is harvesting rain when it rains during a day, or successively over several days, it is logical to think that the total rain over these successive rainy days should form the criterion for the design. This total rain during successive wet days is designated as rain-sum in this paper. There are two elements attached to the rain-sum: firstly for how long (i days, i = 1, 2, 3...) does a rain-spell last in a rainy season, and secondly how much does it rain over this rain-spell of i days. One is interested in that rain-spell which brings the maximum rain. In the probability theory these spells are known as runs.

The frequency distribution of the maximum rain-sum can be carried out and a value corresponding to 80% or 50% reliability level can be obtained. The analysis, therefore, calls upon firstly the characterization of the probability structure of rain-runs or wet spells during the short and long rainy seasons, and secondly the probability structure of the total rain or rain-sum during these wet spells. The maximum of several rain-sums is then to be considered for design purposes. This analysis involving the interaction of rain-sum and rain-run is the subject of the current paper. The daily rainfall data for short and long rainy seasons for Kibwezi (semi-arid) and Kabete (semi-humid) rain gauging stations in Kenya have been used to illustrate the methodology.

THEORETICAL BACKGROUND AND DATA ANALYSIS

Let a day with rainfall more than zero mm be designated a wet day (w), and that with no rainfall, or zero value recorded by the gauge reader, be designated a dry day (d). The probability of occurrence of a wet or dry day depends on the climatic system of a place or region. For example, the probability of any day being a wet day in Kibwezi is 0.20 in the long rainy season. The same probability for Nairobi is 0.50. The occurrence of any day being wet might have some dependence on whether the immediate past day or past several days were wet or not. The phenomenon of such dependence is known as persistence and the process displaying the trend of persistence is known as the Markov process. The simplest type of persistence may be represented by a Markov process of order one, in which today's state is dependent only up to one step behind. The process displaying an insignificant level of dependence is termed a random or independent process. The degree of persistence is quantified through conditional probability or lag 1 serial correlation coefficient. The conditional probability of any day being wet given the previous day was wet is designated by P(w/w) and the same connotation applies to a dry day followed by dry day, i.e. P(d/d). For a random or independent process the conditional probability, P(w/w), is equal to the simple probability of any day being wet, P(w). For the Markov order 1 process or simply Markov process (as addressed in this paper) P(w/w) P(w). The probabilities of rain occurrences obeying a Markov process can be written in the form of the following transitional matrix:

$$\begin{bmatrix} pp & 1-pp \\ 1-qq & qq \end{bmatrix} \qquad (1)$$

when the process is purely random pp = p and qq = q, and the transitional matrix takes the form:

$$\begin{bmatrix} p & 1-p \\ 1-q & q \end{bmatrix} \qquad (2)$$

where pp = P(w/w), qq = P(d/d), P(w) = p and P(d) = q.
The numerical values of p, pp, qq and q lie between 0 and 1, and p + q = 1. A Chi-square statistic based on the likelihood ratio test (Medhi, 1982) can be used to test whether matrix (1) is

equivalent to (2). If they are equivalent the process in question can be regarded as random, otherwise it can be inferred to be following a Markov process. For the process to be random the calculated Chi-square statistics should be less than 3.84 at 1 df and 5% level of significance.

In a sample of size n, there will occur spells or runs of wet days. Each run may last for 1,2,3....i days. In an analysis for rainwater harvesting one is interested in the longest value of i, which is referred to as the critical wet period. This longest period is likely to yield the maximum rain-sum. The probability density function (pdf) of the occurrence of wet spells can be regarded as following the well-known Poisson probability law (Sen, 1980). The distribution of rain-sum (S) has not been well studied. One model which is gaining popularity in the reliability theory is the Weibull probability distribution (Benjamin and Cornell, 1970). In the present analysis, therefore, the Weibull probability density function (pdf) was used to describe the distribution of rain-sum sequences. The pdf's for these two processes under Markov dependence can be written as follows:

$$P(N_w = i) = \frac{\exp[(-np(1-pp)]\ [np(1-pp)]^i}{i!} \qquad (3)$$

$$P(S \le D) = 1 - \exp\left[-(\frac{D}{B})^A\right] \qquad (Hann, 1977) \qquad (4)$$

in which

n = sample size,

$P(N_w = i)$ = probability of occurrence of wet spells equal to i days (i = 1,2,3....),

$P(S<=D)$ = probability of rain-sum less than, or equal to, a particular value of D,

A and B = parameters of Weibull distribution,

p and pp are as defined earlier.

In the study of the maximum rain-sums, one is interested in the largest value of S, denoted by S_m. The determination of probabilities of S_m's requires the involvement of order statistics. Noteworthy work in this direction has been done by Todorovich and Woolhiser (1975) and the following relationships are suggested:

$$P(S_m \le D) = P(N_w = 0) + \sum_{i=1}^{\infty} [P(S \le D)]^i.\ P(N_w = i) \qquad (5)$$

Equation (5) can be simplified to:

$$P(S_m \le D) = \exp[-np(1-pp).\{P(S>D)\}] \qquad (6)$$
$$for\ 0<D<\infty$$

The approximate values of mean and variance of rain-sum and parameters of Weibull distribution A and B were obtained following relationships in Sen(1980) and Haan(1977). The relationships are reproduced below.

$$r = \sin 2\pi(pp-0.5) \tag{7}$$

$$E(y) = \frac{E(x)}{p} \tag{8}$$

$$V(y) = \frac{p.V(x)+(1-p)\ E^2(x)}{p^2} \tag{9}$$

$$\bar{S} = \frac{E(y)}{(1-pp)} \tag{10}$$

$$S_s^2 = V(y)\left[i+2r\frac{i(1-r)-(1-r^i)}{(1-r)^2}\right] \tag{11}$$

$$where\ \ i = \frac{1}{(1-pp)} \tag{12}$$

$$\bar{S} = B\ \Gamma(1+\frac{1}{A}) \tag{13}$$

$$S_s^2 = B^2\ \Gamma\ (1+\frac{2}{A})-\Gamma^2(1+\frac{1}{A}) \tag{14}$$

in which
r = lag 1 serial correlation coefficient between daily rainfalls
E(x) = mean of daily rainfall (mean daily rainfall rate)
E(y) = mean of the rainfall over wet days
V(x) = variance of the daily rainfall
V(y) = variance of the rainfall over wet days,
S, S_s = mean and variance of rain-sum
p, pp, A and B are as defined earlier. stands for the notation of gamma function.
The value of P(S > D) in equation (6) can be evaluated through the Weibull probability integral as follows:

$$P(S>D) = \exp\left[-(\frac{D}{B})^A\right] \tag{15}$$

The parameters A and B can be obtained by iterative solutions of equations (13) and (14). The gamma function values can be obtained by series solutions as documented in Abramowitz and Stegun (1964). A graph can then be plotted between P(S_m <=D) and D which can be regarded as the cumulative distribution function (cdf) of S_m. From this graph, the S_m values corresponding to 80% and 50% reliability levels can be chosen as design parameters.

The analysis requires estimates of p, pp, r, E(x) and V(x) in order to implement equations (1) through (4). In the present analysis probabilities p and pp were approximated by estimates of relative frequencies for data set of each year. Since there are N years of data (N = 55 for Kibwezi, and N = 20 for Kabete) so N values of probabilities were obtained. It should be noted that equations equations (3) through (15) are valid for the Markov process. If the process is found independent or random, still the equations are valid except that pp is replaced by p and r = 0. It is therefore important to establish the dependence level in the daily rainfall process.

Values of p and pp were ranked for each season and median values plugged in equations (3) through (12). Values of E(x) and V(x) were estimated using all N years of daily rainfall including zero values for each season. The short rainy season has been taken from 1 November to 31 December (61 days) and the long one from 1 March to 31 May (92 days). The durations for the short and long rainy seasons are based on the general prevalence of monsoons during these periods and the corresponding agricultural practices. Further, the rainfall processes can be regarded as stationary in view of the near uniform and consistent behaviour of the monsoon system in each season. The assumption of stationality allows for homogeneity in the estimates of the probabilities and other statistics such as mean and variance of the daily rainfall sequences in relation to rain-runs and rain-sums.

RESULTS AND DISCUSSION

The first requirement for the analysis of the rain-sum is to identify the nature of dependence in the occurrence of wet spells, i.e. whether they are random or dependent. Therefore transitional probability matrix (1) was computed and evaluated against matrix (2) for equivalence. Chi-square statistics were computed for each year under consideration; they indicated that the occurrence of wet spells follows Markov persistence, as more than 60% times of the values exceeded the critical value (Table 1). In another study related to drought, the author (Sharma, 1993) found that a Markov model performs remarkably well in predicting the longest dry and wet spells in semi-arid environments of Kenya. This study, therefore, strongly supports the hypothesis of Markov law when applied to occurrence of rain-runs, and hence to rain-sums. Thus rain-sum analysis can be carried out following equations (3) through (15) for individual rainy seasons. Consequently, estimates of probabilities p, pp, r, E(x) and V(x) were obtained using the data of daily rainfall each season and the results are shown in Table 1.
Values of D (D ranging from 1 to 400mm) representing the maximum rain-sum (S_m) associated with 80% and 50% reliability levels, i.e. $P(S_m\ D) = 0.20$ and $P(S_m\ D) = 0.50$ were computed following equations (7) through (14). An easy way to compute such probabilities is to assign the D values ranging from 1 to 400 mm and for each D compute probability $P(S_m\ 1)$, $P(S_m\ )$ ..... $P(S_m\ <400)$ and draw a graph between probabilities and D. This graph is essentially a cumulative distribution function (cdf) of S_m. Values of D corresponding to the exceedance probability of 0.80 or 0.50 will yield the largest rain-sums (S_m) at 80% or 50% reliability levels (Table 2).

It is worth mentioning that in the study of rain-sums, the other distributions such as normal, lognormal and gamma pdf's were also tried. It was discovered that the lognormal and gamma pdf's gave a worse fit, whereas normal and Weibull tended to be satisfactory. The more satisfactory correspondence between observed and simulated cdf's was provided by Weibull model (Fig. 1). In the hydrologic literature normal pdf has been applied to characterize the distribution of sums (Sen, 1980; Chander *et al.* 1981), basing the argument on central limit theorem. However the present exercise indicated the normal pdf to be less satisfactory for modelling rain-sums on a daily basis.

Thus in order to design a rainwater harvesting system a value of 65 mm may be chosen for Kibwezi and 90 mm for Kabete at the 80% level of reliability. In simple terms, if a tank is to be designed for storing rainwater in Kabete then the capacity of the tank is such that it should be able to store water generated by 90mm rainfall over an impervious surface. If the runoff is to be collected from a pervious surface, then the rainfall should be adjusted for infiltration losses appropriately. In the above analysis the evaporation losses are disregarded primarily because

Table 1. Values of rain-sum parameters for long and short rainy seasons in Kenya.

Parameter	*Long rainy season*		*Short rainy season*	
	Kibwezi	*Kabete*	*Kibwezi*	*Kabete*
p	0 18	0.52	0.32	0.47
pp	0.53	0.72	0.66	0 67
q	0.82	0.48	0 68	0.53
r	0.10	0.61	0.48	0 51
E(x) (mm)	2.86	5 91	5.00	3 73
V(x) (mm^2)	107.73	180.30	162 44	72.47
A	0 77	0.71	0.78	0.72
B	28.93	31.31	39.73	19 46
Inference on Chisquare	60% years Markov follow process	100% years follow Markov process	65% years follow Markov process	90% years follow Markov process

Table 2. Values of rainfall statistics for the design of rainwater harvesting systems.

Design criterion	*80% reliability level*		*50% reliability level*	
	Kibwezi	*Kabete*	*Kibwezi*	*Kabete*
Rain-sum (mm)*	65 (50,65)	90 (90, 45)	115 (90, 115)	145 (145, 70)
Seasonal total (mm)	170 (short rains)	300 (long rains)	300 (short rains)	520 (long rains)
Annual total (mm)	430	780	640	980
AMDR (mm)**	50	55	70	75

* The values of the parameters in parentheses correspond to long and short rainy seasons.
** AMDR means annual maximum daily rainfall

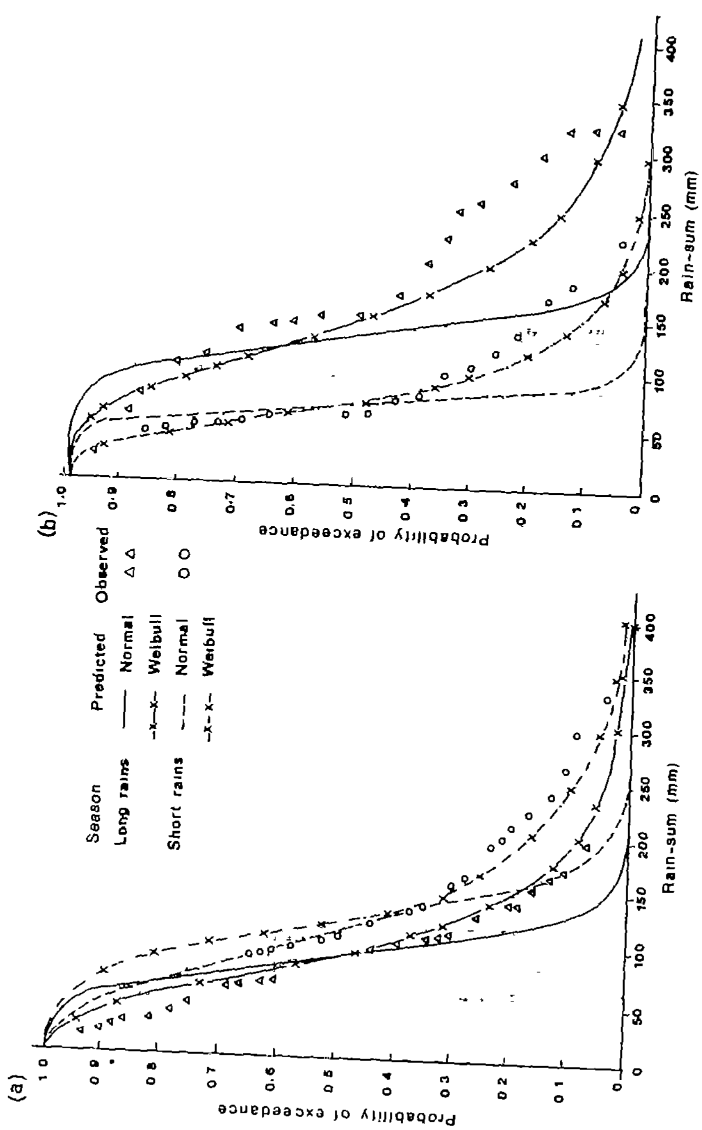

Figure 1. Cummulative distribution function of rain-sum for (a) Kibwezi, and (b) Kabete.

the rain-sum would be collected over a period of rain-spell lasting from 4 to 6 days (Sharma, 1993). The evaporation losses during such a short period would not exceed 10-15 mm and hence insignificant as compared to rain-sum.

It would be worth comparing the design values of rainfall based on the other criteria. The criteria considered are 80% and 50% reliability levels of (i) total annual rainfall, (ii) seasonal total, and (iii) annual maximum daily rainfall. In order to obtain the design values at these reliability levels, one needs to know the probability distribution function of the above sequences. The first two sequences tend to follow the normal probability law (Sharma, 1991), whereas annual maximum daily rainfall process has been shown to obey extremal value type 1 (EV1) or Gumbel distribution (Obasi and Nimira, 1977) in Kenyan environments. Therefore the parameters of these probability functions were estimated by fitting the rainfall data. The desired rainfall statistics corresponding to 80% and 50% reliability levels were estimated and are shown in Table 2. It is evident from Table 2, that the design values based on seasonal and annual totals are too conservative whereas those based on annual maximum daily rainfall (AMDR) are too low. Values based on rain-sum criterion fall in the intermediate range and therefore appear to be more realistic and optimal. It should be noted that the short rainy season is more crucial for design purposes in Kibwezi, whereas the long rainy season brings more critical rain-runs and rain-sums in Kabete (Table 2).

It must also be noted that design criteria based on the concept of rain-sum is just one approach, and is not being claimed as the superior one. There are other elements associated with the design of rainwater harvesting systems such as the cost of the system, ease of handling the water, quality aspects of the water, social acceptability of the system etc., which need to be considered before commenting on the best design criterion. There is need to involve the rain-sum criterion along with other criteria and test its worth in various climatic and socio-economic settings worldwide.

CONCLUSIONS

Based on the present study, it can be concluded that a criterion for designing rainwater harvesting systems can be formed using the rain-sum. The probabilities associated with the largest rain-sum can be computed based on the concept of simple probability of any day being a rainy day, the conditional probability of a rainy day followed by another rainy day, and mean and variance of the daily rainfall sequences during short and long rainy seasons. The rain-sums were modelled using normal and Weibull laws of probability. The Weibull model resulted in a better fit and therefore can be advocated for rain-sum analysis on a daily basis. The value of largest rain-sum corresponding to 80% or 50% exceedance probability can be used as the design rainfall for rainwater harvesting systems. The largest rain-sum values were found to be 90 mm and 65 mm at the 80% reliability level for Kabete and Kibwezi in Kenya. These design values are lower than those based on criteria of annual and seasonal totals, but are greater than that of annual maximum daily rainfall and and therefore more sensible and optimal. There is need to test the proposed criterion in various climatic and socio-economic environments worldwide.

REFERENCES

Abramowitz, M. and **Stegun, I.A.** (1964). *Handbook of Mathematical Functions*, US National Bureau of Standards, Applied Mathematics Series 55. U.S Government Office, Washington DC.

Benjamin, J.R. and **Cornell, C.A.** (1970). *Probability, Statistics and Decisions for Civil Engineers.* McGraw-Hill, New York.
Chander, S., Kambo, N.S., Spolia, S.K. and **Kumar, A.** (1981). Analysis of Surplus and Deficits Using Runs. *Jl of Hydrology*, **49**, 193 - 203.
Haan, C.T. (1977). Statistical Methods in Hydrology. Iowa State University Press, USA.
Medhi, J. (1982). *Stochastic Processes.* Wiley Eastern Limited, New Delhi, India.
Obasi, G.O.P. and **Nimira, J.K.** (1977). Statistical Estimation of the Maximum Probable Rainfall in Kenya Using the Method of Maximum Likelihood. *Proc. Symposium on Flood Hydrology*, Supplementary Report No. 259, p 71. Tansport and Road Research Laboratory, Crowthorne, Berkshire, U.K.
Sen, Z. (1980). Statistical Analysis of Hydrological Critical Droughts, *Jl the Hydraulic Division, ASCE*, **106** (HY1), 99-115.
Sharma, T.C. (1990). A Mathematical Rainfall Simulator, *Proc. Annual Conf Kenyan Society of Agricultural Engineers.* Nairobi.
Sharma, T.C. (1993). A Markov Model for Critical Dry and Wet Days in Kibwezi, Kenya. *Proc National Workshop on Land and Water Management in Kenya* (In press) Nairobi.
Todorovic, P. and **Woolhiser, D.A.** (1975). A Stochastic Model of n-day Precipitation, *Jl Applied Meteorology*, **14**, 17-24.

DISCUSSIONS

A question was raised as to what kind of system was applicable to the rain-sum model. Was it for domestic use, drinking purposes or crop production? **Dr Sharma** responded that it was applicable to any kind of storage system to be designed. The design of storage tank or system should be based on thé rain-sum critera and tested vigorously in relation to other criteria such as annual totals, seasonal totals and annual maximum daily rainfall.

RAINFALL-RUNOFF RELATIONSHIP AND THE POTENTIAL FOR SURFACE-RUNOFF HARVESTING IN THE NGUU TATU CATCHMENT, MOMBASA DISTRICT, KENYA

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ABSTRACT

The design of appropriate rainwater and/or surface runoff harvesting systems requires a basic understanding of the processes responsible for surface-runoff generation in different environments. It is necessary to establish the interrelationship between surface-runoff generation and climatic parameters such as rainfall; this generates information that could be used to design surface-runoff harvesting systems. The paper examines the relationship between surface-runoff generation in a semi-arid coastal catchment and evaluates the potential for surface-runoff harvesting. It is established that the Nguu Tatu catchment has high potential for surface-runoff harvesting and water could be used for a variety of purposes, which range from re-afforestation projects, domestic and livestock uses, to the recharge of ground-water reservoirs.

INTRODUCTION

Water supply through conventional systems such as the construction of surface-water reservoirs and associated pipeline systems is becoming increasingly difficult and problematic due to underlying logistical problems. High rates of siltation have reduced the reservoir design capacities and economic lifespans (Chakela, 1981; Christiansson, 1981). This has led to a serious lack of water for rural and urban populations. The high cost of materials and equipment required in the development and extension of water supply systems has complicated the situation. As a result water resources planners and managers are devising cheaper ways and means of providing safe and clean water. The development of rainfall and/ or surface runoff harvesting systems is seen by many water resources experts as one of the best ways of providing water to the ever increasing population in developing countries (Barrow, 1987). They are cheaper, more convenient and easier to construct compared to conventional systems and, with proper management, they can be used to alleviate serious water shortages not only in rural areas, but also in urban areas. Harvested rainwater can be used for a variety of purposes ranging from agricultural development through irrigation, water supply for domestic purposes and re-afforestation programmes in arid and semi-arid lands.

This paper addresses the issue of surface-runoff harvesting potential in the semi-arid Nguu Tatu catchment. An attempt has been made to examine and establish the various relationships between surface runoff and climatic variables such as rainfall amount and rainfall intensity which give a good insight into surface-runoff harvesting potential.

STUDY AREA

Nguu Tatu catchment covers an area of 2.13km^2 and is located between 3°55′ and 3°45′ S and 39°41′ and 39°42′ 1E in the coastal region of Kenya. The basin is a third-order type with relief ranging from 46m to 122m above sea-level. The rocks comprising the catchment are largely sedimentary shales of jurassic age that yield poor soil capable only of supporting stunted thorn trees and grasses (Casswel, 1956). The drainage density is 3.0km/km^2 (Kitheka, 1993). Annual rainfall ranges from 870mm to 1700mm. This corresponds to a mean annual rainfall of 1200mm. Most of the rainfall occurs during the long rainy season (March, April and May). The short rains occur in the months of October, November and December. Mean annual temperature is 26°C and mean annual evaporation (Penman E) is 2200mm. The actual evaporation is less than 2000mm (Ojany and Ogendo, 1985). As a result of land degradation exemplified by increased land clearance, overgrazing and burning, the catchment has a high surface-runoff response, which implies less infiltration and percolation of water into the subsoils.

The inhabitants of Nguu Tatu catchment have been depending on surface-water reservoirs for domestic and livestock purposes. However, these reservoirs have become silted and design capacities are drastically reduced - by as much as 80% (Kitheka, 1993) - with the result that water supply for domestic and livestock purposes is a major problem. Dredging is expensive, and with the current high rates of soil erosion and sediment discharge into the already silted reservoirs the only option left is to design and develop other rainwater and surface-runoff harvesting systems.

METHOD

The investigation of rainfall and surface-runoff relationship in the Nguu Tatu catchment was based on runoff plot experiments. Five runoff plots were established in various parts of the basin depending on land gradient, ground cover, land use and soil/rock type.

Construction of runoff plots was based on the principles of Dunne (1979) and Ongwenyi (1978). Plots were defined by taking four metal sheets measuring 15cm x 2m, and sinking them 2cm into the ground. A collecting gutter was installed at the lower end of each plot. Runoff was conveyed via the gutter into a large plastic container. A rain gauge was installed on each runoff plot to measure rainfall amount. Measurement of rainfall intensity was achieved by use of a recording rain gauge at the centre of the basin. Runoff from the plots was transferred to plastic bottles and the volume was determined using a measuring cylinder (Ongwenyi, 1978).

RESULTS AND DISCUSSION

The result of simple regression and correlation analysis shows that surface-runoff generation and rainfall amount are highly correlated. The value of multiple correlation for the relationship between surface-runoff generation and rainfall amount is 0.80. The correlation index value obtained is also 0.80, with the coefficient of determination 63% of the variation in surface-runoff generated. This is when the two parameters are considered as independent variables. The computed beta coefficient for the relationship is 0.80, which allows estimation of surface-runoff generation given rainfall amount values using the equation Y= 0.80 RA, where Y is the quantity of surface-runoff generated and RA is, rainfall amount. In the case of the relationship between surface-runoff percentage (of the total rainfall input) and rainfall amount, the multiple regression value is 0.42, which is lower by a factor of 50% when compared to that obtained for the surface-runoff/rainfall amount correlation. The variation in rainfall amount accounts for 17% of the variation, indicating that rainfall amount has lesser contributory role in surface-runoff percentage. However, in the case of surface-runoff depth, the influence of rainfall amount is considerable. This anomaly can be explained by high evaporation losses. The beta coefficient for the relationship between surface-runoff percentage and rainfall amount is 0.42 which when expressed in the simple equation Y = 0.42 RA enables the computation of surface-runoff percentage for a given rainfall amount. In this case Y is the surface-runoff percentage and RA is rainfall amount.

For the relationship between runoff depth and rainfall intensity the multiple regression coefficient obtained is 0.76 with the correlation coefficient of 0.75. This indicates strong positive association. The results of analysis are shown in Table 1.

Using the obtained beta coefficient of 0.76, the equation of the Y = 0.76 RI was written,

Table 1. The results of regression and correlation analysis on the relationship between surface-runoff depth and rainfall intensity.

	Beta multiple		
R	*R2*	*R*	*SE*
0.76	0.76	0.56	0.76

where Y is surface-runoff depth and RI is rainfall intensity. This enables the estimation to be made of the quantity of surface-runoff generated for a given rainfall intensity.

When rainfall intensity is correlated to surface-runoff percentage the multiple regression coefficient becomes 0.40, which is much lower compared to values obtained for the surface-runoff/ rainfall intensity relationship. The generated coefficient of multiple determination is 0.16, which implies that variation in rainfall intensity accounts for 16% of the variation in surface-runoff percentage. Good positive correlation was obtained for the relationship between surface-runoff percentage and surface-runoff depth. The multiple regression coefficient value of 0.66 was obtained (Table 2), which indicates that variation in surface-runoff percentage accounts for 60% of the variation in surface-runoff depth. If the quantity of surface-runoff generated within the catchment changes, runoff percentage will also change. Changes in surface-runoff generation may be caused by influences such as vegetation clearance, overgrazing and trampling, in addition to the occurrence of high-intensity rainstorms. Essentially, surface-runoff percentage refers to the surplus water generated after evapotranspiration, deep percolation and infiltration have taken their share (Chow, 1964; Linsley and Franzini, 1979). On other hand, runoff depth refers to the total volume of water that emanates from a given land area during rainstorms without considering infiltration and evaporation losses.

Table 2. The results of regression and correlation analysis on the relationship between surface-runoff percentage and surface runoff depth

	Beta Multiple		
R	*R2*	*R*	*SE*
0.82	0 66	0.81	6 58

The association between surface-runoff percentage and surface-runoff depth in the Nguu Tatu catchment is strong, with the correlation index value of 0.81. The correlation of multiple determination was 0.66 which implies that variations in the surface-runoff component are strong. During the period of study the mean daily rainfall amount recorded on runoff plots was 7.80mm with a maximum of 15.5mm. The corresponding mode and median is 3.00mm and 7.25mm respectively. Low rainfall amounts were observed to have a higher frequency of occurrence compared to high rainfall amounts, which has an implication for the design of rainwater harvesting systems. Sustainable rainwater and surface-runoff harvesting systems must take into consideration the occurrence of low rainfall amounts which have high frequencies of occurrence as compared to high rainfall amounts. This is the cornerstone for any potential rainwater and surface-runoff harvesting systems in the catchment.

From measurements of the quantity of surface-runoff that flows in gullies and other small rivulets, the computed discharge ranged from $0.25m^3$/sec to $0.5m^3$/sec. These correspond to daily discharge rates of $2.16 \times 10^4m^3$/day and $4.32 \times 10^4m^3$ /day respectively. This implies that within a given rainy season in the catchment, the surface-runoff contributes between $194.4 \times 10^4m^3$ and $388.8 \times 10^4m^3$ of water, which is equivalent to an annual freshwater discharge of between $1788.4 \times 10^4m^3$ and $3576.8 \times 10^4m^3$. This is quite a large volume of water which could be trapped and used for a variety of purposes in the catchment. Currently this water flows into the two small dams located in the catchment, and carries with it large quantities of sediment removed from the degraded land (Kitheka, 1993).

CONCLUSION

The study has established various relationships between surface-runoff generation and climatic variables, mainly rainfall amount and intensity. It was clearly shown that the total quantity of surface-runoff generated from runoff plots is related to the variations in rainfall amount and intensity. However, in the case of surface-runoff percentage, the correlation is rather weak. It has also been established that surface-runoff generation is rapid at the beginning of a rainy season, which is attributed to high rainfall intensities associated with rainstorms at the beginning of the rainy season, and ground cover insufficiency. At the beginning of a rainy season, mean runoff depth is 5.0mm which drops to approximately 4.00mm at the end of the rainy season (both long and short rainy seasons). However, the pattern of variability in surface-runoff generation follows that of rainfall amount and intensity. Surface-runoff depth is much more closely correlated with rainfall amount and intensity fluctuations. The reduction in the volume of surface-runoff generated in the latter period of rainy season is attributed to increased vegetation cover as a result of moisture replenishment. Increased vegetation cover tends to retard the velocity of flow of surface-runoff and leads to increased rates of infiltration and deep percolation (Chow, 1964; Linsley and Franzini, 1979). It is also attributed to a reduction in rainfall intensities in the latter part of a rainy season. The significance of rainfall intensities is in its effect of sealing the soil pores which are avenues through which rainwater infiltrates into the subsoil (Dunne, 1977, 1979).

REFERENCES

Barrow, C. (1987). Water Resources and Agricultural Development in the Tropics. Longman and John Wiley and Sons, New York.

Caswel, P.V. (1956). *Geology of the Kilifi - Mazeras Area.* Government Printer, Nairobi.

Chakela, Q .K. (1981). *Soil Erosion and Reservoir Sedimentation in Lesotho.* UNGI Report No. 54. University of Stockholm, Uppsala.

Christiansson, C. (1981). Soil Erosion and Sedimentation in Semi-arid Tanzania. *Studies on Environmental Change and Ecological Imbalance* Scandinavian Institute of African Studies and Dept of Physical Geography, University of Stockholm, Uppsala.

Chow, V.T. (1964). *Handbook of Applied Hydrology.* McGraw-Hill, London.

Dunne, T. (1977). *Intensity and Control of Soil Erosion in Kajiado Project* Working document No. 12. Ministry of Tourism and Wildlife, Nairobi.

Dunne, T. (1979). *Evaluation of Erosion Conditions and Trends* University of Washington, Seattle, USA.

Kitheka, J.U, (1993). Soil Erosion and Its Impact on Surface Water Reservoirs: A case study of Nguu Tatu Catchment, Northeast of Mombasa District, Kenya. Paper presented at the 4th Land and Water Management Workshop, Nairobi.

Linsley, R.K. and **Franzini, J.B.** (1979). Water Resources Engineering, 3rd edn. McGraw-Hill, London.

Ojany, F.F. and **Ogendo, R.B.** (1985). Kenya: *A Study in Physical and Human Geography,* London, Nairobi.

Ongwenyi, G.S. (1978). Soil Erosion and Sediment Transport in the Upper Tana Catchment with Special Reference to Thiba Basin. PhD Thesis, University of Nairobi.

Tebbutt, T.H.Y. (1983). *Principles of Water Quality Control,* 3rd edn. University of Birminghan and Pergamon Press.

A PRELIMINARY STUDY OF RAINWATER CISTERN SYSTEMS IN YUN-CHIA AREA

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ABSTRACT

The paper shows the potential for rainwater cistern systems in Yun-chia area where a new industrial district is proposed and where water shortage is a severe problem. Various rainwater cistern systems were raised and evaluated to select the most appropriate for rainwater storage. The rainfall records of three stations in the area were analysed. Simulation of cistern storage with daily rainfall data was made to determine the tank capacity required to maintain a stable water supply in this area. Regression equations for tank storage size were obtained under conditions of different percentage of failure and various drafts. These regression equations could provide a convenient way for engineers to set up cistern systems in this area.

INTRODUCTION

The concept of rainwater collection systems can be traced to the early centuries of Roman domination in Sardinia (Crasta *et al.*, 1982), where people built crude systems to collect rainwater for water supply. For the past several decades, due to population increase and concentration, rainwater cistern systems have proved a significant measure for water supply in regions of Africa, Asia and South America. Techniques for rainwater collection can be simply classified into three categories, namely: roof catchment, ground catchment and dam catchment.

The Yun-chia area is a well-planned and newly-developed industrial area. In conjunction with development projects in this area by the Ministry of Economic Affairs in Taiwan, the aim of this study is to evaluate techniques for rainwater cistern systems in order to alleviate the water shortage problems. The analysis is based on the concept of potential water utilization, which is then used to estimate cistern storage size by daily rainfall simulation.

MATERIALS AND METHODS

The total area of the industrial estate, which is located along the tidal land of Yun-chia area is about $160km^2$, (Fig.1). Industries to be located in the estate include petrochemical, chemical and steel. Since the developed water resource cannot be diverted to this new industrial estate due to existing water rights, alternative ways of solving the water supply problem are needed urgently. Preliminary investigations showed that there is no possibility of implementing a ground catchment system, but roof catchment and catchments from paved areas are promising. The major aim of this project, therefore, is to analyse the daily rainfall records in this area and then to design the size of storage required.

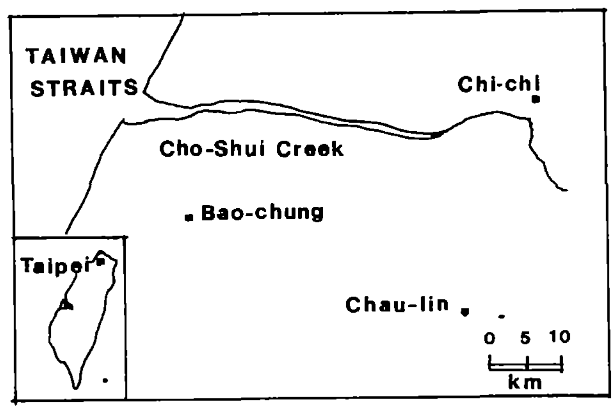

Figure 1. Map of the project area.

The rainfall data from three rainfall stations, namely Bao-chung, Chi-chi and Chau-lin, was collected for analysis. The records from these three stations go back 34, 52 and 26 years respectively.

The statistical characteristics of annual rainfall depth were examined to determine the daily potential water utilization. Frequency analysis based on extreme value type-III was chosen to estimate the minimum monthly rainfall of different return periods. The daily rainfall data was analysed in detail to establish the percentage of time that rainfall depth is equal to, or less than, various depths during the period of study. The tank size design based on daily rainfall simulation can be described as

$$H_{t+1} = R_t - P_D * D + H_t \text{ ; } H_t \quad H_{max} \text{ .... (1)}$$

where

H_{t+1} and H_t are the water depths in the storage tank at time t+1 and t, respectively;

R_t is the daily rainfall depth;

P_D is the ratio of daily depth to the percentage potential water utilization;

D is the daily depth equal to the value of daily potential water utilization;

H_{max} is the height of the storage tank.

This process includes the carry over into the next year.

RESULTS AND DISCUSSION

Annual rainfall

The results of annual rainfall analysis are shown in Table 1. Since Chi-chi and Chau-lin are located on a mountain terrace, the mean annual rainfall is more than 2000mm. However, the mean annual rainfall of Bao-Chung, which is located in an urban area, is only half that of the other two stations. It is evident that the spatial variation of precipitation results from physiographic effects, and the variances in annual rainfall at Chi-chi and Chau-lin are higher than at Bao-chung (see Fig. 2 and Table 1).

Table 1. Statistical characteristics of rainfall data.

	Station		
Item	*Bao-chung*	*Chi-chi*	*Chau-lin*
Average annual rainfall depth (mm)	1120.8	2418 2	2543.6
Standard deviation of rainfall depth	226.0	445.3	544 8
Potential water utilization (mm/day)	3.07	6.63	6.9

Monthly rainfall

In this area, most rainfall is distributed in the months of May through September (Fig. 2). Chi-chi and Chau-lin can recieve 100 mm rainfall per month more than 50% of the time; however, the monthly rainfall of Bao-chung is less than 50mm for 50% of the time.

Drought analysis procedures based on extreme value type-III (Haan, 1977) were used to estimate the minimum monthly rainfall of different return periods. As shown in Table 2, the monthly rainfall would approach zero once every 5 years in Bao-chung, and once every 50 years in Chau-lin.

Table 2. Frequency of minimum monthly rainfall depth (mm).

Station	*Return period (year)*					
	2	5	10	50	100	200
Bao-chung	0.5	0.0	0.0	0.0	0.0	0.0
Chi-chi	5.5	3.3	2.6	2.0	1.9	1.8
Chau-lin	3.8	0 8	0 1	0 0	0.0	0.0

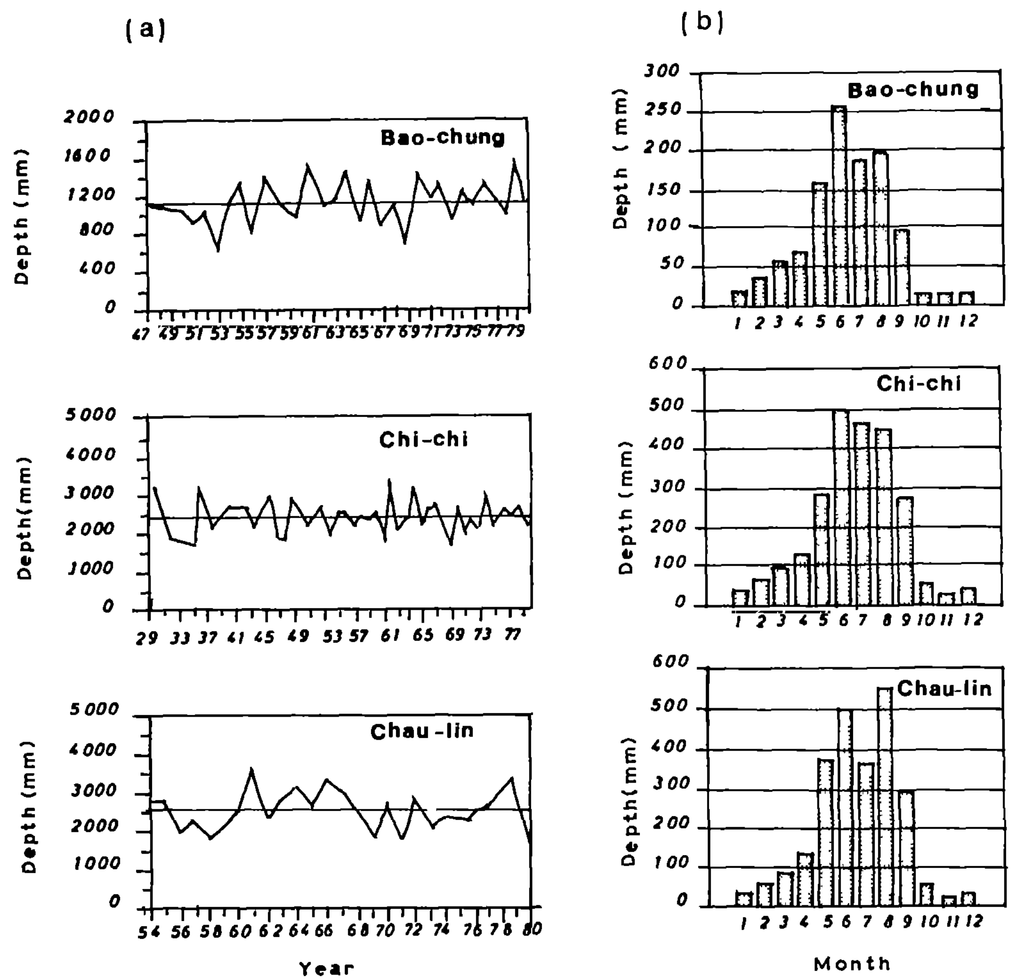

Figure 2. (a) Annual rainfall; (b) monthly rainfall distribution

Daily rainfall

Bao-chung has fair weather more than 78% of the time; the daily rainfall depth is more than the potential water utilization only 13% of the time (Fig. 3). Chi-chi and Chau-lin have fair weather more than 62% of the time , and only about 20% of the time is the daily rainfall more than the potential water utilization. Since the distribution of rainfall is concentrated in summer storms, it is necessary to use rainwater cistern techniques to store water in rainy seasons, to provide water in dry seasons.

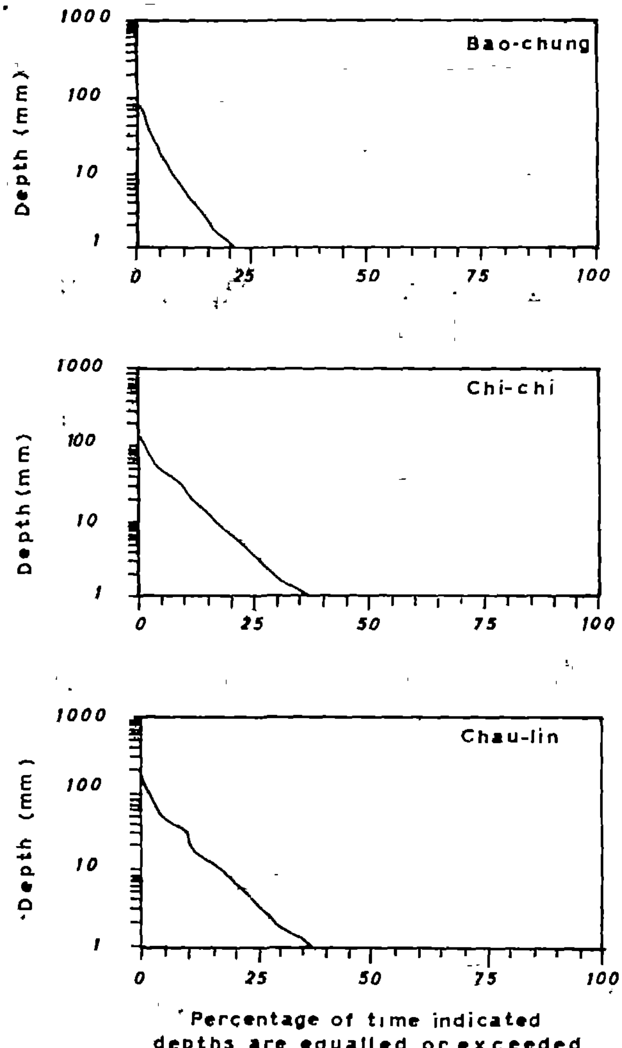

Figure 3. Depth-duration curve (daily data).

Tank storage design

Since this area is a newly-planned district, there is no building or construction on this tidal land yet. Therefore, the tank storage is better designed by height than by volume, because it is hard to make a reasonable assumption of the total catchment area. In this study, the daily depth was assumed to be some percentage of the potential water utilization, which was obtained from annual rainfall analysis. From equation (1), the tank storage design under conditions of different percentages of failure of the cistern approximated the following regression equations:

Bao-chung: $H_{max} = 0.693 P_D^{1.625} P_F^{-0.207}$ ....(2)

Chi-chi: $H_{max} = 0.877 P_D^{1.717} P_F^{-0.190}$ ....(3)

Chau-lin: $H_{max} = 0.763 P_D^{1.777} P_F^{-0.200}$ ....(4)

where H_{max} is tank storage in height;

P_D is the ratio of daily draft to the percentage potential water utilization

P_F is the percentage of failure of the design cistern system.

Table 3. Tank storage design (mm).

Potential water utilization (P_D)	*Historical data*	*Failure (P_F)*		
		2%	*5%*	*10%*
Bao-chung				
5%	18	10	8	6
25%	126	95	82	68
50%	323	256	226	197
75%	691	565	443	379
100%	1552	1440	1363	1213
Chi-chi				
5%	36	16	12	8
25%	254	182	155	130
50%	621	494	445	400
75%	1048	869	805	737
100%	3258	3017	2845	2617
Chau-lin				
5%	38	16	11	7
25%	260	184	167	146
50%	696	554	489	430
75%	1199	994	923	836
100%	3525	3274	3068	2839

Bao-chung $H_{max} = 0.693 P_D^{1.625} P_F^{-0.207}$ ....(2)

Chi-chi $H_{max} = 0.877 P_D^{1.717} P_F^{-0.190}$ ....(3)

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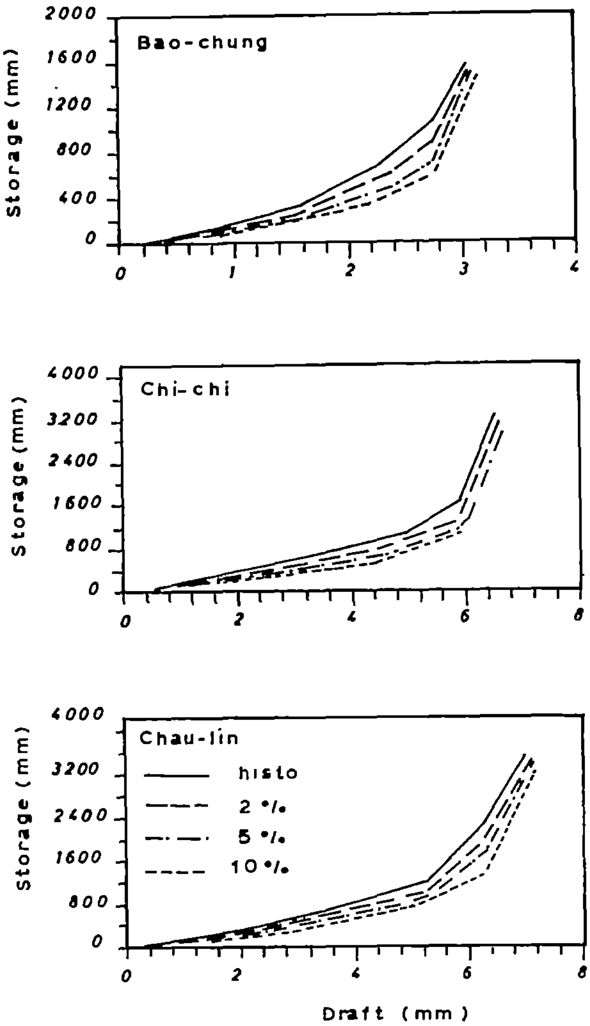

Figure 4. Tank storage design.

CONCLUSION

The study showed potential rainwater cistern systems in Yun-chia area. Because of physiographic limitations, roof catchment and catchment from paved areas are the appropriate ways of rainwater collection. Three regression equations related to daily depth and percentage of failure of the design cistern systems are presented to determine the tank storage. These equations could provide a convenient way for engineers to set up the cistern systems in the area.

REFERENCES

Crasta, F.M., Fasso, C.A., Patta F. and **Putzu, G.** (1982). Carthaginian-Roman Cisterns in Sardinia. *Proc. Int. Conf. on RainWater Cistern Systems*, pp. 37-45. Honolulu, USA.

Haan, C.S. (1977). *Statistical Methods in Hydrology*. The Iowa State University Press, Ames, USA.

AGRICULTURE

OVERVIEW OF RAINWATER CATCHMENT SYSTEMS FOR AGRICULTURAL PURPOSES

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Approximately 900 million people live in areas which suffer from drought and desertification. Survival depends on an adequate supply of water for domestic use, for livestock and for crop production. Although irrigation is of great importance to many people in dry areas, there are increasing problems of salinization and for those who do not have access to a dependable supply of irrigation water, the proper use of rainwater and runoff is critical to survival. It is ironic that areas which suffer from a desperate shortage of water in the dry season, are commonly subjected to uncontrolled runoff, erosion and sedimentation during rainy periods. Efforts to make better use of the limited rain that comes, and to control runoff, must be matters of prime concern.

Whereas the use of rainwater for domestic purposes will usually be a priority, much can be done to improve the harvesting of runoff for crops and livestock. Kenya's Second National Conference on Rainwater Catchment Systems, which took place in August 1992, gave considerable attention to this and IRWCSA has recently broadened its objectives to include the harvesting of rainwater for agricultural purposes. It will be useful to consider in what ways the design of rainwater catchment systems for crops, trees or livestock may differ from the design of systems for domestic use.

The development of rainwater harvesting from roofs involves consideration of the area and nature of the catchment surface, arrangements for concentration of the runoff, a method of maintaining quality, a system of storage that minimizes losses and a system for withdrawal when required. The design of the system should take account of the stochastic nature of the rainfall, the likely demands for water, and the costs in labour and materials for installation and maintenance.

The development of runoff harvesting from ground surfaces for crops, trees and livestock can be considered in a similar way to harvesting from roofs. Catchments can vary in size from micro-catchments of about one square metre such as the round basins or *Zai* used for sorghum production in Burkina Faso, to larger catchments up to a hectare which impound runoff from roads for growing trees in arid areas, and ultimately to the largest catchments which may occupy many square kilometres.

The nature of the surface for runoff harvesting varies greatly. Stable surfaces of rock, tarmac or concrete can produce much cleaner water than bare or vegetated earth surfaces but most runoff harvesting depends on the latter. Herein lies a major difference with roof catchments: there is often a large amount of sediment transported in the runoff and where collection is in surface reservoirs the loss of storage capacity due to sedimentation can be rapid and serious. Methods of controlling sedimentation, for example by improving ground cover, by ridging or by terracing, are of great concern to those involved with surface reservoir storage. One solution, which has been extensively developed in Kenya, is the construction of sand dams whereby water is stored below the surface in sandy rivers with ephemeral flow. Storage within the sand has the added advantage of reducing losses by evaporation.

The main storage for runoff harvesting is within the soil profile itself. Unlike the rainwater tank, the soil store has no top or bottom and can loose water by seepage, by evaporation or by transpiration; but because of the size of storage very large quantities of water can be made available to crops. For example 1 hectare of land which can store 150mm of plant-available water in the top metre of soil can provide 1500m^3 of water for crop production. Losses through the bottom of the "tank" are infrequent in arid and semi-arid areas and only occur in low lying areas or during periods of heavy rainfall when the capacity of the upper horizons is exceeded. Losses from the top are of major concern; hence the interest in mulching with crop residues, stone or plastic sheets, and the importance of removing weeds. Saving as little as 25mm of water in this way can sometimes make the difference between success or failure of a crop such as maize which is particularly sensitive to water stress during the flowering stage.

Whereas the householder may build additional rainwater tanks to store surplus rainwater, the farmer or pastoralist who wishes to store more water in the soil has several alternatives. For example, he or she can use widely spaced ridges and leave half or more of the intervening space bare as a catchment area so that the crop, which is grown close to the ridge where the runoff concentrates, receives an adequate amount of water. Another method is to divert the spate flow from an ephemeral watercourse and spread it over an extended area of land. Water stored in the soil during a single flood event may be sufficient for a quick maturing crop such as sorghum. However, in practice there are considerable difficulties in adopting this latter approach due to the unpredictable nature of floods, the cost of diversion structures, the deposition of sediment and the difficulty of spreading water uniformly over the land.

There are other differences between harvesting rainwater from roofs for domestic purposes and harvesting from the ground for crop or livestock production. The size of the catchment is usually much greater in the latter and, because the catchment is a land surface rather than an impermeable roof, the antecedent rainfall has a major impact on the volume and rate of runoff. Both the roof and the land surface are subjected to varying intensities of rainfall but whereas a 50-year storm will simply exceed the capacity of the domestic rainwater tanks it may cause untold damage in a natural catchment as exemplified by the recent tragedy in Kenya after a railway embankment was washed away by exceptional floods. In both situations, attempts to predict the likely outcome of different rainfall events are important in designing structures for control or storage, but the complexity of this undertaking and the associated hazards are much greater with natural catchments than with roofs.

In dry areas the limitations on available water stored in rainwater tanks leads naturally to economy in use; if the tanks run dry, water may have to be carried for several kilometres. However, most of the water stored in the soil for crop production goes straight back to the atmosphere during the process of transpiration. Only about 1% is used in building up plant tissues. There is considerable scope for the selection and breeding of crops for dry areas that are more efficient in water use.

The survival of people in dry areas will depend increasingly on the harvesting of runoff for livestock, forage, trees and crops as well as the harvesting of rainwater for direct human use. A few papers presented to the conference address this issue. Kanyanjua, Wagura and Njogu report on runoff harvesting for people and livestock in a pastoral area of Kenya. Chu, Liaw and Chang describe a method developed in Taiwan for estimating water in an agricultural catchment and determining the appropriate pond size to meet that demand. As the problems of rainwater harvesting for domestic purposes are resolved it can be expected that greater attention will be paid to harvesting runoff for agricultural purposes. Improved runoff harvesting systems for agricultural purposes should go hand in hand with improved rainwater catchment systems for domestic use.

There are several examples of ancient runoff harvesting systems such as those in the Negev but many of the people now living in dry areas have no experience of water harvesting technology. They may be pastoralists who have been forced to adopt cultivation through shortage of land, or new immigrants from more humid zones. There is therefore a continuing need for research, development and extension of appropriate methods of harvesting rainfall and runoff for agricultural purposes in dry areas.

WATER CATCHMENT UNDER LOW PRESSURE CENTRE PIVOT IRRIGATION WITH RESERVOIR TILLAGE

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ABSTRACT

Reservoir tillage was compared to conventional tillage as a means of conserving water under low pressure centre pivot irrigation. This research was conducted in commercial potato fields in southern Idaho, USA, and consisted of data collection of runoff depths, soil water, and yield over 3 years. Plots were established to give several replications of both conventional and reservoir tillage under the outermost spans, where the highest application rate occurs. The soil was mainly silt loam with slopes ranging from 0.2 to 5%. The sprinkler devices included spray on drops, spray on booms, and rotator spray on drops with an operating pressure of 138 kPa.

Reservoir tillage effectively conserved most runoff water, which was as high as 30% on conventionally-tilled plots. Over the 3 years of this study reservoir tillage increased the average soil water content by 18%. In addition, a statistical analysis showed that reservoir tillage significantly increased the percentage of available water in the top 65 cm of the root zone ($P = 0.01$).

The use of reservoir tillage elevated average yield by 20.5%, and the average percentage of No. 1 tubers was increased from 64% for conventional plots to 67% for reservoir-tilled plots. Reservoir tillage increased the yield significantly ($P = 0.01$).

Reservoir tillage was found to be a viable management method which effectively conserved the applied water and increased yield.

INTRODUCTION

Water constitutes o..e of the principal constraints to increasing food production in our hungry world. Arid and semi-arid regions, the largest underexploited agricultural potential, face the constraints more than any other part of the world due to scarcity of water.

The balance between the demand for water by crops and its supply by precipitation is so tenuous and delicate that even short-term dry spells often reduce production drastically, and prolonged droughts can cause total crop failure and mass starvation. Irrigation, being the artificial application of water to agricultural crops, permits farming in arid regions and the offsetting of droughts in semi-arid or semi-humid regions. That is why it has been said of world irrigation, "It is a modern science - the science of survival". As such, irrigation plays a key role in feeding an expanding population and seems destined to play an even greater role in the foreseeable future.

The ever-expanding needs of an increasing population make great demands on limited available water supplies. During the past three decades, low energy, labour intensive irrigation systems have been replaced with more efficient, but also more energy intensive systems. Correspondingly, escalating energy costs and limited energy supplies are creating rapid changes in operating costs of irrigation systems. Energy accounts for a greater portion of the annual irrigation budget.

Having in mind that irrigation is the greatest consumer of water, and with the rising costs of energy and water, the search for means to increase the efficiency of irrigation and water utilization is becoming all the more urgent.

Recently, low pressure sprinkler technology has been developed in response to increased energy costs and limited water supplies available for irrigation. The most popular application of low pressure sprinkler systems has been with continuously moving, self-propelled centre pivot and linear-move systems. Kincaid (1983), Kincaid, Nabil and Busch (1986), Von Bernuth and Gilley (1985), and Nabil (1987) described and evaluated low pressure application methods which are being widely used with centre pivots. Table 1 provides a comparison between low pressure sprinkler devices used in this study and the conventional high pressure sprinklers, and gives average application rates near the outer end of the lateral.

Data presented in Table 1 clearly show that application rates associated with low pressure systems are greater than high pressure systems, since a given amount of water is applied over a smaller area (reduced pattern width). Such high application rates often cause runoff on all but the most permeable soils. The potential for runoff can be controlled or reduced by lowering the system capacity, increasing the system speed, adjusting the application rate pattern, or by various cultural practices (Gilley and Mielke, 1979). The cultural practice management may include using tillage, surface residue, and crop covers to enhance infiltration and surface storage. Figure 1 shows a centre pivot system with spraybooms mounted on the outer end spans.

Table 1. Centre pivot sprinkler types and application rates near the outer end of the lateral.

Sprinkler type	*Pressure (kPa)*	*Pattern width (m)*	*Application rate (mm/hr)*
High pressure impact	414	30	35
Spray on booms	138	20	52
Spray on drops	138	10	104
Rotator spray on drops	138	15	78

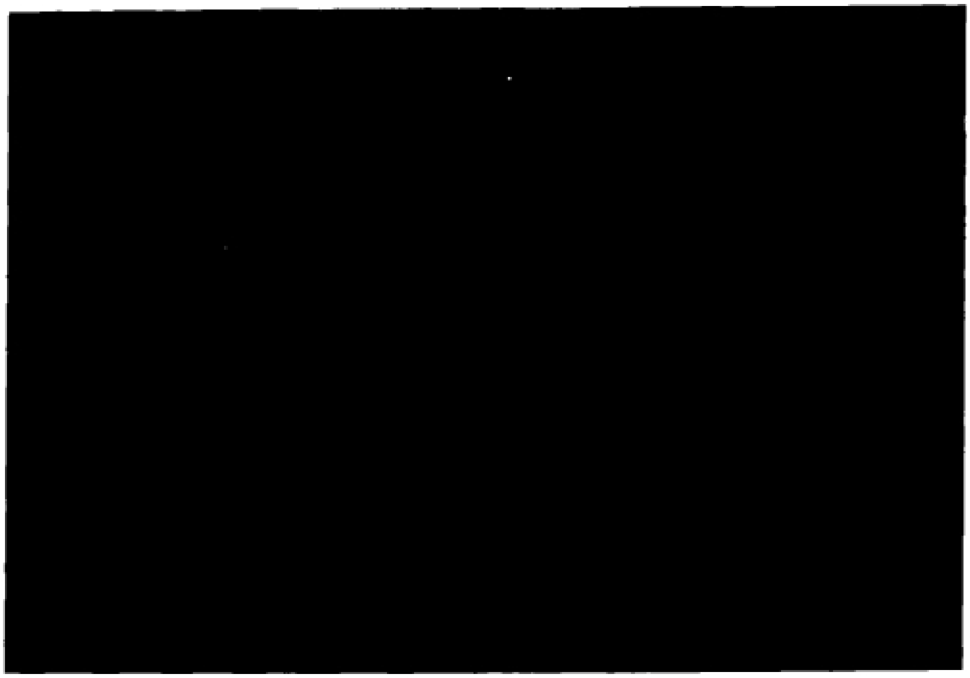

Figure 1. Centre pivot irrigation system with low sprayboom application

Furrow digging, also known in the USA as basin tillage, basin listing or microbasin tillage is the practice of constructing small dikes or dams at intervals along furrows to create surface storage and retain potential runoff, thus allowing it to infiltrate. Furrow diking is not a new technology. Practices similar to diking were first attempted in the United States more than 60 years ago (Knight and Hyde, 1931), and has been used extensively since then in dryland and irrigated agriculture (Daniel, 1950; Kuska and Mathews, 1956; Luebs, 1962; Jones and Clark, 1987; Lyle and Dixon, 1977; Aarstad and Miller, 1973; Longley and Halderson, 1982 a, b).

Although the furrow diking concept originated in the US Great Plains, considerable research has been conducted in the semi-arid tropics of Africa, where the practice is called tied-ridging. The tied-ridge system reduced runoff and soil loss and, in many instances, has increased crop yields (El-Swaify et al., 1985; Lawes, 1966). The potential of tied-ridges to improve soil and water conservation and crop yields in Africa has been recognized, and equipment has been designed and procedures developed for their use (Constantinesco, 1976; Dagg and Macarthey, 1968).

Reservoir tillage, a more recent development (Longley, 1984; Garvin, Busch and Kincaid, 1986) consists of a subsoiler or ripper shank pulled at a depth of about 0.3m followed by a paddle wheel which punches small depressions in the soil to the depth of the shank, thus

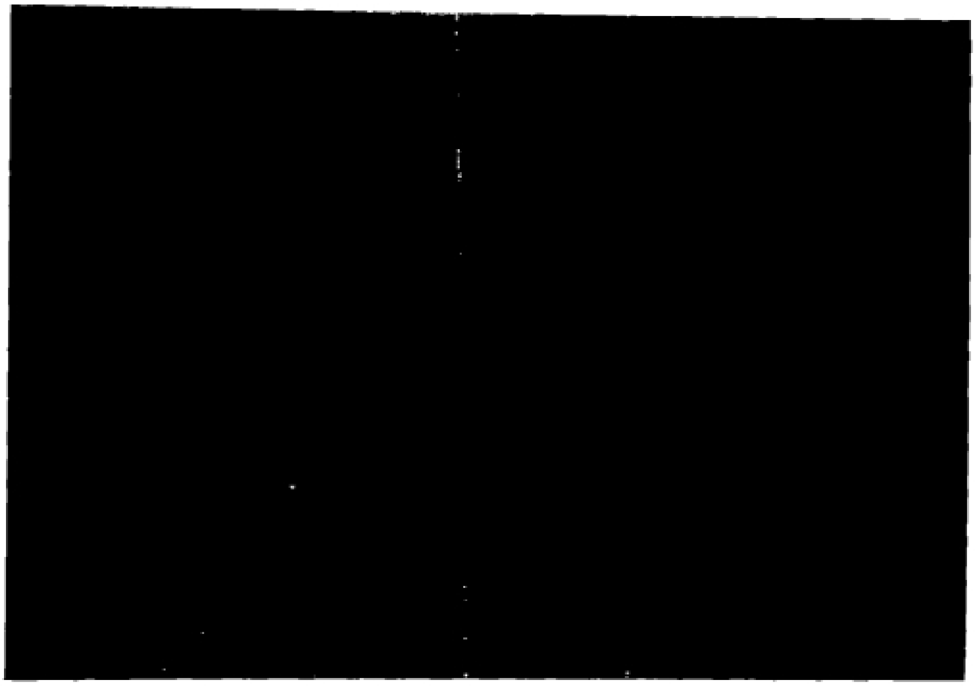

Figure 2. Reservoir tillage machine in operation after potatoes have been planted.

increasing infiltration rates and creating additional surface storage capacity. Figure 2 shows a reservoir tillage machine in operation after potatoes have been planted and hilled on 0.9m row spacing.

EXPERIMENTAL PROCEDURES

The study area lies in the Snake River plain in southern Idaho, USA. The procedures used involved establishing sets of replicated plots on commercially farmed fields that were being irrigated by low pressure centre pivot irrigation systems. The systems had from eight to ten spans, and span lengths varied from 38m to 50m. The soil was mainly silt loam, and the topography varied from nearly level to 5% slopes. In all study fields potatoes were planted. Runoff plots were established in May or June at about 20-30% crop cover, and the tillage was done by the research personnel. There were usually one or two irrigations (20-30mm) applied before tillage.

The reservoir tillage treatments were established using the Dammer-Diker, manufactured by the Agricultural Engineering and Development Company of Tri-Cities, Washington. The sub-surface reservoirs (pits) were 20-30 cm deep and spaced approximately 71 cm apart in the direction of travel. Reservoirs were placed between each row of potatoes which were

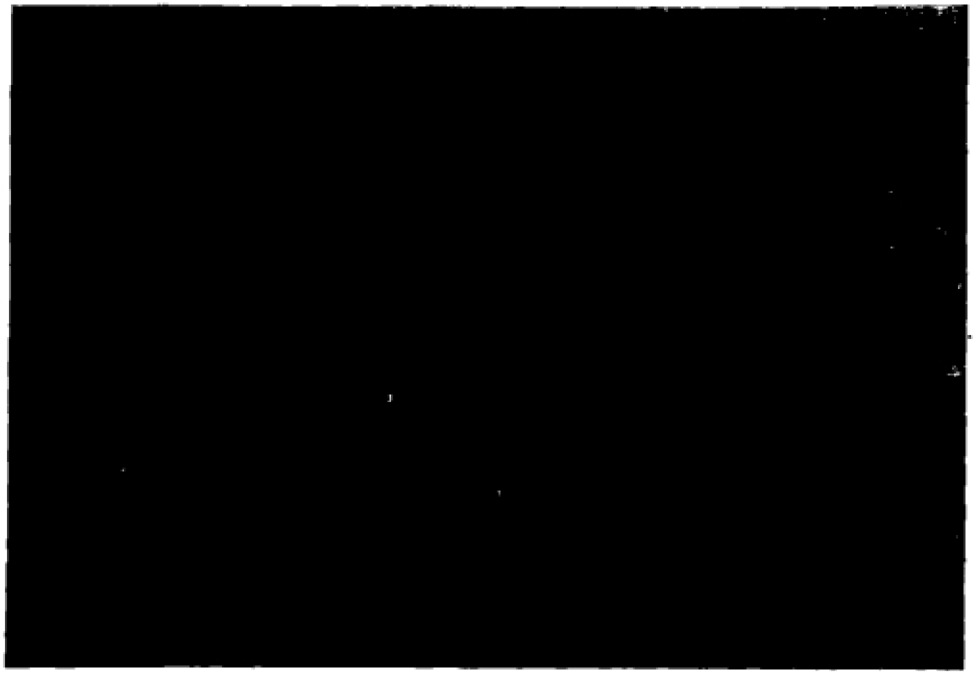

Figure 3 Reservoir tillage effectively conserves the applied water for plant use.

spaced about 90cm. Figure 3 shows the effectiveness of reservior tillage in controlling the potential surface runoff.

Plot areas with uniform soil and slope were selected in the outer two to four spans where the highest application rates occurred. Plots were sized to fit within one span of a pivot to eliminate wheeltrack effects. Plot lengths varied from 32m to 46m depending upon the area of uniform soil and slope available. Plot width varied from 4m to 6m depending upon the number of rows selected to contribute to the runoff measurements. The upslope ends of plots were dammed to prevent surface runoff from upslope areas. Soil water was measured in the upslope and downslope quarters of the plots, so that within-plot surface water movement could be evaluated. Water application, soil water content and runoff were measured throughout the season; crop yield and quality were also measured. Table 2 lists the plot sites, type of sprinklers, and average slopes.

RESULTS AND DISCUSSION

The distribution of water by a sprinkler irrigation system is a two part distribution, first from sprinkler nozzles to the soil or crop surface, and second, the redistribution on the soil surface. The major emphasis in this study was on preventing redistribution of water on the soil surface,

Table 2. Plot site, average slope, runoff, soil water and yield from conventional and reservoir-tilled plots.

Site & year	*Spray type*	*Average slope*	*Runoff*		*SWT (%)*	*Yield (t/ha)*	
			CT (%)	*RT (%)*		*CT*	*RT*
East	SB	0.8	10	0.2	21	29	36
(1st)	SD	0.8	15	0.4	22	24	37
North	SB	0.3	7	0.12	6	32	37
(1st)	SD	0.5	10	0.30	22	28	34
South	SB	3.0	22	3.0	22	36	42
(2nd)	SD	4.0	30	6.5	18	29	37
South	SB	0.64	11	0 14	18	55	62
(3rd)	RD	0.2	10	0.10	7	56	65
West	SB	0.9	13	0.32	18	49	56
(3rd)	SB	1.1	16.5	0 32	23.5	27	33

CT = conventional tillage; RT = reservoir tillage;
SWI = soil water increase.

using reservoir tillage as a method to retain water and achieve higher soil moisture uniformity throughout the field. Table 2 gives percentage runoff, crop yield, and average percentage increase in volumetric soil water content for reservoir tillage as compared with the conventional method.

Runoff

The primary purpose of reservoir tillage is to reduce or eliminate runoff by increasing the intake rate and/or surface storage capacity of the soil so that all water is retained where it is applied. In most cases runoff was eliminated by the use of reservoir tillage. Some runoff occurred from reservoir tillage plots during the second year of study. Steep slopes, and the gradual reduction of pits' capacity through the growing season caused water to overtop the pits and run off the field. Over the 3-year period of this study runoff averaged more than 14% with conventional tillage and less than 1.5% with reservoir tillage.

Soil water

Reservoir tillage consistently sustained higher and more uniform soil water than the conventional plots due to reduced runoff. The average increase in soil water for each plot is given in Table 2. Soil water data taken in the upslope and downslope quarters of the plots clearly indicated an excessive surface water movement in the conventionally-tilled plots. Reservoir tillage was found to be effective in minimizing the variations of soil water levels between high elevations in the field where runoff occurred and at low elevations where runoff collected. The increase in average soil water was found to be 18%. In addition, a statistical analysis showed that reservoir tillage significantly increased the percentage of available water in the top 65cm of the root zone ($P = 0.01$).

Crop yield and quality

Since the system capacity was close to the peak evapotranspiration requirements, conserved water by reservoir tillage furnished adequate water for plant use, prevented crop stress, and consequently increased the yield. Over the 3-year period of this study potato yields increased an average of 20.5%, and average percentage of No.1 tubers was increased from 64% for conventional plots to 67% for reservoir-tilled plots. Reservoir tillage increased yield significantly ($P = 0.01$).

CONCLUSIONS

Reservoir tillage was compared to conventional tillage as a means of controlling runoff under low pressure centre pivot irrigation. Reservoir tillage effectively prevented most runoff, which was as high as 30% on conventionally-tilled plots. As a result, the efficiency of water use under low pressure centre pivot irrigation was improved considerably.

Reservoir tillage was found to be a viable management method for reducing or totally eliminating runoff of the applied water, achieving higher and more uniform soil water content, and increasing production which is often the primary goal. Applying this tillage method allows the use of low pressure centre pivot on medium textured soils and variable topography.

REFERENCES

Aarstad, J.S. and **Miller D.E,** (1973). Soil Management to Reduce Runoff Under Centre Pivot Sprinkler Systems. *Jl Soil and Water Conservation,* **28** (4), 171-173.

Constantinesco, I. (1976). *Soil Conservation for Developing Countries.* pp. 52-62. FAO Soils Bull., 30. Rome.

Dagg, M. and **Macarthey J.C.** (1968). The Agronomic Efficiency of the NIAE Mechanized Tied Ridge System. *Exp. Agric.,* **4,** 279-294.

Daniel, H.A. (1950). Water Conservation for Wheat Production in Oklahoma. *Soil Sci. Soc. Am. Proc.,* **15,** 408-412.

El-Swaify, S.A., Pathak, P., Rego, T.J. , and **Singh, S.** (1985). Soil Management for Optimized Productivity Under Rainfed Conditions in the Semi-arid Tropics. *Advances in Soil Science,* ed by B. A. Stewart, 1. pp.1-64 Springer Verlag, New York.

Garvin, P.C., Busch, J.R. and **Kincaid, D.C.** (1986). Reservoir *Tillage for Reducing Runoff and Increasing Production Under Sprinkler Irrigation.* ASAE Paper No. 86-2093.

Gilley, J.R. and **Mielke L.M.** (1979). Energy Conservation Using Reduced Pressure Centre Pivot Irrigation Systems. *Proc. ASAE Special Conf., on Irrigation and Drainage in the 1980s.* pp. 29-39.
Jones, O.R. and **Clark, R.N.** (1987). Effects of Furrow Dikes on Water Conservation and Dryland Crop Yields. *Soil Sci. Am. Jl.,* **51**, 307-1314.
Kincaid, D.C. (1983). *Impact Sprinkler vs. Spray Nozzles for Low Pressure Centre Pivots.* ASAE Paper No. 82-2020.
Kincaid, D.C., Nabil, M. and **Busch, J.R.** (1986). *Spray Losses and Uniformity with the Low Pressure Centre Pivots.* ASAE Paper No. 86-2091.
Knight, H.G. and **Hyde, A.M.** (1931). *Annual Report of the Bureau of Chemistry and Soils* pp. 45-46.
Kuska, J.B. and **Mathews, O.R.** (1956). *Dryland Crop-rotation and Tillage Experiments at the Colby (Kansas) Branch Experiment Station.* USDA Cir. 979. US Government Printing Office, Washington, DC.
Lawes, B.A. (1966). Rainfall Conservation and the Yields of Sorghum and Groundnut in Northern Nigeria. *Exp. Agric.,* **2**,139-146.
Longley, T.S. (1984). *Reservoir Tillage for Centre Pivot Irrigation.* ASAE Paper No. PNR 84-209.
Longley, T.S. and **Halderson, J.L.** (1982a) *Basin Tillage in Irrigated grain* ASAE Paper No. PNR 82-201.
Longley, T.S. and **Halderson, J.L.** (1982b). *Surface Storage Enhancement with Basin Tillage.* ASAE Paper No. PNR 82-208.
Luebs, R.E. (1962). Investigation of Cropping Systems, Tillage Methods and Cultural Practices of Dryland Farming at the Fort Hays (Kansas) Branch Experimental Station. *Kansas Agric. Exp. Stn. Bull.,* 449.
Lyle, W.M. and **Dixon, D.R.** (1977). Basin Tillage for Rainfall Retention. *Transactions of the ASAE,* **20**(6), 1013-1021.
Nabil, M. (1987). Field Evaluation of Very Low Pressure Centre Pivot Sprinkler Devices in the Pacific Northwest, USA. Unpublished MSc. thesis, University of Idaho, USA.
Von Bernuth, R.D. and **Gilley, J.R.** (1985). Evaluation of Centre Pivot Application Packages Considering Droplet Induced Infiltration Reduction. *Transactions of the ASAE,* **28**(6), 1940-1946.

STUDY OF AGRICULTURE RAINWATER CISTERN SYSTEMS IN MUDSTONE AREAS OF SOUTHWESTERN TAIWAN

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ABSTRACT

Mudstone areas are situated in the southwestern part of Taiwan. The climate is a subtropical maritime type with high temperature and rainfall. However, rainfall is usually unevenly distributed. Summer seasons are wet while winter seasons are very dry. In this region, water shortage occurs in at least 6 months of the year. Because of the compactness and impervious nature, mudstone areas have an insignificant amount of extractable groundwater. Water supply is limited with frequent drought and water shortages. This adverse environment is a constraint to water use for agricultural development in this area. Therefore, more research efforts should be directed to designing ways to store rainwater to satisfy the water needs in mudstone areas.

This paper describes feasible methods for rainwater catchment systems, agricultural water use estimation, and hillslope water use planning, to providing domestic and agricultural water supply in remote and mudstone areas lacking irrigation systems and water resources. These will provide alternatives for alleviating the water shortage problem in mudstone areas and promote efficient rainwater collection, storage and utilization.

INTRODUCTION

The southwestern mudstone area in Taiwan is a large sloping land. Streams are short and swift. The average annual rainfall is about 2412mm, which is considered plentiful. However, the available water supply is limited due to topographic and geologic factors as well as uneven temporal and spatial distribution. Water cannot percolate and recharge the ground-water supply through the impervious mudstone layer, this is the major cause of drought in this area. Hence, the efficient utilization of water resources in mudstone areas that lack both a ground-water and a surface-water supply is a problem that needs to be addressed and solved by the best technical methods.

Farm ponds are an important means of collecting rainwater on the mudstone hillslopes of southwestern Taiwan and are becoming a feature in this area. Besides storing water during the rainy season for dry season use, farm ponds have the capability to reduce erosion and landslide damage. The newly reclaimed land, after the pond has been silted up, can be used effectively to grow agricultural crops. It is also used for irrigation, animal husbandry, aquaculture and recreation. Therefore, it is a very valuable asset in mudstone areas.

This study uses the local weather, land use and agriculture water use patterns to estimate the agricultural water use for this region. The sequential-peak analysis used in water resource system analysis, in addition to rainwater storage simulation analysis and actual farm pond operation are used to establish the optimum agricultural rainwater catchment system storage capacity. This information should be useful in promoting rainwater catchment in this region.

DESCRIPTION OF PROJECT AREA

Extent of study area

The total area of the mudstone region in southwestern Taiwan is about 1014km^2. A complete survey of this large area is not feasible with the limited resources and time available. Therefore, the project is designed over 3 years. The Yucheng, Nanhua and Tsochen counties in Tainan Hsien were selected for the first year's study. This area covers approximately 32,278 ha.

Physiographic conditions

Mudstone areas are usually referred to as badland (Liu, 1984). The soil surface suffers from severe weathering and erosion. Many erosion rills form on hillslopes and plants have difficulty growing on them. The entire area is covered with undulating hills. The elevation ranges between 50m and 200m; it is mostly under 100m. The geology is characterized by soft and loose parent materials; the infiltration rate is very low. Permeability is very poor, with the rate as low as 10-8 cm/sec (Liu, 1984). The surface soil is easily eroded by direct runoff and surface flow. After heavy rain the soil surface forms channels, but the excess water cannot leach through to the ground water. Eventually, landslides occur as pressure builds up within the soil pores.

Hydrologic and weather conditions

Temperature and humidity
The average temperature is relatively high in the southwestern region. According to records from the Central Weather Bureau (CWB), between 1974 and 1991, the maximum temperature occurs in July with an average of about 29.0°C. The lowest temperature is reported in January with an average of about 17.2°C. The mean annual temperature for Tainan area is about 24°C.

The mean annual humidity is about 78.9%. The month with the highest humidity is August with 82.3%, the lowest is January with 77%.

Solar radiation and evaporation
Data from the CWB indicate that between 1974 and 1991, the shortest average monthly sunshine duration occurs in February with 163.9 hours. The July sunshine duration is the longest with 242.0 hours. The annual solar radiation flux is about 8070 g cal/cm^2 (Liu, 1984). Therefore, water is easily lost from the surface due to prolonged exposure to intense sunlight.

The mean annual evaporation is about 1489.9mm. Evaporation in July is the highest at 171.4mm. The lowest evaporation (72.4mm) is reported for the month of February. The average monthly rainfall between October and April is less than the average monthly evaporation rate. During this period, the surface layer would be completely dried; this is the major cause of drought.

Precipitation
Based on the rainfall records published by the Council of Water Resources Planning, Ministry of Economic Affairs, the average annual precipitation for the three counties is about 2187.7mm. The highest precipitation occurs at Nanhua (2407.84mm), followed by Yucheng (2106.80mm)

and Tsochen (2048.5mm). Precipitation is not evenly distributed over the region. Almost 90% of the precipitation is concentrated during summer and typhoon seasons. From October to April (the drought season), the frequency of water shortage increases as the evaporation rate exceeds rainfall received.

DETERMINATION OF RAINWATER CATCHMENT SYSTEM STORAGE CAPACITY

Estimation of water use

This study employs the long-term average monthly precipitation, evaporation, cultivated land area and the irrigation requirement of rainfed crops in the southern region (Tsai, 1989) to study the agricultural water use for the three counties. The sequential-peak analysis method is used to determine the rainwater catchment system storage capacity.

The sequential-peak analysis method uses the following regression equation.

$$K_t = \begin{cases} R_t - Q_t + K_{t-1} & < \quad \text{if positive} \\ 0 & < \quad \text{otherwise} \end{cases}$$

$$K_a = \text{Max } K_t$$

where K_t = desired storage capacity at the beginning of period t

R_t = water release during period t

Q_t = amount of inflow (rain-evaporation) during period t

K_a = the maximum required storage capacity

At $t = 0$, $K_o = 0$ and $K_a = \text{Max } K_t$

If the inflow regression equation is applied repeatedly while considering the release (R_t), the maximum value of K_t is the largest required storage capacity K_a. Besides rainfall and demand, the farm pond storage capacity, in reality, should depend on evaporation and seepage also. Taking all the factors into consideration, the inflow in period t can be estimated by:

$Q_t = QF_t - EV_t - SP_t$

where QF_t = Precipitation

EV_t = Evaporation

SP_t = Seepage loss.

Simulation of farm pond storage volume and release amount

The continuous equation for simulating the farm pond storage volume and release amount is as follows:

$S_{t+1} = S_t + Q_t - R_t \qquad 0 >= S_{t+1} >= K$

where

S_{t+1} = storage volume at period t+1

S_t = storage volume at period t

Q_t = inflow at period t

R_t = release at period t
K = storage capacity.

Assuming the farm pond is full at the beginning of the time period, the continuous equation can simulate the changes in pond storage volume for any value of K and at different release R_t. Failure occurs when the water demand is not satisfied, i.e. S_{t+1} 0. The failure percentage can then be computed. Repeating the same procedures, the relationships of pond storage volume and failure percentage can be determined for other water demands also.

RESULTS AND DISCUSSION

Results from actual survey observations indicate that land in the three mudstone counties is mostly under citrus orchards. Therefore the water demand is similar to the rainfed crop irrigation requirement of about 990mm/yr and is assumed to be evenly distributed for each month of the year. The inflow is estimated from 50-year (1936-1991) average monthly precipitation in Tsochen county. The evaporation rate is represented by 50-year average monthly evaporation records from the areas. The computed water demand for each time period per unit area is then multiplied by the cultivated area for each village. Figure 2 shows the cumulative water demand for each time period.

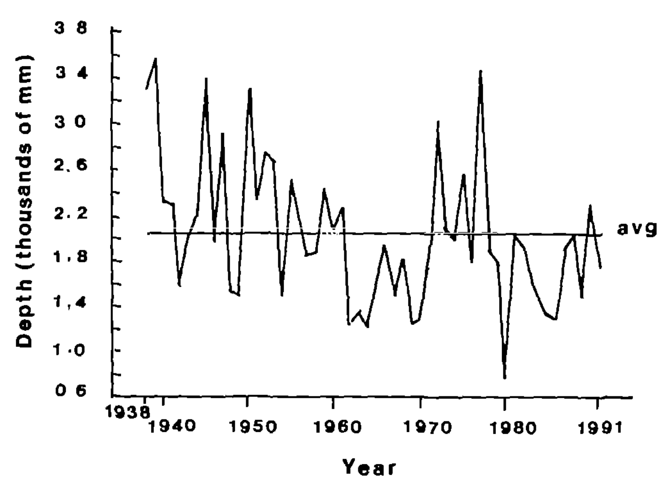

Figure 1. Annual rainfall for Tsochen county

Precipitation records show that a relatively dry period occurred between 1987 and 1990 at Tsochen county (Fig. 1). There were four peak water demands during this period (Fig. 2). The largest occurred in 1990 at more than 42.76 million tons. If the farm pond and reservoir storage capacity is more than 42.76 million tons, the present irrigation water demand can be easily met.

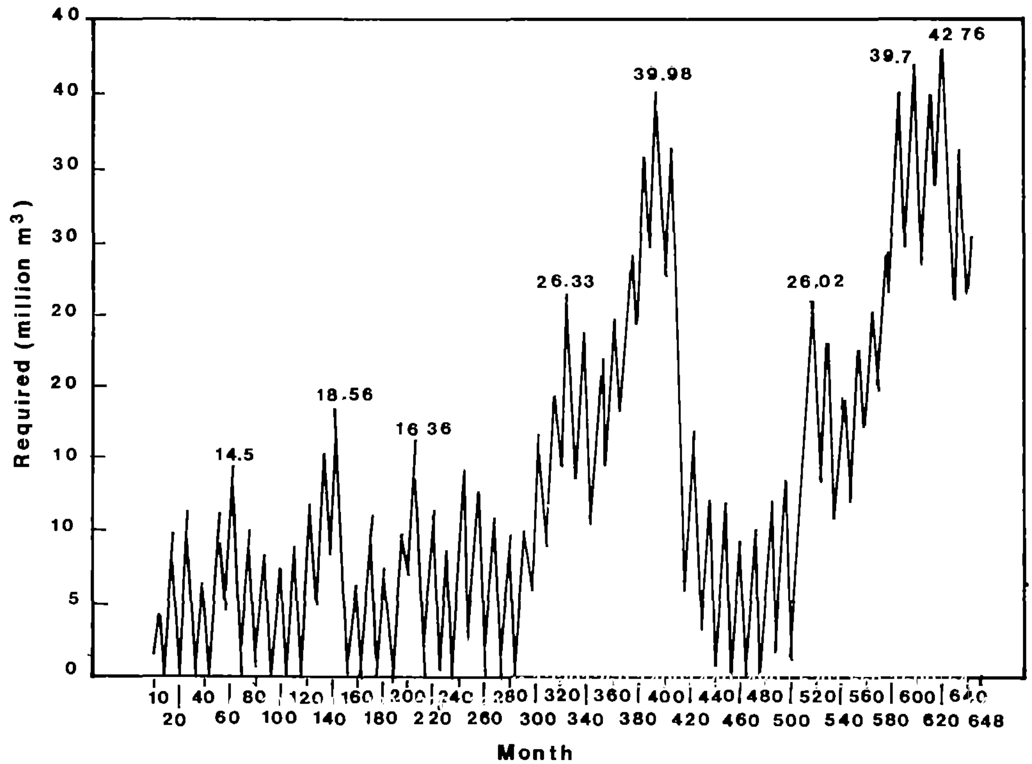

Figure 2. Sequential-peak analysis for Tsochen county.

Assuming different release (R_t) and K values, the farm pond storage/release analysis model, based on the continuous equation, can simulate the changes in storage volume and compute the demand failure percentage (Fig. 3). The results obtained for the farm pond storage release/demand failure inter-relationship provide the necessary and useful information for designing farm pond storage capacity.

REFERENCES

Chu, S.C. and **Fok, Y.S.** (1991). Multiobjective Rainwater Cistern Systems, *Proc. 5th Int Conf on Rain Water Cistern Systems*, p.469-475, Keelung.

Chu, S.C. and **Lo, K.F.A.** (1992). Keelung ISLE Rain Water Catchment Systems: A Case Study. *Proc Regional Conf. of the Int. Rainwater Catchment Systems Assoc.* Kyoto, p. 781-792.

Liu, C.L. (1984). A study on Erosion, Runoff, and Groundwater of Mudstone Slope Region in South Western Taiwan. *Prevention of Disaster: Science and Technology Research Report*, No. 73-18, p.1-70, National Science Council.

Loucks, D.P., Stedinger, J.R. and **Douglas, A.H.** (1981)., *Water Resource Systems Planning and Analysis*, Prentice-Hall, London.

Mays, L.W. and **Tung Y.K.** (1992). Hydrosystems Engineering and Management, pp.270-284, McGraw-Hill, Princeton.

Tsai, M.H. (1989). Studies on the Actual Condition and Future Development of Upland Crop Irrigation in Taiwan. *Taiwan Water Conservancy*, **37**(4), 15-36.

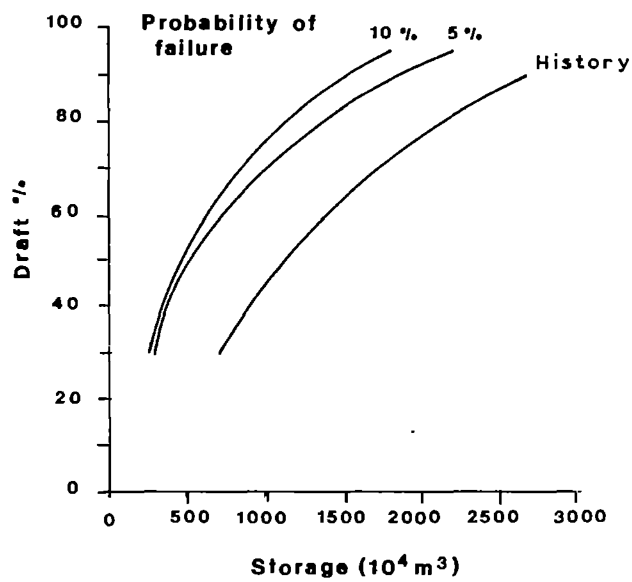

Figure 3. Relationship of draft and probability of failure to farm pond capacity for Tsochen county.

ROAD-WATER RUNOFF SYSTEM FOR AGRICULTURAL AND DOMESTIC USE

M. Mung'ala and P. Mung'ala

Mung'ala Farm, Machakos District, Kenya.

ABSTRACT

Mr and Mrs Mung'ala's 10ha farm is located in the semi-arid Machakos District of Kenya where rainfall averages 600-900 mm/annum. This small farm produces cereals (maize, beans and peas), fruit trees (citrus, mango and pawpaw) and agroforestry tree species (Grevillea, Leucaena and Calliandra).

The Mung'ala's started planting trees in 1978 but experienced massive deaths for some 10 years owing to long droughts. They established a road-water runoff system in 1987. The water is trapped in a temporary dam, led into an underground tank and thereafter to the agricultural fields, all by gravity flow. Some 300 citrus and mango trees are now surviving by means of a "drip" irrigation system that uses 1-3 litre containers dug in next to young seedlings with a small hole at the base which slowly waters the roots. Some of the water is used by domestic animals and for washing.

A village women's group receives free water from the Mung'ala's system to run a 5000 tree seedling nursery, the products of which are by group members themselves for free issue to schools and churches, and sometimes for sale in order to sustain the group's activities.

The nearest water source is a dry river-bed 3km away. There are plans to invite the village community to participate in expanding the water system so as to reduce the back-breaking task of drawing water by the village women and also to provide fresh water, especially for the village nursery and primary school.

INTRODUCTION

The Mung'ala farm is situated some 130km southeast of Nairobi, in semi-arid area of Machakos District, Kenya. It covers about 10 ha (25 acres); the average annual rainfall ranges from 500mm-750mm, and is bi-modal. The short rains come in October-December, and the long rains in March-May. These rains are unreliable and generally erratic, e.g. the 1993 long rains fell only once - on 28 March, 1993. There wasn't a single shower in April, May or June 1993. Soils are sandy, murram and infertile. The natural vegetation is shrubby, dominated by Acacia species. Food crops include maize, beans, cowpeas and pigeon peas; while domestic animals include cows, goats and sheep. Donkeys are used for transporting goods as well as water from shallow dry river-bed wells dug in the sand.

BACKGROUND TO THE RUNOFF WATER HARVESTING

The Mung'ala farm is on the foothills of Kibaoni Hill and hence sloping. A semi-permanent stream flows through it and a murram road runs along one of the boundaries. This road was improved in 1983 through the Rural Access Road Project and among the new features were drainage culverts, two of which drained the water to this small farm, thereby causing two deep gullies leading to the stream. Serious soil erosion started to take place and the Mung'ala's naturally became very concerned. Besides loosing valuable soil, they also realized that very little water was being retained, and that it would cause a lot of problems when they had to retrieve it on their backs, or, when lucky on a donkey, from 4 km away.

In 1987 they decided to "block" this water by damming one gully. A small horse-shoe shaped trough (5m diameter and 1.5m deep) was dug 3m from the mouth of the first culvert. Water collected in it after rainfall but seeped away within a few hours due to the murram base. A season or two later it was decided that an underground tank on the lower side of the trough would be a more appropriate way of storing this water. A 5m x 5m tank with 3m depth (16x16x10ft) was dug and constructed with cut stone. A hosepipe leads water from the trough to the tank by gravity. A pipe was connected to the tank to lead water to the lower part of the agricultural area. Some of the water, however, was scooped manually from the open tank.

A second trough and tank system were constructed on the second gully in 1988. The second tank was also underground but bigger and circular (10m diameter and 5m depth), and built using sand/cement blocks. The two water sources were connected by a 1.5 inch (37.5 mm) piping system. The water was then led to the remaining agricultural area and to the homestead.

METHOD OF WATER DISTRIBUTION

As can be deduced from above, the water flows by gravity from the road-side into the culverts, the troughs (dams), the underground tanks, the distribution pipes and eventually into the tree planting holes. Figure No 1. gives a general plan of the water system.

HOW WATER IS USED

The water is generally used for "drip" irrigation of fruit trees that include banana, citrus, pawpaw and mango. A number of forest trees growing on the homestead - for shade and beauty - have also benefited from the water. A women's group tree nursery with a fluctuating capacity of 5-10,000 seedlings per year has been receiving water from this system since 1988. (They have their own reservoir tank). A little water is given to domestic animals, especially calves and sick cows. After sedimentation the raw water has also been used for washing clothes.

"Drip" irrigation by containers

The dry spells last from January to the end of March, and from June to the end of October, sometimes lasting for 5 months. They can be very severe, especially in March, and from August to the end of October.

During these spells young seedlings, and sometimes even mature trees, wilt and eventually dry up. To enable them to survive the dry hot season, they are watered by dug-in containers with a small hole pierced in the bottom. Water drips slowly but directly into the

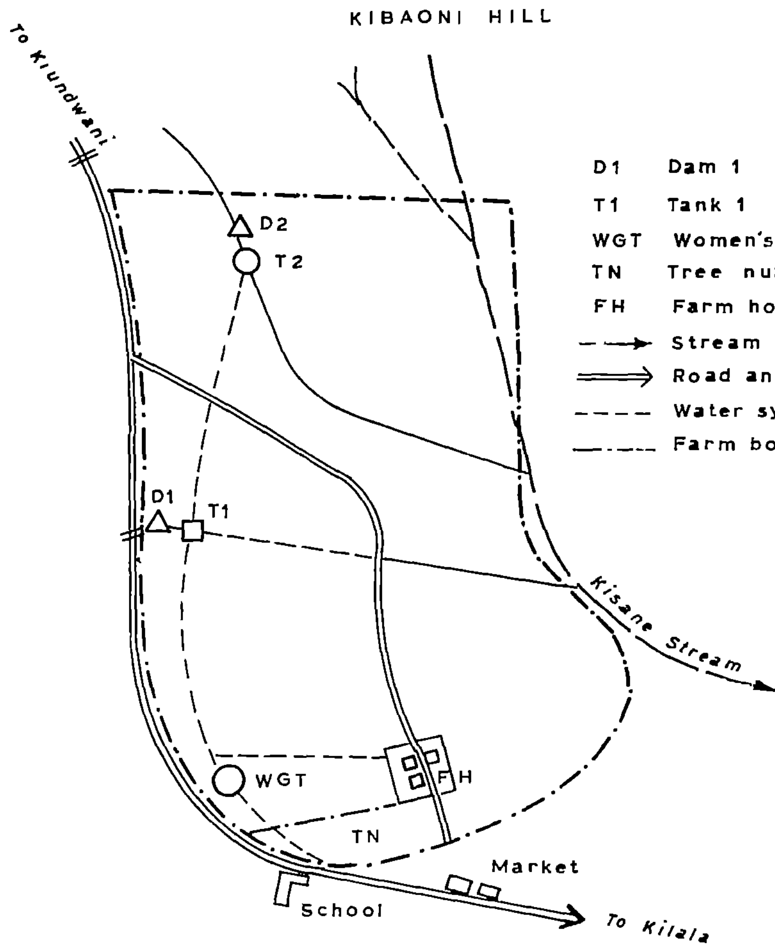

Figure 1. The Mung'ala farm and road-water runoff harvesting system.

rooting system, so that very little water is used with minimum loss to evaporation. The mouth of the metal or plastic container is closed with a stone or other flat objects.

Drinking water

Water for drinking does not come from the road runoff system described above but from roof catchment. One surface round tank, 4m in diameter and 2.5m high collects all the water from one of the houses. This volume is enough to carry the family through the dry season. It is used for drinking and cooking.

CONSTRAINTS

The main constraint to the road-water runoff system is purification. The raw water is usually muddy. It carries a lot of soil and small stones on its way to the earth troughs (dams). It settles briefly before being released into the underground tank where it stays for long periods, depositing a large amount of sand and silt in the process. The water is not purified and hence unsafe for human drinking. As it is generally used for tree irrigation, and a little for animal drinking and occassionally for washing clothes, there is no risk in its usage.

The second problem, as already mentioned is siltation. This is tackled by scooping out the sediment manually just before the start of a rainy season. The tanks are cleaned after the first shower of the new rains.

A third problem is the expenses incurred in constructing the tanks. Due to lack of cheaper technologies, and because the soil types are porous, expensive building materials including cut stones, cement and sometimes reinforcing metal bars have to be used. The masonry labour can also be high. Together this can amount to a prohibitive figure for the average farmer.

ENVIRONMENTALLY FRIENDLY SYSTEM

The road runoff harvesting system described above is environmentally friendly. The troughs hold soil thereby reducing erosion. The water flows by gravity, thereby eliminating the need for a diesel/petrol engine and the resultant polluting fumes. The water is used for raising tree seedlings which are in turn planted in an agroforestry setting to provide fuelwood, fruit, fodder, material for composting, plant tea (liquid manure), and herbal medicine for preserving grain and for spraying citrus trees against aphids and other insects, and for deworming livestock.

FUTURE PROSPECTS

The current utilization of this water system gives encouragement for future expansion. The immediate possibility is to construct one or two additional tanks in order to increase storage capacity and consequently irrigate more fruit trees and expand the women's group tree nursery.

The long-term prospect is to incorporate the village community through participation in the construction of bigger troughs (dams) and tanks for more storage capacity. The water would be used for livestock and for domestic use and human drinking. Purification would be incorporated into the system through a public project. The water would also serve the village shops, nursery and primary schools. Currently the local school children and their teachers go without drinking water for long hours.

CONCLUSION

In semi-arid regions road-water runoff can be harnessed to serve agricultural and domestic purposes as demonstrated by the experience on the Mung'ala farm. Water that would otherwise go to waste, taking with it the top soil, can be trapped, stored and used to enhance agricultural production and good health, thereby raising the standard of living of the rural poor.

Constraints such as reservoir construction technology and funds for implementation of such simple but vital projects can be overcome through community participation. The bottom line is that the idea should be simple - i.e. channelling reasonable amounts of water to agricultural fields and homesteads by gravity, which costs nothing in terms of energy. This method could be replicated all over Machakos District in particular and semi-arid regions in general.

DISCUSSION

Mr P.D Munah asked what was being done to prevent loss of storage in the tank due to siltation. **Mrs Mung'ala** replied that the water which reaches the dam is allowed to settle a bit before being released through a small tank to the main tank, but this is not very effective because the settling time is not sufficient. Furthermore there are losses due to seepage. She intends to plant trees and grass around the dam to trap sediment seepage.

Mr Joshua Kuria asked whether, in view of the fact that road improvement caused the problem of increased runoff and gullying, and the consequent need to build dams and tanks, the owner should not be entitled to compensation. **Mrs Mung'ala** agreed but pointed out that bureaucratic procedures are too slow, and waiting for compensation before taking action would lead to a worse situation. Besides the current environmental laws are not adequate. She commented that the impact of development on those who may be affected by it should be given proper consideration as a prerequisite for sustainable development.

WATER HARVESTING FOR AFFORESTATION: BASIC CONSIDERATIONS

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BACKGROUND

The arid and semi-arid areas of Kenya are characterized by short, highly variable rainfall seasons and high levels of solar radiation. The latter creates high evaporative water demand, largely in excess of available moisture inputs from rainfall. Soil moisture scarcity is the main factor limiting plant survival and biomass productivity.

In recent years, Kenya's ASALs have experienced increased livestock populations associated with increased human populations. The increase in human population is associated with the improved mortality rate and post-independence migration from high potential to marginal potential districts. The migrant farmers introduced land use practices only suited to high rainfall areas which, in addition to overgrazing, have reduced the land's ability to hold rainwater where it falls. High runoff coefficients of up to 60% (Liniger, 1986; Wairagu and Bryan, in preparation) combine with the prevalence of high storm intensities to create heavy surface runoff which renders these areas suitable for runoff harvesting.

Where the runoff is not appropriately utilized, its loss not only lowers the ecological potential of the site but is associated with soil erosion, sedimentation and siltation; problems that are already serious national concerns in Kenya.

WATER HARVESTING

In addition to the rainfall in ASALs having high intensity, it is poorly distributed with only a few isolated heavy storms contributing the majority of annual rainfall (Rowntree, 1988). It has therefore been appreciated that some form of water harvesting and storage is essential to successfully conquer such areas.

Though the mean annual rainfall is low, the quantities of water involved are vast 20mm is equivalent to 200,000 litres of water per hectare. The daily water requirements for Baringo District (19,056,000 litres) can be supplied by 100 ha from such a small storm.

Runoff harvesting for agriculture is an ancient practice, used over 4000 years ago by Nebatian farmers in the Negev Desert of Palestine. They cleared hillslopes of rock and gravel to increase runoff, and constructed ditches to collect the water and carry it to low lying fields. The amount of land under cultivation was determined by the area of hillside or catchment available.

Recent surveys indicate that runoff harvesting has been widely adopted in the arid and semi-arid world. The most common method is by micro-catchment in which runoff is collected from the immediate vicinity of a seedling and stored in the rooting soil beneath it. Each micro-catchment unit consists of two parts: a runoff collection and a runoff storage area.

Micro-catchments are easy to install, are compatible with most land tenure systems and result in a low level of damage due to failure compared to large engineering works.

It is an established fact that the majority of cases of failure in micro-catchment runoff harvesting are associated with poor design. Design programmes that do not consider the rainfall characteristics, site, hydrological response, etc. often result in failure.

The purpose of this paper is to highlight aspects of micro-catchment design and application that should be adequately addressed in order to achieve successful runoff-based reforestation.

DESIGN AND APPLICATION OF MICRO-CATCHMENTS

As in any water resources development project, successful micro-catchment runoff harvesting demands the preparation of an exhaustive runoff masterplan. The aim is to relate the demand to supply so as to determine sizes of catchment and storage facilities. The computations should follow the procedure below.

Catchment area

1. The runoff potential (RP) is a function of the mean rainfall and the runoff coefficient thus:

$$RP = MAR * RC \text{ (mm)}$$

2. The seedling moisture demand from runoff is the water deficit (MD), i.e. balance between mean annual rainfall and mean annual potential evaporation thus:

$$MD = MAR - MAPE \text{ (mm)}$$

3. The catchment area to storage area ratio CSAR is a function of both RP and MD thus:

$$CSAR = \frac{MD \text{ (mm)}}{RP \text{ (mm)}}$$

which for the Njemps Flats works out to:

$$CSAR = \frac{1310}{130} = 10 \text{ mm}$$

If a planting area of $1 m^2$ is adopted, then a $10\ m^2$ catchment area is needed to collect enough runoff.

The size of the catchment area is therefore site specific and cannot be extrapolated to other areas. However, the optimum plot size computation methodology can be readily applied on any site.

Runoff storage area

The runoff is stored underneath the seedling and not ponded in an adjacent hole. The soil should therefore be deep and porous to hold the maximum possible quantity of available water (FC-PWP). The total available soil moisture in the rooting zones is calculated using the formula below (Yaaron, Danfors and Vaadia, 1973).

$$d = \frac{Dsa\ AWC}{100}$$

where d = millimetres of available water in the rooting zone
D = depth of rooting zone (mm)
Sa = soil bulk density (volume/volume)
AWC= available water capacity, i.e balance between field capacity and permanent wilting point.

For the soils of the Njemps Flats and assuming a 50cm rooting depth, the total available water amounts to

$$d = \frac{500 * 1.3 * 23}{100} = 143 \text{ mm}$$

The deeper the rooting zone, the bigger the moisture reservoir. Some operations, such as treating the planting hole soil with peat, have been found to increase the AWC by up to 83% (Wairagu, in preparation). The possibility of using peat (where available) to improve soil moisture holding in micro-catchments should therefore be explored.

Runoff reliability

Runoff-based farming is a slight modification of rainfed farming systems. With the high variability that characterizes ASAL rainfall, runoff farming has a high chance of failure, despite moderation by the multiplier effect of micro-catchments. Runoff harvesting is therefore most successful when used for species that can survive both short and prolonged droughts.

Soil salinity

The majority of soils in arid and semi-arid areas suffer from varying degrees of salinity, which increases with soil depth. If such soils have poor drainage or shallow saline water tables, the saline water table could be elevated to the rooting zone causing salinity toxicity. This is potentially a serious problem whose magnitude is not fully understood. It would be interesting to establish the possible relationship between death of *Prosopis* and salinity on the Njemps Flats.

CONCLUSION

In conclusion, it should be stated that the design of water harvesting systems is site specific. Successful runoff harvesting designs must take into consideration the following factors:

- Soil characteristics (runoff, depth, erodability and profile chemistry);
- Precipitation characteristics (depth, distribution and reliability);
- Water demand (mainly evaporation).

Because ASAL rainfall is intermittent, storage is an integral part of runoff harvesting systems. Since runoff is stored in the rooting soil underneath the seedling, measures that improve the water-holding capacity of this soil should be explored.

REFERENCES

Liniger, H. (1986). Research on Soil and Water Conservation in the Semi-arid Highlands of Laikipia. *Proc. 3rd Nat. Seminar on Soil and Water Conservation.* Kabete, Kenya.

Rowntree, K.M. (1988). Storm Rainfall on the Njemps Flats, Baringo District, Kenya. *Jl of Climatology*, **7**, 297-309.

Wairagu M.M. (in preparation). Observations on the Response of the Available Water Capacity of Two Clays to Peat Treatment.
Wairagu, M.M. and **Bryan R.B.** (in preparation). A Methodology for Runoff Prediction on the Njemps Flats of Baringo District, Kenya.
Yaaron, B., Danfors E. and **Vaadia Y.**, (1973). *Arid Zone Irrigation* Spring-verlag, New York.

DISCUSSIONS

Mr Burgess asked the author how he arrived at the runoff coefficients in view of the fact that in the field, soil conditions vary greatly causing difficulty in determining the runoff coefficients. He added that laboratory studies may not be accurate enough and that the design equation presented relied on the accuracy of the runoff coefficients.
The author responded that the studies presented were field based. Runoff coefficients were determined experimentally from runoff experiments and were found to agree with those given in the engineering books, and hence were quite accurate. For similar soil types, cover conditions and slopes, the runoff coefficients did not change much. In fact antecedent moisture was a more significant factor in the short term.

CLIMATOLOGICAL AND HYDROLOGICAL FACTORS INFLUENCING THE EFFECTIVENESS OF RAINWATER HARVESTING FOR CROP PRODUCTION IN SEMI-ARID KENYA

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INTRODUCTION

About 83% of Kenya's land surface is classified as arid and semi-arid land (ASAL); it supports approximately 34% of the human population and 50% of the livestock. The main constraining factor to crop and livestock production is the shortage of rainfall which is characterized by low total amounts, strong seasonal concentration and high variability from season to season and year to year, making these ASAL areas susceptible to drought, with agricultural, meteorological as well as hydrological aspects. These have an important bearing on the effectiveness of rainwater harvesting techniques (RWH) for crop production in low rainfall areas of Kenya.

Research efforts into RWH in Kenya have concentrated on the potential of the technique to supply water mainly for domestic and livestock purposes, and to a lesser extent for crop production. It is also evident that most of the research into RWH for crop production has been on the design of the technologies considered appropriate for the ASALs. Less work has been done on climatological/meteorological, edaphic and hydrological aspects of the semi-arid areas as they relate to soil moisture release characteristics and crop production (Mutiso and Mutisya, 1993).

This paper examines the extent to which the foregoing factors influence the effectiveness of RWH systems in the ASALs of Kenya. Specific examples are drawn from Machakos District where fieldwork was carried out.

CLIMATOLOGICAL ASPECTS OF SEMI-ARID LANDS

Regional and local rainfall controls

The availability of rainfall for crop production in the semi-arid lands and East Africa in general is influenced by the following controls as reported by Mutiso, Mortimore and Tiffen (1991).

- The regional circulation pattern and the intertropical convergence zone (ITCZ).
- Latitude, which affects the timing of rainfall minima and maxima, as the thermal equator follows the sun's zenith.
- Topography and aspect, which influence the intensity of the ITCZ and the amount of rainfall.
- Inland lakes, for instance, Lake Victoria, which provide local sources of moisture.

The easterly trade winds and ITCZ are the major rain producing agents in East Africa and hence the major source of water being harvested for crop production. The movement of ITCZ over East Africa normally disturbs the monsoonal windflow and provides the basis for increased instability and rainfall activity. This usually results in the seasonal nature of the East Africa rainfall regime which is characterized by two distinct wet seasons in eastern Kenya, namely Short rains (October-December, *Nthwa*) and Long rains (March-May, *Uua*) with a comparatively dry period between them.

Nonetheless, not all regional rainfall behaviour can be explained in terms of the ITCZ. The drought of 1984, for example, has been analysed by Anyamba and Ogallo (1990). Using wind data from 29 upper air stations in Africa, they showed that cyclonic activity in the Indian Ocean during April inhibited rain formation over East Africa. Similarly there are also local rainfall controls, namely "free" and "forced" convective systems.

Rainfall patterns, trends and variability

The most common climatic parameter that is used to indicate the amount of rainfall available for the purpose of crop production is the mean annual value.

However, the means conceal extreme events and do not take into account run-off losses, evapotranspiration and the distribution of rainfall during the growing season. Despite the use of climatic data for drought prediction and crop planning in semi-arid Kenya, it can be concluded that no model so far provides a reliable indicator of agricultural output in the farming system as a whole, in areas of diverse conditions of soil and slope. An examination of some selected data in Machakos District shows that there is insufficient evidence of generalized trends to support a firm hypothesis linking climatic with environmental change. Variability, rather than long-term change, was the most important characteristic of rainfall behaviour during the period 1957- 1990 (Mutiso, Mortimore and Tiffen, 1991).

Parry, Carter and Kanijn (1988, pp. 154-63) carried out an investigation of secular rainfall trends in Machakos and two neighbouring districts (Kirinyaga and Embu). Four station series were used, namely, Embu, Kerugoya, Machakos Town and Makindu. Eleven-year running means were plotted to smoothen the series. They found (Table 1) that Machakos and Makindu had statistically significant negative trends for the long rains. For the short rains, Machakos had a statistically significant positive trend while Makindu had a negative trend that was not significant (at 5% probability). However, taking all four stations together, there does not appear to be a widespread general trend in the smoothed series. In every case, the range of annual rainfall is much greater than the difference between one average mean and the next. Thus, there is no evidence on the time-scale of the next decade or so, of significant changes in the climatic parameters.

In order to test this conclusion at a larger number of stations within the district, the rainfall series for the years 1957-88 were plotted for five additional stations. These range from AEZ 3 (Kangundo and Kabaa, with 806-900mm annual rainfall) to AEZ 4 (Katumani and Kampi ya Mawe, with about 700mm and Kibwezi, with 650mm). Regressions of seasonal rainfall on year produced a range of values, but no evidence of a generalized, significant trend (Table 2).

Table 1. Linear least-square regression of seasonal rainfall 11-year moving averages for four stations (after Parry *et al.*, 1988: p. 157, p. 157).

Season	*Correlation (r) with year*			
	Kerugoya	*Embu*	*Machakos*	*Makindu*
Long rains (Mar -May)	-0.20	0.24	-0.48*	-0.38*
Short rains (Oct.-Dec)	0.53*	0.40*	0.33*	-0.22
Periods	1936-85	1914-85	1897-1985	1907-85

*Significant at 5% probability.

Table 2. Linear least-square regression of seasonal rainfall.

Season	*Correlation (r) with year*				
	Kabaa	*Kangundo*	*Katumani*	*Kampi ya Mawe*	*Kibwezi*
Long rains (Mar.-May)	0.41*	0 39*	-0.32	-0.09	0.25
Short rains (Oct.-Dec)	0.04	-0.40*	-0.29	-0.31	0.67*
Periods	1957-88	1957-88	1957-88	1962-88	1957-88

* Significant at 5% probability

In Sahelian Africa a significant reduction in mean and annual rainfall occurred after 1970, amounting to over 30% in some areas (Mortimore, 1989). To test this possibility in Machakos District, mean seasonal rainfall during the periods 1957-71 (15 years) and 1972-90 (19 years) is shown in Table 3 for the five stations. The differences are randomly variable and not significant.

Table 3. Mean seasonal rainfall up to and after 1971 for five stations.

	Long rains			*Short rains*		
	1957-71	*1972-90*	*Change (%)*	*1957-71*	*1972-90*	*Change (%)*
Kabaa		312.86	324 39	13.3	341 77	4 7
Kangundo		362 94	365.60	0.7	321 26	-1.5
Katumani		304 39	307 41	1.0	308.83	-14 4
Kambı ya Mawe	318 83*	290.48	-8 9	301 89	349.53	15 8
Kıbwezı	263 90	238.61	-9 6	428 45	398.56	-7 0

*Period 1962-71

The conclusions of Parry *et al.* (1988) therefore, are confirmed with respect to long-term trends in Machakos District. Consequently, detailed models are necessary for predicting soil moisture and thereby agricultural potential in a given area.

Drought climatology

Another climatic or meteorological factor influencing the effectiveness of rainwater harvesting in semi-arid Kenya is drought. Drought is defined as a deficit in available water for the specific purposes for which it is required (Palukinof and Farmer, 1982). Consequently, drought is defined here in relation to rainwater harvesting for crop production and covers agricultural, meteorological and hydrological aspects.

The meteorological aspects of drought are those factors that have led to the failure of rains. They involve an arbitrary shortfall in expected moisture (rainfall) resulting from a change in the region's rain-producing mechanisms, some of which may be linked to shifts in atmospheric circulation (Parry *et al.*, 1988; Farmer, 1981; Mutiso, 1988).

Hydrological aspects of drought include changes in the levels of stream flow and underground water levels. The latter is important because it determines the surface and ground-water resources. Low stream flow implies reduced water for harvesting for both modern and indigenous small-scale irrigation systems on hill slopes and in valley bottoms, and of water contained in surface, sub-surface and sandy river beds downstream. These are also the main source of domestic and livestock water supply in semi-arid Kenya.

Agricultural drought is difficult to define. It requires some judgement regarding the combination of a number of factors that must be present for drought to occur. These include crop type and its root and shoot morphology, certain physical properties of soil, the length of the growing season, rainfall regime, surface and ground water resources and the evaporative demand of the environment. Three types of agricultural drought are recognized in Kenya, namely, national, regional and local; these are important in understanding the degree of a society's vulnerability to drought and the adjustment mechanisms. Agricultural and hydrological droughts have greater socio-economic and political impact in the semi-arid areas of Kenya.

Spatial patterns of drought and famine vulnerability

National drought directly affects 10% of Kenya's population in all ecological zones within one province or two, and lasts two or more growing seasons. This type of drought occurs once in every decade and the most recent one, which received a lot of attention from scientists and planners, occurred in 1984 (Parry *et al.*, 1988; Mutiso, 1988, 1990; National Environmental Secretariat, 1985; Akong'a, 1989; Downing, Gitu and Kamau, 1989; Parry and Carter, 1990, Anyamba and Ogallo, 1990; Neumann *et al*, 1989; Oreze and Gev, 1989; Cohen and Lewis, 1989). Among the Akamba the famine was nicknamed *Nikw'a ngwete*, i.e. "I am dying while holding money in my hands", meaning that the food was not readily available even to those who had money.

During the 1984 drought, two-thirds of Kenya, including Machakos, had a seasonal rainfall total of about 100mm which was inadequate for crop production. This failure was marked by a late onset, low intensity and short duration of rains. The drought was widespread, affecting all parts of the country except the coastal strip. Many areas in the Rift Valley, central and eastern Kenya received less than 40% of their seasonal rains (Macodras, Nthusi and Mwikya, 1980; Anyamba and Ogallo, 1990). The Government of Kenya stepped in quickly to offset what would otherwise have been widespread and disastrous effects of the drought by requesting international aid, and subsequently importing yellow maize in the second half of the year.

Regional drought, which affects the production of less than 10% of the population at a time, lasts one or two growing seasons and is generally confined to the medium and low potential areas especially the semi-arid areas, of the country. Wisner, (1976) notes that the occurence of this type of drought varies according to the type of crop and animal husbandry practised in the area affected. With local maize one would expect such a drought once every three or four years (NES, 1985). However, with the adoption in Machakos District of the early ripening, drought tolerant and/or elusive Katumani composite B (*Zea mays*), the frequency of regional drought is reduced.

SOIL MOISTURE RELEASE CHARACTERISTICS OF MACHAKOS SOILS

Soil moisture content appears to increase with depth in the soil profile and volumetric moisture content at each specific depth at each profile varies substantially at each specific suction pressure.

In terms of structural and hydrological characteristics of the Machakos soils, the distribution of pore size with depth is significant. The profiles with relatively greater and more uniform pore volume throughout the profile include Simba, Matiliku, Kianzabe and Mukamukuu. These soils (except for Matiliku which is developed on undifferentiated Basement complex), are developed on Tertiary basic igneous rocks. The total pore volume on average ranges between 59 and 48.1%. The profile with relatively lower and uniform pore volume includes Makindu and Darajani where the total pore volume ranges between 45.4 and 37 percent. Finally, the profiles whose total pore volume increased with depth include Potha and Matungulu. The Matungulu pore volume ranges between 41 and 50% in the top and sub-surface levels, to 39.5% at 150cm depth, whilst at Potha, much lower, it ranges from 40% at the surface to 38.2% at the bottom of the profile.

Profile waterholding capacity

Running totals for maximum water-storage capacity at saturation, field capacity and wilting point give a fair idea of the potentiality of an area for crop production. It is, however, important to note that soil moisture is of limited value since not all moisture present at any given time and depth is available to plants. For instance, that moisture present above the field capacity (2.5 pF) or below the permanent wilting point (4.2 pF) is not utilized by plants. Hence, the concept of water-holding and available-water capacities in Tables 4 and 5 become crucial in the discussion of soil moisture release characteristics and the subsequent effects on plant growth.

It can be observed from Table 4 that the Muka Mukuu, Kianzabe, Kangundo, Matiliku, Matungulu and Simba soils hold almost twice as much total water at field capacity (FC) and wilting point (WP) as those of Mtito Andei, Potha, Darajani, Makueni and Makindu. It appears from this table that the Volcanic derived soils have higher water-holding capacities than the Basement soils.

Table 4. Summary of profile water-holding capacity.

Water-holding (mm of H_2O)	*Site FC*	*Site WP*	*Soil Origin*	*Soil Textual Class*
300	Mtito Andei	Mtito Andei	BS	Sandy clay
	Kabaa	Kabaa	BS	Clay loam
	Darajani	Darajani	BS	Sandy loam
301-600	Matiliku	Matiliku	BS	Clay
	Makueni	Makueni	BS	Clay loam
	Makindu	Makindu	BS	Clay loam
601-900	Simba	-	-	Silt clay loam
	Muka Mukuu			Silt loam
	Kianzabe	Muka Mukuu	VOL	Silt clay
	Kangundo	Kianzabe	VOL	clay
	Matungulu	Kangundo	VOL	Silt clay
		-	VOL	

BS = Basement complex system; VOL = Volcanic.

Source: Field data (1986).

AVAILABLE WATER CAPACITY

Available water capacity is the difference between field capacity (0.3 bars), and permanent wilting point (3 bars), i.e. the amount of water expressed as a percentage by volume or as available water content in millimetres of water for a given depth of soil. It is a true measure of the amount in a given soil type can store and make readily available to plants whenever it is needed.

The available water is not uniformly available to all plants because of differences in their root morphology, and hence their ability to extract water. In some cases the replenishment of water in the depleted soils may be slow enough to cause wilting (Sanchez, 1976). Table 5 shows that both water-holding capacity and available-water capacity have deep implications, although the Volcanic soils of Muka Mukuu, Kianzabe and Kangundo hold 832.9; 780.2; 767.2mm of water at field capacity and 742.8; 645.3; and 669.9mm of water wilting point, respectively, only 90.7; 134.8; 97.9mm of water is available for plant use and that the plants, depending on root morphology, may wilt on these soils while there is still more than 742.2; 645.3 land 669.9mm of water in these profiles.

Table 5. Profile water-holding capacity and available-water capacity.

Site	*Field capacity (mm)*	*Wilting point (mm)*	*Available water capacity (mm)*	*Soil origin*	*Soil texture*
Muka Mukuu	832.9	742.8	90.7	VOL	Silt loam
Kianzabe	780.2	645.3	134.0	VOL	Silt
Kangundo	767.2	669.9	97 9	VOL	Clay
Mtito Andei	249.8	199.8	50.7	BS	Sandy clay
Kabaa	471.2	371.06	100.1	BS	Clay
Darajani	405.6	337.7	67.9	BS	Sandy loam
Makueni	586 6	489 7	96.9	BS	Sandy clay
Makindu	517.6	404.7	112.9	BS	Silt
Potha	392 2	246 2	146.0	BS	Sandy clay

BS = Basement complex system, VOL = Volcanic

Source: Field Data, 1986

Mtito Andei, Kabaa, Darajani, Makueni and Potha soil profiles hold 249.8mm, 471.2mm, 405.6mm, 586.6mm, and 392.2mm at field capacity and 199.8mm, 371.06mm, 337.7mm, 489.7mm, 404.7mm and 246.2mm at permanent wilting point, only 50.7mm, 100.1mm, 67.9mm, 96.91mm, 112.9mm and 146.0mm of water is available for the plants at 150cm depth. Plants whose rooting depth does not exceed 60cm will definitely wilt on most of these soils despite the relatively large volume of moisture remaining in the profile.

CONCLUSION AND RECOMMENDATIONS

The physical properties of soil have great influence on crop production in any given climatic regime. It is important to note that the survival of plants in a bimodal rainfall regime such as Machakos District depends on the persistence of water between the field capacity and wilting point which can be extracted or harvested. The water conditions may persist for a considerable period of time below the apparently dry soil.

As the soil quickly dries due to high rates of evapotranspiration, the suction pressure needed to extract water increases, and reduces water movement towards the plant roots. If the soil moisture is retained at lower levels of the profile, only deep-rooted crops such as the pigeon peas will have access to this moisture. Shallow-rooted and recently germinated crops, which are only capable of drawing water from the surface or sub-surface will wilt and probably die, particularly when other physical factors (such as bulk density and murrum crust "petroplinthite") are taken into account. Not all plants wilt and die, however. Signs of water stress in plants can appear in the form of decreased vegetative growth which, in the case of Katumani composite maize for instance, is evidenced by stunted growth and small maize cobs or leaf wilt and chlorosis.

It is concluded that what matters most is not so much the water- holding capacity of soils but the available-water capacity. This is the amount of moisture which is available to crops depending on their root morphology. The Volcanic soils have a much higher water content at field capacity than the Basement soils. The much higher sand content and poor water-holding capillary pores of soils developed on Basement rocks, as well as the persistently high soil surface temperatures, mean that the little water held by these soils is either lost into the ground water or evaporated. Consequently, crops grown on soils developed on Basement rocks require seasonally well-distributed rains, supplementary irrigation or agronomic practices to increase soil moisture. These include a reduction in plant density or planting a quick ripening, drought resistant variety, and rainwater harvesting by conservation of surface and ground water resources. Therefore a good understanding of each particular area is important for the effectiveness of rainwater harvesting for crop production in semi-arid Kenya.

REFERENCES

Akong'a, J. (1989). Drought and Famine Management in Kitui District, Kenya. ed. by P. Little and D. Brokenshaw. *Anthropology and Development in East Africa,* Bolder.

Anyamba, K. and **Ogallo** (1990). Meteorological Causes of the 1984 Drought in Kenya. *Proc. of the Environment 2000 Conference: Kenya's State of the Environment.* UNEP.

Cohen, J.M. and **Lewis, D.B.** (1989). The Role of Government in Combating Food Shortages; Lessons from Kenya 1984-85. *Drought and Hunger in Africa; Denying Famine a Future,* ed. by I. Glantz and H. Michael.

Downing, T.E., Gitu, K.W. and **Kamau, C.M.** (eds) (1989). *Coping with Drought in Kenya; National and Local Strategies.* Lynne Rienner, London.

Fairburn, W.A. (1963). *Geological Survey of Kenya,* Report 59. Government Printer, Nairobi.

Farmer, G. (1981). Regionalisation and Study of an Alleged Change in the Rainfall Climatology of East Africa. PhD dissertation, University of Sheffield, UK.

Griffiths, J.F. (1969). The Climate of East Africa. *East Africa, Its People and Resources,* ed. by W.T.W. Morgan, Nairobi.

Griffiths, J.F. (1972). *Climates of Africa.* Elsevier, New York.

Government of Kenya (1973). *Ground Water Resources in Kenya : Sectorial Study and National Programming for Community and Rural Water Supply,* Sewerage and Water Pollution Control. Report No. 7, WHO, Brazzaville.

Hounan, D.E., Burgas, J.J., Kalik, M.S, Palmer, W.C. and **Rodda, J.** (1975). Drought and Agriculture. Technical Note No. 138. World Meteorological Organization, Geneva.

Institute of Applied Geosciences (1986). *Water Resources Reconnaissance Study in Machakos District.* Ministry of Water Development, Delft, The Netherlands.

Kanshasha, D.A.R, (1982), A Study of Effective Rainfall for Crop Production. Thesis submitted for M.Sc. University of Nairobi, Kenya.

Oreze and Gev (1989), *Hunger and Public Action*, Oxford, University Press.

Macodras, M.W., Nthusi, P.N. and **Mwikya J.** (1989). Synoptic Features Associated with the Failure of the 1984 Long Rains in Kenya., pp. 67-72.

Musingi, K. (1990). Effective Rainfall and Bean Yield in a Tropical Semi-Arid Environment: A Case Study of South Eastern Machakos District Kenya. Unpublished MSc. Thesis, University of Nairobi, Kenya.

Mutiso, S.K. (1986). African Resources: Appraisal, Monitoring and Management. *AREA*, **18**, (1), 69. Institute of British Geographers.

Mutiso, S.K. (1988), Water Resources and Crop Production in Machakos District, Unpublished PhD Thesis, University of Reading, UK.

Mutiso, S.K. (1990). Agricultural Drought and Famine Coping Mechanisms Among the Akamba of Eastern Kenya, *Proc. of the Environment 2000 Conference:* Kenya's State of the Environment. UNEP. October, 1990.

Mutiso S.K. and **Mutisya D.N.** (1993). Rain Water Harvesting for Crop Production in Kenya. Research Needs and Priorities. *Proc. 2nd Nat. Conf. on Rainwater Catchment Systems in Kenya.* Nairobi.

Mutiso, S.K. and **Thompson, R.D.** (1987). Future Water Supply in Machakos District, Kenya. *AMBIO*, **14**, 6.

Mutiso S.K., Mortimore, M. and **Tiffen M., (1991).** *Rainfall, Environmental Change and Dryland Management in Machakos District, Kenya 1930-1990.* Overseas Development Institute, UK.

National Environment Secretariat (1985). *CBS/NES Survey of "Drought Responses: Preliminary Findings*, Nairobi.

Neumann, N. ,Trostle, R., Baksh, M., Ngare, D. and **Bwibo, N.** (1989). Household Response to the Impact of Drought in Kenya. *Food and Nutrition Bulletin*, **2**. The United Nations University.

Nieuwolt, S.N. (1978). *Seasonal Drought in East Africa.* University of Nairobi, Kenya.

Nieuwolt, S.N. (1979). *Tropical Climatology*, John Wiley, New York.

Palukinof, J.P. (1986). *Drought Strategies in East Africa*: The Climatologist's Role in Climatic Change.

Palukinof, J.P, and **Farmer, G.** (1982). Strategies for the Amelioration of Agricultural Drought in Africa. *Proc. of the Technical Conference on Climate: Africa*, pp. 222-248, World Meteorological Organization, Geneva.

Parry, M.L. and **Carter, T.R.** (1990). *The Impact of Climatic Variation on Agriculture.* International Institute for Applied System Analysis and UNEP.

Parry, M.L., Carter, T.R. and **Kanijn, N.T.** (1988). *The Impact of Climatic Variation on Agriculture: Assessment in Semi-arid Regions.*, Reide Dordrecht, The Netherlands.

Stewart, J.I. (1982). Impact of Weather Analysis on Agricultural Production and Planning Decisions for the Semi-arid Areas of Kenya. *Jl Applied Meteorology,* **21**, 11.

Stewart, J.I. (1980). Research on Crop Water Use and Drought Responses in East Africa, *Proc. Int. Workshop.*

Stewart , J.I. and **Hagan, R.M.** (1969). Predicting Effects of Water Shortage on Crop Yield. *Jl. Irrigation Drainage*, **95**, 91-104.

Wisner, B.G. (1985), *World Development Report,* World Bank, Washington, D.C.
Wisner, B.G. (1986). Kenya: Policies and Prospects for Restoring Sustained Growth as per capita Income, World Bank (manuscript), Washington, D.C.
Wisner, B. (1976). An Overview of Drought in Kenya. Natural Hazards Research Paradigm, Working Paper No. 30. Sheffield University, U.K.

EXCURSIONS

6TH INTERNATIONAL CONFERENCE ON RAINWATER CATCHMENT SYSTEMS

EXCURSION GUIDE

By G. M. Mailu, D B. Thomas, J. M. Wanyonyi and S. K. Mutiso

COUNTRY BACKGROUND

The Republic of Kenya covers an area of approximately 583,000km^2. It is bounded by latitudes 5°00′ north and 4°30′ south, and longitudes 33°55′ and 41°52′ east. The population is approximately 23 million.

The geology of the area is characterized by a range of rocks which vary in age from the Precambrian to Quaternary periods.

The main physiographic features include the central highlands which are bisected by the East African Rift Valley. The associated mountains include Kilimanjaro, Kenya, Aberdare ranges, Longonot and Elgon. The first two are capped by snow, despite their proximity to the Equator, because of their altitudes which are approximately 6,000m and 5,000m respectively.

Most of the Kenya lakes are associated with the Rift Valley; they include Turkana, Baringo, Nakuru, Naivasha and Magadi. However Lake Victoria is associated with general downwarping.

According to the hydrological classification, Kenya is divided into five drainage areas, namely Lake Victoria, Rift Valley, Athi River, Tana River and Northern Ewaso Nyiro River drainage basins.

The country may be broadly divided into two ecological zones, namely, high rainfall areas and arid and semi-arid areas. The high rainfall areas are associated with the central highlands. They receive reliable rainfall which is above 1000mm per annum. They are the granary of the staple and export crops of the country and they are generally called the high potential areas of the country. They form only 20% of the country and support about 70% of the population. The arid and semi-arid lands (ASAL) constitute about 80% of the country and support only 30% of the population. They receive unreliable rainfall of less than 750mm per annum and they are characterized by high probability of crop failure. However, they support a high percentage of the livestock in the country.

Agriculture and tourism constitute the backbone of the economy. The main crops for export are tea, coffee, pyrethrum and horticultural products. The main attractions for tourism are the physical features and wild animals. A good number of national parks and game reserves are well distributed in the country and they are easily accessible from the capital city, Nairobi.

The three field excursions were deliberately tailored to provide the delegates to the 6th International Conference on Rainwater Catchment Systems with a broad spectrum of the phenomena mentioned above. The excursions focused on practical problems and how rainwater harvesting technologies have been developed to solve them in the ASAL.

While delegates were able to observe many features, each excursion was limited to the main features, as described below.

EXCURSION A - KITUI CENTRAL

The main objective of the excursion was to observe the impact of sub-surface dams and roof catchments on the socio-economic development of the central part of Kitui District, which is within the ASAL of Kenya. The conflict between sand harvesting and rainwater harvesting was demonstrated. Other features of interest included gypsum mining for cement manufacture at Athi River, horticultural farming on the slopes of the Iveti hills and Yatta Plateau.

The itinerary involved travelling eastwards from Nairobi city (about 1500m above seal level) through Machakos town to the northern fringes of the central region of Kitui District (100m asl). Stops were made at various sites as described below, the last of which was Migwani surface dam about 215 km east of Nairobi.

Site A1 - Gypsum Mining

On crossing the Athi river, about 44km east of Nairobi, the delegates came across many mounds of gypsum scattered across the flat Kapiti Plains. The gypsum deposits are shallow (less than 2m depth); there is a ready market for the gypsum at the Portland Cement Factory which is less than 8km west of the mines.

Site A2 - Kaseve Horticultural Farming

About 12km east of Machakos town there is a small market called Kaseve, located on the lowlands of the Iveti hills. The lowlands are quite dry and experience frequent crop failure. However the market is the centre for the sale of horticultural crops, which are grown throughout the year by irrigation on the upper slopes of the Iveti hills, about 8km northwest of the market.

Site A3 - Tiva River

Tiva is a seasonal river about 155km east of Nairobi. At the point where the Kitui-Machakos road crosses the river there is heavy deposition of sand on the river bed, indicating that the river is mature in age.

Although there is no surface flow almost immediately after rains, shallow wells are dug to a depth of less than 1 metre for water supply for domestic and livestock purposes.

However sand harvesting has exposed the water table in many sections of the river bed, thus rendering the water vulnerable to evaporation. The result of this is a lowering of the water table and development of salinity.

Site A4 - Mutulu Roof Catchment

Mutulu Primary School is about 15km south of Kitui town. For many years the school had suffered from a lack of water as there are no rivers or boreholes in the neighbourhood. However in the mid 80s large tanks were constructed to store all the water tapped by roof catchment from all the buildings. This has resulted in self-sufficiency in water supply for the school, even during the driest seasons of the year.

Site A5 Ndiangu Sub-surface Dam

In the mid 1950's a weir was constructed across the Ndiangu river at the point where the Kitui-Thika road crosses it. The purpose was to reinforce the stability of the road across the sandy river bed.

The weir has effectively held all the water that percolates into the sand upstream. This has resulted in raising the water table upstream of the weir to near surface levels for a stretch of about 300m. In fact the surface is always wet even during the dry seasons. Downstream of the weir no attempt has been made to dig wells as the water table is reported to be too deep. It is envisaged that if more weirs were constructed downstream, the dry river bed could develop into a perennial stream.

Site A6 - Kaui Leaky Sub-surface Dam

About 15km north of Kitui town, the Kitui-Migwani road crosses the Kaui river and a weir was constructed to stabilize the sandy bed to enable vehicles to cross. The foundations of the weir have been breached over the years. Although the weir can effectively hold the sand upstream, the water that has percolated into it filters downstream. However, farther downstream there is a natural dam that effectively holds the sand and the percolating water and has raised the water table to the surface. It is possible to get water upstream of the leaky weir by digging wells to a depth of 1m.

Site A7 - Migwani Surface Dam

Migwani Market has the most efficient water supply in the whole of Kitui District. The main sources of water are boreholes, roof catchment and a surface dam. The main focus for the excursion was the surface dam.

The new dam which was constructed in the early 1970's is constructed downstream of an older dam which had partially silted-up. The new dam has an outlet across the weir to provide for a downstream watering site for domestic and livestock purposes, without interfering with the reservoir. The environs of the old and new dams have been effectively fenced and natural vegetation has grown up around the dam for about 20m.

The vegetation has effectively prevented silting caused by surface runoff from the surrounding farms. The old dam serves as an effective silt trap. In effect Migwani dam has very clean water suitable for many purposes.

EXCURSION B - KITUI NORTH

The main objective of the excursion was to assess the impact of rock catchment technology on the water supply in the northern region of Kitui District which is within the ASAL of Kenya. The conflict between sand and rainwater harvesting was observed; other features of interest were large and small scale farming by irrigation, and crop failure in the semi-arid lands.

The itinerary involved travelling to the northeast, through Thika town, and thereafter to the east through Mwingi town to the Yambyu rock catchment about 222km east of Nairobi.

Site B1. Thika Coffee Plantations

The coffee plantations were observed from the fly-over in the western suburbs of Thika town, about 40km northeast of Nairobi. The plantations are at the margin of the high potential area of Kenya and rain is augmented by irrigation for the success of the crop. Further east the high potential zone gives way to semi-arid conditions where crop failure is a common feature, and coffee plantations are rare.

Site B2 - Yatta Furrow

About 105km east of Nairobi, the Nairobi-Mwingi road crosses the Yatta furrow, constructed in the mid 1950's. It drains water from the Thika river and runs for a distance of about 60km. The furrow has supplied water for domestic, livestock and small-scale irrigation purposes to an area which could not otherwise have been inhabited.

Site B3 - Kwa Kimindu

About 10km northeast of the Yatta furrow bridge, the delegates observed small-scale irrigation farming. Horticultural crops such as karela, (bitter gourd), french beans, onions, tomatoes and fruits are grown. The flood irrigation system is common and the water is tapped from the Yatta furrow by gravity flow.

Site B4 - Kiio Rock Catchment

Kiio rock catchment is about 175km east of Nairobi. It is 8km west of Momboni market. The catchment and the dams are very good and have previously supplied a large capacity reservoir. However, during the reconnaissance survey in July 1993 the rock catchment was dry and people were digging wells in pursuit of the lowering water table. Observations have proved that there is a downward loss of water, possibility due to the fracturing of rocks.

Site B5 - Kwa Kavili Rock Catchment

Kwa Kavili rock catchment is about 8km northwest of Mondoni market. Delegates had an opportunity to see the construction of a rock catchment in progress. The excavation of the reservoir and construction of the dam was observed.

There is a better site for a rock catchment in the neighbourhood of which the community was very well aware, but it was not chosen because of the high cost involved.

Site B6 - Tyaa River

The bridge across which the Mwingi-Nairobi road passes is approximately 207km east of Nairobi and 2km southwest of Mwingi town.

A lot of shallow wells have been dug within the river bed for a long distance downstream from the bridge. Donkeys, which are used to transport water, are a common feature. Lorries frequently come to collect sand from the same river bed and people are busy piling mounds of sand. The water table is likely to be lowered, and the salinity that has been reported could be associated with evaporation due to exposure of the water table by sand harvesting.

Site B7 - Yambyu Rock Catchment

Yambyu rock catchment is about 13km north of Mwingi town. On completion, a good staircase down to the bottom of the reservoir had been constructed for maintenance purposes. A pipe has been fitted through the dam to provide water for domestic and livestock purposes away from the reservoir to prevent pollution and a fence has been constructed around the reservoir to keep people and livestock away. However, the fence has been damaged and animals find their way into the reservoir, particularly at the tailing point. Discoloration of the water is an indication of pollution. The capacity of the dam is quite high, and it can sustain water supply during the driest seasons; it is recommended that pollution control should be maximized.

EXCURSION C - NAIVASHA

The objective of the excursion was to give delegates an opportunity to observe problems of rainwater harvesting not only in the ASAL on the floor of the Rift Valley, but also in the high potential areas on the eastern shoulder of the Rift Valley. Besides rainwater harvesting issues, the results of volcanicity were observed including dormant volcanoes, step faulting, Lake Naivasha and the geothermal activities in Ol Karia.

The intinerary involved travelling north-westwards from Nairobi to Lake Naivasha. Initially there is an upward climb of about 100m between Nairobi and the View-Point, which is the highest spot on the eastern shoulder of the Rift Valley. Thereafter, there is a descent of about 100m from the View Point to Lake Naivasha in the floor of the Rift Valley (Fig. 2).

Site C1 - Muguga

Muguga is a neighbourhood within the high potential highlands of Kenya. It is underlain by permeable volcanic rocks which do not encourage surface runoff. Although rainfall is high (900-1000mm), there are few rivers, and a severe lack of water is demonstrated by the large number of donkeys which fetch water from afar.

The delegates visited a farm belonging to Mr Eluid Nganga who has six heads of cattle and about 3000 chicken. The farm is only 1 acre and the farmer practises zero grazing.

He obtains water for his animals from roof catchment. The supply is sustainable even during the driest seasons. It was observed, however that, more water could be collected if the gutters and downpipes were well maintained.

Site C2 - View Point

The View Point is the highest spot along the Nairobi-Naivasha road on the eastern shoulder of the Rift Valley.

It overlooks the step faulting on the eastern scarp of the Rift Valley, dormant volcanoes such as Longonot, and the expansive plains that form the floor of the Rift Valley. The altitude at the View Point is estimated to be 2500m above sea level. It is usually a very cold zone and the only crops that do well are tea, pyrethrum and fruits such as apples and pears.

Site C3 - Ihindu Market

The market is situated on the foot hills of the Rift Valley scarp, a few metres above the floor of the Rift Valley.

The residents depend on water from hand-dug wells, most of which are shared by domestic animals and people, so they are vulnerable to pollution from livestock. It was noted that the water in the wells fluctuates considerably and is not dependable for long-term needs.

Site C4 - Karai Dam

Karai settlement is east of Lake Naivasha. For many years the residents have relied on water from excavations along the road, which are fed by runoff from the road. They have constructed a big weir across one of the excavations to hold the flow. The main constraint of this source is its vulnerability to pollution as people, domestic and wild animals use the same source. The only other source is a borehole which has recently been drilled, with financial assistance from the Church of the Province of Kenya (CPK) Diocese of Nakuru. Arrangements are being made to equip it with a submersible pump.

Site C5 - Karati

Karati settlement is about 25km east of Lake Naivasha. With the financial assistance of the CPK, Diocese of Nakuru, the settlers have constructed elaborate roof catchments, storage tanks and pumping systems which have enabled them to keep good cattle under zero-grazing, and to grow fruits and vegetables.

Site C6 - Lake Naivasha

Lake Naivasha covers an area of approximately 150km^2 and has an average depth of about 8m. The main river that discharges into the lake is the Malewa river whose catchment is the Aberdares Range. There is heavy abstraction of the river water upstream and there is a fear that this may affect the water level of Lake Naivasha.

The water of Lake Naivasha is fresh although there is no surface outlet. The outlet is assumed to be underground, but this has yet to be proved. The lake is a source of fresh-water fish and it provides a lot of water for irrigation in the surrounding area. The biggest threat to the lake is *Salvinia molesta*, a weed that is choking the lake. Currently experiments to eradicate the weed by biological means are underway.

Large horticultural farms are the main feature on the southern fringes of the lake. Although fruits and vegetables are grown, flowers are the main crops. Kenya ranks third in the world, after Colombia and Thailand, in the export of cut flowers and the Sulmac Estate along Lake Naivasha is probably the largest carnation growing enterprise in the world. About 90% of the flowers are exported to Europe and Japan.

Site C7 - Ol Karia Geothermal Power Station

The Ol Karia geothermal power station is located a few kilometres to the west of the horticultural farms. The wells that provide super-heated water and steam have been drilled to depths of about 1.6km and each well can provide approximately 1.5-2 megawatts at a pressure of 4 bars. A total of 25 wells are linked to the power station. Geothermal power supplies about 10% of Kenya's power requirements. It is estimated that the life-span of the geothermal field is approximately 25 years.

Site C8 - Hell's Gate

Hell's Gate National Park is in the neighbourhood of the geothermal power station. The delegates were able to see zebra, warthog, impala, eland and gazelle among other wild animals Intrusive conmendite rocks form the pillar at the entrance to Hell's Gate from which the name is derived.

OBSERVATIONS AND RECOMMENDATIONS

During the field excursions, delegates made various observations and recommendations, some of which are given below.

Excursion A

1. Localization of shallow wells
It was observed that shallow wells along various dry river beds were localized. It was recommended that research be carried out to determine the controlling factors, with particular focus on grain size of the sand, possible barriers across the river beds, and the thickness of the sand.

2 Monitoring of water quantity and quality
It was observed that no data are available on the water quantity and quality of the shallow wells in various river beds. It was recommended that they should be monitored in order to evolve strategies for sustainable development and management of the resources.

3. Sub-surface dams
It was observed that there is a great potential for sub-surface dams to transform dry river beds into perennial rivers. It was recommended that proper research be carried out to establish effective means of trapping sands during flood flow, and the spacing of sub-surface dams that would transform seasonal to perennial streams.

4. Surface dams
Initial plans for water supply for domestic and livestock purposes at Migwani dam were very good. However, there has been a breakdown of the established system and a lot of water is being wasted in an ASAL where every drop matters. It was recommended that the watering points be rehabilitated.

Excursion B

1 Leakage at Kiio rock catchment
It was observed that the capacity of the reservoir was quite large, yet it does not hold much water, particularly during the dry seasons. Lateral leakage was not suspected as there were no signs of such leakage downstream from the dam. However, heavy fracturing was observed in the surrounding area and further observation of the reservoir bed indicated such fracturing. It was recommended that research be carried out to establish such leakage and the resources required to seal the fractures. The investment involved in the construction of the rock catchment is so high that effective sealing would be justified.

2 Sand harvesting
Delegates expressed dismay at the high rate of sand harvesting along the Tyaa river, the consequences of which would be depletion of the sub-surface storage and possible introduction of salinity into the water. It was recommended that sand harvesting from river beds with effective sub-surface water storage should be banned while long term measures are implemented on the basis of research into the rate of sand replenishment, and the impact of evaporation on sub-surface storage.

3. Storage from rock catchments
Some rock catchments indicated a lack of researched design, both in the location and construction of the dams. It was recommended that research be initiated on the design which would ensure maximum effectiveness of a catchment.

4 Assistance for construction works
The 6th International Rainwater Catchment Systems Conference Committee donated five bags of cement to the Kwa Kavili Rock Catchment Committee as a token of appreciation for the hard work the community had demonstrated. They were presented by the President of the International Rainwater Catchment Systems Association during the field excursion on 4th August 1993. The Kwa Kavili community received the bags with deep gratitude.

Excursion C

1 Need for rainwater harvesting in high potential areas
It was observed that although the eastern highlands of the Rift Valley received more rainfall than the ASAL, farmers need to utilize rainwater harvesting techniques because the geological conditions do not encourage surface runoff. It was recommended that research be carried out throughout the Republic to establish not only geological, but also other factors that necessitate rainwater harvesting, and map the zones according to their potential.

2 Impact of rainwater harvesting on improved agriculture
It was observed that rainwater harvesting was responsible for improved small-scale farming of livestock, and horticulture. It was recommended that the practice be encouraged in order to reduce the dependence of small-scale farmers on large-scale farmers, and to ensure food security for the former.

3. Future of Lake Naivasha
It was observed that there was heavy abstraction not only from the Malewa river which feeds Lake Naivasha, but also from the lake and from ground-water in the surrounding area. It was recommended that research should be undertaken to establish the optimum abstractions which would not adversely affect the ecological system of the lake.

4 Life-span of the geothermal field
The delegates noted that the life-span of the geothermal field is estimated to be about 25 years, and that the field contributes about 10% of Kenya's electrical power. It was recommended that research should be carried out on alternative sources of power, to come on stream after the depletion of the geothermal field.

5. Water pollution in Karai
It was observed that people, domestic and wild animals were watering from the same source, a dam which resulted from road-works excavation. The delegates were quite sympathetic and they donated a sum of Kshs 13,000 (US$ 200) for fencing which would separate the watering point for animals from that of people. The fund would also subsidize dredging of the dam and construction of silt traps.

IRCSA ACTIVITIES

REPORT ON IRCSA ACTIVITIES 1991 - 1993

by J. Gould

University of Botswana

Following the formal election of the Executive Committee and the approval of the Constitution at the last plenary session of the 5th IRWCS Conference in Taiwan in August 1991, considerable progress has been made by the Association. Amongst the activities supported by the association during the last two years have been the Regional IRCSA conference held in Kyoto, Japan in October 1991 in which a large number of IRCSA supporters participated and through which the Japanese National IRCSA branch has been established. This major conference enabled the IRCSA executive to hold a special executive meeting at which it was agreed to embark on a membership drive with the assistance and logistical support of the International Water Resources Association (IWRA). The executive board proceeded to produce a leaflet which was printed in Taiwan and is being mailed out to prospective members via IRCSA's network of Regional Directors and with the assistance of W.A.S.H.

Although the initial response to the membership drive has been a little slow, it is hoped that increasing interest in IRCSA will be generated through both the 6th IRCSA conference and the Tokyo International Rainwater Utilization Conference in August 1994, and that both of these events will encourage more people to join IRCSA.

Amongst other noteworthy activities which have taken place during the last two years under the auspices of the association are the following:-

i) Kenyan rainwater harvesting workshop held in September 1992 in Nairobi, which attracted more than 120 participants from Kenya and other African Countries and resulted in a comprehensive report of the proceedings.

ii) Rainwater catchment systems technology and application workshop held in Gaborone/Kanye in Botswana in March 1993. This meeting attracted over 60 participants including 6 from other countries in the region. Comprehensive proceedings of this workshop were also produced.

iii) Technical meeting at the University of Virgin Islands, Water Resources Research Institute to consider recommendations on rainwater cistern water quality standards.

Globally an enormous amount of work is going on in the field or rainwater catchment systems design, implementation and research. While IRCSA's objective of liaising with as many of the disparate organizations ranging from small NGO's to large international organizations such as UN agencies involved in this activity have been partially successful, the logistical difficulties are enormous. Nevertheless, we do have seven Regional Directors and forty National Representatives now in place.

In order for IRCSA to more effectively achieve its key objectives of helping to promote, coordinate and support increased dissemination of RWCS technologies though encouraging exchange of information between all those working in this field, a permanent office needs to be established from which alctivities can be effectively coordinated. In addition to support from the membership, financial support from a donor or foundation is also required. The imminent termination of the WASH project and the possibility that the production of RAIN-

DROP by the Rainwater Harvesting Information Centre currently based at WASH may soon end also requires a response from IRCSA.

IRCSA's achievements in the period 1991 - 1993 have been considerable and thanks is due to all those individuals and organizations who through their hard work and cooperation have helped IRCSA with its activities. In particular, thanks are due to the local organizing committee of the 6th IRWCS Conference for all their hard work and dedication in making this conference and the present meeting possible.

The challenges for the next two years are considerable. Whilst activities in some countries and regions are substantial, renewed effort and new initiatives are required in others. The continued hard work and enthusiasm of all IRCSA members and supporters should help ensure that the association is able to build on these good beginnings and help promote the continuing spread of Rainwater Catchment Systems Technology worldwide.

IRCSA AND JAPAN - IRCSA

by Isao Minami

Synopsis

The Regional Conference 1991, of the International Rainwater Catchment Systems Association (IRCSA) was held in Tokyo, Japan from October 4th to 10th, 1992. The aims of this conference were to collect information on rainwater catchment systems from the participants from all over the world, and to spread to Japan, the idea of direct utilization of rainfall. This conference was very significant for the Japanese, providing the opportunity to recognize the importance of direct utilization of rainwater from the standpoint of water resources and environmental preservation, even though much of Japan has average annual rainfall of 1800mm/year. Before the conference a Japanese branch of IRCSA (JIRCSA) was established, the headquarters of which are in Kyoto City. Soon after this, several interesting projects in rainwater utilization were started under the supervision of JIRCSA. We would like to extend our gratitude to all the participants who come to the Japan conference from all around the world and especially to our colleagues in the International Rainwater Catchment Systems Association.

Relationship between Japan-IRCSA and IRCSA

IRCSA is the central global organization in the field of rainwater harvesting and Japan-IRCSA was established in Kyoto, as a branch of IRCSA to especially reflect Japanese concerns. The aim of rainwater catchment technologies is to create local products reflecting natural, socio-logical, economical and engineering aspects appropriate to the local areas. Practical studies on rainwater catchment systems should be undertaken by each country with regard to then particular needs.

For systematic development of IRSCA, we would like to recommend the system below to define the relationship between IRCSA and subsidary associations

Sub-IRCSA <. . .> Central Headquarters <. . .> J-IRCSA
IRCSA

Figure 1. Relationship between IRCSA and Sub-IRCSAs

New Project by Japan-IRCSA

After the regional conference, Japan-IRCSA set up a cooperation project; "rainwater utilization, reforestry and environmental development of remote islands" with Nakajima town, Ehime Prefecture, Japan, involving six islands in Seto inland sea. Components of this project included rainwater storage, development and intensification.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

D.B. Thomas

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1. The Conference noted that, in some many countries, there has been a lack of government support for the promotion of rainwater catchment and that the poorest communities are often paying the greatest price for water.

The Conference recommends that governments take steps to promote rainwater catchment systems and give consideration to the establishment of a rainwater catchment department within the relevant ministry.

2. The Conference noted the need for information systems to create awareness of the potential of rainwater among politicians, policy makers and administrators; their help should be sought in raising the status of rainwater in the public eye. The conference also recommends that more attention is given to formulating appropriate messages that can be used by the media to promote rainwater harvesting for crop production and rainwater catchment for domestic supply.

3. The Conference noted the need to improve the availability of information on rainwater catchment systems and recommends the establishment of information centres at national or regional level. The Conference further recommends that technical information should be compiled from conference proceedings and other sources and should be made available in the form of action sheets together with bills of quantities and the names and addresses of contact persons who can provide more details.

4. The Conference noted the importance of community participation in the development of rainwater catchment systems and recommends that communities are involved from the earliest stage of planning in what should be done and how it should be carried out. The Conference also recommends that more attention should be given to the process whereby communities are enabled to solve their own problems and to providing them with the assistance which will improve their capacity to achieve their own goals.

5. The Conference noted that in many societies the provision of water for domestic use has been considered the task of women and recommends that communities be sensitized to the difficulties faced by women and the possibilities of rainwater catchment systems in reducing the time and effort spent in collecting water.

6. The Conference noted that the affordability of a given technology depends on the time frame for repayment and recommends that assistance be given in the form of loans from a revolving fund to which the community and government or donor agencies make contributions. The support given by the Government of Thailand for the construction of rainwater jars provides a good example.

7. The conference noted that the benefits of rainwater catchment systems include, *inter alia*: a solution, or partial solution to problems of water shortage; good quality water; positive environmental benefits in the control of runoff; minimal demands on land; low cost through use of locally available materials; decentralized systems under the control of the local people;

income generation for local artisans; suitability for financing through revolving funds; minimal demands for energy, e.g. in pumping; and community involvement.

8. The Conference noted that, currently little attention is given to rainwater catchment systems in training institutions and recommends that the subject of rainwater harvesting be included in the syllabi of schools and colleges. The relevant professional groups such as architects, engineers and agriculturalists should be given training in the principles and practices of rainwater harvesting.

9. The Conference recognized that further research is needed into the use of rainwater catchment systems for agricultural purposes and that the reasons for non-adoption, in some instances, need further investigation. In particular the problems associated with labour demands and land tenure warrant further attention.

10. The Conference recommends that the International Rainwater Catchment Systems Association should promote the use of all kinds of rainwater catchment systems including roof catchments, rock catchments, ground catchments, open reservoirs and sand dams.

11. The Conference recommends that further research is carried out on the following aspects of roof catchments: flushing mechanisms, use of cistern roofs to catch water; safety of roofing materials; guttering systems; inlet mechanisms; outlet devices and the use of local materials.

12. The Conference notes that existing drinking water standards may be in appropriate for water collected from roofs and recommends that the relevant health authorities should carry out epidemiological studies to determine the health risk associated with drinking water collected from roofs and that they should develop appropriate standards. The same authorities should also investigate the effects on water quality of the catchment system, especially the use of asbestos roofing materials and the effect of storage components. IRCSA should draw up guidelines on appropriate standards in consultation with the relevant international agencies.

13. The Conference recommends that rainfall data should be collected and used to supplement existing data in determining cistern capacity.

14. The Conference supports the efforts of the international external support community to promote sustainable water resources and settlements development. The conference shares the objectives of the United Nations Conference on Human Settlements (Habitat II) to be held in Turkey in 1996, and encourages the provision of support to its preparatory activities. The Conference recommends the development of integrated strategies for the implementation of the Recommendations of Agenda 21, especially those related to Chapter 18 on the "Protection of the quality and supply of fresh water resources" and Chapter 7 on "Promoting sustainable human settlements development" as well as for the achievement of the goals agreed at the World Summit for Children.

The Conference requests the multilateral and bilateral external support agencies to strengthen their assistance programmes for improving socio-economic conditions in developing countries and for the provision of appropriate water supply and sanitation services to low-income communities.

ISBN 9966-9891-1-0

Produced by Engineering Design Consultants Ltd, P. O. Box 38638, Nairobi.
Printed by Westlands Secretarial Services Ltd., P.O. Box 49885, Nairobi.