THE ROLE OF WATER RESOURCES IN DEVELOPMENT

Proceedings of the 13th Annual Symposium of the East African Academy September 1977

edited by
John B. Castelino
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ENYA NATIONAL ACADEMY FOR ADVANCEMENT OF ARTS AND SCIENCES

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sponsored by the
German Foundation for International Development
and the
Ministry of Water Development, Kenya Government

KENYA NATIONAL ACADEMY FOR ADVANCEMENT
OF ARTS AND SCIENCES • NAIROBI

The Kenya National Academy
for Advancement of Arts and Sciences
P.O. Box 47288
Nairobi, Kenya

First published 1979

Printed by
Printing and Packaging Corporation Limited
Likoni Road, P.O. Box 30157, Nairobi

Contents

PREFACE

The annual symposia of the former East African Academy were established to provide a forum for discussion of various problems and a medium for dissemination of knowledge among the members of the Academy and the public, and this, the thirteenth and the last one, was planned to bring to the notice of all interested in the role of water resources in development the opportunity for development projects with probable high social value.

The symposium was organized by the former Kenya Branch of the East African Academy, now the Kenya National Academy for Advancement of Arts and Sciences, and was held in Nairobi from 13 to 16 September 1977.

Everybody knows that water has a vital role in every earth environment from the depths of the sea to the highest mountain; from the driest desert to the wettest rain forest; and from the tropics to the polar icecaps. It is for this reason that since the dawn of civilization, increased numbers of people and proliferation of their activities have depended on the amount and distribution of water. Water development and water policies of a country always are very important as is evident from the many physical and administrative measures to control its distribution and use. Even so, water problems are becoming increasingly critical in many regions. The reason is that in many regions problems are less apt to relate to water quantity than to its quality. Briefly stated, water problems are few but basic: distribution in space (too much or too little); distribution in time (too much in some seasons or years and not enough in others); chemical quality (too highly mineralized, lacking in desirable minerals, containing deleterious minerals); and pollution.

Our Academy was motivated by such problems to organize this symposium on the 'Role of water resources in development'. The papers presented and read form the contents of this book. We hope that this information will contribute to Kenya's programme for rural water development and provide a basis on which future research needs can be assessed and from which research programmes can be planned.

The Kenya National Academy is greatly indebted to the speakers, especially for their cooperation in facing some formidable challenges, both in interdisciplinary communication and in the range of new material received; to the chairmen of sessions and all who participated in the cogent and lively discussions; and to many others who contributed significantly to the occasion. My own appreciation is particularly to Dr J. B. Castelino, the then Secretary, Kenya Branch of the East African Academy, who single-handed organized the symposium; to Ms Helen van Houten, for invaluable editorial assistance; and to the printers for their cooperation and patience.

CANUTE P. M. KHAMALA
Chairman/Kenya National Academy for Advancement of Arts and Sciences

WELCOMING ADDRESS

PROFESSOR CANUTE P. M. KHAMALA, *Chairman*
East African Academy, Kenya

I have great pleasure in welcoming you all, on behalf of the East African Academy, Kenya, to this 13th symposium on the Role of Water Resources for Development. We are very grateful to the various national and international agencies that have assisted us financially to make this symposium possible. This year's symposium provides a forum for the discussion of one of the most important aspects of life—water. Logically, after the United Nations Conferences on water in Argentina early this year, and the one on desertification, which has just wound up in Nairobi, we felt that we should provide a follow-up medium for the dissemination of the accumulated knowledge on this subject among the members of the East African Academy and the public. In this connection, the symposium will focus on points sifted from these huge, amorphous conferences, that are relevant and useful to our own national and regional development. The symposium will also review and bring together up-to-date information on results of research related to many aspects of water resources development in Kenya. The material has hitherto been found in many annual reports and very largely in files of various ministries which have limited circulation. Our government recognized the importance of water in national development a long time ago and consequently created a separate fully fledged Ministry of Water Development.

A casual look at the programme will reveal that presentations at this symposium will include detailed discussions of possible obstacles to water resources development such as the lack of water, the depletion of fossil water, as well as social problems. Among those who will present papers for discussion at this symposium are geologists, hydrologists, biologists, private planners, government planners, civil engineers, economists and social scientists. The interdisciplinary character of the symposium will ensure that from the beginning there will be very lively discussions and intensive departmental comparison of experiences, views and outlook.

Several planning methods will be presented. Lack of planning which has characterized the exploitation of water resources in other countries has resulted in a crisis situation and catastrophic results are indicated if vigorous corrective measures are not taken. Developing nations like ours, which are presently in the process of developing their water resources, would do well to take heed of the unsuccessful experiences from elsewhere. Many methods for water resources planning have several common ideologies. These call for long-range, regional, non-traditional, multi-disciplinary planning and utilization of the entire spectrum of sophisticated modern methods such as computer modelling, input-output analysis, etc.

In addition, planning programmes for water resources development must meet the criteria of the cost effectiveness and take into account non-hydrological as well as hydrological elements. They must allow for flexibility, organizational development and a large number of economic, political and social constraints. This is an enormous task for any planning agency anywhere, but we have little choice but to plan. The consequences of unplanned water use could hit us back too hard. The basis of any planning for water exploitation is contained within the system of water rights as practised by any specific nation or region. These rights are usually defined by customs, tradition or law. Water resources both surface and underground are communal in nature in that the actions of any one user affect the quantity and quality of water available to other users of the same stream or aquifer. To put it more specifically: will Kenya's second pipeline project be one to carry water from Lake Victoria to the semi-desert areas in the northeastern parts of our republic? A system of water rights that can maximize effective management is a correct one. This must, however, take into account the specific local situation and the long-term goals of the society.

As demand for water grows and becomes acute, the number of economic and social factors to be included within the sphere of planning will have to increase. In the same way the surrendering of traditional individual water rights will have to become more widespread. It would be logical for water planners to foresee such a situation and prepare in advance the legal framework already needed in many situations for more effective water management which will be needed even more in the future.

Several optimistic surveys of potential water resources will also be discussed at this symposium. Particularly impressive is a paper describing the water resource maps of large underground aquifers underlying the arid and semi-arid areas of our republic. The intensive exploitation of underground water resources is an important development strategy with a lot of advantages. Large-scale transfer of water to desert areas, although it increases the potential of the desert area for development, may have ecologically deleterious effects if not planned and managed properly. Unfortunately this important topic will not receive the great emphasis it deserves at this symposium.

In addition to surface, underground and rain water resources, other topics that will be treated at this symposium include non-conventional water resources such as ocean water, municipal and industrial effluents, etc., water conservation, and methods of efficient water use. Unfortunately, in spite of technological improvements, we do not seem to be closer to an economically feasible method of desalination of ocean water for *agricultural use*. On the other hand, depending on the quality obtained, water from treated effluents can be used for unrestricted irrigation, artificial lakes, industrial cooling and even as a municipal supply.

One of the key factors in the rise and fall of the so-called hydraulic civilization (which developed in arid areas with large quantities of surface water originating from distant humid regions) was the improper utilization of irrigation technologies. It would be wise to take into account the lessons of these former civilizations in our own water use practices, and this probably applies even more to the so-called advanced nations than to the developing ones.

I commend the objectives of the symposium which are to identify the most important problems in the development of water resources for human betterment in our country, establish research priorities related to water resources management and propose cooperative programmes between national and international agencies. I would say that the East African Academy, Kenya, is very much interested in this cooperation and will participate in appropriate programmes.

Finally, I wish to congratulate the chief organizer of this symposium, Dr J. B. Castelino, and all the others. Once more, I welcome you all and wish you a very successful symposium and a very pleasant stay in Nairobi.

OPENING ADDRESS

THE HON. DR J. G. KIANO
Ministry of Water Development, Kenya

Mr Chairman, distinguished guests: First of all let me join the other speakers in welcoming you very warmly, especially those of you who may have come from outside Kenya. We in Kenya are always happy to be a part of the international community and we appreciate visits such as yours because it is through such visits that we get an opportunity to exchange ideas, to discuss the various problems facing our respective countries, and to compare notes for our mutual benefit.

When I was invited to come and address you, I was particularly happy because this gives me a chance to be with people who are actively involved in matters of water development but are not in the ministry. This is an additional opportunity to know their views as outsiders and thus accelerate our work. It is rather ironic that matters of water development, of desertification and of human settlement, all of which are basic to the well-being of mankind, are receiving the attention of the international community only at this rather late hour. This is not to say that nations or individuals did not take interest in the problems of water utilization or desertification earlier, but these problems have not been highlighted on an international scale until very recently.

In many areas where water is plentiful, it has been taken for granted for too long. In such areas if you were to be seen selling a glass of water to somebody you would be considered an extreme kind of Shylock. Within the last three or four years, however, the indispensability of water in any form for national, regional and international development has come to be recognized. You will recall, for example, that in 1976 there was a conference in Vancouver which dealt with habitat and human settlement, and among the recommendations of the Vancouver conference was that by the year 1990 adequate supply of clean water should be made available to all the people on the globe. That resolution was again emphasized at the United Nations Water Conference which took place earlier this year in Argentina. As Professor Khamala stated, at that conference a lot of information was pooled, not only for the scientists but also for policy makers and administrators, in order to help them seek ways of providing adequate water to their people by that target date.

Last week we dealt with another aspect of development and its relationship to water by concentrating our attention on the propensity and spread of arid zones and the continued land degradation by various factors, most of which are connected with man seeking ways to make a living. At that conference water featured very prominently indeed. What can be said to have come out very clearly from these three conferences is, first of all, that every nation should have a clear picture of the water available to it, in terms of rainfall and of surface water such as rivers and lakes, as well as the water available under the surface. All available water resources should be clearly assessed.

Once this is done, it becomes necessary as the second step to devise methods of water conservation, for example, protecting water catchments, forests, and the general vegetation, building dams in order to capture the water that would otherwise flow to the seas, and training people not to dig too close to the river banks. Having done the assessment of available water and figured out methods of conservation, the third step is planned utilization of water: better distribution of water, more economic usage of water in agriculture, industry, and domestic consumption, and also the purification of water to make it free of water-borne diseases. These three, the assessment of water resources, the conservation of available water, and the proper utilization of water, are the major aspects of water development that concern us all.

If one was to take Kenya as an example, about 75% of Kenya's land lies in the arid areas or in what you may call the very low rainfall zone. This being the case, can Kenya relax in her planning of proper water utilization? Of course, the answer is no. One will find that in such places as Nyanza Province, Central Province, the central part of the Rift Valley, parts of the coastal belt and the Taita Hills, water, particularly surface water, is readily available for distribution. But when one looks at the northern and the northeastern parts of Kenya, and very large parts of Eastern Province of Kenya, one wonders what pattern of water distribution would be most economical. And here the problem is, how do we get some of the water from the better watered areas to those areas that do not have any permanent rivers flowing through them?

In order to deal with this problem we have taken a number of positive approaches, as our great President, His Excellency Mzee Jomo Kenyatta, announced in one of his speeches at Uhuru Park. As the President stated, we have already embarked on a major exercise of drawing the national water master plan. The main aim of this plan is to give us the information necessary on the water resources available, to put together in a logical form the various information that may be lying in various libraries, as the chairman said, and to indicate to us the most effective way of utilizing these available water resources.

But even while we are engaged in this national master plan exercise the people themselves cannot wait before starting on specific projects. Therefore what we are already doing both as a ministry and also in collaboration with other ministries is first to initiate the rural water supply programme. This is a programme designed to provide clean water for domestic use in the rural areas. This alone has its own inherent problem, one which I hope you will look into here. We go there as planners and say that the total population to be covered by this project is so many families; we draw projections to see how many people are likely to be in that area in 1990 or by the year of 2000, we estimate the average amount of water that one family may require and on this basis we build a big intake or reservoir, and we decide what size of diameter of pipes we need to make sure that the average use of water estimated per family will be achieved. No sooner do we finish doing so and the water gets to the people, than we find that all our calculations have gone wrong because these people's use of water before the supply of piped water was highly economical as they usually had to walk 4 or 5 kilometres to get the water. Instead of taking a full bath, they would only wash their faces, feet and hands and then go out looking very clean because their faces were clean. But when water flows readily, usage habits are immediately transformed. More water is used by the family, health improves because they wash themselves, animals are given water and when there is a garden around the house some minor irrigation takes place. Thus all our calculations are mixed up. The average consumption we had estimated becomes obsolete and we now have to begin thinking about additional intakes and so on. Planning becomes in itself an educational process for us because we have learned that after we provide water using the old set of statistics, new unforeseen demands arise, but now that we have established what these demands are we shall be wiser in our planning in the following years.

Rural water supply programmes feature prominently in the government's development plan and many of these programmes are government financed. In addition, we have self-help projects which the government and the people work hand in hand to implement. People look at the government's five-year development plan. If they get the idea that perhaps the government plan will not deliver water to their area, let's say by the year 1985, they are not prepared to wait for that. They get together, collect funds and call upon our department to say, 'please give us planners, advisers and engineers there to do the design free of charge'. The residents of the area then collect the money to pay for the scheme but very often, long before the target figure is reached they are back to say 'we have collected all the money we could, now you have to take over this baby'. We don't object to this as we feel that the readiness of the people to play a part in providing water for themselves on a self-help basis is in itself a great contribution to the development capital in the country. The funds they collect, the free labour they give, would otherwise have to be met by the government, and so we gratefully appreciate this self-help input into the various projects. We have already created a section in the Ministry of Water Development to handle the matter of self-help water projects.

We have also what we call the minor urban water supply programmes which are of great interest. You may recall that what used to be very small towns or villages about 15 years ago have now become small townships, or what the economists call growth centres, in the respective rural districts, as a result of agricultural development there. These small trading centres have now become towns. Other smaller towns have become bigger towns and it has now become very important for us to provide such areas with water. This results in another major exercise which is wholly government sponsored and that is to supply water to the growth centres. We call this project the minor urban water supply programme. This programme is very much interrelated with industrial development because one of the fundamental policies of the government is to spread industrialization and decentralize industrial development so that industries are not concentrated in towns. In order to carry out such policy of spreading out industrial activities you require a lot of water. Perhaps the ordinary man in the street may not know that water is an essential element of industrialization. Some of you from western Kenya will recall the crisis we faced when those in the Ministry of Commerce and Industry, and I was there then, approved a huge textile factory for Eldoret; but we had not had enough consultations with water people. We had approved a major industry but we had not looked into the adequacy of water for industrialization. Fortunately we have solved that one, the factory is operating and Eldoret is growing. What I am trying to illustrate is that in following our policy of spreading industrial development in the country, this programme of minor urban water projects is a key one.

As I said earlier, a great portion of Kenya is either arid or semi-arid. I am referring to North-Eastern Province and also to Marsabit, Turkana and parts of Eastern Province. There the problem is not only providing drinking water but also providing water for livestock and trying to change the pattern of living from nomadic to sedentary settlement because it is only through sedentary settlement, where people are living together, that you can provide other essential services such as schools and hospitals. For such activities water is absolutely essential. If you build a primary school for a nomadic group and then they decide to move and leave your school there without children, it would be a poor return on the investment. As we cannot provide boarding schools for both primary and secondary education in all these areas, changing from a nomadic way of life to either group ranching or a little farming, as some of the Turkana people are doing already, has become a very important and exciting exercise in development. The establishment of proper range management techniques is helping people to change their patterns of livestock management from the old uneconomic type of units to the kind of livestock farming that really brings higher incomes. So for those areas we depend very much on what we talked about earlier, underground water. A whole series of boreholes becomes necessary. Examination of the aquifers or the underground lakes becomes a major exercise. We have a section in the department known as Water Resources and Research to deal with this aspect. And this has also been emphasized by the water master plan. At the same time in those areas we have to think in terms of a series of dams on dry river beds so that when it rains in the highlands and water flows through seasonal rivers a series of dams can capture the water instead of letting it flow into the ocean.

The fourth type of project we have at the ministry we call multi-purpose. The Tana River Development Project is an example. The government intends to build a huge reservoir on the Tana, and by controlling the flow of water, generate electricity. In addition we shall be able to irrigate the lower part of the Tana River Basin and we can also utilize the water for domestic usage. This kind of multi-purpose approach to water utilization necessitates co-operation between the various ministries.

I have given you these examples to show you that the government of Kenya is concerned with the proper utilization of water. It is also very concerned in the matter of water conservation. As the population of Kenya grows the pressure on the arable land increases. Such pressures could lead to land degradation and ultimately to desertification. The trend must be reversed by teaching the people better land use through proper agriculture, utilizing the land to effect a sustained and viable agricultural production, and most importantly gradually reclaiming that land made barren through mass abuse in the past. Such reclamation is taking place in areas like Hola where a lot of cotton is being grown.

The irrigation along the Tana River and the reclamation of land in southern Turkana where some of the pilot water projects are now in existence are some of the aspects that we have to look at. We all agree that water is indispensable for development as it is indispensable for life. And that is why I was very happy indeed when I was invited to come and share with you our views, our concern, and also our dedication, to these matters of water development, and I wish to assure you that your findings will receive very close attention from my ministry and from the other ministries involved in rural development, in water conservation and in reafforestation and I only hope that you shall continue to be sympathetic to us and to be in touch with us, so that we can continue to exchange ideas.

I would like to thank the Deputy Vice Chancellor very much for welcoming me back here. I am not a stranger here; I have always said I opened the doors as the first African lecturer here and then you came in later.

Thank you very much.

RAINFALL OVER EAST AFRICA: A REVIEW

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Abstract
Normal distribution of rainfall in East Africa during the year and its different months along with the diurnal variation of rainfall is briefly described. An attempt is made to explain these time and space variations of normal rainfall in terms of normal regional and local circulations of the atmosphere. The possible cause of anomalous rainfall is indicated and trends of research in this field are described. An outline of research studies on rainfall and water resources currently in progress in the Department of Meteorology, University of Nairobi, is presented.

Rainfall
Excellent maps of East African rainfall (Tomsett 1969) are available for each month separately and for the year as a whole. We present rainfall maps for the year (fig. 1) and for four typical months of January, April, July, October (figs. 2–5). April and October represent seasons of 'long rains' and 'short rains' respectively. January and July represent relatively dry seasons. The important features seen on these charts are as follows:

Annual rainfall
1. The largest rainfall is around Lake Victoria, the mountain peaks and along the coastal strip facing the Indian Ocean.
2. Around Lake Victoria, relatively larger amounts are on the northeastern side.
3. There are extensive areas with rainfall less than 40 cm. These areas are:
   a) Northeast Kenya with a strip extending into southern Kenya,
   b) Central Tanzania.

The phenomenon may be explained as follows:
1. Lake area, coastal areas and the mountain ranges have their own strong local circulations which interact with the large-scale global circulation and produce large amounts of rainfall in their neighbourhood. In general, the effects are qualitatively similar. During the day, the air rises over the land bordering the lake, that bordering the sea coast and over the mountain slopes. During the night, the reverse occurs. These upgliding and down-gliding currents interact with the seasonal air currents and produce sharp

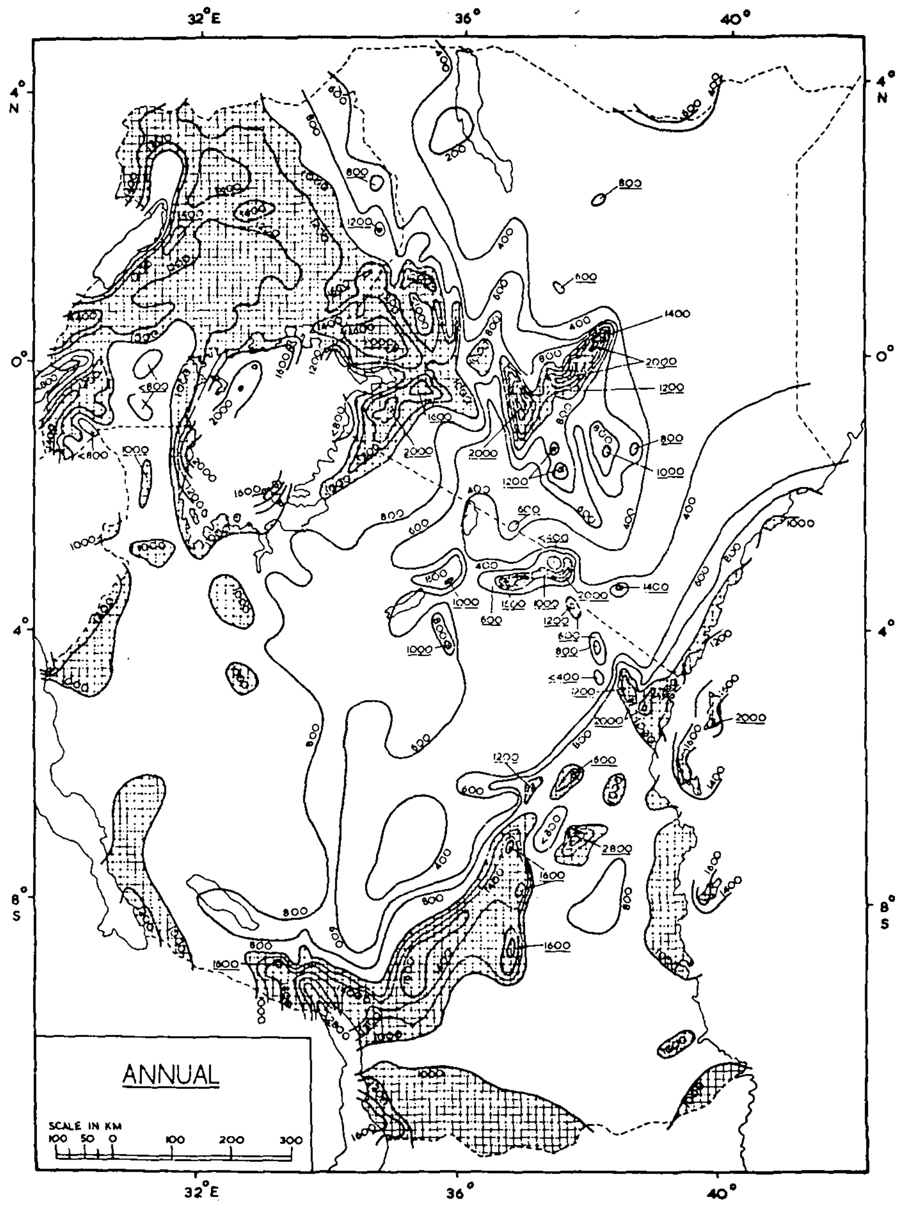


Figure 1. Annual rainfall map for East Africa.

zones of wind and temperature discontinuity, horizontal velocity convergence and upward vertical velocity. Tropical atmosphere is convectively unstable. In other words, if there is a mechanism to lift the unsaturated air near the ground to the condensation level which is about a kilometre above the ground, then buoyancy forces lift the air further up, to several kilometres above the ground, creating conditions favourable for precipitation. The sharp zones of horizontal velocity convergence and upward vertical motion in the lower layers of the atmosphere described above are particularly favourable for such precipitation in the neighbourhood of Lake Victoria, the sea coast and the mountain peaks.

2. The large-scale flow over the lake area is easterly, with a northerly component during northern winter and southerly component during southern winter. The lake breeze during the day interacts with the large-scale easterly flow and creates more rainfall on the eastern side of the lake. The orography on the northeastern side of the lake is steeper and hence there is a greater intensity of rain on this side of the lake.
3. The dry region of northeast Kenya extending into south Kenya and even central Tanzania is a challenging question to a theoretical meteorologist. Classifying the earth's problem climates, Trewartha (1962) regards this as Africa's most impressive 'climatic anomaly'. Figure 6 shows the relatively dry region in northeast Kenya which could be an extension of the Sahara.

Isopleths of rainfall suggest that the Sahara-Arabia desert conditions have extended into Somalia and the same system of isopleths extends into northeastern Kenya and even further southwards to Tanzania. While this is undoubtedly the shape of rainfall, we have reason to believe that the meteorological factors for the Sahara and for northeastern Kenya semi-desert conditions are somewhat different. The Sahara is due to the subtropical ridge which girdles the whole earthsphere. It is the author's opinion that the East African semi-desert conditions described above are associated with strong cross-equatorial flow. Using the condition of inertial instability, the vorticity equation and the equation of continuity, the author (Asnani 1968) has suggested that the air approaching the equator in the lower and middle troposphere suffers horizontal velocity divergence and subsidence. After crossing the equator, it starts rising but it needs time and ample supply of moisture from below before it can have favourable conditions for rainfall. The equator acts like a dynamic valley. Hence in the regions of cross-equatorial flow, one is likely to encounter relatively dry weather conditions provided that other orographic features do not interfere appreciably. In East Africa, there is appreciable north-to-south cross-equatorial flow in northern winter and south-to-north cross-equatorial flow in southern winter in the lower and middle troposphere.

Do we have similar conditions elsewhere in the world? Yes, in northeastern

Brazil. Figure 7 shows the annual rainfall of northeastern Brazil. The climatic anomaly in the form of a semi-arid region extending right up to the Atlantic Ocean was highlighted by Trewartha (1962). The rainfall pattern is almost identical to that seen over the Tanzania, Kenya and Somalia region. There is south-to-north cross-equatorial flow over this region in the lower troposphere almost throughout the year.

Seasonal rainfall

January

The highest rainfall of more than 20 cm is in southern Tanzania. There is a general decrease of rainfall northwards, with less than 5 cm over large parts of Kenya and northern Uganda except in the neighbourhood of Lake Victoria and some mountain peaks.

April

There are two belts of high precipitation (> 15 cm):

1. The belt extending from southern Uganda across Lake Victoria to western Tanzania.
2. The belt extending from Lake Malawi (Nyasa) northeastwards to the eastern coast of Tanzania and Kenya.

Between these two rainy belts, there is a belt with diminished rainfall, the lowest rainfall being less than 5 cm in central Tanzania. Mountain peaks have their local precipitation maxima.

July

Rainfall is confined to Uganda and adjoining districts of Kenya, to narrow eastern coastal strip of Kenya and northern Tanzania and isolated mountain peaks. The weather is relatively dry (rainfall < 2.5 cm) over the rest of East Africa.

October

Rainfall is confined to Uganda, Lake Victoria, coastal districts of Kenya, east coast of Kenya, north coast of Tanzania and to isolated mountain peaks. The rest of East Africa is relatively dry with less than 2.5 cm rainfall during the month. Against the background of general causes of spatial variation of annual rainfall, the seasonal variation of rainfall in East Africa can be attributed to the seasonal shift of the Inter-Tropical Convergence Zone (ITCZ). The position of ITCZ during January and July is shown in figure 8. It moves with the relative position of the sun and occupies the southernmost position during January and northernmost position during July. It crosses the equator during April-May in its northward journey and during October-November, in its southward journey. There is considerable rainfall in its neighbourhood, particularly on the equator side.

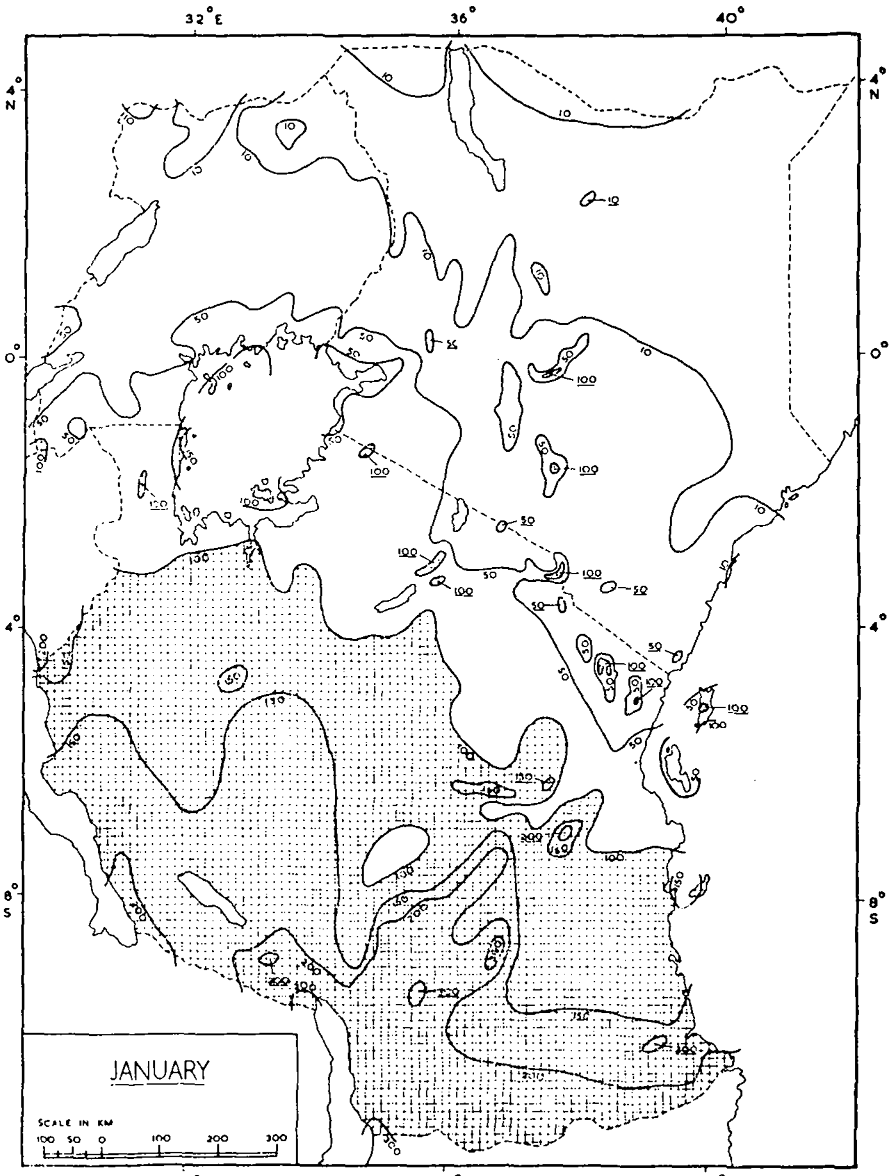


Figure 2. January rainfall map.

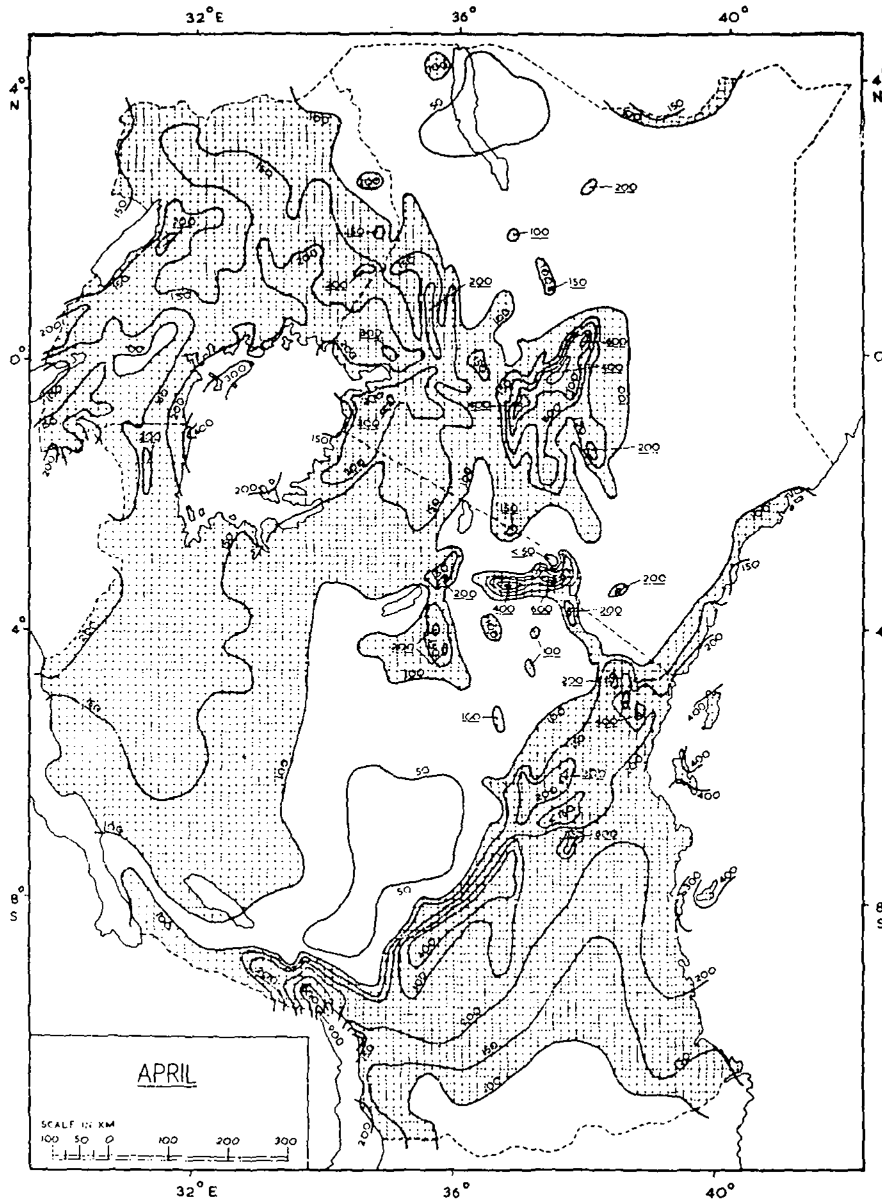


Figure 3. April rainfall map.

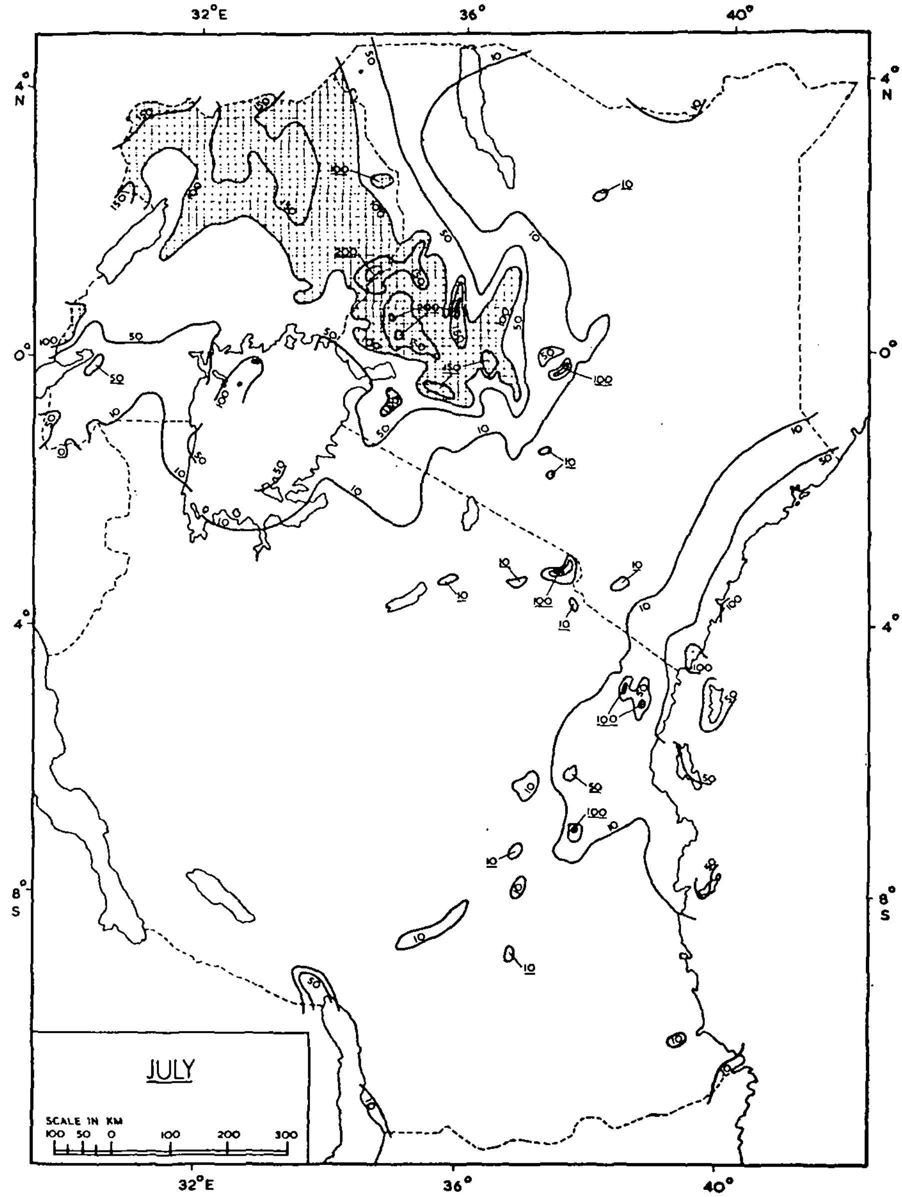


Figure 4. July rainfall map.

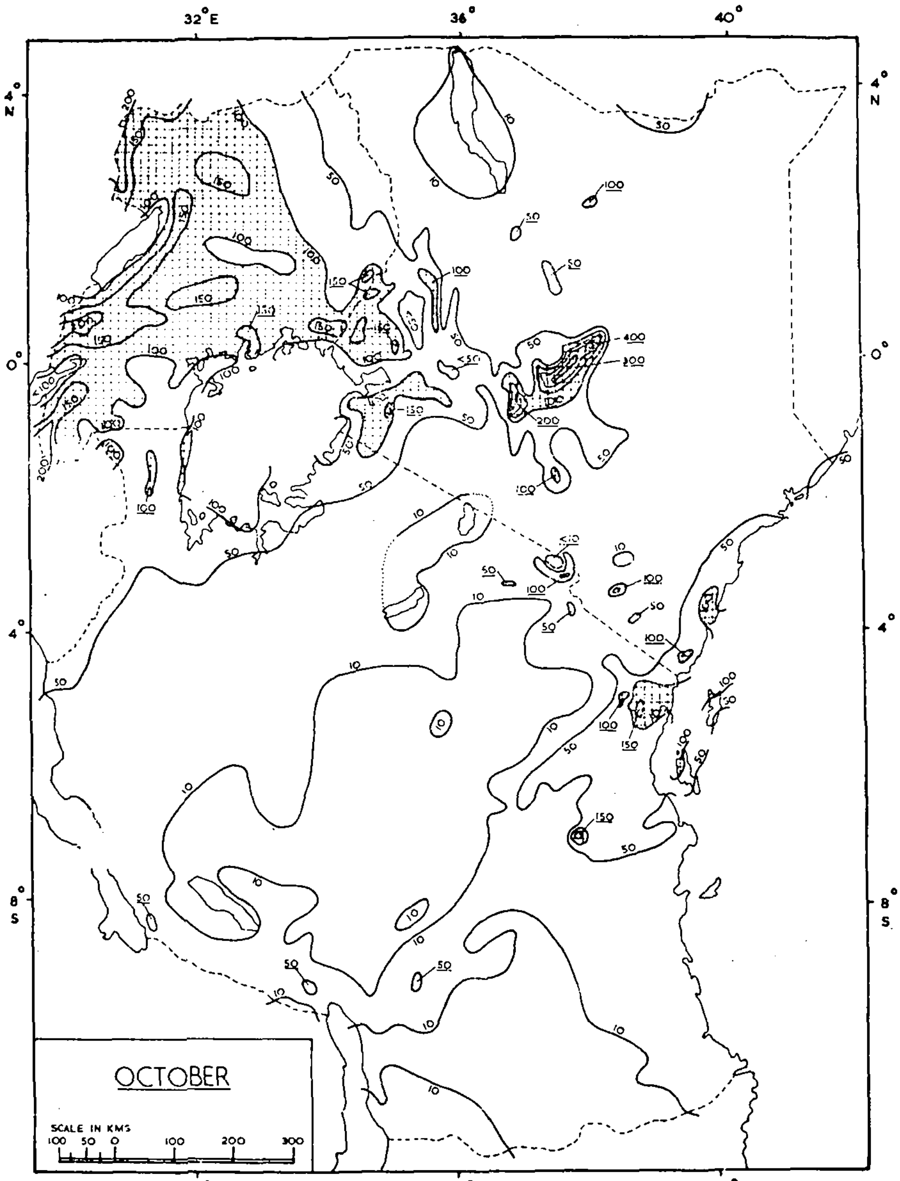


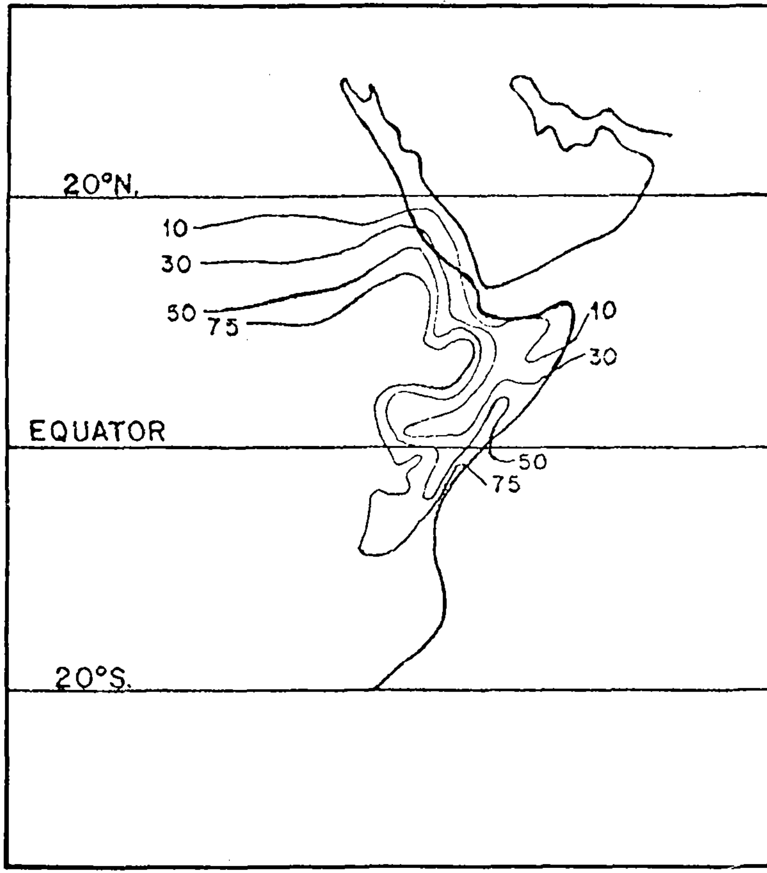
Figure 5. October rainfall map.

Diurnal variation of rainfall

Within the framework of large-scale features of seasonal flow which determine the seasonal pattern of rainfall, it will be seen that there are characteristic features of diurnal variation of rainfall peculiar to each part of East Africa. In the tropical land regions, there is a general tendency for afternoon showers. Afternoon ground heating sets up first a dry convection, sending air parcels upward to condensation level. At this stage, convective instability manifests itself and leads to cloud build-up leading to precipitation. While this feature is clearly discernible in East Africa, closer analysis reveals considerable departure from this general pattern. For East Africa, we have an excellent observational analysis of the diurnal variation of precipitation (Tomsett 1975) for 54 individual stations in different months. We have performed similar analysis for four more stations to cover some areas in greater detail. These 58 stations could be grouped in 12 classes depending on proximity of location, similarity of orographic features and similarity of pattern of diurnal variation. This will be presented in a separate detailed paper (Asnani and Kinuthia in prep.). Suffice it here to mention that the diurnal heating cycle along with diurnal local circulations interacting with large-scale flow are able to explain qualitatively the observed diurnal variation of patterns of rainfall in East Africa. For example, in Nairobi, there is more rainfall during late night and early morning and less rainfall at other hours of the day. The large-scale flow in the lower troposphere near Nairobi is easterly. The local circulation set up by the local terrain is upslope from the east during afternoon/evening and downslope from the west during late night and early morning. As a result, there is more horizontal velocity convergence and forced upward motion during late night and early morning than during the afternoon/evening. This qualitatively explains the major feature of diurnal variation of rainfall over Nairobi and the neighbourhood.

Climatic changes

The attention of the world has recently been focused on climatic changes, whether there is shift in rainfall belt and temperature regimes. In the tropics, we are directly concerned with rainfall rather than with temperature although temperature anomalies are instrumental in causing rainfall anomalies. The Department of Meteorology at the University of Nairobi is alive to this problem. One of our students (Mr Ogallo) recently completed his M.Sc. thesis entitled 'Periodicities and Trends in the Annual Series over Africa'. He undertook analysis of 69 stations distributed over the whole continent of Africa in respect of their annual rainfall series spreading over periods of over 40 years. At each station he examined the data in respect of periodicities and long-term trends. With the record of rainfall extending over less than 110 years, we cannot, with the present methods of analysis, draw conclusions for periods exceeding 30–35 years. Within this limitation, his conclusions have been that there is evidence of oscillations rather than of uniform trend of increase or decrease of rainfall



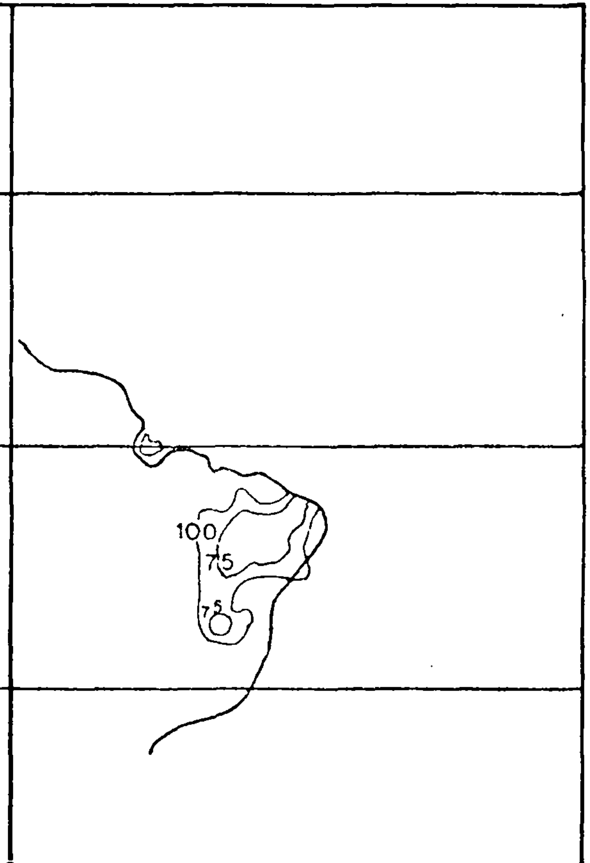


Figure 6. Annual rainfall in the relatively dry region of northeastern Kenya (cm).

Figure 7. Annual rainfall in northeastern Brazil (cm), showing a pattern very similar to that over the Tanzania, Kenya and Somalia region.

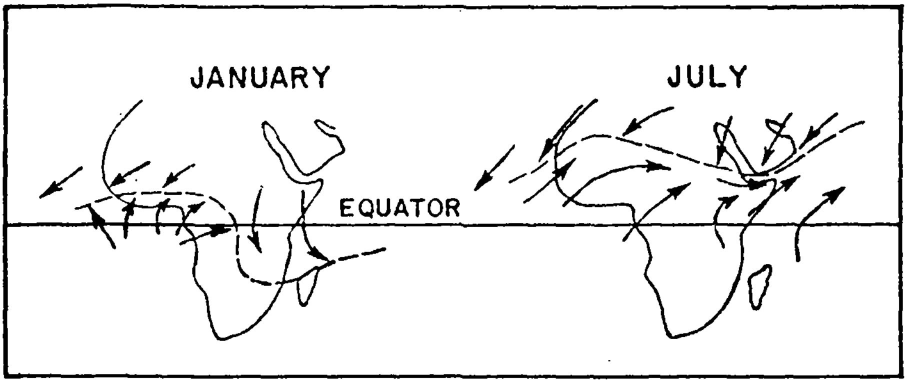


Figure 8. Surface position of Inter-Tropical Convergence Zone in January and July.

over different regions of Africa. This is in line with other conclusions of world rainfall drawn by other authors based on regular meteorological records of rainfall which rarely exceed the 100-year period. Mr Ogallo is currently examining in greater detail the rainfall records of East African stations bordering the Sahara to see if there is a tendency for shifting of the rainy seasons. He is also, as his Ph.D. project, looking into the possibility of building a forecast model on the basis of periods which have already been identified.

Climatic changes are caused by a number of factors including the physical and chemical composition of the atmosphere. The Department of Meteorology at the university is actively involved in a feasibility study currently in progress with respect to a baseline station on Mt Kenya. When this station is finally selected, it will be one of the important stations in the global network of observatories monitoring the content of CO_2, particulate material, turbidity, ozone, etc., in the atmosphere over long periods of time. This will help in the understanding and possible forecasting of large-scale anomalies in weather over the globe.

Other research studies on rainfall and water resources

At present, the Department of Meteorology has over 20 students writing their second-year M.Sc. theses and two students writing their Ph.D. theses. Meteorology is connected with rainfall and hence the work of each of these students has a bearing on rainfall and water resources. Particular mention should be made of the department's research work currently in progress having a direct bearing on water resources. These studies deal with:

1. Water balance in river catchments.
2. Water balance over Lake Victoria.
3. Meso-scale rainfall patterns over Nairobi.
4. Evapotranspiration estimates for East Africa.

5. Rainfall anomalies during contrasting years like 1967 and 1972.
6. Kenyan floods of April 1977.
7. Incidence of floods and droughts in East Africa.

Acknowledgements
At the moment, very close cooperation exists between the University Department of Meteorology and the National Meteorological Services in East Africa. There is free access to the data collected by the Meteorological Services. Frequent discussions and contact facilitate precise definition of problems that need research. This facility is gratefully acknowledged. Contacts have also been established between the University's Department of Meteorology and the Kenya government's Departments of Water Development and Agriculture. With their cooperation, we are now tackling problems associated with water resources in Kenya. The department is partly supported by the United Nations and functions as a component of the international project, 'East African Institute for Meteorological Training and Research'.

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THE OCCURRENCE OF DRY SPELLS DURING THE EAST AFRICAN LONG RAINS

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Abstract
The occurrence of dry spells during the East African long rains poses a threat to the farming community in as much as they may impose unbearable moisture stress on crops at a critical phenological stage. The frequency and probability of their occurrence has, however, not hitherto been examined. This study was undertaken to fill this gap. Rainfall data for 45 stations for the period 1950–1970 has been analysed to delineate the number of dry spells during the East African long rains, with particular emphasis on the agricultural regions of East Africa. The results indicate that the probability of a dry spell lasting 3 days during the long rains in the agricultural regions ranges between 30% and 50%. The probability for dry spells lasting 5 days ranges between 10% and 50% while the probability of a 7-day dry spell in these regions ranges between 5% and 26%. The results also indicate that the probability of dry spells lasting 10 days or more although low does exist and is as high as 12% for the agricultural areas of East Africa. It is suggested that the 3-day dry spell probabilities although high can possibly be forecast reasonably accurately with the aid of routine synoptic charts. However, the longer dry spells are much more difficult to forecast and the probabilities are offered as a first guide to the farming community.

Introduction
A study of dry spells is essentially a study of non-availability of water from the atmosphere in the form of measurable rain. This kind of study is, therefore, very relevant in overall discussion of the role of water resources in development. Specifically, to the extent that protracted dry spells may impose unbearable moisture stress on crops which may be very crucial for an agricultural economy such as that of Kenya, such a study could provide a useful ready guide to planners.

It is known that weather phenomenon of a type at a place tends to persist. Persistence such as that observed in weather phenomena has led to the theory of persistency which is the basis for objective weather forecasting. Considerable work has been carried out on the theory of persistency which is the basis for

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Table 1. Cumulative observed frequency length of dry spell in days

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Uganda:																				
Gulu	504	260	143	83	50	31	23	17	11	6	3	1	1	0	0	0	0	0	0	0
Soroti	516	323	211	120	84	59	41	28	21	13	12	8	6	6	6	5	4	4	4	2
Masindi	561	328	190	120	86	49	29	21	9	5	3	2	2	1	0	0	0	0	0	0
Mbarara	467	279	183	122	85	70	60	52	41	34	23	30	21	18	16	13	11	11	13	8
Bukalasa	572	307	180	112	66	43	25	18	15	9	6	4	3	1	1	1	0	0	0	0
Tororo	544	257	146	72	43	31	19	10	3	2	1	0	0	0	0	0	0	0	0	..
Fort Portal	494	222	134	80	45	33	18	15	11	11	8	5	5	5	4	2	2	0	0	0
Moroto	346	247	181	144	123	103	84	70	59	51	45	34	29	27	23	22	20	17	13	10
Kabale	436	233	151	94	75	58	47	34	32	23	20	19	15	14	13	12	10	9	9	9
Arua	533	258	232	153	104	72	48	36	28	19	14	10	6	5	3	3	2	1	1	1
Entebbe	469	226	134	81	49	32	19	16	9	8	5	5	4	3	1	1	1	0	0	0
Kenya:																				
Lamu	352	217	144	109	84	67	58	48	39	35	34	28	23	20	19	16	16	16	15	15
Meru	363	245	171	135	107	90	78	66	55	45	40	37	36	32	27	26	17	16	15	14
Mombasa	422	268	181	131	103	78	63	49	40	33	29	21	15	11	9	7	6	5	3	2
Eldoret	384	261	198	150	125	97	70	49	40	34	27	17	15	14	11	8	7	7	6	4
Dagoretti	384	243	181	128	97	61	52	52	42	33	25	22	20	18	17	15	13	13	9	8
Kericho	388	172	92	48	29	13	12	7	5	2	1	1	1	1	0	0	0	0	0	0
Kitale	420	212	132	92	58	40	27	15	13	11	8	6	6	4	3	2	2	2	2	1
Kisii	406	216	132	92	64	42	32	23	28	12	8	7	6	4	3	3	2	1	0	0
Voi	269	251	206	148	117	100	87	79	68	61	51	46	43	40	36	32	28	25	23	22
Nanyuki	415	246	170	123	90	74	59	44	35	25	19	16	12	11	9	4	4	3	3	3
Makindu	354	258	199	155	121	100	89	71	59	53	48	43	40	36	32	28	27	25	22	21
Marsabit	271	198	154	121	101	86	73	67	61	58	54	47	47	43	38	36	32	29	24	21
Mandera	262	207	185	158	133	120	107	95	89	82	77	75	70	65	55	50	48	46	43	41
Maralal	355	262	207	172	153	123	110	88	74	59	53	44	38	34	32	41	26	22	18	17
Garissa	359	259	210	170	133	108	94	79	69	56	46	37	33	30	28	27	23	19	16	16
Tanzania:																				
Tanga	208	382	260	195	157	119	106	91	78	71	61	52	45	35	29	24	21	16	14	12
Musoma	727	421	280	200	140	105	75	55	42	31	24	17	13	11	8	3	2	2	2	1
Lindi	690	434	293	214	148	111	87	68	52	48	40	30	24	18	13	12	12	8	7	5
Kigoma	828	376	214	112	61	31	22	13	6	2	0	0	0	0	0	0	0	0	0	0
Shinyanga	742	425	275	170	120	99	75	53	40	32	22	14	11	8	7	7	6	4	2	1
Bukoba	663	306	173	100	65	41	33	22	14	10	7	5	3	1	1	0	0	0	0	0
Dar es Salaam	606	298	292	223	174	138	120	102	80	63	58	48	40	36	32	29	26	16	14	12
Arusha	598	396	286	217	170	143	113	90	74	59	49	38	29	27	25	19	12	10	8	..
Singida	631	421	289	226	167	137	105	88	76	60	47	38	32	28	25	23	20	16	15	13
Morogoro	655	381	262	197	150	118	87	68	52	41	34	31	29	27	25	20	17	14	13	11
Iringa	674	417	296	206	151	119	98	74	63	46	40	34	27	25	21	18	19	18	14	11
Mahenge	711	280	255	174	127	97	82	63	48	37	25	17	14	11	9	9	8	6	6	5
Songea	596	308	196	134	95	74	60	47	38	31	26	22	20	17	15	15	15	14	14	7
Mbeya	623	303	175	110	74	54	36	28	21	16	9	5	3	3	3	2	2	1	1	1
Mpanda	871	498	305	188	124	79	53	36	23	17	13	10	8	5	4	3	2	2	2	1
Kibondo	797	420	242	143	86	62	43	35	29	24	14	7	6	6	4	1	1	1	1	1
Dodoma	605	407	295	226	179	145	123	101	80	69	61	45	40	34	30	25	22	20	16	13
Tabora	763	406	224	142	101	63	46	25	15	10	8	7	5	5	3	2	1	1	0	0
Kitunda	749	465	294	213	154	118	94	74	60	47	36	28	22	21	16	3	11	8	8	8

objective weather forecasting by scientists such as Jorgensen and Williams. Jorgensen (1949) investigated the persistency of rain and no rain periods during winter at San Francisco and defined 'skill' score forecasting. Williams (1952) studied weather sequences of wet and dry days in relation to the logarithmic function. Ramabhadran (1952) used Williams's and Jorgensen's findings to study rain spells at Poona, India, during the monsoon season. Torance (1959) studied the occurrence of dry spells in Rhodesia and Malawi during the rainy season, although he did not take into consideration the theory of persistency.

This paper presents results of the study of dry spells during the East African long rains for the period 1950–1970. In the calculations of probabilities of dry spells we have taken into consideration the theory of persistency.

Source of data

The data were extracted from the Meteorological Department's daily rainfall records for 45 stations all over East Africa (11 from Uganda, 16 from Kenya and 19 from Tanzania). The stations were selected in such a way that aerial distribution would permit the preparation of maps of isopleths of dry spells for analysis.

Methodology

The daily rainfall records for 45 stations all over East Africa were used to extract the frequency of dry spells of various lengths for the period of study (1950-1970) during the East African long rains. In deciding the period of study (the rainy season), reference has been made to the study of the onset and cessation of the long and short rains in East Africa by Alusa and Mushi (1974).

The study revealed that on the average the onset and cessation dates are as below:

Onset date	Cessation date	Country
12–16 March	15–19 July	Uganda
17–21 March	5–9 June	Kenya
12–16 November	6–10 May	Tanzania

Uganda and Kenya have their long rainy season in the same period while Tanzania being further to the south has a different period though there is some overlapping period (March–April).

The definition of a rainy day is that adopted by the Meteorological Department, that is, a day with a total rainfall of at least 1 mm.

A dry spell is a period of a dry day or days between two successive rainy days. A dry spell which continued into another month is broken into two and thus the dry spell is deemed to have been broken. This enables monthly analysis of dry spells. This assignment of dry spells is arbitrary, but it is reasonable as it would underestimate the frequency of dry spells of long duration on the onset and cessation of the rains though it has a tendency to increase the frequency of short duration of dry spells in the wettest months. An alternative method would be to assign a dry spell to the month in which it started. This would give an underestimate and overestimate of the frequency of long duration at the onset and cessation periods respectively.

From the rainfall records for the period 1950–1970 monthly frequency of dry spells of lengths of 1 day, 2 days, . . . > 20 days are tabulated for each station. The monthly total frequency for each station for the period of study is thus derived. If we let f_{ijk} be the frequency of the length of dry spell i for the month j and the year k, then

$$f_{ij} = \sum_{k=1}^{21} f_{ijk} \qquad (1)$$

gives the total frequency of the length of dry spell i for the month j for a station.

Table 2. Monthly and seasonal probabilities of a dry day

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Nov.	Dec.	Season
Uganda:									
Gulu			54.5	40.8	38.4	43.0			44.2
Soroti			70.5	50.3	51.2	60.2			58.1
Masindi			58.2	49.4	57.9	60.5			56.5
Bukalasa			60.5	41.9	48.2	62.1			53.2
Mbarara			52.7	44.3	61.6	90.6			62.2
Tororo			51.6	34.1	36.7	53.3			44.0
Fort Portal			38.6	30.2	43.8	61.9			43.6
Moroto			69.3	64.3	61.6	72.4			66.9
Kabale			45.2	31.4	50.7	84.6			52.9
Arua			67.4	62.5	62.2	60.5			63.2
Entebbe			39.9	27.1	38.4	60.6			41.5
Kenya:									
Kericho			42.2	21.0	20.4	37.0			30.2
Kitale			57.1	32.7	33.2	41.6			41.2
Kisii			43.2	31.1	42.6	50.6			41.9
Voi			68.5	63.7	81.7	91.7			76.4
Nanyuki			67.6	36.5	48.5	25.1			44.7
Makindu			74.0	59.8	80.2	92.9			76.7
Dagoretti			66.7	40.2	45.3	102.2			63.5
Eldoret			70.8	49.8	54.2	63.8			59.7
Lamu			90.6	57.6	38.6	43.2			57.6
Meru			68.4	42.5	64.1	92.9			66.9
Mombasa			77.6	49.7	45.2	59.7			58.1
Marsabit			71.1	46.2	62.1	84.9			66.1
Mandera			90.5	73.8	91.2	97.5			88.3
Garissa			94.0	64.4	104.2	89.2			88.1
Maralal			83.9	74.0	77.1	55.7			72.8
Tanzania:									
Tanga	73.0	81.3	54.8	43.2			56.4	68.4	62.7
Musoma	69.7	63.7	51.5	40.8			78.6	67.3	61.2
Lindi	63.0	53.8	53.0	51.0			40.6	30.0	43.8
Kigoma	53.8	51.8	41.0	46.0			61.0	54.2	55.7
Shinyanga	58.1	56.8	48.1	56.0			31.4	40.3	37.9
Bukoba	56.2	44.9	31.6	23.8			69.2	71.4	67.4
Dar es Salaam	77.6	77.2	62.7	46.7			70.6	68.1	63.4
Arusha	75.1	71.5	63.1	31.9			84.0	62.2	67.0
Singida	64.2	53.8	64.1	73.5			67.3	64.7	59.6
Morogoro	69.7	66.3	55.9	33.7			89.1	53.8	63.4
Iringa	55.6	58.9	57.0	66.8			79.1	63.0	55.2
Mahenge	54.2	53.3	41.8	39.7			77.0	44.2	45.6
Songea	34.9	32.9	33.2	51.6			60.3	52.1	59.0
Mpanda	56.5	56.5	65.9	62.4			66.8	35.2	38.7
Mbeya	27.5	27.2	34.1	41.4			90.5	63.1	69.0
Dodoma	59.1	55.8	70.2	75.1			53.8	39.6	48.0
Tabora	48.1	43.3	47.0	56.2			81.3	61.6	65.1
Kitunda	55.0	56.8	62.1	73.8			52.2	49.6	50.6
Kibondo	50.0	52.5	49.3	50.2					

$$f_i = \sum_{j=1}^{4/6} f_{ij} \tag{2}$$

gives the total frequency of the length of dry spell i for the season. The rainy

Table 3. Probabilities of 1 or more days, 2 or more days, etc., given a dry spell has lasted 5 days

Station	$\frac{f_5}{f_t}$	1 $\frac{f_6}{f_5}$	2 $\frac{f_7}{f_5}$	3 $\frac{f_8}{f_5}$	4 $\frac{f_9}{f_5}$	5 $\frac{f_{10}}{f_5}$
Uganda:						
Moroto	35.4	83.7	68.9	56.9	48.0	41.5
Kabale	17.2	77.3	62.7	45.3	42.7	30.7
Arua	19.5	69.2	46.2	34.6	26.9	18.3
Entebbe	10.4	62.0	46.0	34.0	22.0	12.0
Soroti	16.3	70.2	48.8	33.3	25.0	15.5
Masindi	15.3	57.0	33.7	24.4	20.5	5.8
Mbarara	18.2	82.4	70.6	61.2	48.2	40.0
Bukalasa	11.5	65.2	37.9	27.3	22.7	13.6
Tororo	7.9	72.1	44.2	23.3	7.0	4.7
Fort Portal	9.1	73.3	40.0	33.3	24.4	24.4
Kenya:						
Kericho	7.5	44.8	41.4	24.1	17.2	6.9
Kitale	13.8	69.0	46.5	25.9	22.4	17.2
Kisii	15.8	65.6	50.0	35.9	28.1	18.8
Voi	31.7	85.5	74.4	67.5	58.1	52.1
Nanyuki	21.7	82.2	65.6	48.9	38.9	27.8
Makindu	34.2	82.6	73.6	58.7	48.8	43.8
Dagoretti	25.3	80.4	62.9	53.6	43.3	34.0
Lamu	23.9	79.8	69.0	57.1	46.2	41.7
Meru	29.5	84.1	73.0	61.7	51.4	42.1
Mombasa	24.4	75.7	61.2	47.6	38.8	32.0
Eldoret	32.6	77.6	56.0	39.2	32.0	27.2
Marsabit	37.3	85.0	72.1	66.2	60.2	57.4
Mandera	50.8	90.2	80.3	71.5	66.9	61.7
Maralal	43.1	80.3	71.9	57.5	48.3	38.6
Garissa	37.0	81.4	70.8	59.5	51.9	42.1
Tanzania:						
Tanga	25.8	75.8	67.5	58.0	49.7	45.2
Musoma	19.3	75.0	53.6	39.3	30.0	22.1
Lindi	21.4	57.0	58.8	45.9	35.1	32.4
Kigoma	7.4	50.8	36.1	21.3	9.8	3.3
Shinyanga	16.2	82.5	62.5	44.2	33.3	26.7
Bukoba	9.8	63.1	50.8	33.8	21.5	15.4
Dar es Salaam	28.7	79.3	68.9	58.6	46.0	36.2
Arusha	28.4	84.1	66.5	52.9	-3.5	34.7
Singida	26.5	82.0	62.9	52.7	45.5	35.9
Morogoro	22.9	78.7	58.0	45.3	34.7	27.3
Iringa	22.4	78.8	64.9	49.0	41.7	30.5
Songea	15.9	77.9	63.2	49.5	40.0	32.6
Mahenge	17.9	76.4	64.6	49.6	37.8	29.1
Mbeya	11.9	73.0	48.6	37.8	28.4	21.6
Mpanda	14.2	63.7	42.7	29.0	18.5	13.7
Kibondo	10.8	72.1	50.0	40.7	33.7	27.9
Dodoma	29.6	81.0	68.7	65.4	44.7	38.6
Tabora	13.2	62.4	45.5	24.8	84.9	9.9
Kitunda	20.6	76.6	61.0	48.1	39.0	30.5

season consists of 6 months in Tanzania and 4 months in Uganda and Kenya.

$$f_T = \sum_{i=1}^{20} f_i = \sum_{i=1}^{20} \sum_{j=1}^{4/6} \sum_{k=1}^{21} f_{ijk} \tag{3}$$

gives the total frequency of dry spell of all lengths for a given station for the period of study. The cumulative frequency cf_i for each station of the length of dry spell i is calculated from

$$cf_i = f_T - \sum_{i=1}^{i-1} f_i \tag{4}$$

where f_T and f_i are as defined above.

If P_i denotes the probability of a dry spell lasting at least i days then P_i can be computed from

$$P_i = \frac{cf_i}{f_T} \tag{5}$$

where cf_i is the cumulative frequency of a dry spell lasting at least i days and f_T the total frequency of dry spell for a given station for the period of study.

These values of P_i are expressed as percentages and plotted on maps.

To calculate the conditional probability of a dry spell, given it has lasted a given length, it is assumed that the events are *not* independent, i.e. persistency of one type of weather phenomenon.

If E_1 and E_2 are dependent events, then

$$P_r\{E_2/E_1\} = \frac{\{P_r E_1/E_2\}}{\{P_r\ E_1\}} \tag{6}$$

where $P_r\ \{E_2/E_1\}$ is the conditional probability of E_2 given E_1 has already occurred, $P_r\ E_1$ is the probability of E_1 occurring and $P_r\ E_1/E_2$ is the probability of both E_1 and E_2 occurring. Hence

$$P_r\{\ i + 1/i\ \} = P_r\ \frac{\{i + 1, i\}}{P_r\ \{i\}} \tag{7}$$

where $P_r\ \{i + 1/i\}$ is the conditional probability of a dry spell lasting at least $i + 1$ days, $P_r\ \{i\}$ is probability of a dry spell lasting at least i days, and $P_r\{i + 1, i\}$ is the probability that the dry spell will last at least i and $i + 1$ days.

But

$$P_r\ \{\ i\ \} = \frac{cf_i + 1}{f_T} \tag{8}$$

and

$$P_r\{i + 1, i\} = \frac{c_i f + 1}{f_T}; \tag{9}$$

hence

$$P_r \{i + 1/i\} = \frac{(cf_i + 1)}{f_T} \div \frac{cf_i}{f_T} = \frac{cf_i + 1}{f_i}. \quad (10)$$

Since most crops can perhaps withstand 1 day's dry spell, but may begin to show moisture stress effects after 2 days or more, the probability of dry spells lasting 3, 5, 7, 10, 15 and 20 days was determined and probability maps constructed. Conditional probability of a dry spell lasting at least 1 or more, 2 or more days, etc., was calculated and maps constructed.

Results and discussions

Table 1 gives the observed cumulative frequency of dry spells lasting from 1 to 20 days for the 45 stations used in this study. These tables reveal the following interesting features:

1. High frequency of dry spells of short duration is found in the wet areas of the region such as Kericho, Kitale and also in regions where the rain can be considered as being predominantly convective in origin such as Mombasa. This is to be expected as convective activity may result in scattered rain resulting in many short dry spells. It will be noted for example that up to 56% of the dry spells in Kericho are cases of dry spells lasting 1 day only.
2. High frequency of dry spells of long duration is found in the drier areas. Dry spells of duration $\geq$ 10 days are more common in dry places like Mandera (31%) compared to say Kericho (0.5%). It suggests the possibility that the drier areas get their rains from more organized synoptic scale systems with few short dry spells occurring during the time of the rains. The longest dry spell ever recorded during the long rains for the period under study is 61 days in both Kenya (mostly in the northeastern region) and Tanzania (Dodoma) and only 34 days in Uganda (Mbarara).

Table 2 shows the seasonal and monthly probabilities of a dry day in the period 1950–1970. The results indicate a low probability of a dry day in the wetter areas as compared to a high probability in the drier areas as one would expect. For both Kenya and Uganda, April is in general the wettest month and the low probability of a dry day during this month is also to be expected. It is also noteworthy that stations in northern Uganda have their lowest probability of a dry day in May. This again agrees with the observed shifting of the rain belt northwards and the one long rainy season in northern Uganda. In Tanzania the period of lowest probability of a dry day varies. Regions with onset and cessation pentades of the rains (Alusa and Mushi 1974) similar to those in Kenya have the same pattern of probabilities. The other stations have their lowest probability of a dry day during March and April in most cases.

Conditional probabilities of dry spells for the lengths 3, 5, 7, 10 and 15 days have been computed, but only those for 5 days are shown in table 3. We observe that there is a sharp rise of probability given a dry spell has lasted 5 days and then a decrease as i increases. The sharp rise is due to the fact that, given that a dry spell has lasted 5 days, persistence theory would suggest that the probability of the spell lasting another day is very high. The conditional probability, however, goes down and the 50% probability (call it x) gives the time when a rainy and dry day have an equal chance of occurring. The x value is attained faster in the wetter areas than in the drier areas as we would expect. However, it seems to us to be very useful statistics for the farming community in as far as it gives the degree of risk involved in planting during a dry spell.

Figures 1, 2, 3 and 4 show the percentage frequency (probability percentage) of dry spells lasting at least 3, 5, 7 and 10 days respectively. All the figures show high and low percentage frequency of dry spells in the drier and wetter areas respectively. It is found that the percentage frequency of dry spells lasting at least 3 days is as high as 60% in the drier areas of Kenya and Tanzania and only 30% in the wetter areas. The percentage frequency of dry spells lasting at least i days ($i = e$, 5, 7 and 10) is generally lower in Uganda than in Kenya and Tanzania. This seems to tie up very well with the distribution of the rainfall in Uganda (rather uniform).

A relatively tight gradient which runs southwest to northeast exists over the border highlands of Kenya and Uganda in all the figures. In figures 1 and 2 the pattern of the isopleths is sinusoidal while in figures 3 and 4 the pattern over the same region is about straight. This may be due to the fact that rainy spells of long duration are due to more organized large-scale synoptic systems; thus the convective influences which tend to increase the frequency of dry spells of short duration is becoming less significant as the length of the dry spell increases. The probability of a dry spell lasting at least i days decreases with increase in i; this decrease is shown in the maps, e.g. the highest probability of a dry spell lasting at least 10 days is only 30%.

Conditional probability maps for 1, 2 or more days have been constructed for the lengths 3, 5 and 7, but only those for 3 have been included due to lack of space. Figures 5 and 6 show the conditional probability of a dry spell lasting 1 or more days, 2 or more days given the dry spell has lasted at least 3 days. Figure 5 shows a sharp rise in the probability and figure 6 shows a decline in the probability of a dry spell. This is expected as explained earlier in the conditional probability tables. These two figures (5 & 6) show similarity to figure 1, particularly over the Tanzania region.

Conclusion

This study reveals the association of dry spells with relief and mean annual rainfall distribution in the region, i.e. it is found that there is a low probability of dry spells (particularly of long duration) in the wetter areas of the region. Though the cut-off value of 1 mm for a rainy day is rather low, the results of this work may constitute a base for defining moisture stress on crops. Work is in progress to examine the frequency of dry spells with a rainy day defined as

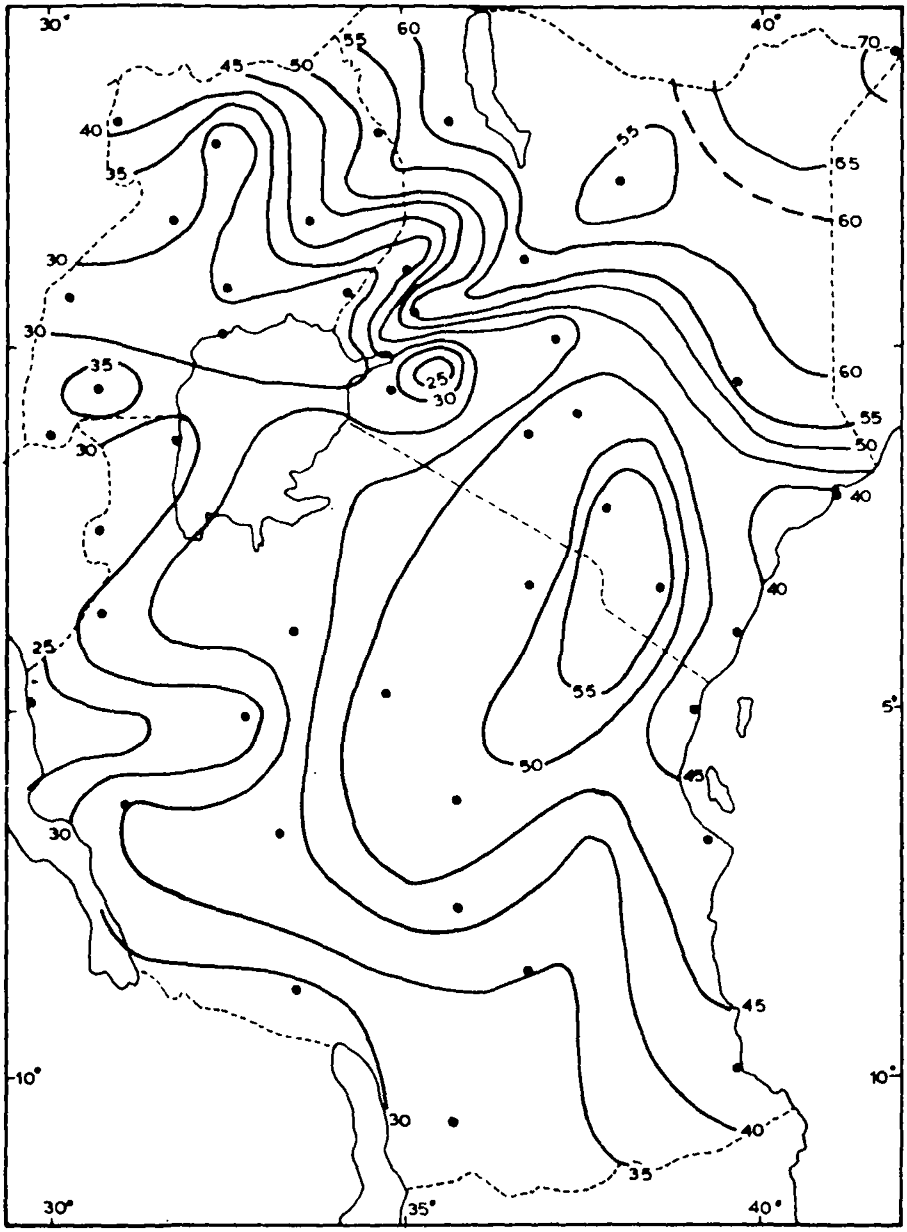

Figure 1. Percentage frequency of dry spells lasting at least 3 days.

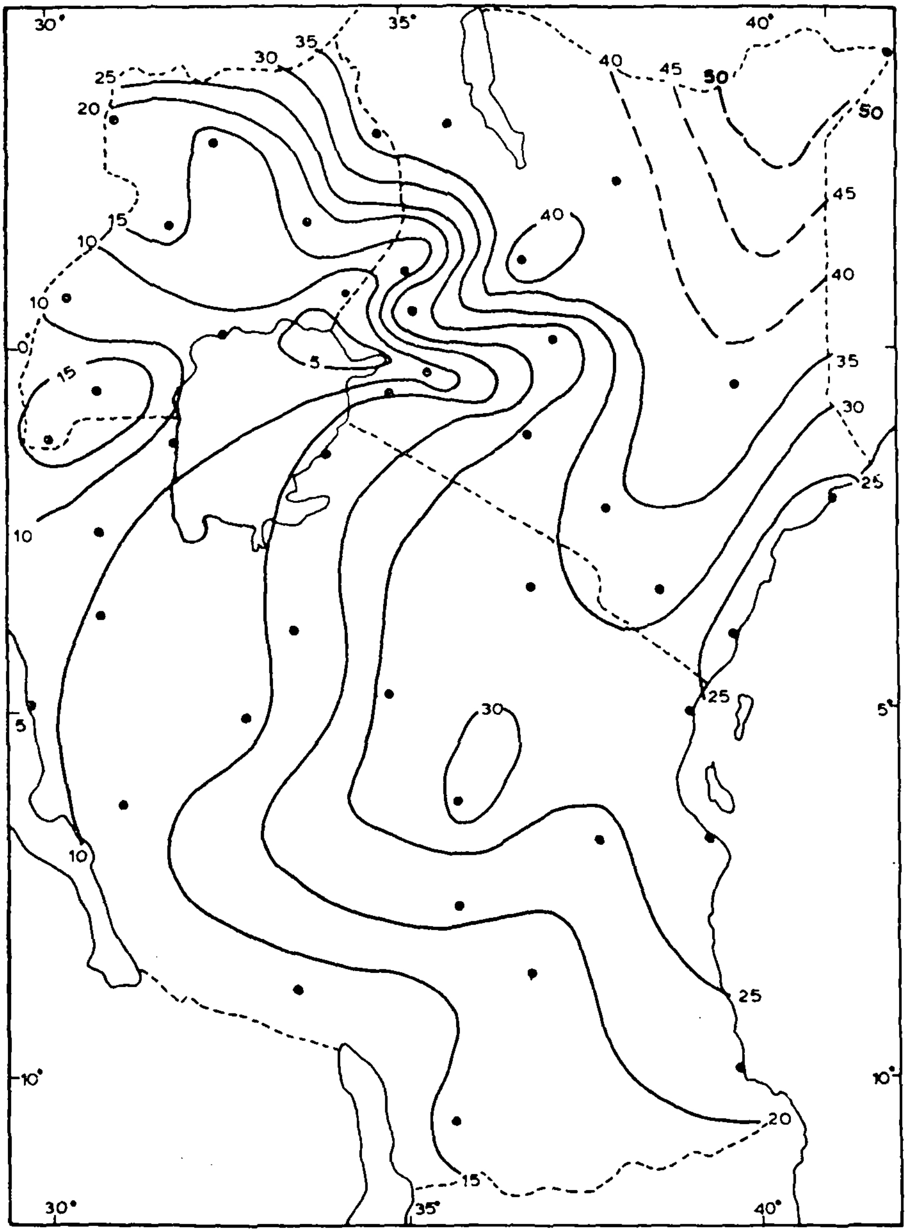

Figure 2. Percentage frequency of dry spells lasting at least 5 days.

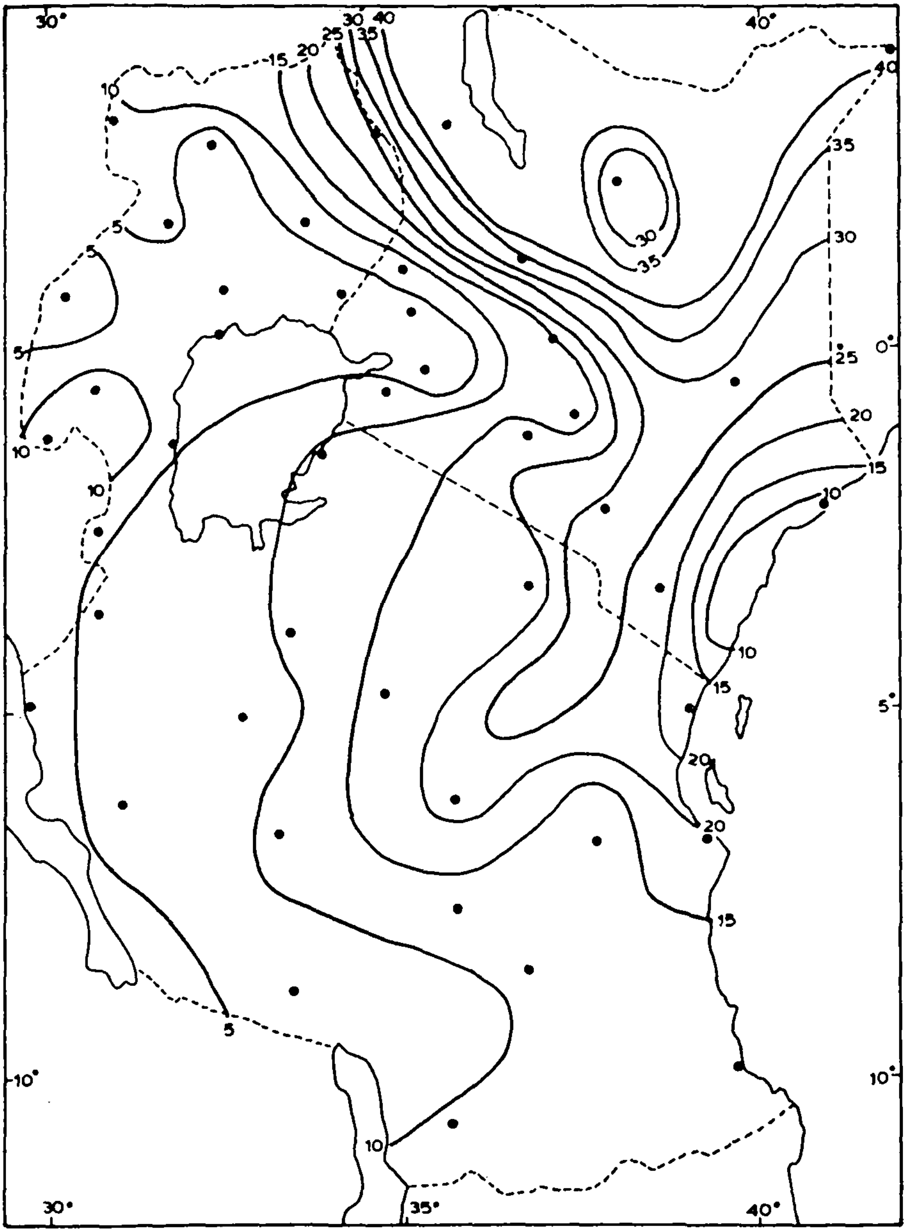

Figure 3. Percentage frequency of dry spells lasting at least 7 days.

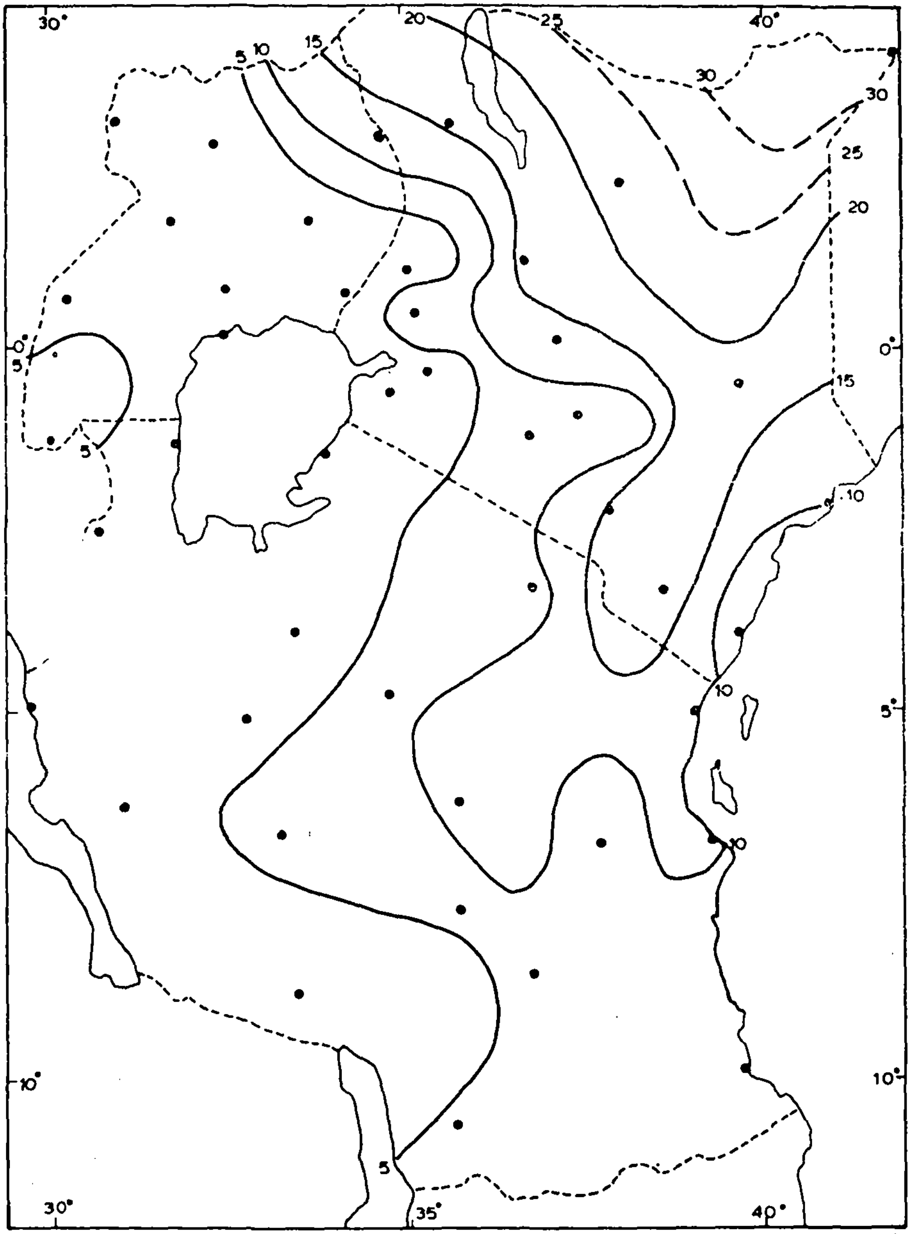

Figure 4. Percentage frequency of dry spells lasting at least 10 days.

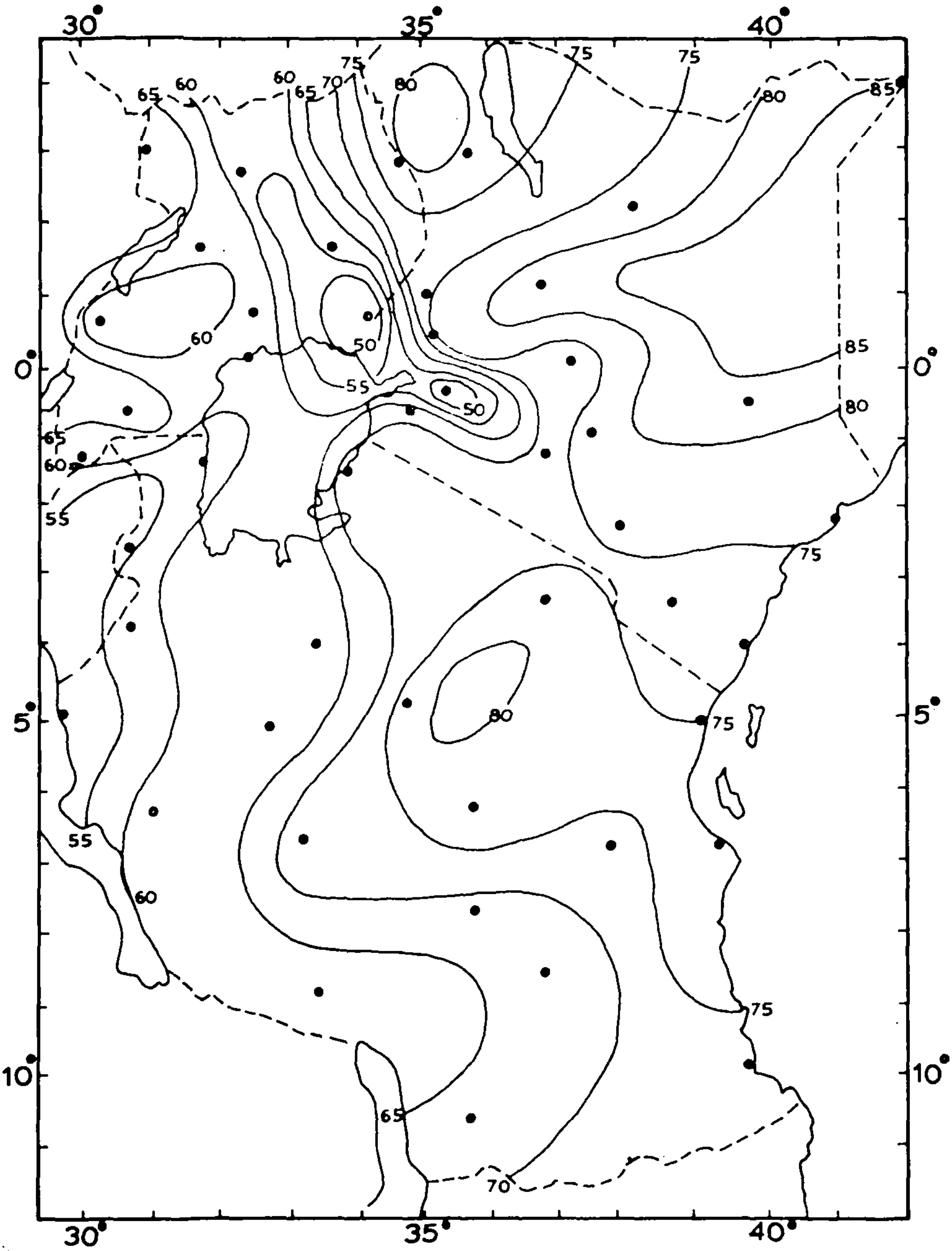

Figure 5. Conditional probability of a dry spell lasting 1 or more days after the dry spell has lasted at least 3 days.

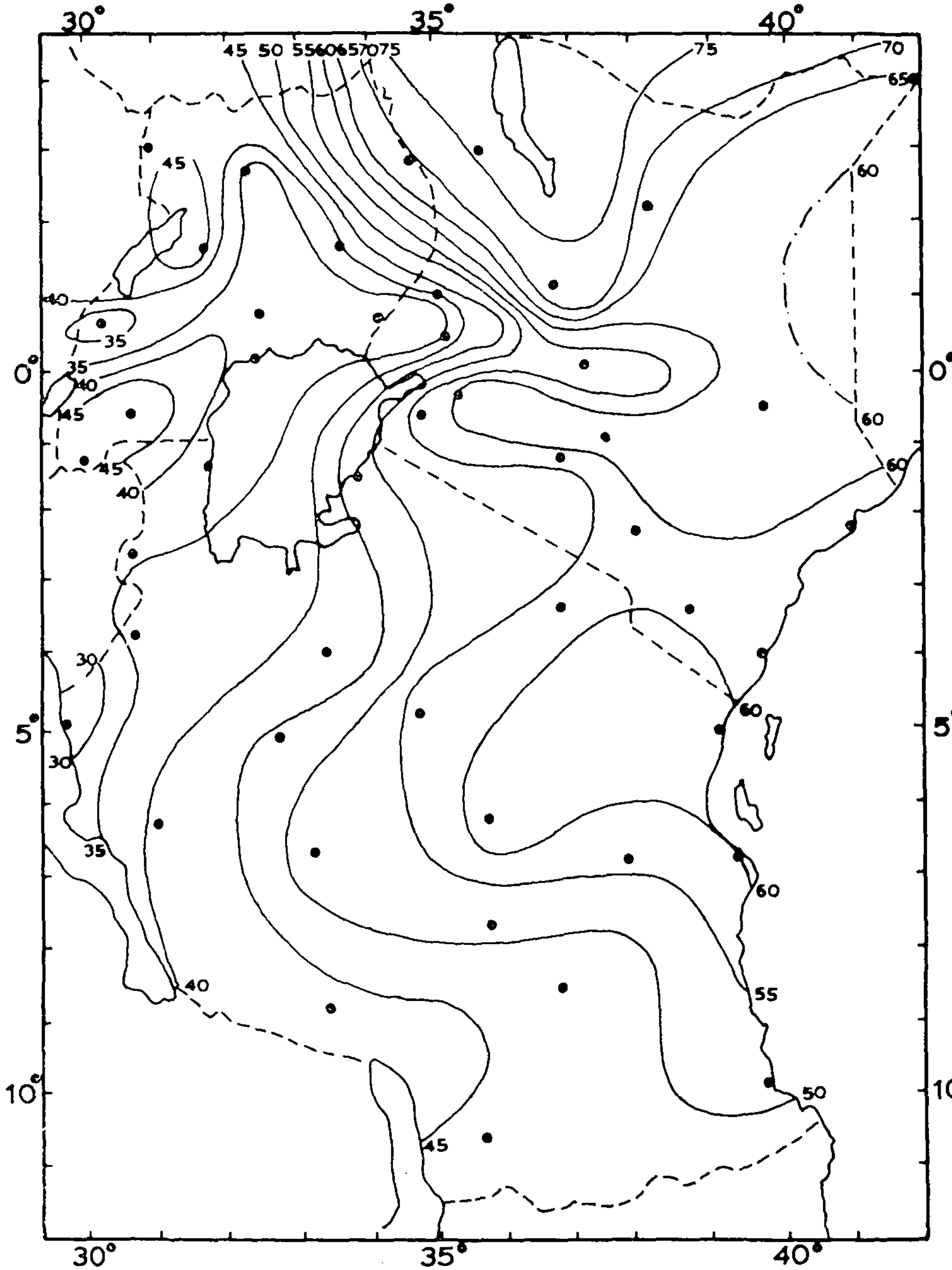

Figure 6. Conditional probability of a dry spell lasting 2 or more days after the dry spell has lasted at least 3 days.

a day with at least 5 mm of rainfall or with rain exceeding the potential evapotranspiration for the region.

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DESCRIPTION OF CURRENT FLOOD PREDICTION METHODS IN KENYA

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Abstract

Flood estimation is an important aspect of hydrology. For centuries hydrological data have been collected in some countries of the world. In Kenya, data collection started comparatively recently. The data collected can be analysed to estimate floods in rivers using various hydrological techniques. These flood values in turn have varying applications, e.g. project design, flood drainage and mitigation and flood forecasting. There are various hydrological techniques for estimation of floods. The method used depends on the hydrological conditions of the catchment and also on the hydrological and meteorological data available. The techniques used, therefore, vary from one country to another and even from one place to another. The methods used currently in Kenya are discussed in the paper. These methods have been grouped into five categories and each category described in detail. The five categories considered are as follows:

1. Empirical methods
2. Indirect methods
3. Statistical methods
4. Rainfall and runoff
5. Catchment models

MATHEMATICAL MODEL OF THE UPPER NILE BASIN (HYDROLOGIC)

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Abstract

The several years' hydrometeorological data collection and publication (since 1967) within the Upper Nile Basin was a preparation for the development of a mathematical model which would simulate the basin's hydrology in terms of individual subcatchment outflows, lake levels and discharges and route the discharges down Lakes Victoria, Kyoga and Mobutu Sese Seko interconnecting channels. This paper is mainly about the development and calibration of the complete model which is a combination of:

—The catchment model (commonly known as the Sacramento model) which is a conceptual system for modelling the headwater portion of the hydrologic cycle, based on percolation, soil moisture storage, drainage and evapotranspiration characteristics.

—The lake model simulates the natural behaviours of the lake system and assists in assessment of various lake regulation alternatives. It operates under two modes namely—Mode I, for short-term data operates under equation:

$$\text{RUNOFF}_{\text{LAND}} + \text{PRECIPITATION}_{\text{LAKE}} - \text{EVAPORATION}_{\text{LAKE}} = \text{NBS (Net Basin Supply)}$$

and Mode II for long-term data operates under equation:

$$\text{OUTFLOW}_{\text{Lake}} + \text{STORAGE}_{\text{Change}} - \text{INFLOW}_{\text{Upper Lake}} = \text{NBS}$$

—The channel model (one dimensional hydraulic routing procedure) provides a link between the three lakes and is based on the continuity equation:

$$b_s \left(\frac{\partial y}{\partial t}\right) + \left(\frac{\partial Q}{\partial x}\right) = q$$

and the momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}(Q^2/A) + gA\frac{d}{dx}(y+z) + gAS_f = 0$$

where S_f is frictional slope incorporating Manning's roughness coefficient, n.

The main inputs to the complete model are basin *rainfall* and *evapotranspiration*.

Possible future applications include discharge forecasting, modelling

diversions, hydropower station outflows, reservoir planning, subcatchment calibration and as a general water management tool.

This modelling was an undertaking of Hydrometeorological Survey of Lakes Victoria, Kyoga and Mobutu Sese Seko, a joint project of the governments of Kenya, Tanzania, Uganda, the Sudan, Egypt, Rwanda, Burundi and UNDP/WMO. The actual developing and calibration of the Upper Nile Basin Model was done under contract by Snowy Mountains Engineering Corporation of Australia 1976/77.

A REVIEW OF SOME METHODS USED IN DETERMINING ACTUAL EVAPOTRANSPIRATION IN EAST AFRICA

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Abstract
A brief review of some of the methods used in East Africa for determining actual evapotranspiration/evaporation is presented. The methods reviewed include: empirical methods, atmospheric water balance method, and the energy budget method. Examples of work done in East Africa using these methods are presented.

Introduction
The East African economy, like that of many developing countries, is essentially based on agriculture. Thus the importance of water as an initial input can hardly be overemphasized. In East Africa, however, water resources are not only ill managed but are also underutilized. Plenty of water is, to date, still being allowed to flow into the wilderness during periods of excess rains. A point to recall is the 8 May 1977 flood episode in Nairobi. It is evident that proper water management is a must for the East African countries. In order that a country can efficiently exploit the available water resources it is necessary to have a clear understanding of the time and spatial distribution of the components of water balance over the country. It is well known that these water balance components include: rainfall, actual evapotranspiration, run-off, water deficit and the state of soil moisture. In East Africa, rainfall is the only water balance component available in a satisfactory form. For planning purposes, the remaining components have to be estimated. The actual evaporation/evapotranspiration is often hard to determine. However, there are several methods commonly used for estimating evaporation/evapotranspiration rates for water surfaces/soil surfaces (bare or covered with vegetation). These include:

1. Empirical method
2. Atmospheric water balance method
3. Energy budget method
4. Aerodynamic method and
5. Water budget (hydrological cycle) method.

In methods 1-4, unlike the water budget method under item 5, a knowledge of the state of the atmosphere is necessary. Furthermore, the water budget method for estimating actual evaporation is, unlike the others, widely used by hydrologists in determining evaporation from reservoirs, etc. Subsequently, details regarding its application and the difficulties associated with its use can easily be retrieved from any standard textbook on hydrology. Thus the water budget method will not be reviewed in this paper. It is therefore proposed in this paper to review methods under items 1–3 above. The review includes, among other things, examples of work done in East Africa using some of these methods. The aerodynamic method, although it has also been used in East African (Nimira 1976), will not be reviewed here.

Empirical method for estimating actual evaporation/evapotranspiration

This technique entails using empirical formulae such as those of Penman (1948) and Thornthwaite (1948). The empirical formulae give estimates of the open water potential evaporation/potential evapotranspiration. Knowing the temporal distribution of rainfall and the maximum ground water storage, it is then possible, using special tables like those of Thornthwaite and Mather (1957), to estimate the actual evaporation/ evapotranspiration and other components of the water balance for any location. However, it is pertinent to mention that in general these formulae need to be applied with confidence only in those regions for which they have been developed.

Here in East Africa and in West Africa (Woodhead 1968; Rijks, Owen and Hanna 1970; Obasi 1970), the Penman method (1948, 1963) is, to date, considered to be the most suitable for evaluating open water potential evaporation/ evapotranspiration. The first East Africa maps for open water potential evaporation were produced by Woodhead (1968) and Rijks, Owen and Hanna (1970). In these works, the Penman method was used in the evaluation of potential evaporation.

In the study of the agroclimatology of the highlands of Eastern Africa, Brown and Cocheme (1969, 1973) presented in a limited way some results of the components of the water balance for certain East African highland stations. In the evaluation of these water balance components they used 100 mm and 200 mm as values for the maximum ground storage of water. They, however, remarked in the study that effective ground storage of water varies in the depth of the soil and the root system of the crop. Pant and Rwandusya (1971) assumed, in their study regarding the climatic classification of East Africa, a value of 100 mm for the maximum ground storage of water for all locations in East Africa. Such assumptions for the values of maximum ground water storage capacity constitute the major deficiency in the use of the empirical formula approach for the estimation of actual evapotranspiration/evaporation. Nonetheless, as observations for maximum ground storage of water are not readily available we still have to estimate maximum ground water storage capacity.

Recognizing the limitations inherent in assuming constant maximum ground storage of water for the whole of East Africa, Obasi and Kiangi (1973, 1975) extracted vegetation and soil type information for the whole of Kenya from Russel (1961). This information then permitted the estimation of maximum ground storage of water for some 53 Kenyan stations. This exercise was accomplished by using tables published by Thornthwaite and Mather (1957). The estimated values of maximum ground storage of water for the 53 Kenyan etations are shown in tables 1 and 2. These values range from 100 mm to 300 mm.

Following Thornthwaite (1948), Obasi and Kiangi (1973) used the maximum ground water storage values in tables 1–2 in the estimation of actual evapotranspiration values for 53 Kenyan stations. In this approach precipitation is treated as income and potential evapotranspiration as expenditure. The soil moistuie stored in the soil is taken as a reserve capable of being drawn in whole or in part for as long as it lasts. The differences between the actual evapotranspiration values from Obasi and Kiangi (1973) and those from Pant and Rwandusya (1971) are easily seen in table 3. These differences highlight the fact that estimation of actual evapotranspiration is highly dependent on proper specification of the maximum ground water storage capacity. The

Table 1. Maximum groundwater storage capacity for some Kenyan stations and their respective climatic types

Stations	Maximum ground water storage capacity (mm)	Climatic type
Lokitaung	100	E
Moyale	250	D
Mandera	200	E
Lodwar	150	E
Marsabit	150	D/C_1
Kapenguria	250	C_2
Kitale	250	C_1
Maralal	250	D
Habbaswein	150	E
Wajir	150	E
Eldoret	200	C_1
Marigat	100	D
Isiolo	200	D
Kapsabet	250	C_2
Kipkabus	150	C_1
Rumuruti	150	D
Nanyuki	100	D/C_1
Equator	250	C_1/C_2
Subukia	250	C_2
Kisumu	300	C_1/C_2
Ahero	150	C_1
Koru	250	B
Ol Joro Orok	250	C_1/C_2
Lamuria	150	D/C_1
Molo	250	C_2
Nakuru	200	D/C_1
Garissa	150	E

Table 2. Maximum groundwater storage capacity for Kenyan stations and their respective climatic types

Stations	Maximum ground water storage capacity (mm)	Climatic type
Kericho	250	B
Kagumo	250	C_1
Naivasha	200	D
Kathiga (Embu)	250	D
Mwea	250	D/C_1
Kedong	250	D/C_1
S. Kinangop	250	B
Kabondori	250	D/C_1
Masara	250	C_1
Kimakia	250	A
Thika	200	C_1
Narok	250	D/C_1
Ruiru	200	C_1
Muguga	200	C_1
Nairobi	200	D/C_1
Kitui	200	C_1
Wayu	150	D
Galole	200	E/D
Machakos	250	D/C_1
Magadi	250	E
Makindu	150	D
Lamu	250	D/C_1
Loitokitok	200	D/C_1
Voi	250	D
Malindi	300	D/C_1
Mombasa	250	D/C_1

example given in table 3 has been chosen mainly because Pant and Rwandusya have presented details of the water budget component for Garissa, a Kenyan station.

In another development, Morton (1976) has developed a model for establishing climatological estimates for actual evapotranspiration. The model requires observations of air temperature, dew point temperature, ratio of observed to maximum possible sunshine duration or global radiation and the average pressure at the station. The model has been found to give reasonable results in the United States of America, Canada and the central highlands of Kenya. A project is currently being carried out (Nyenzi 1977) in which the Morton model is being utilized in the estimation of potential and actual evapotranspiration over the whole of East Africa. The results of this project are expected to be out very soon.

Atmospheric water balance method

The actual evaporation/evapotranspiration rates for water surfaces/soil surfaces (bare or covered with vegetation) may also be estimated in a different way if one considers the atmospheric water balance. The components of the atmospheric water balance are often given by:

$$AE - \langle P \rangle = R_a + S_a \quad (1)$$

where AE is the actual evaporation/evapotranspiration over an area, $\langle P \rangle$ is the areal rainfall, R_a is the net outflow of water vapour and liquid water or solid water content from the atmospheric column of interest and S_a is the change of the total water content in the same portion of the atmosphere. Knowing the precipitation $\langle P \rangle$, the net outflow R_a and the change of total water content S_a, then the actual evaporation/evapotranspiration AE can easily be determined from equation 1. This approach in the estimation of actual evapotranspiration has been used by meteorologists such as Peixoto and Obasi (1965) and Palmen (1967). In this approach we require wind and total specific humidity observations from a network of radiosonde stations defining the area σ over which the actual evapotranspiration is to be estimated.

Table 3. Actual evapotranspiration for Garissa (units in mm)

Months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
Authors:												
Obasi and Kiangi (1973)	14	10	29	59	24	8	3	6	6	20	72	71
Pant and Rwandusya (1971)	10	6	26	55	17	5	2	5	4	22	65	65

The mathematical expressions for R_a and S_a are normally given as:

$$R_a = \frac{1}{\sigma g} \int_\sigma \int_0^{p_s} \nabla (\vec{V}q)\, dp\, d\sigma \quad (2)$$

$$S_a = \frac{1}{\sigma g} \int_\sigma \int_0^{p_s} \frac{\partial q}{\partial t}\, dp \quad d\sigma \quad (3)$$

where g is the acceleration due to gravity, p_s is the pressure at the lower boundary of the atmospheric column of horizontal area σ, $\vec{V}$ is the three dimensional wind vector, p is pressure, q is the total specific humidity and $\nabla (\vec{V}q)$ is the three-dimensional convergence/divergence of the total specific humidity. Numerical evaluation of equations 2 and 3 is normally done by using finite difference technique for evaluating the integrals.

The atmospheric water balance technique for determining the actual evapotranspiration was used by Kiangi (1972) to estimate the actual evapotranspiration over a triangular area defined by lines connecting the three East African radiosonde stations (Nairobi, Entebbe and Dar es Salaam). The actual evapotranspiration values obtained for the triangular area compared well with those estimated by Budyko (1956) and Peixoto and Obasi (1965). For easy reference, the computed monthly values of actual evapotranspiration over the triangular area (1.3×10^5 km^2) together with precipitation amounts are shown

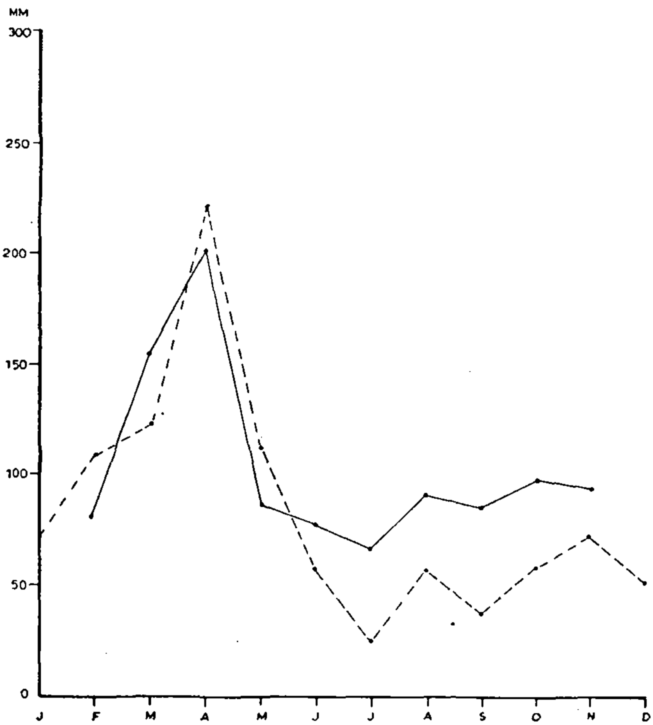

Figure 1. Mean areal actual evapotranspiration (solid line) and mean areal precipitation ⟨p⟩ (dashed line).

in figure 1. This technique for estimating areal actual evapotranspiration is particularly suitable for large catchment areas and large water bodies like Lake Victoria. Nonetheless, its use in East Africa is rather limited because of the sparsity of the radiosonde stations. However, we hope that the network of radiosonde stations will soon improve so that an independent check of the existing values of actual evapotranspiration can be made.

Energy budget method

In situations where the horizontal divergence of sensible heat, latent heat and energy storage including photosynthesis can be neglected the energy budget equation reduces to basically a distribution of the net radiation, latent, sensible heat and soil heat fluxes. Thus the energy budget equation reduces to:

$$LE = R_N - H - S \qquad (4)$$

where L is latent heat of evaporation, E is evaporation/evapotranspiration, H is sensible heat flux and S is soil heat flux. Net radiation R_N and heat flux in the soil S are directly measurable using net radiometers and heat flux plates respectively. However, direct measurements of the sensible heat flux H are difficult to come by. Thus an indirect approach is often used in which the remaining energy is partitioned between evaporation and heating of air. The energy-budget equation can then be written as:

$$E = (R_N - S)/(1 + \beta)L \tag{5}$$

where β is the ratio commonly known as Bowen ratio and defined as:

$$\beta = \frac{H}{LE}. \tag{6}$$

From turbulence theory, the formal transport equations for sensible and latent heat fluxes are given as:

$$H = -\rho C_p\ K_H\ \frac{\partial\theta}{\partial z} \tag{7}$$

$$LE = -L\rho K_W\ \frac{\partial q}{\partial z} \tag{8}$$

where ρ is the air density, C_P is the specific heat at constant pressure, K_H is the coefficient of eddy transfer of sensible heat at height Z, θ is temperature, K_W is the coefficient of eddy transfer of latent heat at Z, and q is the specific humidity.

On substituting equations 7 and 8 into equation 6, the expression for the Bowen ratio β becomes:

$$\beta = C_P K_H\ \frac{\partial\theta}{\partial z}\Big/ LK_W\ \frac{\partial q}{\partial z}. \tag{9}$$

In finite difference form, equation 9 can be written as

$$\beta = \left(C_P\ K_H\ (\theta_{z_2} - \theta_{z_1})\right) \Big/ L\ \ K_W\ (q_{z_2} - q_{z_1}) \tag{10}$$

where $Z_1 < Z_2$.

It is immediately seen that equation 10 depends on the prevailing atmospheric stability conditions because K_H and K_W have long been known to be functions of stability (Priestley and Swindbank 1947; Pasquill 1949). However, under neutral stability or by working very close to the ground where strong wind shear minimizes the effects of thermal stratification, the ratio $K_H/K_W \simeq 1$ may be assured. In practice therefore, the gradient measurements need to be taken as close to the surface as possible. This will not only result in the minimization of buoyancy effects but also in the reduction of the effects of advection and changes in energy or water vapour storage in the intervening air layers. Recommended heights above the surface lie in the interval 0.1 to 0.2 m for cases of strong heating or advection and up to 1 m for normal conditions (Gangopadhyaya et al. 1966).

In situations where stability is different from neutral, we need to know, among other things, the values for the ratio of K_H to K_W before we can estimate the Bowen ratio β given in equation 10. The ratio of eddy transfer coefficient for heat to that for water is often evaluated from expressions relating this ratio K_H/K_W and Richardson number R_i. The Richardson number R_i is defined by:

$$R_i = g\ (T_2 - T_1)(Z_2 - Z_1) \,/\, \bar{T}\ (U_2 - U_1)^2 \tag{11}$$

where T is the virtual temperature in degrees Kelvin, g is acceleration due to gravity, U is the horizontal wind speed, and Z is the distance in the vertical. The subscripts 1 and 2 refer to levels and $Z_2 > Z_1$. The thermal stratification criterion is such that

$R_i > 0$ implies stable condition,
$R_i = 0$ implies neutral condition, and
$R_i < 0$ implies unstable condition.

Pruitt, Morgan and Laurence (1973) have presented equations relating the ration K_W/K_M to the Richardson number R_i. These equations are given, for the case of unstable and stable stratification, as:

$$K_W/K_M = 1.13(1 - 60R_i)^{+0.074} \tag{12}$$

$$K_W/K_M = 1.13(1 + 95R_i)^{-0.11} \tag{13}$$

where K_M is eddy transfer coefficient for momentum. In a similar way, Businger (1966) and Dyer (1965, 1967) have presented the following expressions for the case of unstable and stable atmospheric conditions respectively:

$$K_H/K_M = 1.35\,(1 - 9\xi)^{\frac{1}{2}}/(1 - 15\xi)^{\frac{1}{4}} \tag{14}$$

$$K_H/K_M = 1.0 + 4.7\xi/\,0.74 + 4.7\xi \tag{15}$$

where $\xi = Z/L_1$ and L_1 is the Monin-Obukhov characteristic length. Panofsky (1963) and Campbell (1973) have related ξ to R_i, for the case of unstable and stable stratification respectively, as:

$$\xi = R_i(1 - 18R_i)^{-0.25} \tag{16}$$

$$\xi = 1.84R_i^{1.09}. \tag{17}$$

On substituting equation 16 into equation 14 and combining the resulting expression with equation 12 we obtain

$$K_H/K_W = 1.35\left(1 - 9R_i(1 - 18R_i)^{-0.25}\right)^{\frac{1}{2}}$$

$$1.13\left(1 - 15R_i(1 - 18R_i)^{-0.25}\right)^{\frac{1}{4}}(1 - 60R_i)^{.074}. \tag{18}$$

Similarly, submitting equation 17 into equation 15 and combining resulting expression with equation 13 we obtain:

$$K_H/K_W = 1.0 + 8.65R_i^{1.09}/(0.84 + 9.77R_i^{1.09}) \quad (1 + 95R_i)^{-0.11}. \tag{19}$$

The expressions for K_H/K_W given in equation 18 and equation 19 are for unstable and stable conditions respectively.

The ratio K_H/K_W in equation 10 can now be estimated from equations 18 and 19. Thus the Bowen ratio β in equation 10 can be estimated once measurements of temperature θ and specific humidity q are known at Z_1 and Z_2. The net radiation R_n in equation 5 can easily, as mentioned earlier, be measured by means of net radiometers. The soil heat flux S is somewhat difficult to measure accurately. Nonetheless, it constitutes a small component of the budget. Even then, S can be measured with the use of heat flux plates (Deacon 1950; Monteith 1958). Once the various components in equation 5 are known, the actual evaporation/evapotranspiration is then obtained by substitution. Here in Kenya, Nimira (1976) has used the energy budget method in the estimation of evaporation rates for Lake Nakuru. His results show that the mean daily evaporation estimates for Lake Nakuru are reasonable and compare favourably with similar estimates for Lake Victoria.

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NON-CONVENTIONAL WATER SOURCES: A REVIEW OF IDEAS AND POSSIBLE APPLICATIONS IN KENYA

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Abstract
The paper reviews research literature on the less obvious sources of water. Dew, soil moisture, fog, mist and atmospheric vapour are considered as possible sources. Consideration is given to the application of various methods of exploiting these resources in the arid areas of Kenya, especially in the intermediate technology range. The need for more research on these topics is emphasized.

Text
When one considers the water resources of East Africa, one's mind turns initially to thoughts of rivers, lakes and boreholes, and then perhaps to rock or artificial catchments for rain such as pans, and maybe to desalination, cloud seeding and suchlike. It is perhaps because most of us live in well-watered and hospitable climates, where we are used to having water available in terms of tens of gallons rather than single pints, that we do not realize how much the reliable provision of just a few cupfuls of water a day can contribute to the life of an inhabitant of a dry area. For the bushman, rivers and lakes are few and far between, and the other sources require a combination of technical knowledge, money and incentive to make them work. It is the intention of this paper to look at less well known sources of water and the methods which could be used by those living in arid areas to exploit them.

It is rarely conceived that there is a large reservoir of water in the form of water vapour. As an example, taking recorded meteorological data (E.Afr. Met. Dept), typical relative humidity at Wajir at 0900 East African time is 75% and the average dry bulb temperature at the same time is 25°C. Then at an atmospheric pressure of 990 millibars, the air over Wajir contains about 15 g of water per kg of air, or nearly 18 g per m^3. Assuming that the 1 km of air near the ground is well mixed and contains the same proportion of water throughout, it can be concluded that in 1 km^3 of air over Wajir there is about 16 million litres of water. The assumptions involved are generous, but it gives an idea of the potential of such a source, and the figures are typical of Kenya's arid area.

The problem is how to realize this potential. One could not expect to remove anything more than a fraction of 1% of this water, but even that would yield something like a 1000 litres per km^2 a day.

It should not be forgotten that the soil, though by outward appearance dry, contains large amounts of water within the soil pores. Monteith (1957) gives a diagram showing that a dry sand, no longer able to support vegetation, nevertheless contains 2½% by weight of water, equivalent to about 50 litres in 1 m^3 of 'dry' soil. The hygroscopic properties of some soils are well known, and as an example he reports that Ramdas and Katti found the moisture content in the surface layer of the Indian 'black cotton soil' increased from 2.6% to 7.7% of dry weight by absorption overnight. Unfortunately, a soil dry enough to absorb moisture from the atmosphere is rarely wet enough to yield it to plant roots. However, Halacy (1966) describes experiments conducted in Japan, and frequently repeated elsewhere, in which plastic sheets or miniature glass houses have been used to distil this water out of the ground and condense it in a container. About 1 litre of water a day can be collected from 1 m^2 of ground in this way. The principle of operation is similar to the solar still, but one does not need even a brackish supply of water as a raw material. The soil moisture is replenished constantly by diffusion from deeper layers of soil and by absorption of atmospheric moisture.

Such experiments have usually emphasized the usefulness of providing small quantities of water for the survival of intrepid explorers. But why should the African's admirable ingenuity not be put to good use here. A plastic fertilizer bag and an empty tin might well become standard equipment for the Turkana tribesman crossing the desert. But the technique must first be demonstrated to him. The possibility of using this technique on a larger scale does not seem to have been considered yet.

Returning to atmospheric moisture, are there ways of tapping this reservoir? A great deal has been written about dew as a source of water. Review papers by Milthorpe (1960) and Stone (1957) show the degree of controversy that exists between experts, many of whom express diametrically opposed views. Enthusiastic and rather subjective investigations by Hubbard and Hubbard (1905) led them to assert that, 'There is still in this country [England] at least one wandering gang of men . . . who will construct for the modern farmer a [dew] pond which, in any situation, will always contain water, more in the heat of summer than during the winter rains'. However, Martin's 3-year investigation into dew-ponds around 1910 gave almost conclusive proof that the ponds were replenished more by mist and fog than by dew. Many writers have since indicated that the maximum theoretical deposit of dew in a single 10-hour night, computed from energy considerations, is of the order of 0.8 mm, certainly not enough to replenish a dew-pond.

More recent investigations into dew have verified this maximum figure experimentally. The measurement of dew is difficult, and artificial dew gauges so far devised cannot properly imitate the physical characteristics of natural collectors such as plants and rock. Also, it is difficult to distinguish between dew formed from truly atmospheric moisture, that formed by distillation of soil moisture and guttation, or the moisture exuded by plants onto their leaves.

There are many cited examples, though few are backed up by quantitative measurements, of plants being grown by reliance on dew. Went (1955) says that in California, tomatoes are grown in an area where no rain falls during the growing season. On Lanzarote in the Canary Isles, the author has seen small depressions 1 m or so across, lined with black volcanic pebbles, said to condense dew which then trickles to a solitary onion plant in the middle. Grape vines are said to suffer less from drought than normal when grown on rocky slopes; near Amman, tomatoes are said to be grown almost entirely on dew, and it has been claimed that the spreading thorn tree, by its shade, derives from the atmosphere enough moisture to survive. Gilbert White (1906) mentions that some dew-ponds are overhung with 'two moderate beeches that doubtless afford it much supply', and L. and J. Milne (1964) describe how, on a clear starry night, they stood under a tropical raintree in Trinidad and became soaked by the drips from the leaves. Whether this last experience was the result of condensation dew or guttation they were unable to tell, but at least it gave rise to a thick carpet of grass under the tree, whereas that exposed away from the tree was thin and dry.

Research by Arvidsson and Hellström (1955) in Sweden and Egypt indicated that dew could provide water in usable amounts. They constructed large funnels of various materials, supported about 1 m above the ground. Dew was collected on them on about a third of the nights on which the apparatus was exposed, cloud cover preventing radiation and the subsequent cooling necessary for dew formation on the other nights. Dew collected on the inside and outside of a wooden funnel with a plan area of 1 m^2 gave a maximum collection on one night of 0.4 litre.

Meteorological data for Kenya are sparse and give little indication as to when and where dew can be expected to form. However, observant persons will have noticed the row of drips frequently found under the eaves of buildings in many parts of the country, in the early morning, even in warm dry weather. A Kenya government standard single grade 9 house with a plan roof area of 29 m^2 would, applying the above average figures, collect 320 litres of dew water a year. This may seem a small amount compared with the amount of rainwater normally collected, but might be a significant amount at the end of a long dry period. It is surprising to note how many buildings in Kenya, even in dry areas, do not have gutters and a storage tank.

Monteith (1957) conducted a series of careful experiments on dew on a playing field in England. Though the environment in which his experiments were conducted was very different from that of arid Kenya, he did verify one fact that is often mentioned: the necessity of a light wind. In order to condense the moisture present in the atmosphere as dew, it must be brought into contact with the condensing surface; a light wind speed, i.e., 2–3 m/s, will stir up the 100 m or more of air nearest the ground and bring most of it into contact with the condensing surface. A stronger wind, over 5 m/s, always resulted in net evaporation. The Arid Lands Meeting asked, in their reviews of research (UNESCO 1953; Deacon, Priestly and Swinbank 1958), if it would be possible to choose areas with significant amounts of dew for planting crops that can use it effectively and to enhance its formation in places where there is none at present. Went (1955) has suggested that rows of trees be planted in suitable locations to reduce wind speed to that required for dew formation. Though we know that the maximum dew precipitation is small, various authors have referred to the capability of plants to 'attract' dew. It is suggested by Slatyer and McIlroy (1961) that plants might concentrate the precipitation of dew, but only at the expense of surrounding areas. Certainly, if an artificial dew collector could do this as effectively as the tropical raintree appears to have done, then there may well be scope for developing this source. A vast amount of data collection and investigation on dew has been done by Duvdevani and others in Israel (1957), with particular emphasis on the part it plays in arid land agriculture. They are convinced that dew absorbed through the leaves of plants plays an important part in maintaining plants through periods of drought.

Gindell (1973) describes how pine, tamarisk and eucalyptus seedlings were planted in the Judean Hills. Near each plant was arranged a plastic sheet, 1.3 m^2 in area. The dew collected on the sheet was led to the plant pit. Saplings planted in heat and drought conditions unsatisfactory for survival nevertheless survived until the rains 4 months later, while those without the dew supply dried up and died within 1 month. The plastic sheet may also have had a significant effect in preserving soil moisture from evaporation.

Dew has often been credited with providing large quantities of water which have actually been the result of interception of mist and fog. In this case, the moisture is already condensed, but is in the form of small droplets floating about in the air, too small to fall to the ground. Martin acknowledges the role of mist interception as a source for his dew-ponds, and it is likely that some of instances of plant survival mentioned above owe more to this than to direct condensation of dew.

There is still much controversy over the effect a forest has on climate, particularly with regard to rainfall. The transpiration rate of trees in Kenyan highlands forests is of the order of 3 mm a day, so that even if the forest encourages suitable climatic conditions for rainfall, it must exceed this figure to be of any net advantage, with an additional allowance for rainfall intercepted by the leaves and reevaporated. For mist and fog interception, experimental results show that interception of the cloud droplets which coalesce on the leaves and eventually run down to the ground can be several times greater than that required for transpiration. This is a very important factor in groundwater recharge. The loss of this water source through the destruction of forest may be far more significant than has yet been admitted.

It is usually the orographic cloud, formed by the adiabatic cooling of moist air masses forced to rise over high ground, which appears as fog at ground level on the tops of hills. This type of fog, or low cloud, does not rely upon the existence of forests for its formation, but results purely from the fall in pressure and hence temperature, associated with rising air masses. There are many high points in Kenya's volcanically disturbed physical geography which are topped by such clouds. Mount Kenya is an obvious example, but Marsabit, Machakos and the Ngong Hills are examples of more arid upland regions with potential for mist interception. The significance of mist and fog interception was noted by Hursh and Pereira when considering the water economy of the Shimba Hills, and in Japan, special 'fog prevention forests' or belts of trees have been planted for the specific purpose of straining moisture out of the fog, as reported by Hori (1953) and Kashiyama (1956). This process has been used for many years by the people inhabiting the escarpment facing the moist southeasterly winds near Kitui, and in other parts of Kenya. A tree is chosen, such as a gum tree, which has its branches pointing upwards away from the stem. A rope coiled around the stem with its loose lower end resting in a bucket can collect a bucketful of water which originates from mist and fog interception in the upper branches. Some work on this subject was done at the EAAFRO station at Muguga in 1961. In preliminary trials, fog-catching gauges there showed up to three times as much water was caught in them as in a standard rain gauge.

Nagel (1956, 1962) investigated mist and fog interception on Table Mountain and along the coast of South West Africa. Table Mountain has an almost permanent covering of cloud, nicknamed the 'tablecloth'. Nagel set up rain gauges, some of which had fog catchers mounted above them. The fog catcher consisted of a gauze cylinder with its axis set vertically above the axis of the rain gauge. His results showed fog interception over a year to be equivalent to 3294 mm of rain, compared to actual rainfall over the same period of 1940 mm. On theoretical grounds, he concluded that the amount of water available in the fog was about 12 times that actually intercepted. Further experiments gave similar results in other locations. One surprising result was that the amount collected by a flat gauze screen mounted on a lorry and driven through the fog at different speeds did not vary very much with the speed. The results of such experiments are often complicated by the fog catcher's ability to intercept rain, drizzle and dew as well.

Twoney (1957), in similar experiments in Tasmania, found that a section of flat mesh 36″ high and set vertically above an 8″ rain gauge yielded about 10 times more water than a rain gauge without mesh. Taking the water content of a cloud to be 1 g/m^3, he points out that with a light wind of only 4 m/s this represents a potential catch of 14 litres of water per hour passing horizontally through a 1 m^2. Nagel quotes a measured wind speed of 13 km/s for Table Mountain, which could theoretically yield nearly 47 litres per hour. Twomey's mesh was of steel wire with 3.2 mm per aperture. Nagel's mesh was finer, with 1.6 mm per aperture and was similar to mosquito wire, a cheap and readily available material throughout the tropics. Some work to test different types of fog catcher was done in Hawaii and is described by Ekern (1964).

A simple method of catching mist to promote the germination of seeds is to put a stake in the ground next to the seed. The stake will intercept mist and other precipitation, and guide it down to the seed. Kerfoot (1968) gives an extensive review of work on this topic which leaves little doubt as to its potential. In Kenya, the Ngong Hills, being easily accessible to Nairobi, provide an excellent venue for a pilot study.

It seems that people in ancient times had similar ideas. Jumikis (1965) reports extensively on the discovery of rock mounds on hilltops in Theodosia (Crimea). The mounds, over 2 000 years old, were 30 m in length, 25 m wide and 10 m high, and were connected with tile pipes to the coastal town. Appropriately known as aerial wells, they have counterparts in many places. Jumikis mentions the fogaras of Tunisia, and the rotaras of Morocco, and references in his and many other writers' work to the teleilat of Israel are common. Unfortunately, information on how they may have worked is hard to come by. After extensive investigations, Evenari, Shana and Tadmor (1971), concluded that the teleilat or stonemounds found on hillsides in the Negev Desert had nothing to do with dew at all. Their observations failed to show any significant deposition of dew on the mounds, certainly not enough to cause the water to drip off and wet the ground underneath. Apparently the name *teleilat el einab* (translated from the Arabic as 'the hillocks for grape vines') is a misnomer based on wishful thinking, similar to the English dew-ponds which do not catch dew. They advance the theory that the mounds are the result of stone clearing from the rocky slopes, for the purpose of increasing run-off into the valleys where most of the fertile soil is to be found. Their rather surprising conclusion was that shallow slopes of about 10 %, split into small plots of about 10 ha and cleared of stones, gave the best yield of run-off water which was then stored in cisterns for irrigation in the valleys. Steeper slopes gave less run-off; doubling the area less than doubled the run-off, and the clearing of stones did not cause significant problems of soil erosion. The idea therefore was to prevent rainwater from infiltrating and to encourage it to flow quickly to collecting channels. This device worked particularly well with the lighter rain showers. It is an interesting contrast to Kenya, where almost the exact opposite is aimed at, that is maximum infiltration with avoidance of direct run-off. Their results apply to the loess soils and particular climate of the Negev and do not necessarily apply elsewhere. One is reminded, however, of the claim that grapes grow better on stony hillsides. Could this be due to more effective infiltration of rainwater, rather than dew formation or absorption?

As for the Theodosian aerial wells, whether it was fog interception, dew formation, direct run-off or some hygroscopic quality of the rock resulting in what Jumikis and *Tropical Agriculture* (1935) call 'dehydration of air' that was primarily responsible for the water that flowed down the tile pipes is a question yet to be satisfactorily answered. Jumikis reports various inconclusive experiments, notably by Chaptal (1932) and Knappen (1933) between the wars, but the writer has been unable to trace any record of more recent work. One is tempted to dismiss these artifacts as historical follies, yet it is unreasonable to think that the construction of 13 such pyramids requiring the stacking of nearly 40 000 m^3 of rock and the associated pipelaying would have been undertaken unless the builders were fairly sure of success.

Monteith, assuming the source to be dew, applies theory to the teleilat and taking them to be conical, 1.2 m high and 3 m in diameter, deduces a yield of up to 3 litres a night. On the same basis, the aerial wells of Theodosia could yield up to 300 litres a night each, not an outstanding quantity. But if fog interception is assumed to be the source, the figure jumps to 12 000 litres a day in favourable conditions. The writer has been told of aerial wells which in recent years caught useful amounts of moisture from mists rising up over the western side of the Andes, though no details of design or yield are available. Such a well might be able to supply a small village and the spirit of *harambee* should soon be able to produce materials for the impermeable collecting foundation and labour to build the rock pile.

If aerial wells do collect atmospheric moisture, then Chaptal and Knappen proved that inspired guesswork was no way to design them. Their wells generally failed to produce reliable and significant quantities of water, although showing that they could produce useful quantities on occasion. Further research could show where and how locally available materials could be used to build aerial wells which would be both more efficient and reliable.

Dixon (1967), drawing upon the work of Dannies (1959) and Hall (1966), considers a more sophisticated method of extracting moisture from the atmosphere by absorption in hygroscopic substances. He proposes a device similar to the solar still, where the sun's energy is used to distil water from silica gel or glycol instead of salty water. The gel would be regenerated by radiative cooling and absorption of moisture during the night. Very little experimental data are given, but making reasonable assumptions as to efficiency, he concludes that it might be as effective as a conventional solar still, with the added advantages of not requiring even a raw water source or any pumping, and hence no artificial power source. Because the mechanism depends on hygroscopic materials rather than a cold condensing surface, the yield is not limited by the energy considerations applicable to dew. Assuming a gel bed depth of just over 0.4 cm, Dixon estimates a yield per day of about 1 lb of water per square foot.

In conclusion, several possibilities exist for producing small but useful quantities of water in dry areas. The technology involved, though not yet fully understood from a theoretical or practical point of view, is likely to be simple and in many cases will enable easily portable apparatus to be used. With full realization that these possibilities exist, it remains for the techniques to be demonstrated to those who would use them. Cheap and simple apparatus is the prerequisite of success. Sophistication and efficiency may follow in time, hopefully spurred on by a renewed research interest in this field.

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AVERAGE INTENSITY–DURATION CURVES AND THE ESTIMATION OF PRECIPITATION IN NAIROBI

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Abstract
In this study an average intensity–duration curve, for the Nairobi area, for rainfalls with flooding capabilities, is developed.

$$i = 40t^{-0.647}$$

where i = average intensity of precipitation in mm/h;
t = duration of precipitation in hours. The equation is developed by means of regression analysis in which the correlation coefficient, the standard errors, standard deviations and the significance tests are carried out.

Introduction
Rainfall data are greatly needed, particularly the time profiles by the design engineers of heavy showers that create flood conditions. There have been attempts to find out the relationship between rainfall intensity and time by McCallum (1959) and some similar studies on rainfall were made by Brazell (1953) and Holland (1967). The prediction of probable maximum rainfall over the East African region, in a very general way, was attempted by Sansom (1953) and Lumb (1971). These attempts do not meet the requirements of a design engineer for Nairobi.

The objective of this work is to establish a mean model for intensity duration curves for all maximum rains, referred to as storms, that have so far occurred in the Nairobi area between the years 1960 and 1976. Statistical analysis is used to arrive at the model. This model is also verified with recent rainfall data of 1977. This model is applicable only for storms of two or more hours duration. However, it is unlikely that rainfall of less than two hours would cause any serious flooding.

Data, method and discussion
The self-recording rain-gauge data for 1960 to 1976 for three stations, namely Wilson Airport, Embakasi Airport and Dagoretti Corner, are used in the study. Rainfall with probable flooding capabilities, that is, rainfall of about 80 mm occurring in a relatively short time with no break, is selected. A total of 16 significant rainfall episodes of this type is obtained. It can be seen that the three

stations are of nearly the same geographical conditions and are close together, so that a storm affecting one is likely to affect the other two.

The intensity-duration curves are hyperbolic in shape; the intensity i is proportional to the reciprocal of the duration. A general form of this equation is

$$i = kF^x/(t+b)^n \qquad (1)$$

where i is the intensity in mm per hour,
t is the rainfall duration in hours,
f is the frequency of such rainfall, and
k, b, n and x are the constants to be determined for the Nairobi area. As there were 16 storm episodes in 16 years, the frequency of such rainfall episodes is one per year. Equation 1 could be expressed as:

$$i = zk/(t+b)^n. \qquad (2)$$

By trail and error approach the best value for $b = 0$; hence the above equation could be expressed as

$$i = k/t^n. \qquad (3)$$

This is a general curve. An average curve which can fit the 16 cases is determined with the help of statistical analysis (Nyendwa 1977). The relation is linearized by transformation into a logarithmic relation. And by regression analysis the following equation is obtained:

$$i = 40/t^{0.647}. \qquad (4)$$

McCallum (1959) in his analysis of different places in East Africa obtained indices for t varying between 0.55 and 0.85. His work involves analysis of individual rainfalls. However, his work shows how the index for t varies from place to place. Equation 4 helps us to correctly estimate the rainfall over Nairobi.

P, the total precipitation or accumulated rainfall during the time t, could be estimated by integrating i over the total duration. Since i is a function of t and t is an average value between two limits, i and t could be taken out of the integral.

Therefore, $P = it = 40t^{0.353}$. (5)

Equation 5 is verified using independent data of rainfall collected at Embakasi Airport during April 1977. A good agreement between the computed and measured rainfall is found.

Conclusions

This model is especially good for rainfalls of over 80 mm of a duration between 5 to 12 hours. It is unlikely that rainfall of duration over 15 hours will be storm rainfall but will rather be of very low intensity not likely to cause flooding. This model, in most cases, gives an overestimate for rainfall less than 80 mm and for long duration. This overestimate is better in certain hydrological designs.

It is to be noted that for rainfall that causes flooding, the standard deviation which is computed to be 1 65 is to be added to the intensity i. For rainfall that does not cause flooding the intensity i is to be used as it is. In cases where the rainfall is less intense, the standard deviation, 1.65, is to be substracted from the intensity *i* for better estimates. Thus the model has the capability of estimating for different types of rainfall.

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THE POTENTIAL OF DEW MAKING AS A SOURCE OF WATER

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Abstract
This paper examines the processes involved in the formation of dew and methods of its collection and measurement. Dew as a source of water is examined. Potential experiments with (1) endothermic chemicals, (2) spraying of typical manures and (3) increased surface areas are described as possible artificial methods for increasing dew formation. The importance of this artificial dew making in dry farming areas and the mitigation of drought conditions are pointed out.

Introduction
Rain water or irrigation are the main sources of water in most agricultural processes today. It is found that naturally occurring vegetation in most parts of the world depends neither on rainwater or groundwater, but on other sources like dew, fog and mist. Though the estimated maximum amount of dew that could fall during a night is only a few millimetres, its benefit to plants is direct, maximum and without any waste. In most plants, the amount of water received from dew will be quite adequate for its growth and survival, even though people tend to overlook dew as a possible source of water, particularly for plant growth, because of its formation during night time.

Interest in dew as a water resource started at the beginning of the century (Hubbard and Hubbard 1905; Martin 1910). Some of the studies are of a quantitative nature as reported by Went (1955) and Chang (1968). Muller (1968) examined the dew formation in terms of negative heat balance of the surface, though the equations discussed by him are unrealistic and complicated.

Process of formation
Before the formation of dew is examined, one has to define 'dew'. It is the deposit of water on the earth's surface, either covered with vegetation or not, as a result of meteorological processes within the surface laminar boundary layer (a few metres of atmosphere above the earth's surface). This process is related to the condensation of water vapour on and near the earth's surface and is distinctly different from collection of water drops either by distillation of soil or exudation from leaves by guttation.

During the night, the surface laminar boundary layer develops into a static layer within 1 m or so from the ground. This layer of air will have minimum temperature usually during the night and there will be no convection in it. The heat transfer takes place in this layer mostly by conduction and radiation. The layer above this is the dynamic layer, in which the heat transfer is mostly by radiation, convection and eddies. When the atmospheric moisture is sufficiently high, and the sky is not fully covered with clouds, the heat losses from the surface will be sufficiently high so that the temperature will be below the dew point and the excess water vapour within the static surface is given out to the surface of the earth. These nocturnal radiation losses also result in the formation of tiny water drops on the aerosols of the layer, just above the static layer. When the wind speed is moderate, the eddies will be existing in this dynamic layer. These eddies bring down the tiny drops to the surface. Some droplets gravitate down as they grow to sufficiently large sizes due to collision and coalescence. These drops of the dynamic layer are also collected as dew on the surface. As some of the drops are being forced down there will be adiabatic compression. This raises the temperature, though this is normally small and does not affect evaporation. The total condensed water thus collected on the earth's surface as a result of these processes is called 'dew'.

From the above descriptions, one can appreciate that the conditions for the formation of dew need not be a 'moist, calm and clear night', as is generally believed. Even when the sky is partly covered with clouds there could be sufficient radiative loss from the earth's surface and the lower levels of the atmosphere to such an extent that the temperatures could fall below the dew point and there could be sustained condensation of water vapour. It is also wrongly believed that clear air conditions are essential. The presence of sufficient concentrations of aerosols in the dynamic layer enables the condensation of atmospheric water vapour. The droplets so formed are collected at the surface through the eddy motion in these layers. The dew that is collected could never be pure (though it is generally believed to be pure water) but is polluted because of the presence of dissolved and undissolved condensation nuclei floating in these layers (Patnaik 1974). The light winds help the collection of these floating condensing particles. With strong winds, the eddy circulation is destroyed and the static layer is disturbed. Thus the conditions helping dew formation and collection are destroyed. There may also be strong evaporation removing the dew that is already collected. Thus light winds help in the formation of dew in large amounts.

Collection and measurement

Though the amount of dew collected per night over arid regions is very small, when collected over a surface of a 1 m^2, the quantity of dew is about 1 litre. Boyko (1955) has gathered evidence to show that in ancient days stones and gravel might have been used to trap dew. By constructing large funnels of various sizes, supported about 1 m above the ground, Arvidson and Hellström (1955) have collected about 0.4 litres per 1 m^2. On a green coloured plastic sheet of 1 m^2, the author (Patnaik 1970) has collected about 0.5–0.6 litres of dew per night.

The measurement of dew is very difficult. Presently there are not instruments capable of measuring the amount of the dew correctly. The difficulties are: (1) there would always be considerable loss of dew through evaporation; (2) the measuring area of the instrument would always be different from the natural area on which dew is collected, hence there could be certain variations in the dew amounts measured from that of the natural surface conditions. Basically, there are three methods of measurement: (1) to expose dry preweighed plates of hygroscopic material, like gypsum or silica, during the night; the increase in weight gives the amount of dew deposited; (2) to weigh the dew deposited on a suitably exposed plate of a recording sensitive balance; (3) to use a dew gauge devised by Duvdevani (1947). This gauge consists of a rectangular wooden block 12½″ × 2″ × 1″ with coats of a special red paint whose surface tension characteristics in relation to water ensure the formation of dew in characteristics drops. The size, form and distribution of the drops of dew that appear on the upper surface of the block the next morning could be compared to a series of standard, full-scale photographs of the surface of the block covered with a known weight of dew. Thus the dew amounts are estimated. Though the instrument is simple and robust, the measurements are always less than the true amounts of dew. A device that could measure dew correctly, in every sense, is yet to be developed. However, a good estimate of the amount of dew can be obtained by the methods used for measuring evaporation where the formation of dew appears as negative evaporation. These methods are, however, not as yet simple enough for routine use.

Dew as a source of water is very important in arid and semi-arid areas. A large pan, made of stone or clay, with many sharp projections over its entire area, with a central water collecting hole is a most efficient 'dew pan'. The material of the pan has high heat capacity and the colour of the material is to allow maximum nocturnal cooling. These pans are being developed.

Artificial dew

Generally, the amount of dew at a place is about 1 mm. It is possible to increase its formation many times by suitably controlling the conditions of its formation, both at the surface and in the laminar layer of the atmosphere (Patnaik 1973a, b). (1) The plants should be treated with a chemical like potassium nitrate which acts as manure and also lowers the surface temperature further. Surface temperature is lowered because while the nitrate dissolves in dew as a result of its endothermic property, the surface temperature decreases further. This enables the removal of more precipitable water and hence the formation of more dew. (2) The formation of dew increases if the lower levels of the atmosphere are sprayed at an appropriate time, because this spray acts as a condensation nucleus for the formation of fog and dew droplets. These then reach the surface and add to the dew amounts. (3) A few fine plastic nets of green colour should be fixed at 10, 15, 20 and 25 cm from the ground level. The dew is collected on all the nets. The total amount, in this case, is many times more than what is normally measured on the normal surface. Thus by suitable techniques the amounts of dew formed could be augmented. These methods are efficient and could be adopted locally and they compare favourably with artificial rainmaking methods.

Conclusions

The formation of dew is not properly understood. Generally, the amounts are underestimated. In the areas of drought and during the arid conditions, the plants take dewwater straight. The artificial increase of dew formation is very useful in these cases. Collection of dew by 'dew pan' also helps to solve the water problem to some extent. However, much is to be done in understanding the processes of dew formation and the possibilities of artificial methods for its increase.

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ASSESSMENT OF GROUNDWATER IN THE NAIROBI AREA

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Abstract
The assessment of groundwater in the Nairobi area was executed during the UNDP/WHO/NCC–SF Sewerage and Groundwater Survey carried out in Nairobi between 1972 and May 1975. The survey was financed jointly by UNDP and the Nairobi City Council and was supervised by WHO who had been designated as the executing agency. Sweco, a Swedish consulting firm, was appointed by WHO to carry out the survey. The Nairobi City Council seconded five engineers including a project co-manager and semi-professional staff to the project. The purpose of carrying out studies on groundwater was to find out if groundwater could be utilized as a supplementary source of water for Nairobi. The finding of a substantial quantity of water could postpone the construction of Chania II project estimated to cost $50 million, part of which would be loaned by the World Bank. Moreover in 1973–1974 when a water shortage was foreseen it was requested to find out the practicability of incorporating the groundwater into the Council's water system.

The study which took more than 2 years was carried out in two stages. During the first stage all the existing data and the available reports were evaluated. A few measurements were also taken during this time. This stage of the study recommended a drilling programme along a 12 km line in the Kabete area and 14 km line along the Gigiri area. During the second stage of the survey drilling of 18 boreholes was carried out so as to locate well fields and determine the usable water quantities in these areas. The production costs of water in the two areas investigated was found to be higher than the cost of water from Chania II project. A rough estimate of the water production cost in a third area showed better results. A comprehensive investigation would however have to be carried out before any major recommendations could be given.

Introduction
The government of Kenya originally requested UNDP assistance in 1968 for the preparation of master-plan studies for water supply, sewerage, solid wastes and drainage for Nairobi and Kisumu. In the beginning of 1969, the first revision of the request was prepared deleting the study for Kisumu. Yet in another request dated May 1970, the studies for water supply were left out. The groundwater study was one of the technical studies included in the request.

The scope of the study was widened after the first few revisions of the request and was even later on extended to cover the implementation of the recommendations given in the preliminary survey.

Funds for the Nairobi master plan for sewerage and groundwater survey were provided jointly by the UNDP and the Nairobi City Council. WHO was designated as the executing agency for the project while the City Council of Nairobi was designated as the cooperating agency. The project known as the UNDP/WHO/NCC–SF Sewerage and Groundwater Survey was started in August 1972 under a project manager appointed by WHO and was completed in 1975. Professional staff were supplied by the Nairobi City Council. Before Sweco, the consulting firm appointed by WHO, started its studies, a lot of the existing data and reports needed for the project had already been collected by the counterpart engineers. Other reports prepared by the project team included leakage of the Nairobi water distribution system, infiltration into sewers, utilization of sewage effluent for irrigation, solid wastes, etc.

Scope of the study

When the original request for assistance was made to UNDP for the preparation of the master plan for water supply and sewerage in Nairobi and Kisumu, the government of Kenya had already applied for a loan from the World Bank to finance the first stage of the Chania Water Supply Scheme. It was felt essential at this time to evaluate the potential of groundwater in the Nairobi area as a supplementary source of water supply for the city. Furthermore, the World Bank, who are going to partly finance the Chania II project expected to commence in 1979, were interested to find out the prospects of groundwater as a marginal source for water supply to the city. A postponement of this scheme estimated at about $50 million would mean postponement of investment and consequently savings in interest charges. Groundwater would however have to be found in substantial quantities and at reasonable cost. Besides, in late 1972, when the groundwater study was in progress, a water shortage was foreseen in Nairobi for 1973–1974. A request was made to determine the practicability of the incorporation of the groundwater into the existing water supply system.

The groundwater study was carried out in two stages, firstly under the supervision of a Sweco hydrologist ending with a report in March 1974, and secondly under the supervision of a Scandiaconsult international hydrologist. This paper has been based on the two reports above and deals briefly with the steps taken and the methods adopted to assess the groundwater potential in the Nairobi area.

Collection of borehole data

All the borehole data needed for the preliminary studies were collected from the Ministry of Water Development which maintains records of all water boreholes drilled in Kenya. Records go back to 1927 and are available in computer print-outs.

Study of previous reports on groundwater

As part of the preliminary groundwater studies, all the available reports on groundwater in the Nairobi area, some dating more than 20 years, were reviewed. The conclusion and recommendations made by the previous investigators and the results of their work were very much appreciated and were fully incorporated in the reports.

Results from the study of previous reports

The study of previous reports on groundwater revealed the following facts:

1. Whiston (1953) clarified the general picture of the aquifer in the Athi River drainage area (see fig. 1). According to Whiston, lake beds are the most important aquifers in the area but although he tried hard to investigate, the recharge quantity and source remained unclarified. Another of his important findings was the existence of a dry weather flow in the rivers traversing Nairobi which increases to a certain maximum line west of Nairobi and then decreases. The conclusion drawn from this was that there must be discharge from shallow aquifers into the rivers and probably also some recharge into the lake beds aquifer from the riverflow downstream of the maximum flow line.

2. Gevaerts (1970) updated the hydrogeology of the Nairobi area, an area covering 6 200 km². Gevaerts has divided the area into 12 subareas depending on the occurrence of the main groundwater supply. He came to the conclusion that about 85% of all the groundwater extraction originates from the Upper Athi Series, a formation which was referred to by Whiston as the Lake Beds. Gevaerts also carried out analysis of water rest levels from a number of boreholes He found no depletion of boreholes due to overdraft of the groundwater. In his investigations he found out that the quality of groundwater was good except for its fluoride content which is over 1.5 mg/l for a major part of the area.

3. From a report on the Nairobi Conservation Area by Chilton (1970), the estimated groundwater abstraction was found to be 14 900 m^3/day. Some aquifer parameters, namely the specific capacity, storage coefficient and the transmissivity, were also calculated from borehole pumping tests in some areas. The results showed the specific capacity to increase from west to east, an effect he attributed to the increasing penetration of the aquifer. During the survey, water samples from 40 boreholes were analysed. The results revealed that shallow boreholes had low fluoride content while deeper boreholes showed higher fluoride content. The amounts of dissolved minerals were also found to increase from west to east.

4. The relationship between precipitation and water table in the Nairobi conservation area has been studied by J. Kigoni (1972, B.Sc. degree report—University of Nairobi). His report contains computation of the average monthly

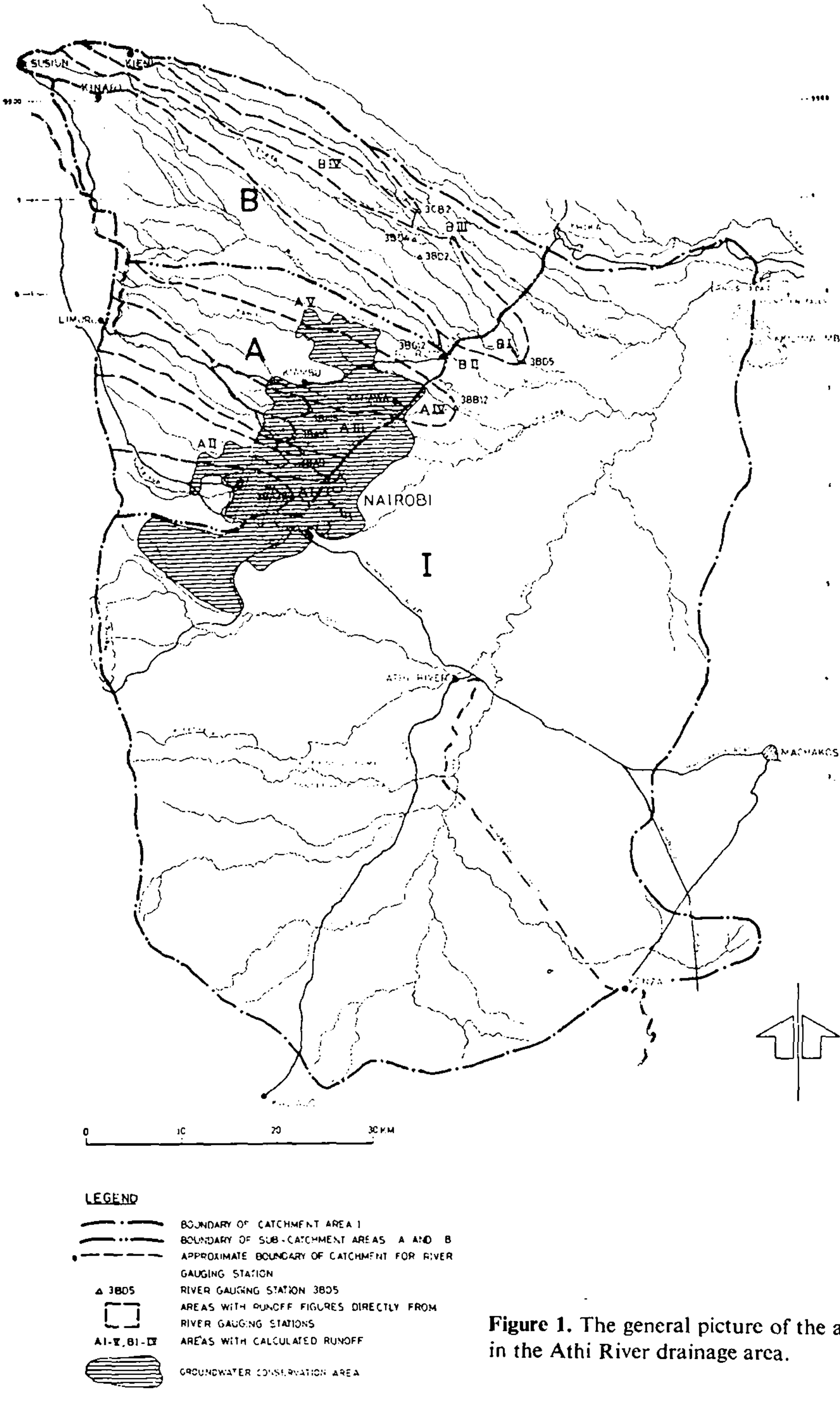


Figure 1. The general picture of the aquifer in the Athi River drainage area.

precipitation over an area 1 800 km^2 for the years 1962–1969. Kigoni found that the rainfall peaks did not correspond to peak rises of the groundwater table except in a small, western part of the conservation area. There, a clear relationship exists, with the groundwater table rising with a delay of 2 months after the peak rains. The groundwater table is thought to be free here which would explain the direct recharge.

5. In 1972, Gaita, one of the counterpart engineers seconded to the project, studied the fluoride content of 57 water samples taken from different boreholes all over the conservation area. The study revealed that the fluoride content varied from 0 to 25 mg/l although 10 mg/l was rare.

Reference was made to the United States Public Health Service drinking water standards and the conclusions thereof were that the optimum fluoride content in Nairobi (temperature 25°C) is 0.8 mg/l and the maximum allowable content 1.5 mg/l. From his 57 samples, 16 samples had a fluoride content of less than 0.9 mg/l and 34 samples greater than 1.5 mg/l. Hence using the above criterion, the bulk of Nairobi borehole water is not recommended for drinking unless defluoridation of the water is carried out.

Preliminary assessment of groundwater

The first step in assessing the groundwater resources involved as described above, the collection and evaluation of all the available hydrological and geological data, borehole logs and the chemical analysis of the groundwater. The data for the Nairobi area were compiled and detailed maps were prepared to show the location of boreholes, their yields, the fluoride contents, water rest levels, etc.

From the basic data obtained a map showing the boundary of Nairobi aquifer was also prepared (fig. 2). The area of the aquifer was calculated to be 1 800 km^2. The altitude varied from 2 700 m on the west to about 1 400 m on the east. The depth of the aquifer was also assessed from the borehole details available. One borehole at Nairobi Railway Station showed a depth of 460 m before reaching the basement rock with an increase of the aquifer depth towards the west and a decrease of the aquifer towards the east. To locate the direction of flow of the groundwater in the above area, pressure contour lines were plotted on a map on the basis of water rest level readings in borehole all over the area. The pressure contour map indicated nearly that the direction of flow of groundwater is from west to east and more or less parallel to the direction of flow of rivers in the area. The direction of flow however changes in the eastern part of the aquifer towards the discharge point at Fourteen Falls.

After all the above information was obtained and studied, a water balance study for the Upper Athi River catchment area at Fourteen Falls and at two smaller areas that were parts of the main catchment area (fig. 1) was carried out. The purpose of this study was to assess the groundwater potential in the entire area, taking into account rainfall over the area, the evapotranspiration losses, etc. Fourteen Falls was chosen because the groundwater flow was considered to converge at this point and to pass through a 1.5 km wide and very shallow section of the aquifer where the basement rocks form the base and sides for the outcropping water bearing formations. The groundwater was supposed to discharge into the river just upstream of Fourteen Falls.

Surface water flow measurements during dry weather flow periods and a gauging station RGS 3 DA 2 about 10 km further upstream of the falls had strengthened the theory of groundwater discharge into the river. The water balance study led to the conclusion that the quantity of groundwater available in the Nairobi area is in the order of 240 000 m^3 per day. At the time the study was conducted only 16 000 m^3 of groundwater per day was being abstracted.

Further investigations revealed that the usable groundwater in the Nairobi area was only about 150 000 m^3 per day or about 10 times the existing abstraction. It should be noted here that these figures are subject to errors originating from available data, assumed figures where data were missing, and errors in the applied methods.

Artificial recharge possibilities of the Nairobi area aquifers

Artificial recharge may be undertaken to replenish aquifers with insufficient groundwater. This may be done by injecting surface water (raw) into the aquifer by gravity. Possibilities of artificial recharge in the vicinity of Nairobi area were found not very good due to the following reasons:

1. The surface water usually has very high turbidity at high flow when optimum conditions for infiltration are prevailing.
2. The confined and semi-confined aquifers have very low storage coefficients.
3. The multi-layered aquifer in the area has a low permeability coefficient.

Possibilities of defluoridation of the Nairobi groundwater

Another aspect of the groundwater investigated was the possibility of defluoridation. From the previous studies, the concentration of fluorides in the groundwater in the area varies between 0.2 and 25 mg/l, but falls mainly in the range 0.5 to 1.5 mg/l, or in the higher range 5 to 12 mg/l. According to the International Standards for Drinking Water (WHO Geneva 1971) the recommended control limits for fluorides in drinking water are 0.7 to 1.0 mg/l taking into account that the annual average of maximum daily air temperature is 25°C. In previous editions of these standards 1.5 mg/l was suggested as the maximum allowable level above which trouble may arise (mottled teeth). Various methods that could be used were examined. Blending of the groundwater with the city water was found a possibility. Fluoride removal by means of the ion exchange methods using either activated alumina, bone char or "Defluoron 2" was also considered. The recommendation was that a pilot plant using samples of the actual water to be treated would be necessary in order to determine the best media and the processes to be used.

Recommendations of the preliminary groundwater survey

On the basis of the review of the previous studies, investigations and calculations, it was concluded that the potential of groundwater in the Nairobi area was several times the existing abstraction. It was recommended that test wells be drilled along a 12 km line in the Kabete area and 14 km line in the Gigiri area in order to identify and locate optimum well fields, estimate the groundwater potential and usable capacity available in these areas and to prepare input data for a preliminary engineering analysis cost estimate.

Execution of the drilling programme

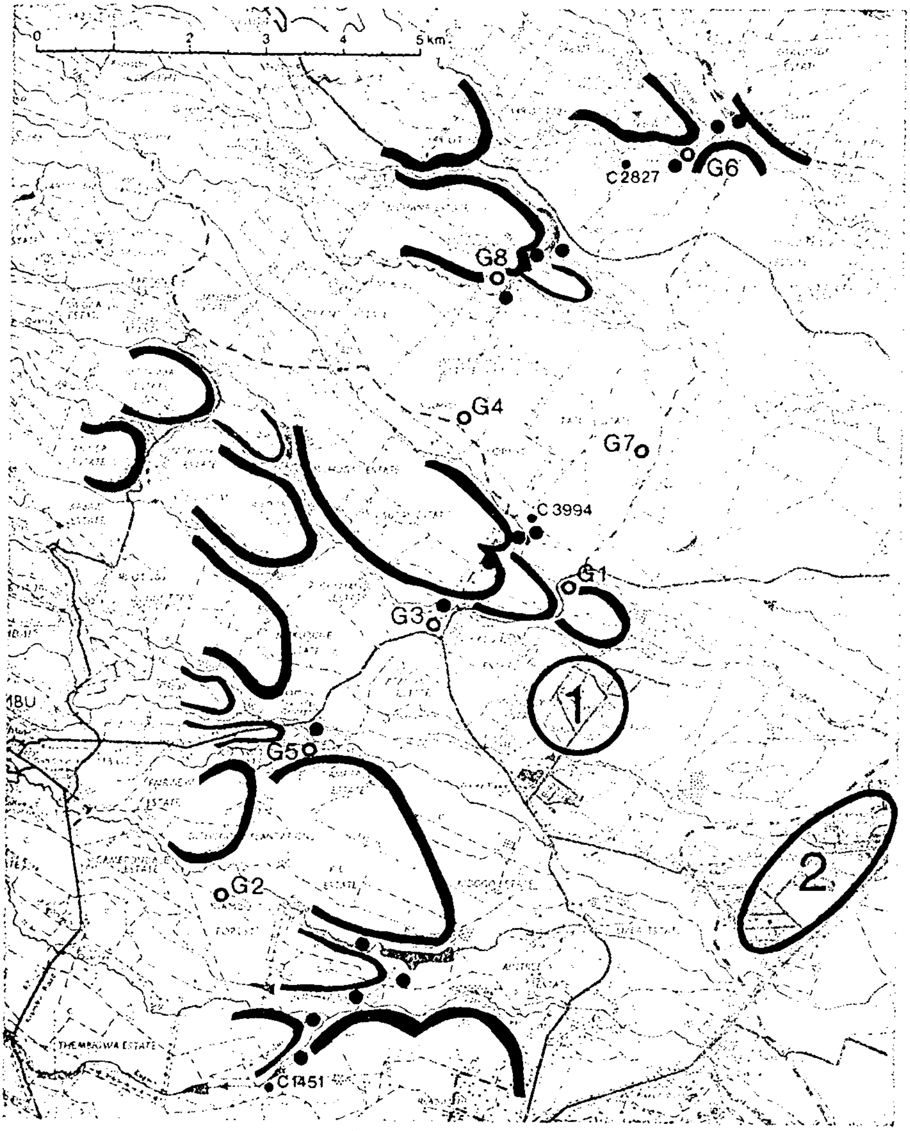
It was initially intended to sink 5 production and 5 observation wells in each of the two areas but due to previous unsatisfactory results in the programme in the Kabete line only 4 production and 2 observation wells were drilled along this line. Eight production and 4 observation wells were drilled in the Gigiri line. Drilling of the boreholes started in February 1974 along the Kabete line by the contractor Craelius Terratest East Africa Ltd with two percussion cable tool rigs. Production boreholes were drilled to a diameter of 250 mm but at greater depth this was reduced to 100 mm. Observation boreholes were on the other hand sunk with a diameter of 200 mm to a depth of about 10 m and thereafter with 150 mm diameter. In some of the boreholes GO2, GO3, GO4–1 and GO4–2 (see fig. 2) piezometers were inserted in order to measure the pressure in the confined aquifers separately. Rock samples were collected at every 1.5 m depth at every borehole during the drilling. The samples were washed, dried and taken to the Ministry of Water Development for logging.

Test pumping of the boreholes was carried out with a view to:

— Investigating any relationship between yield and borehole depth.
— Investigating any relationship between water quality, borehole depth and rate of pumping.
— Determining the transmissivity (T).
— Estimating the maximum borehole capacity at the steady state conditions of the respective boreholes.

Testing the borehole yield was carried out with either a bailer, piston pump or a submersible pump. A bailer was used only when the first aquifer was struck to determine if it was worthwhile to use a piston pump.

Some boreholes were test pumped at a constant rate for say 6–8 h and then the recovery was measured. This was found necessary in the determination of transmissivity. In places where both production and test wells existed both the constant rate pumping and the step draw down tests were carried out. Water level changes in the observation wells were noted during pumping and recovery by using an electric dipper. The yield was measured by means of a 227 litre barrel and a stop-watch and also a water meter installed about 2 m from the outlet. Adjustments of the yield were made by means of a valve on the outlet pipe. After the evaluation of the test pumping results of the boreholes GWS 2,



• C 2827 Existing borehole (WD-number)

o G 2 Investigated borehole site number 2 in the Gigiri Line

● Proposed new borehole in the Gigiri Line

Contour of lava front

(1) (2) Position of larger groundwater supplies

Figure 2. The Nairobi aquifer and borehole locations in the Gigiri line.

GWS3, and GWS4, all of which had observation wells, it was considered that sufficient information had been achieved, especially with respect to transmissivity.

The remaining funds were therefore utilized in sinking more production wells to identify new well fields and the carrying out of proper test pumping for these wells. Test pumping of up to 121 hours duration were carried out. Water samples were taken from each borehole at every new aquifer and also at the end of each step of test pumping. Special attention was given to fluoride, iron and manganese, all of which were higher than allowable in most of the wells.

Results of the drilling programme

From the loggings of all the samples, trachytes were found to prevail in the Kabete line while tuffs, welded tuffs and agglomerates prevail in the Gigiri line. Phonolitic rocks were struck in borehole KO 1 only at the Kabete water treatment works. Clays were found at the bottom of most of the boreholes and a depth of 12 m was recorded at the Kamiti corner between 194 and 206 m in borehole GWS3. Values of transmissivities of the different aquifers along the Gigiri line were found to be between 3 and 92 m^3/day.

The Theis and Jacobs methods were used for the calculations but it is doubtful if the methodology was the best due to the nature of the aquifers. Values of the permeability obtained fall between 1×10^{-5} and 1×10^{-6} m^3/s, which is quite low.

Conclusion of the study

1. *Kabete line*—Boreholes in this area can only yield between 100 and 200 m^3/day (1000–2000 gph). High values of fluoride up to 20 mg/litre can be expected. The groundwater potential in this area was estimated at 1 800–2 200 m^3/day from a total of 12 boreholes. Due to the poor yield of the boreholes in this area and the high fluoride content it was not considered practicable to utilize the groundwater as a source for Nairobi City's water supply.

2. *Gigiri line*—The best well fields were found to be between the Kamiti and Kianjibe river valleys where 5 well fields would yield about 5 000 m^3/day. The expected fluoride content of the mixed water from all well fields would be in the order of 2 mg/l. Both iron and manganese were found to be high. Concentrations of up to 0.8 and 2.4 mg/l iron and manganese respectively were encountered in some of the boreholes. Removal of these two would be required before mixing the water with the city water. From a cost estimate prepared for the proposed well systems in this area the production water cost of the Gigiri water at the price prevailing in 1975 was found to be sh 2.25/m^3 compared to about sh 0.80 for the surface water from the existing water sources and Mid Chania Phase II. The groundwater potential was therefore considered unfavourable and the water too expensive.

Table 1. Estimated borehole capacity at steady state conditions (test pumping 24–121 hours)

Borehole	Date (1974)	Hours pumped	Yield at end of test pump gph	gph	Estimated capacity m^3/d	l/s
KWS1	3 Apr.	24	1 500	1 500	160	1.9
KO1	...	...	...	1 000	110	1.3
KO3	21 May	1.3	690	500	50	0.6
KWS4	9 Sept.	48	2 800	2 500	270	3.2
KO4	...	...	...			
KWS5	3 July	24	2 000	2 000	220	2.5
GWS1	7 Oct.	58	2 600	2 000	220	2.5
GWS2	13 Aug.	92	4 000	3 000	330	3.8
GWS3	1 Nov.	121	7 200	6 500	710	8.2
GO3	...	...				
GO2	11 June	1	855		(sand in pump)	
GWS4	23 Aug.	72	3 300	30 000	330	3.8
GO4–1	5 June	2	1 700	?		
GO4–2	13 June	24	2 700	2 700	300	3.4
GWS5	8 Nov.	72	4 500	3 500	380	4.4
GWS6	19 Nov.	72	4 000	3 500	380	4.4
GWS7	1 Dec.	74	4 000	2 500	270	3.2
GWS8	13 Dec.	95	4 300	3 000	330	3.8

3. *Kikuyu–Limuru area*—Following discussions during a WHO review mission in July 1974, a request was made to investigate this area as a possible source of water for Nairobi. A rough estimate of the groundwater potential based on the dry weather flow in the rivers and the Kikuyu Springs was given as 8 500–17 000 m^3/day. Boreholes in this area were estimated to yield an average of 300 m^3/day. No drilling was carried out during the entire drilling programme but this area was proposed for a future groundwater investigation. The proposed area covers a strip of land between Dagoretti Forest and Limuru measuring about 5–6 km by 20 km long. The fluoride content of the water is usually below 1.1 mg/l. An estimate of the cost for the drilling including test pumping was about sh 2.50 at the 1974 prices. The drilling programme would take 1½ to 2 years. The cost of production of water from this area was found to be either sh 1 05 or sh 1 45 depending on whether iron and manganese are removed from the water or not. Taking the lower figure it seems that it would be economical to exploit the groundwater in this area for incorporation into the city water supply. However, comprehensive investigations are first required before final recommendations are made. Nairobi would also need to be given priority in this area.

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GROUNDWATER RESEARCH IN THE TAITA HILLS: A PRELIMINARY REPORT

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Abstract
The Taita Hills in SE Kenya abruptly rise up to 1 500–2 000 m from the surrounding peneplains (alt. 600–800 m). The hills are important raincatchers with annual precipitation of over 1 500 mm (against 500 mm on the plains). Rainfall and run-off data for the aıea are inadequate. Due to steep relief run-off is very high.

The hydrogeology of the area requires non-conventional approaches because of the complex structures of the metamorphic Basement rocks in the hills, which differ from the Precambrian system to which they belong. Porosity and permeability are very variable and will have to be estimated through alternative methods. The usual geophysical prospecting methods for groundwater might fail in certain areas. In addition, the discontinuous character of aquifers adds to the complexity of groundwater exploration in the Taita Hills.

Introduction
The Taita Hills, which are situated west of Voi, cover an area of about 700 km². They rise abruptly to altitudes of 1 500 to 2 200 m, from peneplains which lie between 600 and 800 m above sea level. The hills consist mainly of metamorphosed sedimentary rocks of Precambrian age and are an erosion residual mountain complex which remained relatively untouched by the pre- and sub-Miocene peneplanation processes which levelled most of the surrounding landscape.

Due to their sudden high altitude the Taita Hills catch a year-round bimodal precipitation of between 1 200 and 1 500 mm annually, as compared to the surrounding semi-arid peneplains with only 400 to 600 mm. Because of these favourable rainfall conditions the Taita Hills are densely populated by the Wataita people. Increasing population pressure, combined with subsequent agricultural practices, cause ever-increasing soil erosion problems, which in turn adversely affect the groundwater regime in the area.

In 1975/76 a team of the joint Kenya-Austria Mineral Exploration Project (Mines and Geological Department, Ministry of Natural Resources, and Austromineral) carried out the geological mapping and mineral resources investigation of the 1:50 000 sheet 189/4, Taita Hills. In 1976 the Kenya government requested a groundwater exploration project as a follow-up to the geological work done by the team. The present paper represents a first attempt to evaluate the groundwater situation in the Taita Hills and, in addition, indicates some of the fields for further investigations and research.

Precipitation, evaporation and run-off

Precipitation

Due to their high altitudes the Taita Hills catch much precipitation from the humid air masses which move inland from the coast with prevailing winds between east and south. Average annual rainfall on the surrounding semi-arid peneplains is between 400 and 600 mm. In the hills the year-round precipitation, made up of rain and mist drip in the highest parts, amounts to a considerable 1 200–1 500 mm or more. The rainfall is bimodal, both in the hills and on the plains, with peaks around April and November (fig. 1). Important variations in total rainfall for certain years or groups of years tend to occur equally and simultaneously in the hills and on the plains (fig. 2).

The rainfall pattern within the hills is very irregular. Although a general increase in precipitation occurs with higher altitude (fig. 3), the east and south facing slopes and peaks attract far more rain than the western and northern parts at the same altitude. This is a rain shadow effect, resulting from orographic factors and prevailing wind directions, which explains the low rainfall in Maktau, station 6 in figure 3.

Efforts to analyse the rainfall pattern in the Taita Hills immediately prove the inadequacy of the rainfall data since the older rainfall stations were situated mainly in the zones of higher rainfall. Only recently (1975–1976) the Water Department of the Ministry of Water Development has increased the number of rain gauges in the Taita Hills, as part of a water conservation programme. The lack of sufficient reliable long-term rainfall data, combined with the complexity of the rainfall distribution pattern within the hills, make it impossible to draw an accurate detailed isohyets map of the area.

Evaporation

Much scarcer than the rainfall data is the information on evapotranspiration in the area. Figures from open evaporation pans are available for short periods of observations from Voi and Wundanyi only, with the following results:

VOI: alt. 560 m, aver. evaporation: 2 550.8 mm/year

WUNDANYI: alt. 1 465 m, aver. evaporation: 1 294.3 mm/year

Transferring evaporation data into evapotranspiration figures is a rather doubtful method, but extrapolation of these values to other areas of the mountainous region will produce results of even lower reliability.

Run-off

Data on run-off in the area were non-existent until 1976, when the Water Department, again in the framework of its water conservation programme in the Taita Hills, installed six staff gauges in some of the main rivers of the area.

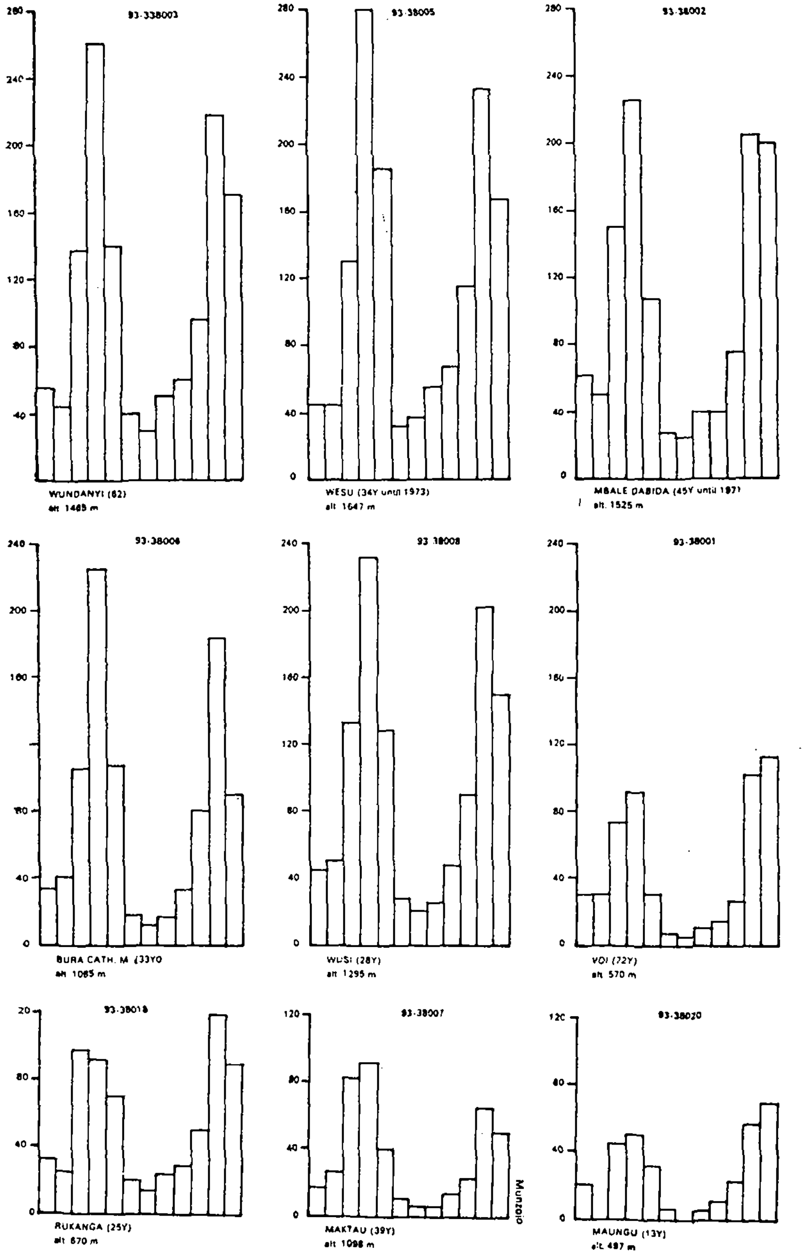

Figure 1. Bimodal precipitation histograms of nine stations in and near Taita Hills.

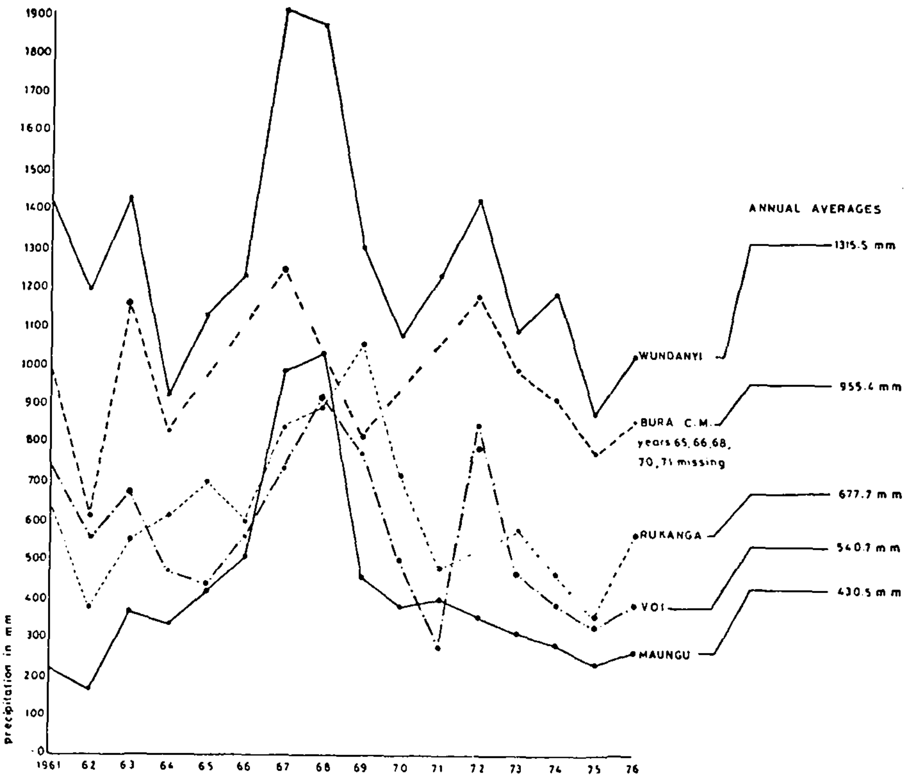

Figure 2. Annual rainfall for period 1961–1976 for five stations in and near Taita Hills.

However, no useful data are available yet. Only one staff gauge existed outside the hills, in the Voi River at Voi where it has not perennial surface flow.

Due to the strong relief the drainage network has steep gradients, thus run-off is very high. Only the higher parts and certain forest reserves are still covered with good forest (often the original mist forest) which slows down run-off and increases infiltration rate, thus contributing to groundwater recharge and maintaining a base flow in the drainage network. However, much of the forest has been cleared and poor agricultural practices have ruined the top soil and caused severe soil erosion with violent run-off, near-to-zero infiltration and no remaining base flow. Within rainstorms the run-off dashes down the valleys in flash floods which make the computation of river discharges possible only if during the whole flood all water level changes have been properly recorded, preferably by a self-registering gauge. These instruments are not available in the area and the once or twice daily readings of the staff gauges are bound to miss the short flash floods which represent nearly the only and certainly the main discharges of most streams in the Taita Hills.

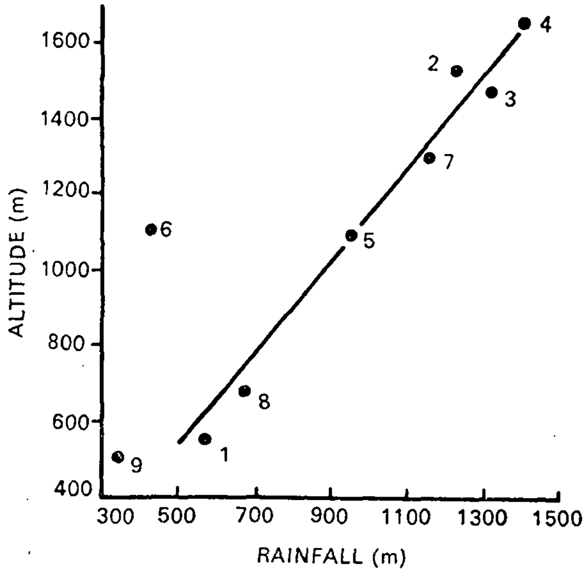

Figure 3. Increase of rainfall with altitude. 1 = Voi, 2 = Mbale Dabida, 3 = Wundanyi, 4 = Wesu, 5 = Bura, 6 = Maktau, 7 = Wusi, 8 = Rukanga, 9 = Maungu.

Geology, geomorphology and soils

Geology

The whole area of the Taita Hills consists of or is underlain by Precambrian metamorphites of the Basement System or Mozambique Belt, which is a zone of metamorphic rocks extending some 5 000 km from Mozambique northwards to Ethiopia. In many places these Basement rocks are covered by residual and colluvial soils, young sediments or slope deposits.

Lithologically the metamorphic rocks in the Taita Hills belong to two different series. The northern part is dominated by quartz-feldspar gneisses and associated amphibolites which are para-metamorphites of psammitic and semi-pelitic origin. In the southern part marbles, biotite-amphibole gneisses and schists prevail, revealing a calcareous and more pelitic origin of the present rocks. The northern and southern parts are separated by an intermittent zone of small ultramafic intrusions, which are thought to belong to and represent a regional upthrust plane. The rocks north of the upthrust plane are less intensively metamorphosed than the southern ones which show higher degrees of mineralization with the presence of kyanite, sillimanite and graphite.

The Taita Hills rocks show intense pegmatoid veining, mainly coarse-grained quartzo-feldspatic rocks. Most are veins of anatectic origin, which are crosscutting the foliage. However, there are also real magmatic intrusion pegmatites, which are segregation bodies, conformable to the foliation.

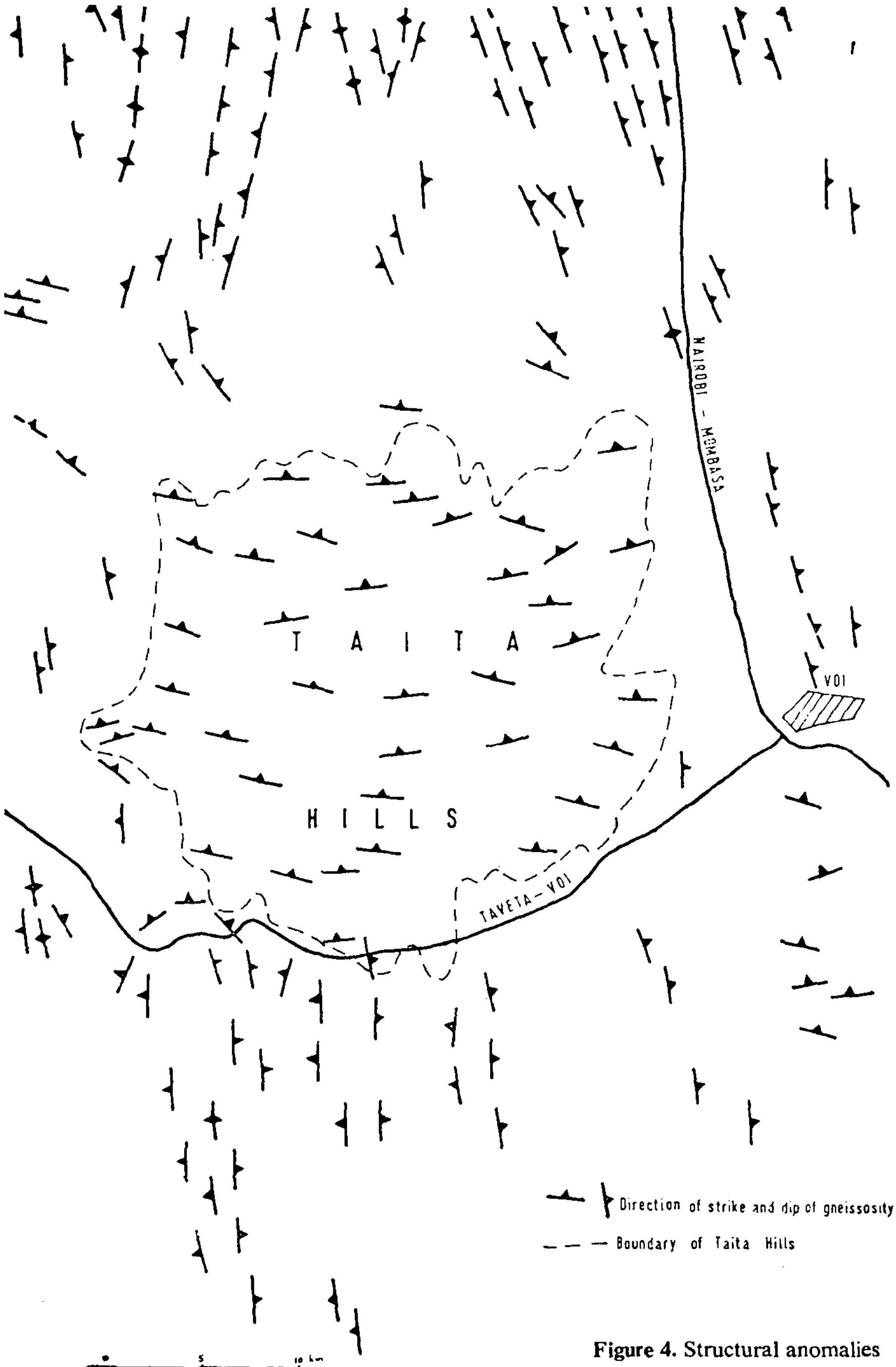

Figure 4. Structural anomalies of Taita Hills in general trend of Mozambique Belt.

Structurally the Taita Hills rocks differ considerably from the Basement rocks in the surrounding peneplains. In general the Mozambique Belt shows an average strike of the foliage in NNW-SSE direction with often intensive folding patterns giving varying dips in eastern and western directions. The Taita Hills rocks, however, present a more or less E–W strike and a fairly general dip in northern direction at average angles between 10° and 30° (see fig. 4). No intensive folding occurs, only a slight warping in places. Generally speaking the Taita Hills have a kind of domal or upwarping structure. Important faulting happened in the Taita Hills, mainly along N–S running faults or fault systems. Although no lithologic correlations have been made yet to prove it, the topography gives directions for blockfaulting in various stages and at several places, with E–W and other fault directions as well. In addition to the faulting, considerable large-scale joint systems occur in approximate directions N–S, E–W, NW–SE and NE–SW. Moreover much medium- and small-scale jointing or fracturing is observed in the area.

In the central northern part of the hills important amounts of kaoline are found which must have resulted from intensive tropical weathering of quartz-feldspar gneisses on old erosion surfaces, which at present are undergoing new incision from erosion. In several places also strong differential weathering can be observed along joints and faults.

Geomorphology

In general it applies that the quartz-feldspar gneisses of the Kenyan Basement System are more erosion resistant than the biotite-amphibole gneisses. Consequently many of the inselbergs on the Basement peneplains are dominated by quartz-feldspar gneisses. It is hard to say at this stage how far this also applies to the outstanding relief of the Taita Hills, but it is clear that in many valleys hard banks of quartz-feldspar rocks have formed waterfalls and rapids where the easier erodable biotite-hornblende gneisses have been scored out.

The drainage net of the Taita Hills falls within three major catchments: northward drainage of Kishushe and Mbololo rivers to the Tsavo and Galana, southward drainage of the Mwatate and Bura rivers and eastward drainage of the Goshi or Voi River, which covers the largest area within the Taita Hills (about 45%).

The drainage patterns are complex rectangular systems, with main N–S running fault valleys and more or less E–W running subsequent or strike valleys towards which again drain smaller joint valleys, part of which run roughly in NE–SW or NW–SE directions thus disturbing the rectangular grid. In some valleys trellis patterns have developed. Deranged patterns, with partly internal and impeded drainage, are found in strongly kaolinized zones in the central northern part of the hills. In the competition between the Mbololo subcatchment and the upper Voi River valley some cases of stream capture have taken place, of which elbows of captured and beheaded streams can be recognized. Stream capture is inherent to this type of drainage system on rocks with a low-angle dip.

Due to the steep relief and the intensity of faulting and jointing, the drainage texture of the systems is medium to fine, considering drainage density and stream frequency. The dip of the rocks causes at places an asymmetric valley development. North facing slopes are gentle dip-slopes where run-off is fast and where soil and vegetation do not settle easily. South-facing slopes sometimes show abrupt cliffs and as a rule are cut-slopes on which, in spite of their steepness, infiltration may be easier and where soils and vegetation hold better.

Soils

The soils in the Taita Hills are developed from different parent materials in different positions. A part of these soils are residual soils developed in weathering material *in situ*, and show the remains of gneissic structures in the C horizons. These soils are strongly characterized by their parent material. Other soils are colluvial soils developed in weathering material derived from various rock types which have mixed in the process of movement down the slopes. In places with a very thin cover of weathered rock, shallow stony soil types developed. In recent and subrecent alluvium of valley fills, deep undifferentiated soils developed. Due to soil erosion many soil profiles are truncated, leaving only the lower part of the profile.

Different soil types can each have their own specific infiltration rates. However, under varying conditions of slope, vegetation cover and erosion, infiltration characteristics may vary greatly. Nevertheless, it is thought that the preparation of a preliminary reconnaissance soil map may contribute to the differentiation between areas with higher and lower infiltration potentials.

Hydrogeology

Porosity and permeability

The Taita Hills are no exception to the rule that the hydrogeology of metamorphic rocks is a complex one. Very low porosity and permeability of the rocks as such and much bigger values for fractured zones complicate the uniformity of the aquifer concept and its application in the Taita Hills groundwater regime. Their characteristic heterogeneity makes it questionable in how far any hydrological parameters can be determined for these rocks.

In the Taita Hills the groundwater regime is governed by primary and secondary porosity. Total pore space is made up of the following forms of porosity:

1. Interstitial porosity or the micropores in between the crystals and grains of the metamorphic rocks, size 10^{-1} to 10^{-3} mm. Weathering may increase the number of larger pores and bring the total pore space, which normally lies between 0.1% and 1%, up to 2% to 3% or more. The micropores are discontinuous and therefore, as well as for the small size, permeability is

extremely low. Hydrogeological research elsewhere has found average hydraulic conductivity values between 10^{-5} and 10^{-7} cm/s for gneisses and schists (UNESCO 1975). This porosity will harœly yield to a borehole since the water it contains is rather immobile. Moreover the limited total pore space does not contribute much to the storage capacity of an area. The relative immobility of the water makes it easily take up solution salts from weathering products in the rock.

2. Fissure or foliage porosity which rates from microporosity to mainly mesoporosity. It is less discontinuous than the interstitial porosity and although the width of these pores is often limited (about 10^{-1} to 10^{-2} mm), their other dimensions can amount to many centimetres, thus contributing much more to the permeability of the rock than the interstitial pores. The total pore space depends on the intensity of foliage or lamination of the rock and on the pressure in the rock, which will tend to close the fissures with depth. Their opening near the surface mainly results from pressure relief. In general this porosity is not of direct importance for borehole development. However, seepages, springs and swamps may depend on fissure porosity. Interstitial and fissure porosity will gradually become secondary porosity due to weathering and pressure relief, jointing and solution.
3. Secondary porosity which consists of faults and joints which are macropores ranging from open fractures in the rocks, several centimetres wide, many metres deep and sometimes kilometres long, to dense zones or swarms of finer fractures which also represent a large total pore space. Macroporosity can have excellent large-scale permeability with nearly infinite hydraulic conductivity. The value of macroporosity for groundwater regime depends on the density and degree of intersection and interconnection of the fault system and/or joints networks. What is important is that the macropore systems draw water from the mesopores or fissure systems, which in turn can collect water from the interstitial pores. Consequently the faults and joints porosity is the only system in metamorphic rocks which is of use for borehole development. Only if a fracture system of sufficient size and many intersections and interconnections is struck a yield of any importance can be expected.

A thorough study of both primary and secondary porosity is required for the area. As to the primary porosity, Sikes (1934) stated that in general the silica-rich biotite gneisses of the Kenya Basement are the metamorphites with highest porosity (primary), especially after some weathering. However, the typical biotite gneisses in the Taita Hills are poor in silica and the silica-rich rocks cannot be regarded as biotite gneisses. Therefore, in this respect, Sikes's ideas on groundwater behaviour in metamorphic rocks do not contribute much to the work in the Taita Hills.

Detailed laboratory analyses of representative samples of various rock types, unweathered and weathered, will give certain values for primary porosity (through volumetric tests) and for permeability (through permeameter tests). This may then lead to a rough estimate of total primary porosity of the aquiferic zones in the area, which follow the general gneissosity trend in the hills with an average dip of about 20° to the north.

As to secondary porosity, totally different and more important research will have to be done. The faults and joints systems both are expressions of tectonic and structural activities in the Basement System. However, no essential structural geological work has been done yet in the Taita Hills area. Hence the need for structural analyses of the metamorphic tectonites, which will involve detailed plotting of faults and joints, measuring of their orientation ('dip and strike' of fracture plane), of their spacing and of their concentration as well as statistical representation of orientations and trends and swarms of main fracture zones.

It is also necessary to have accurate plotting and detailed geological mapping of seepage zones, springs and swamps in order to try to relate these natural discharges of groundwater to both lithology and structure, as they may indicate rocks with highest porosity and/or joint and fault systems. In this respect, one has to keep in mind that information concerning the lithology with highest primary porosity cannot be extrapolated and/or translated into an aquifer concept, since hardly any groundwater flow takes place in the gneisses themselves but rather in the secondary porosity of fractures. If any flow will occur in the primary pores, it will mainly be in the foliage fissures, following the foliage dips which are 10° to 30° to the north. Such flow will be highly discontinuous due to frequent interception and diversion by fractured zones.

Solution and weathering

Special attention is required for the crystalline limestone zones in the area. Firstly they are expected to have a relatively large interstitial porosity due to the coarse-grained and rather incoherent crystal structure. Secondly the soluble character of the limestone may cause solutional cavities. Although no such cavities have been observed in the Taita Hills, they are known to exist not far away in Tsavo East National Park. Other solutional effects are known from the limestone quarries at Kibini near Sultan Hamud, where water percolating through joints systems has considerably widened the joints by solution. The increase of both primary and secondary porosity may be of importance to the groundwater situation in the area, in particular the southern part, the biotite-amphibole unit, where crystalline limestones are abundant.

In addition to the fracturing of the metamorphic rocks, weathering is also one of their important features, particularly since the weathering in general develops best in the fractured zones, as a result of increased weatherable rock surface, constant moistening of weathering surfaces and the carrying away of weathered products.

Unfortunately not much information exists on weathering patterns in the

Taita Hills rocks. From preliminary field observations it is clear that, as is to be expected, there is a straight correlation between degree of fracturing and intensity of weathering, leading to differential weathering with subsequent erosion along fractured fault or joint zones. Erosion of the weathered rock in fact removes much of the porous material, thus reducing both recharge and storage capacity. However, deeper down, no erosion takes place and here zones of weathered and fractured rocks represent potential borehole development sites.

Information from boreholes

Previously, from 1930 to 1949, ten boreholes were drilled in the Taita Hills (see figs. 5 & 6), mainly in the lowest parts of the hills (see fig. 7), like river valleys, footslopes and fanlike deposits. In those days drill logs were very succinct and did not supply much information on the subsurface geology. Figures 5 and 6 show that water was always struck in 'weathered gneiss', which is probably correct. Where weathered gneiss occurs deep under a 40 or 50 m thick zone of sound rock, as shown in the diagrams of boreholes P81 and C480 (fig. 5), the vertical borehole must have passed an inclined fracture zone, fault plane or joint plane. The fractured zone made the weathering of the rock at depth possible, since the weathering cannot be attributed to hydrothermal or pneumatolitic alterations which do not occur in the Taita Hills according to the geological and mineralogical investigations. Figures 5, 6 and 7, however, show that weathering to great depth—along fractured zones—does not necessarily guarantee good borehole yields. Fractures at depth may gradually close due to compaction, and clay from weathering of mainly feldspars may tend to fill up fissures and minor fractures and heavily reduce permeability.

In most of the other boreholes the weathered zone is only the normal one at the top with a maximum depth of less than 20 m. Water was always struck in these top weathering layers and there is no relation between depth and yield. Probably for this reason most drilling did not go very deep. An interesting observation, however, is to be made on borehole C938 (fig. 6) which was drilled in fanlike deposits of weathered basement materials. Its yield was far below average but probably could have been much higher if drilling had been continued and passed through the weathered bedrock until the underlying rather impervious hard rock was reached.

Preliminary conclusions

From the above the following preliminary conclusions may be drawn:

1. A structural analysis of the metamorphic rocks in the Taita Hills is necessary for a more complete understanding and knowledge of the fault and joint systems, which constitute the main means for groundwater movement in the area.
2. No deep drilling operations are recommended since most weathering zones

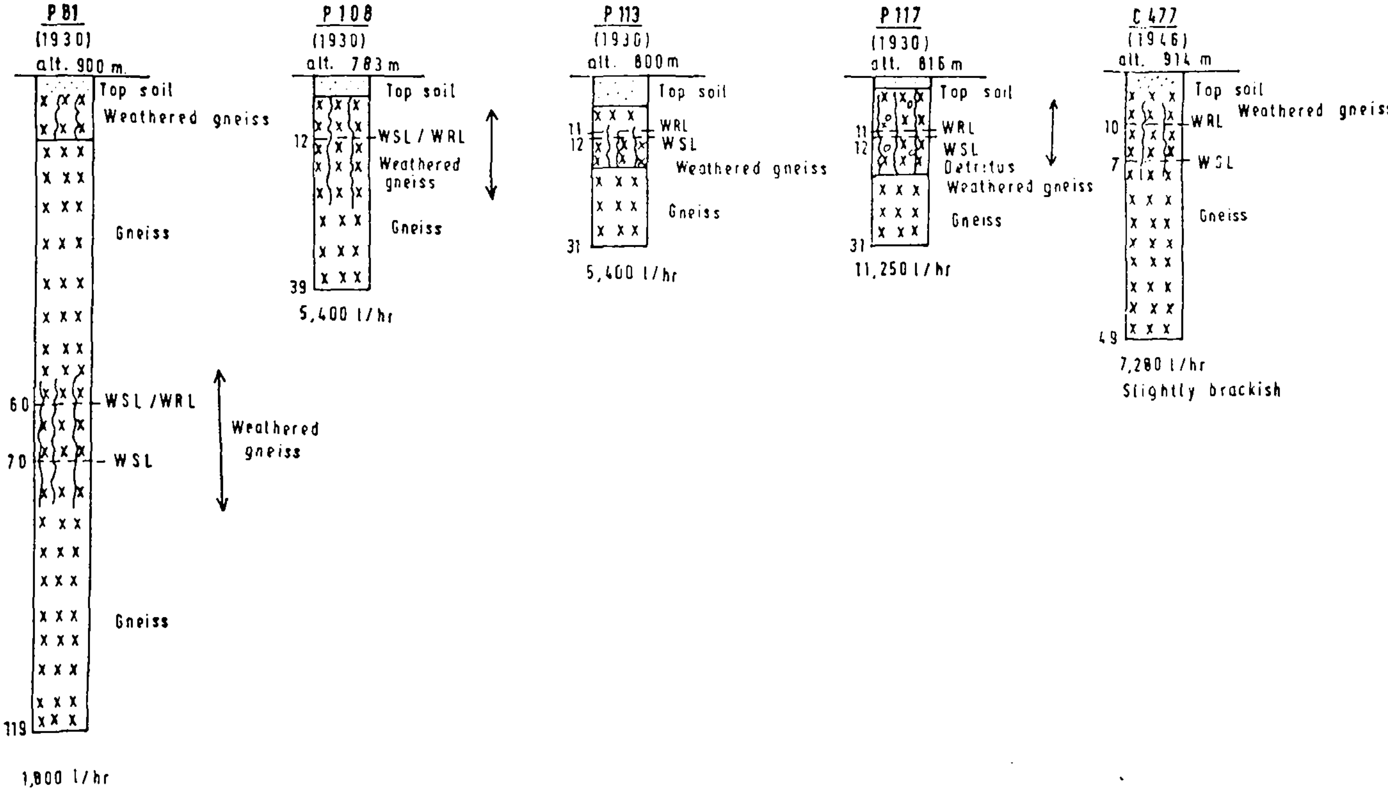

Figure 5. Borehole diagrams. WSL = water struck level; WRL = water rest levels; *P81* (etc.) = number of borehole; *1930* (etc) = year of completion; altitude is in metres above sea level; depth in metres from surface; yield in litres per hour (l/hr).

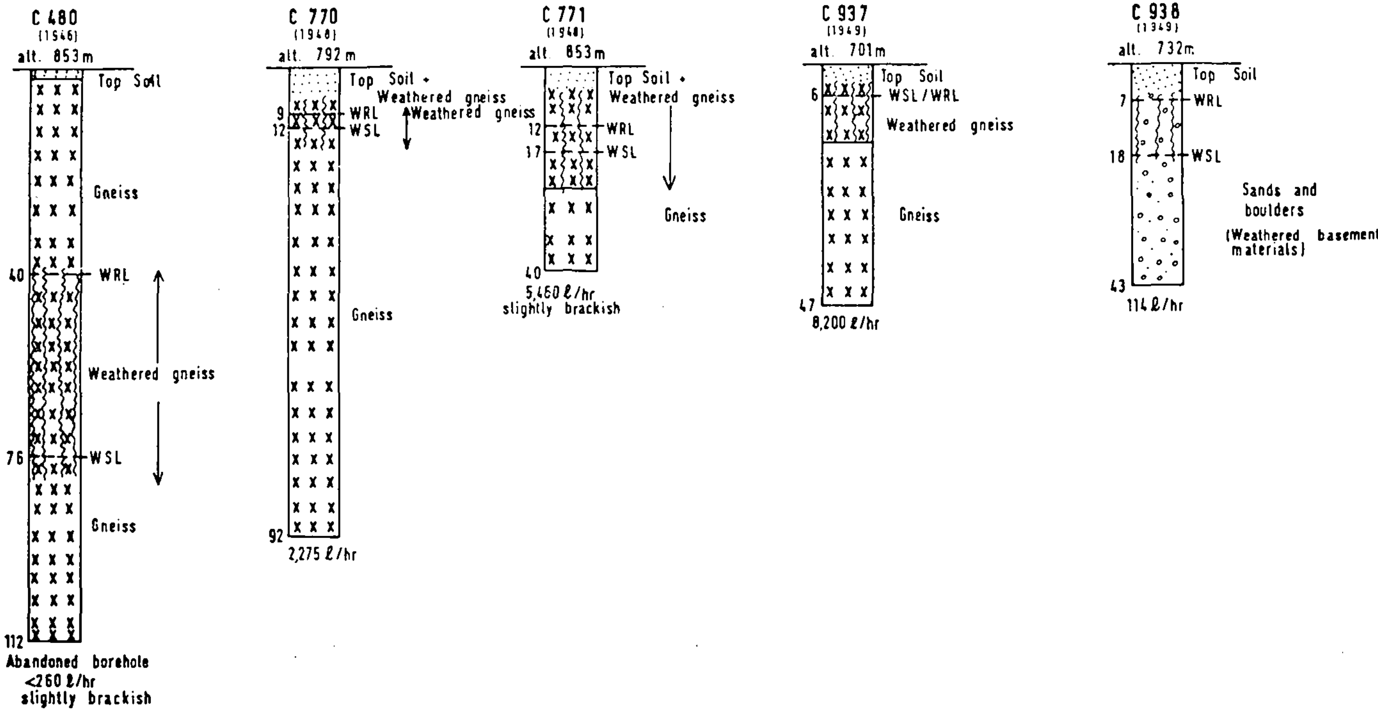

Figure 6. Borehole diagrams. Key as in figure 5.

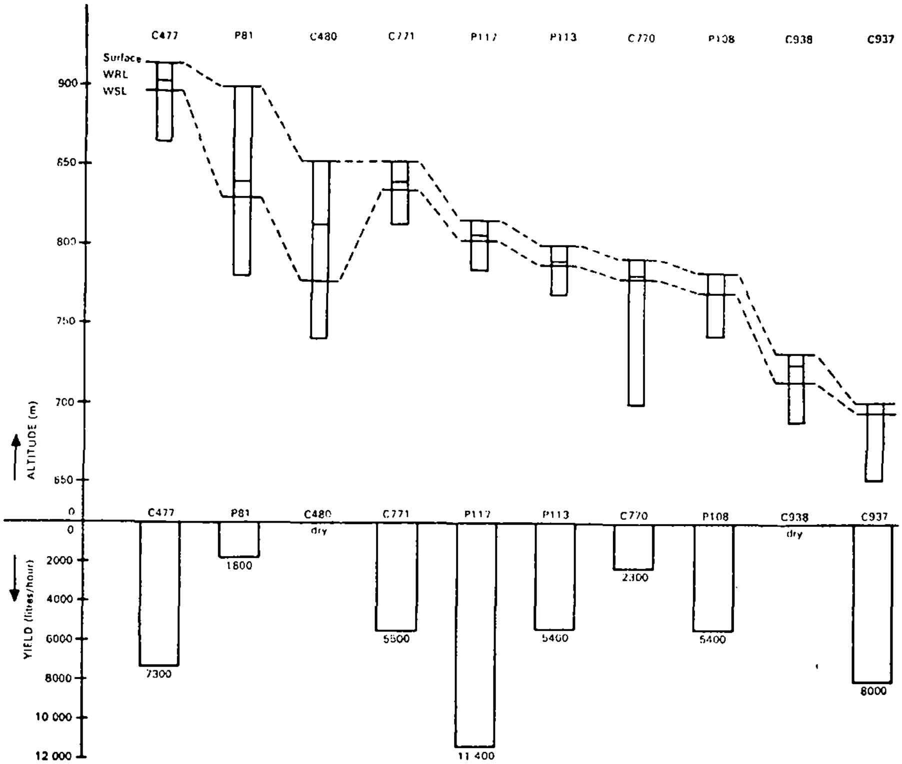

Figure 7. Diagrams of boreholes in Taita Hills, showing relations of surface altitudes, depths, water struck levels (WSL) and water rest levels (WRL) with corresponding yields.

do not extend to great depth, and if so, they are likely to be clayey with low transmissivities since the non-soluble weathering products are not removed. Fractures at depth also tend to close and chances of striking major fracture zones at depth are limited.

3. The best results are to be expected if a borehole can be sited on the intersection of major fault or joints systems with intensive interconnections of fractured zones, rather than on a zone of strong weathering with a fair storage capacity but limited transmissivity.
4. Since striking of a near-to-vertical fracture plane with a vertical borehole is next to impossible, the Water Development staff have in the past recommended horizontal drilling operations. Thus, taking advantage of the steep topography, it is expected to be easier to strike a major fault or joint zone. Although the equipment that will be provided under the Austromineral Kenya Groundwater Project can only drill at angles up to 45°, it is thought that even this will constitute a valuable tool for more successful drilling.

5. Several of the old boreholes have either dried up or become brackish or saline. The salinity can probably be explained by the fact that overpumping drew too much water of low mobility from the micropores and mesopores with high contents of soluble salts. As large fracture systems drain water from larger areas, especially in case of interconnections of several systems, this paper proposes to make use of explosives in boreholes for artificial fracturing of the subsurface rock. This would in the first instance considerably increase the amount of fissure porosity which yields to the fracture system. Secondly it is hoped that it will cause artificial interconnections of existing fracture systems, and thirdly, due to increased flow, it may solve many of the existing salinity problems, provided overpumping is not repeated.

Hydrochemistry

Out of the ten boreholes in the area the water of only one (C937) has been analysed. Since this borehole lies in a wider part of the Voi River valley one might expect that it received much of its water from surface water infiltrating into the valley fill. Its chemical composition, however, points to a different source. A high magnesium content of 113 ppm, just about at the permissible limits (100 to 125 ppm), shows that the water of this borehole most probably originates from weathered biotite-amphibole gneisses. Although the borehole had an acceptable chemical composition and a good yield of 8 000 litres per hour it is now abandoned.

For borehole C477 (fig. 5) only the fluoride content has been determined (1 3 ppm) It has now been abandoned since it became too alkaline, probably due to overpumping. After the present recovery period of many years its water may have regained its acceptable chemical composition which can be maintained by careful pumping practices. No information is available on hydrochemistry of other boreholes in the area Field observations, however, show that the water of the streams in the northern part of the area has an excessive hardness, resulting in deposition of secondary limestone along the lower reaches of their valleys where gradients ease down. This high calcium content of streams in the northern quartz-feldspar zone is remarkable in view of the predominant occurrence of crystalline limestone in the southern part of the hills.

In the course of the project full hydrochemical analyses will be carried out for water samples of the existing boreholes, of representative springs and swamps and of streams, for water quality purposes, as well as for possible correlations of lithology and groundwater movements.

Other techniques

Of the many groundwater research techniques only those which are currently being considered for the work in the Taita Hills will be mentioned We realize however that in the course of the project the use of additional techniques may become necessary or desirable.

Geophysical prospecting methods

The Taita Hills are rather unfavourable for most geophysical methods because of their rather steep relief. Gravimetric and seismic methods which require very detailed surveying and levelling operations are particularly difficult to realize. The lithology also restricts the use of certain techniques, like magnetic and electro-resistivity methods. Due to their potential magnetic characteristics, the occurrences of magnetite, biotite, hornblende and serpentinites can very much complicate the interpretation of the magnetometer records. The occurrences of graphite in the southern part, in gneisses as well as in crystalline limestones, can complicate the use of the electro-resistivity method. The very high conductivity of graphite may overshadow the effects of any groundwater occurrences on the resistivity curves. Nevertheless in certain areas, mainly the fanlike deposits and footslopes east and north of the hills, which are zones with expected groundwater potentials, electro-resistivity and seismic methods can work out satisfactorily.

Groundwater tracing and stable isotopes

In order to obtain information about the course and time of groundwater movement in the Taita Hills, groundwater tracing techniques have been considered. As it is now, however, this requires too much and too detailed observation and water sampling for the manpower available in the framework of the project. Therefore at present the use of stable isotope techniques, tritium in particular, are under consideration. The tritium technique, if successfully applied, may give information about the time when the water infiltrated, and thus indicate the period that the water travelled and stayed underground. Nevertheless, the possibilities of application of this technique still have to be worked out.

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ON THE APPLICATION OF THE ELECTRICAL METHOD OF GEOPHYSICAL PROSPECTING TO THE LOCATION OF UNDERGROUND WATER, WITH AN EXAMPLE FROM THE RIFT VALLEY OF KENYA

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Introduction

By working on the earth's surface, it is sometimes possible to estimate where groundwater occurs and under special conditions to obtain information on water quality. Although several other methods such as gravity, magnetic, seismic, geologic and air photo interpretation are available for the search of groundwater, only the electrical resistivity method will be dealt with in this paper. All methods provide only indirect indications of groundwater and underground hydrologic data must be inferred from surface information. Correct interpretation requires supplemental data from subsurface investigations such as logging to substantiate surface findings.

Electrical properties of water-bearing rocks

The electrical resistivity of a rock formation limits the amount of current passing through a formation when an electrical potential is applied. It may be defined as the resistance in ohms between opposite faces of a unit cube of a material. If a material of resistance R has a cross-sectional area A and length L, then its resistivity can be expressed as

$p_o = RA/L$ ohm-metres

The application of electrical methods to the location of underground water rests on the fact that water in the pores of rocks will change their conductivity appreciably, so much so that conductivity of the mineral substances is virtually without effect. In practice there are four main factors which determine the resistivity of a rock formation:

1. The amount of water contained in the rock formation
2. The salinity of water in the rock formation
3. The manner of distribution of water
4. The temperature of water contained in the formation.

Archie's law, a relation among the first three factors, is given as

$p_o = p_w \, \o^m$ and $F = p_o/p_w$,

p_o = the bulk resistivity of the rock,

y_w = the resistivity of the fluid saturating the rock,

$\emptyset$ = fractional porosity,
m = cementation factor—a constant depending upon the manner of distribution of water in the rock, and
F = formation factor.

The value of exponent m is somewhat larger than 2 for cemented and well-sorted granular rocks and somewhat less than 2 for poorly sorted and poorly cemented granular rocks, and to a first approximation may be assumed to be 2.

Of the first three primary characteristics that affect resistivity, all are not equally important. The resistivity of rocks varies most widely because of differences in water content, which may vary by a ratio of 1 000:1 between various rock types at the earth's surface. Because the water content enters Archie's law as a squared quantity, this range in variation of water content contributes a 1 000 000:1 variation of bulk resistivity, other factors being the same. The salinity of the contained water is second in importance, partly because it enters Archie's law only as the first power and partly because the range of variability for water resistivity is limited by interactions with the minerals in a rock to a ratio of about 500:1. All other factors being equal, variations in water salinity can cause only about a 500:1 range in bulk resistivity. Distribution of water in the pore structure is the least important factor in as much as it causes no more than a 20:1 range in resistivity, all other factors being equal.

The resistivity of a water-bearing rock is affected by temperature and pressure variations, though to lesser extents than it is affected by the factors discussed above. Unless the temperature range is extreme, the effect of temperature changes on the bulk resistivity of a rock is no different from the effect of temperature on the resistivity of the electrolyte contained in the rock. For most electrolytes, the resistivity depends on temperature as

$p_t = p_{18}/[1 + 0.002\ (t - 18)]$ where p_{18} is the resistivity at reference temperature of 18°C, and t is the temperature.

Temperatures within the first few miles of the earth's surface rise gradually with depth at a rate of about 0.5° per $33\frac{1}{3}$ m in sedimentary rocks and about 0.2°C per $33\frac{1}{3}$ m in igneous rocks. This increase in temperature causes an increase in the conductivity of the rock, at least until the boiling point of water is reached. However, the boiling point also increases with increasing pressure, and where the thermal gradient in the earth is normal, the *boiling point* is not exceeded at any depth. Only in rare cases is the temperature in the earth high enough to remove water from the rock as steam. This occurs in regions of recent volcanism such as at Eburru and Olkaria in the Kenya Rift Valley, where hot intrusive rocks raise the temperature of the surrounding rock above the boiling point of water. In such cases the conductivity of the rock is that of the solid minerals.

There are no fixed limits for resistivities of various rocks; igneous and metamorphic rocks yield values in the range of 10^2 to 10^8 ohm-m; sedimentary and unconsolidated rocks 10 to 10^4 ohm-m. Fine-grained materials such as

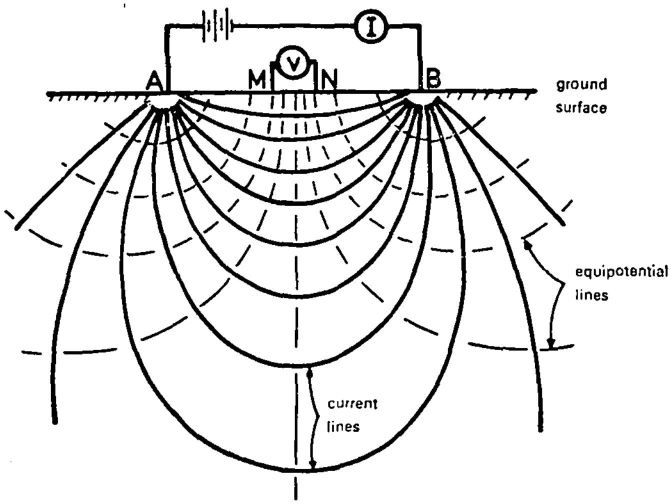

Figure 1. Electrical circuit for resistivity determination and electrical field for a homogeneous subsurface stratum.

clay containing fixed groundwater yield values in the range of 5 to 10 ohm-m; while moist coarse-grained sands and gravels yield values in the range of 50 to 200 ohm-m.

Electrical resistivity method

Actual resistivity is determined from an apparent resistivity which is computed from measurements of current and potential difference between pairs of electrodes placed in the ground surface. The procedure involves measuring a potential difference between two electrodes (MN in fig. 1) resulting from an applied current through two other electrodes (AB in fig. 1) outside but in line with the potential electrodes. If resistivity is uniform in the subsurface zone beneath the electrodes, an orthogonal network of circular arcs will be formed by current and equipotential lines as shown in figure 1. The measured potential difference and current yield an apparent resistivity over an unspecified depth. If the spacing between electrodes is increased, a deeper penetration of the electrical field occurs and a different apparent resistivity is obtained.

Current electrodes consist of metal stakes driven into the ground and potential electrodes are porous cups filled with a saturated solution of copper sulphate to inhibit electrical field from forming around them. In order to minimize the polarization effects either a low-frequency current or reversible direct current is used. In practice, various standard electrode spacing arrangements have been adopted; most common are the Wenner and Schlumberger arrangements.

In the Wenner arrangement, the electrodes are located as shown in figure 2; and the apparent resistivity is given by $p_a = 2\pi a\ (V/I)$ where a is the distance between adjacent electrodes, V is the voltage difference and I the applied current.

The Schlumberger arrangement, shown in figure 3, has the potential electrodes close together and the apparent resistivity is given by $p_a = K(V/I)$ where

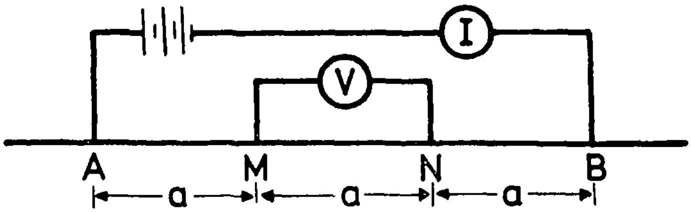

Figure 2. Wenner electrode arrangement.

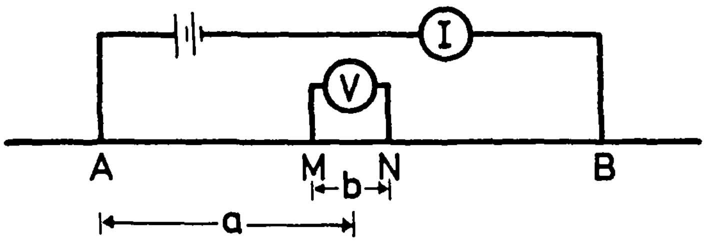

Figure 3. Schlumber-ger electrode arrangement.

$K = \pi(a^2/b - b/4)$ and $a \geq 5b$, where a and b refer to the distances shown in figure 3.

When apparent resistivity is plotted against electrode separation (a for Wenner, and $AB/2$ for Schlumberger) for various spacings at one location, a smooth curve can be drawn through the points. The interpretation of curves like those shown in figures 7 and 8, in terms of subsurface conditions, is a complex and frequently difficult problem. The solution can be obtained in two parts: (1) interpretation in terms of various layers of actual (as distinguished from apparent) resistivities and their depths, and (2) interpretation of the actual resistivities in forms of subsurface geologic and groundwater conditions. Part 1 can be accomplished by using theoretically computed resistivity curves of 2, 3 and 4 layers cases for various ratios of resistivities. Curves and explanation of curve matching techniques have been published by Money and Wetzel (1956) for the Wenner configuration and by La Compagnie General de Geophysique (1955) for the Schlumberger configuration. The auxiliary method of curve matching has been well described by Zohdy (1965). Part 2 depends upon supplemental data. Comparing actual resistivity variations with depth to data from a nearby logged test hole enables correlation to be established with subsurface geologic and groundwater condition. This information can then be applied for interpretation of resistivity measurements in surrounding areas.

Resistivity surveys can cover either vertical investigations at selected locations by varying electrode spacing or they can furnish isoresistivity maps of an area. In areal studies a constant spacing may be adopted to measure resistivities only at a particular depth of interest such as an aquifer, whereas vertical electrical soundings (VES) may be used to investigate the water table, aquifer, impermeable formation and bedrock depths. Any factors which invalidate the assumption of lateral homogeneity disturb the electrical field in the vicinity of the electrodes and interpretation becomes complex. In areas that are extensively faulted and consist of steeply dipping formations vertical soundings should be used with caution. Other common hazards are buried pipelines, cables and wire fences. Extremely dry conditions may necessitate moistening the ground around electrodes with salt water to establish proper earth contact.

Finally, even under the most favourable conditions of horizontal stratification the relationship between true resistivity and apparent resistivity is complex, and it is almost impossible to select arbitrary locations in virgin territory and determine the presence of water by isolated electrical soundings. It is only through a comparative study of the common characteristics and the progressive deformation of a nearby continuous set of electrical soundings that it becomes feasible to draw precise conclusions. The determination of absolute values depends on other favourable circumstances. For example, if drill holes to a sufficient depth exist in the area, and the presence of an aquifer has been established, it is possible to calibrate the electrical soundings so that the variations of resistivity with depth can be determined fairly accurately in the space between individual boreholes. Another possible source of calibration would be an outcrop, or the presence at very shallow depth of the most important beds.

It is also generally impossible to determine water yield from electrical soundings. While the increase in conductivity in sand can as a rule be taken as an indication of the presence of water, a moist clay which does not yield water may give the same indication. Saline waters are easy to locate but the better the indication the less usable they are. Moist beds of low yield are likely to give better indication than gravels of high yield. Finally beds with the best type of water may give indications that are most readily confused with those from formations that are not water bearing. Since various resistivity distributions quite different from each other can lead to similar sounding curves every interpretation must be based on the integration of all geological and geophysical information available in the region.

An example

Numerous electrical soundings have been conducted in the Rift Valley by the Water Development Ministry personnel in search for groundwater, and other electrical surveys have been carried out by various contractors over the last 10 years with the specific aim of locating thermal reservoirs—the source of numerous hot springs, geysers and steam fumaroles present in the Rift Valley. As an example to illustrate the location of underground water by the electrical resistivity method a survey conducted by the author on behalf of the East African Power and Lighting Co. Ltd is described below.

The aims of the survey were to obtain information on the depth of water table in the Eburru area (fig. 4) with special reference to the geothermal phenomena present there, and to infer from this the possibility of drilling for hot water. The elevation of Eburru peak is 2 680 m.

General geology and hydrology

The geology of Eburru ridge shown in figure 5 has been described by Thomoson and Dodson (1963). It is located to the northwest of Lake Naivasha (elevation 1 884 m) and forms a slightly curved arc aligned east-west and concave to the south. It is a volcanic pile covered with pyroclastics resting upon a visible basement of trachytes which outcrop in a series of north-south trending fault scarps. The small ridges of coalescing pumice cones south of Eburru and the vents of obsidian flows on the summit and northern flanks are a result of a north-south faulting/fracturing system. Related to this late upsurge of magma is a phase of phreatic explosive activity centred on the summit and northern slopes leaving a complex of craters over the area. The structural element of the Eburru area is that of a north-south trending fault system, though the Eburru massif is elongated with a pronounced east-west axis. Reasons for this are speculative but if it is assumed that it is sited on the east-west cross fault, the intersection of this and the dominant north-south trend would provide optimum conditions for the formation of a vent and the resultant growth of the volcanic pile.

All geothermal manifestations in the area are contained within the fracture/ fault system as shown in figure 6, and indications of geothermal activity are limited to low-pressure steam vents or gently steaming ground. In the main crater the country rocks surrounding the main vents have been completely altered to white kaolin clay. Mason (1967) states that the shallow wells drilled on the Eburru ridge tapped steam only and that nothing is known of the water table beneath the ridge. Thompson and Dodson (1963) also point out the possibility of anomalies in the water table at Eburru due to the different levels of aquifers in a faulted area. People living in this area condense the steam for domestic and stock use as there is no other form of water available and also use the steam for drying pyrethrum flowers. Thus the location of subsurface water took an added importance for the local population.

Electrical resistivity work

Eight deep Schlumberger soundings shown in figures 7 and 8 with the maximum AB/2 spacing ranging from 1.2 km to 2.7 km were conducted in the Eburru area at the locations shown in figure 6. The locations of soundings carried out by Group Seven (1971) are also shown. These are prefixed by the letter *K* The interpretation of the soundings in terms of real resistivities and layers thicknesses is given in table 1.

Evaluation of data

Using the resistivity data available, a map of the elevation of water table in the Eburru area is shown in figure 6. The map shows that the water table follows more or less the regional topography and reaches its highest elevation at the Eburru crater as shown by VES B/23. The depth of the water table is

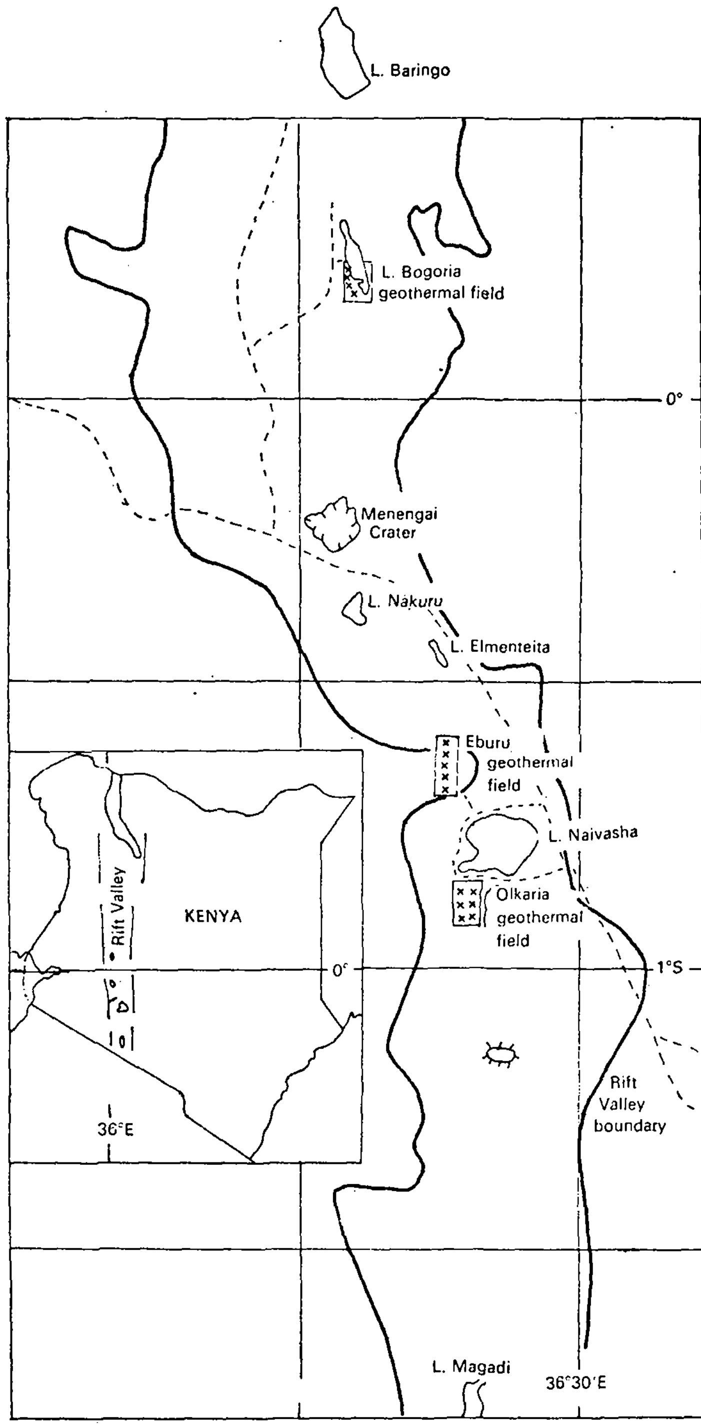

Figure 4. Location of geothermal area.

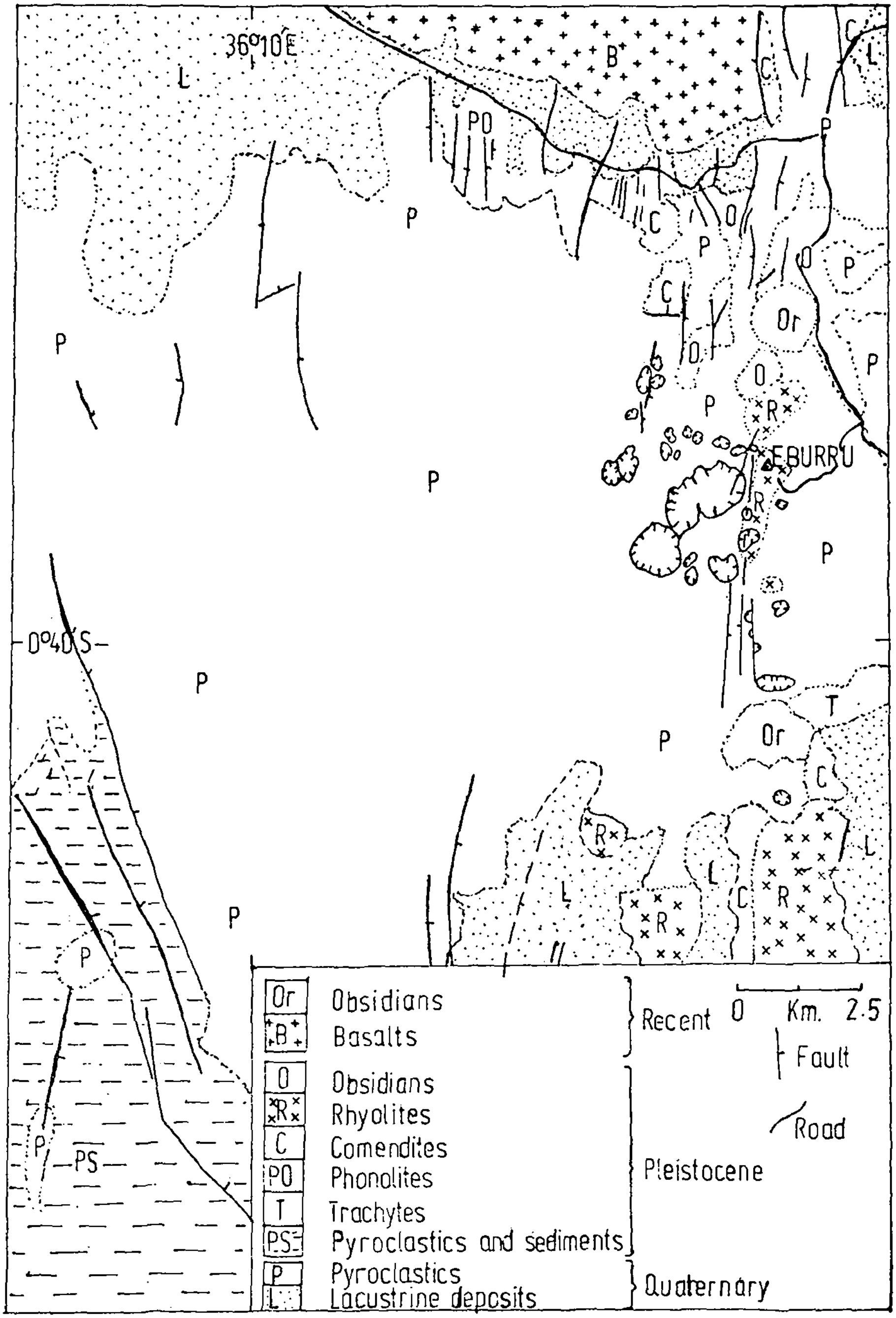

Figure 5. Geology of Eburru area.

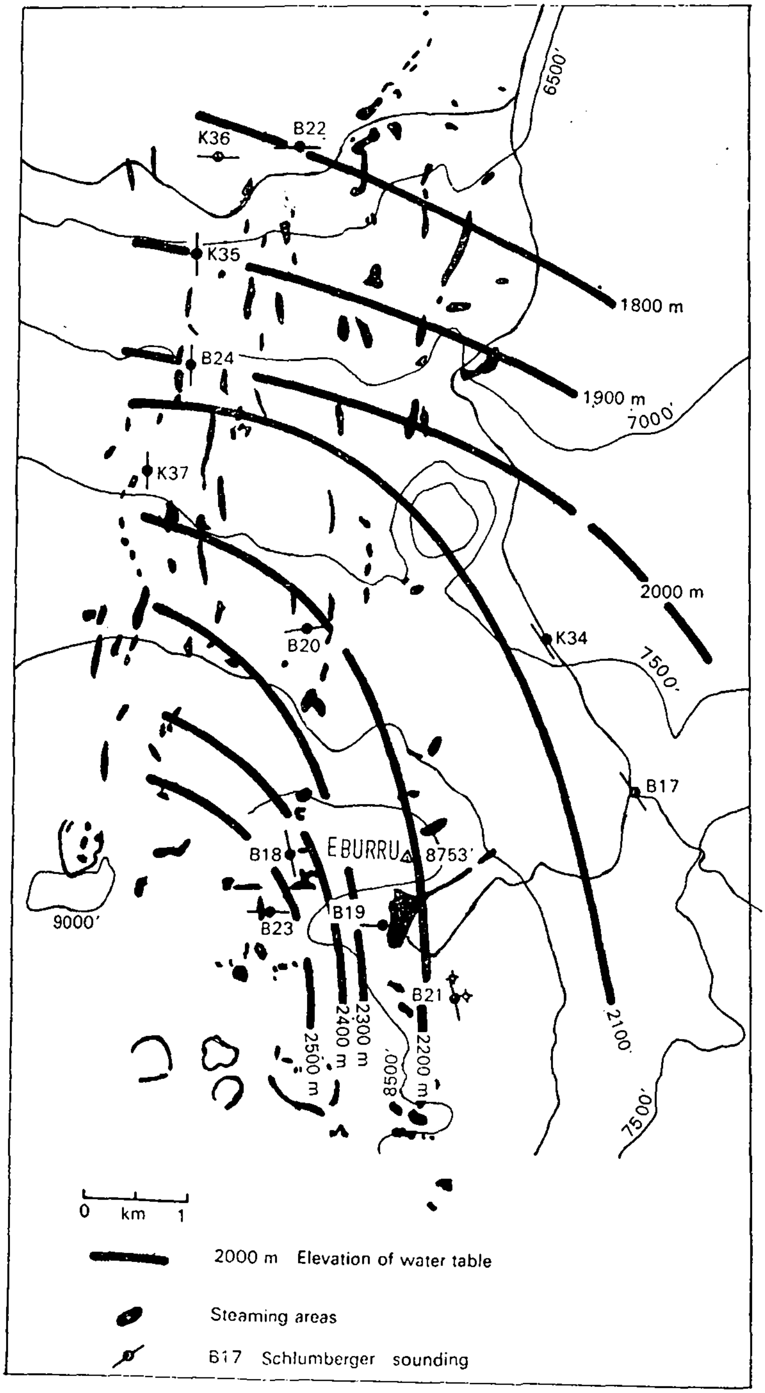

Figure 6. Elevation of water table determined by electrical soundings.

considered to be the top of the layer having low to moderate resistivities, but the low resistivity could also be due to hydrothermal alteration of the rock. The high surface resistivity similarly could be accounted for if the rocks are desaturated because of steam ascending through faults and fractures to feed the fumaroles. A 160 m deep hole (C704) is present in the area and VES B/21 was located at this hole with a view to obtain calibration for the soundings done in this area. The depth to the low resistivity layer (17 ohm-m) as interpreted from the curves is 290 m and the hole is not deep enough to test if the low resistivity is due to the presence of a water table or a hydrothermally altered layer. Drilling records indicate no evidence of hot or cold water, and the hole has been discharging steam at low pressures for the last 20 years.

Conclusion

The electrical study in the areas has been 'successful' in mapping a low resistivity layer. Whether this layer is water saturated or a layer altered by hydrothermal

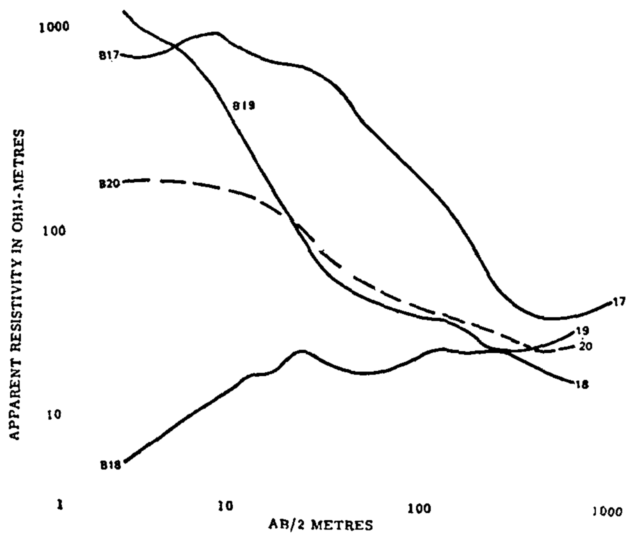

Figure 7. Schlumberger soundings.

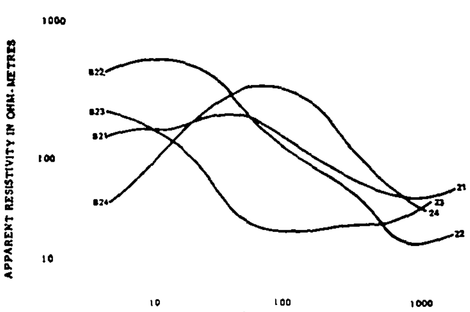

Figure 8. Schlumberger soundings.

Table 1. Interpretation of soundings

Sounding	Resistivity ohm-metres	Depth to bottom of layer in metres
B/17	850	70
	150	310
	25	1 050
	70	
B/18	4.7	5
	47	31
	11.6	92
	46	220
	17	
B 19	1 250	12
	132	42
	37	320
	14	770
	70	
B/20	150	32
	44	170
	24	
B/21	80	12
	160	48
	40	290
	17	580
	43	
B/22	140	4
	350	23
	55	125
	24	1 300
	39	
B/23	110	17
	18	425
	37	
B/24	24	8
	480	48
	24	

action with rocks containing clay and kaolin is uncertain. Clay and kaolin deposits occur in the area associated with areas of thermal activity. The study has produced results which are not easy to interpret on their own, and the situation has been complicated by the interaction of steam with the water table. Moreover, the highly faulted nature of the area has invalidated our basic assumption of the presence of laterally homogeneous media. Eburru is a volcanic junkheap, and interpretation of electrical soundings in terms of layer thicknesses in such a situation may not be meaningful. Indirect methods of predication are very risky in volcanic formations disrupted by a complex series of faults of varying age, and something must be known of the succession before predications can be made. In relatively unfaulted, stratified rocks extrapolations between known successions can be made with confidence. To aid the interpretation of the resistivity data and to make any reasonable predications, additional data are required and this may be provided by a deep test hole situated in the main steaming area.

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APPLIED HYDROGEOCHEMISTRY: SOME KENYAN EXAMPLES

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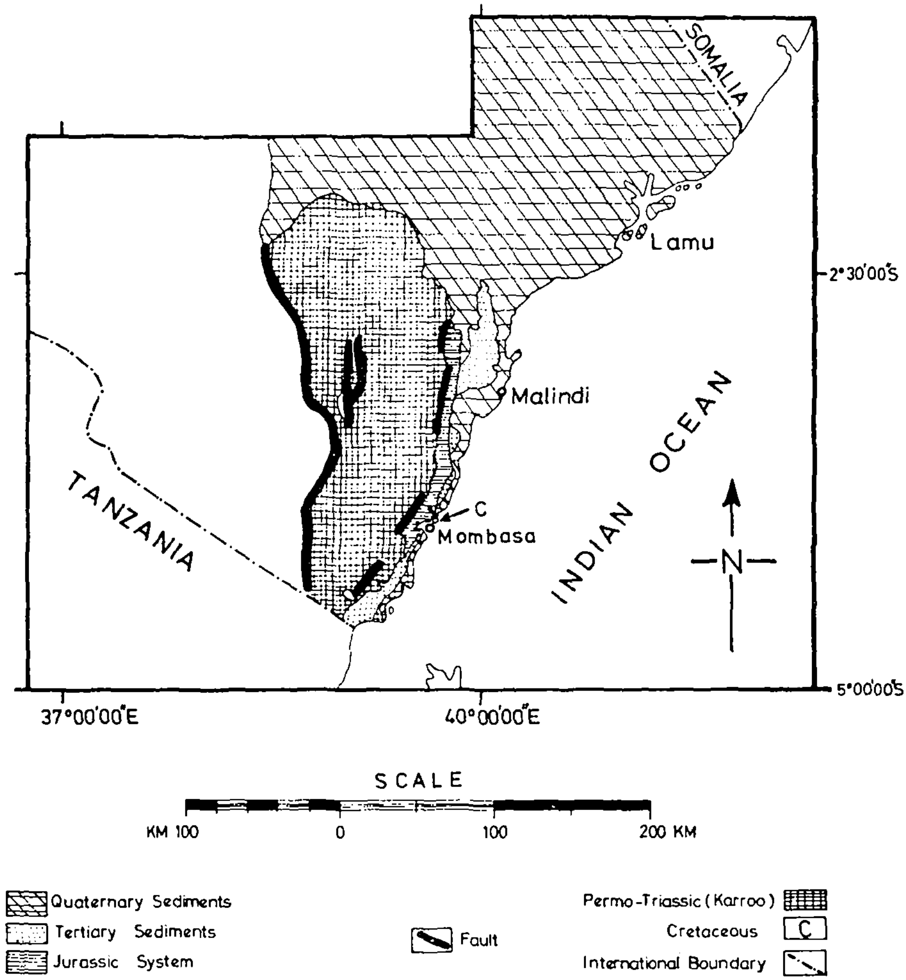
Abstract
It is now a well-established fact that the chemical quality of subsurface waters depends very much upon the geochemical character of containing rocks. That this same general rule applies to groundwater resources of coastal Kenya is reflected in hydrogeochemical data from the sedimentary aquifers of this area. Such data as have been acquired from the chemical analyses of groundwater samples from the area can be usefully employed for determining or predicting, on the basis of chemical quality, the potential utility of groundwaters in this region for various agricultural and domestic purposes.

Introduction
Coastal Kenya is made up of sedimentary formations whose outcrop patterns and general stratigraphical succession are shown in map 1 and tables 1 and 2 respectively. These rocks range in age from Permian to Recent. As a result of differences in their depositional environments and mode of formation, there is the inevitable variation in their geochemistry, and hence in the hydrogeochemistry and chemical quality of waters obtained from them.

The geology of south coastal Kenya has been described by Caswell (1953, 1956), Thompson (1956) and Williams (1962). More recently, Hove (1976) has summarized the geochemical factors of groundwater quality in sedimentary formations of this area. This was a logical extension of the work begun by Hove and Ongweny (1973) who attempted to assess the chemical quality of groundwater resources throughout Kenya on the basis of quantities of dissolved substances in over 7 000 samples of water drawn from more than 1 000 boreholes and wells. The result was a division of the country into four groundwater 'provinces' of which coastal Kenya was one. It was thought at the time that that division would form the basis upon which more detailed subsurface water studies of an applied nature would consequently be carried out in each of these 'provinces'.

Hydrogeochemical data from test boreholes and wells in sedimentary aquifers of coastal Kenya could be usefully employed for determining the suitability of groundwaters in this area for agricultural and domestic use. Thus the principal objective of the present paper is to demonstrate the applicability of such sample data to this purpose. Data have therefore been selected for groundwater



Map 1. Post-Carboniferous geology of coastal Kenya.

samples from the Duruma Sandstone Series (Permo-Trias) and Quaternary strata of the south Kenya coast. The Jurassic-Cretaceous and Tertiary formations of this area may be geochemically interesting but their value as aquifers is rather limited Therefore, in the present paper, attention is focused mainly on three groups of productive sedimentary aquifers, namely the Duruma Sandstone Series, the Fossil Coral Reef and Breccia, and Quaternary sediments other than those of the Coral Reef formation.

Summary of geology

The oldest sediments of the south Kenya coast are represented by Permo-

Table 1. Late Palaeozoic–Mesozoic succession of coastal Kenya

Era	System	Stage		Representative	Lithology & approx. thickness	Depositional environment
Mesozoic	Cretaceous	Neocomian		Freretown Limestone	Limestone, some shales	Marine
	Jurassic	Kimmeridgian Oxfordian Callovian Bathonian Bajocian		Changamwe Shales Coroa Mombasa Limestone {Rabai Shales {Miritini Shales	Limestones and shales, some flaggy sandstones and siltstones, c.1300 m	Marine and estuarine
				{Kibiongoni Beds {Kambe Limestone	Grits and arkosic sandstones 300 m	Continental and deltaic
	Triassic	Upper	Duruma Sandstones	Mazeras Sandstones and Shimba Grits	Flaggy sandstones, shales, siltstones and intercalated limestones, at least 2 000 m	Lacustrine and marine
		Lower		Mariakani Sandstones		
Palaeozoic	Permian			Maji-ya-Chumvi Beds	Shales with intercolated silt-stones and limestones, 1 000 m	Marine and lacustrine or deltaic
				Taru Grits	Grits and arkosic sandstones, shale bands, 160 m	Continental
	Carboniferous			Taru Grits (?)		

. . . Pronounced unconformity — — —Slight unconformity

Table 2. Cainozoie succession of coastal Kenya

Era	Period	Epoch	Representative	Lithology & approx. thickness	Depositional environment
		Recent	Alluvium; marine, littoral and aeolian sands	Unconsolidated & semi-consol-idated sands & silts, up to 60 m	Fluviatile, marine, coastal dune, littoral, continental
Cainozoic	Quaternary	Pleistocene	Coquinas and aeolian sands Lagoonal deposits Fossil Coral Reef Magarini Sands	Unconsolidated quartz sands, cemented calcareous sands, coral limestone and breccia, up to 200 m	Coastal dune, continental, littoral, shallow marine
		Pliocene	Magarini Sands Marafa Beds	Sands, clays, pebbles, some sandstones and conglomerates, up to 160 m	Coastal dune, continental, deltaic, shallow marine
		Miocene	Baratumu Beds	Sandy marls, marly limestones, sands, clays, less than 500 m	Shallow-water, littoral

Triassic formations of the Duruma Sandstone Series (Karroo Series). The succession overlies the Precambrian Basement with a pronounced unconformity, and largely comprises gritstone and sandstone strata with some finely laminated shaly members containing carbonaceous material and traces of coal. In the basal and middle parts of the succession are some intercalations of limestone. The differences in lithology, cementing materials, fossil content, etc., reflect palaeo-environmental changes associated with subaerial, lacustrine, deltaic and shallow marine conditions.

Intraformational saline materials are common, particularly in the Middle Duruma Series (the Maji-ya-Chumvi Beds and Mariakani Sandstones), which must have been deposited in a landlocked basin under semi-arid conditions that favoured rapid evaporation of water and subsequent precipitation of large amounts of salts. The principal evaporites are carbonates, sulphates and chlorides which are now found in varying proportions throughout most of the succession. The distinct exception is the Upper Duruma Series (the Mazeras Sandstones and Shimba Grits) which were deposited under subaerial conditions where saline deposits were not abundant and are now rare or even absent.

Post-Karroo rocks of Mesozoic age are represented by the Jurassic System and a tiny limestone outcrop (Freretown Limestone) which is the only one of Cretaceous age on the Kenya coast. The former contains a fossiliferous marine limestone succession (Bajocian-Bathonian) which terminates with predominantly shaly beds (Callovian-Kimmeridgian). These rocks are faulted against older rocks to the west and rest unconformably over the underlying Karroo. The depositional environment is definitely a marine one which is clearly reflected in marine fauna like ammonites. A marine transgression is generally associated with these Jurassic limestones and shales, the latter of which are locally intercalated with flaggy sandstones and siltstones of a probable estuarine origin.

The entire Jurassic succession in this area is well bedded, compact and massive. These rocks are areally restricted and have minimal potential as groundwater reservoirs except, perhaps, where they are fissured, cavernous or weathered. Even then they yield only limited quantities which are, however, hard and unlikely to be potable.

Tertiary sediments are rather poorly represented in the area as formations of this age are of restricted occurrence. Early Miocene rocks (Baratumu Beds and Fundi Isa limestones) crop out in the Malindi-Fundi Isa area where they have been seen to consist of fossiliferous shallow water sandy marls, marly limestones and some calcareous clays and sands of littoral origin. In the Malindi area, this group of sediments is overlain by late Pliocene sands, clays and pebble beds (Marafa Beds). Some of the sands and pebble beds have locally been cemented, largely by clay minerals, into sandstones and conglomerates. These rocks may be calcareous in those localities where they are cemented by carbonates.

The Tertiary rocks here have little potential as water containers, partly because of their restricted areal extent and partly because of their thinness (they never exceed about 100 m in thickness). What little water there is, is generally hard and unpotable.

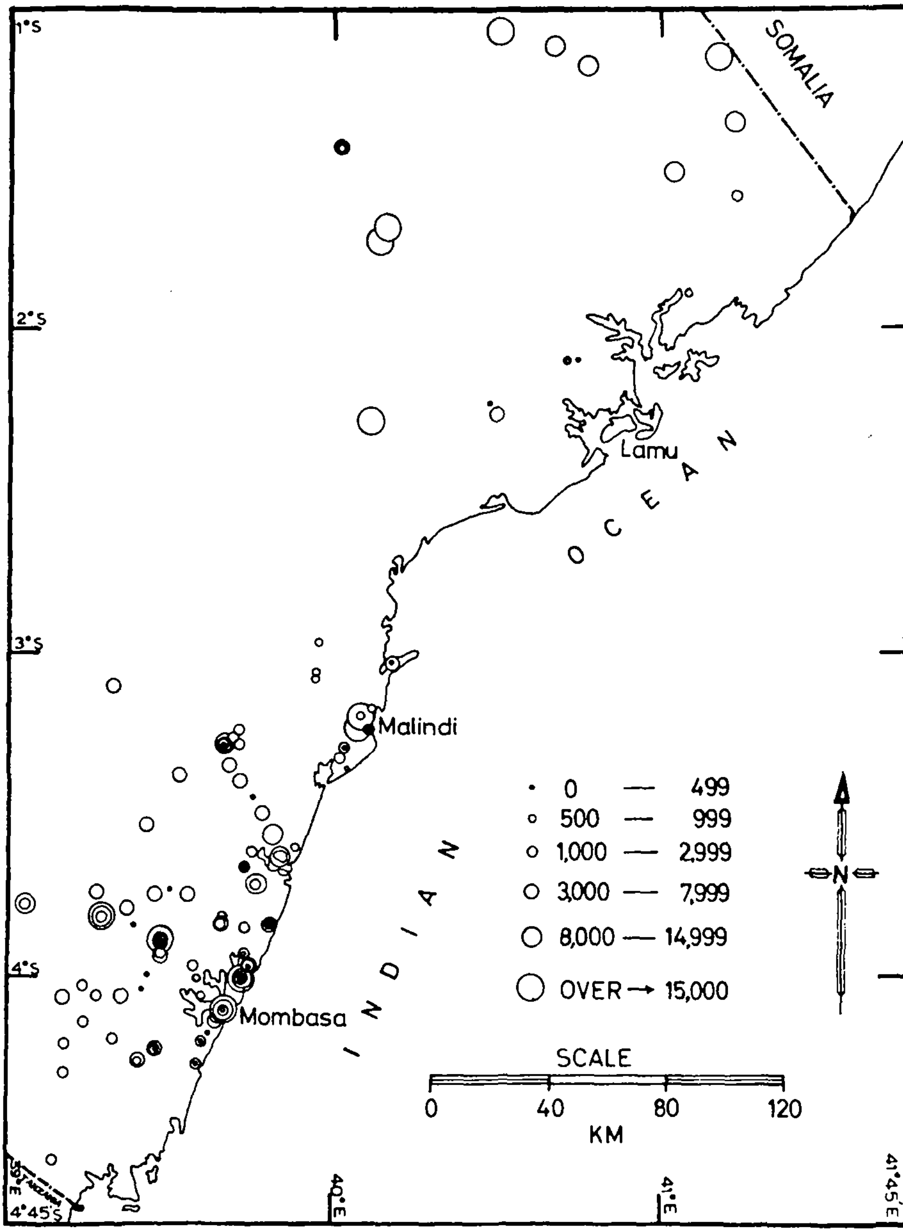
Sediments of Quaternary age are commonplace in this area. They comprise wind-blown and lagoonal sands, silts and clays, fossil coral reef limestones and breccias, coquinas (cemented calcareous sands), and isolated patches of gypsiferous beds and alluvium. These sediments are of no consequence as water bearers where they are too thin or where they yield hard unpotable water. The sediments of this age include those of two well-known formations—the Red Magarini Sands and the Fossil Coral Reef and Breccia. The former consists of largely uncemented siliceous sands with quartz grains which are now coated by thin films of Fe oxides, hence their characteristic bright red colour. The latter occurs in a narrow zone along the shoreline and consists of coral reef limestone representing the true fossil coral reef and coral breccia derived from the disintegration of the fossil reef.

Hydrogeochemistry and water quality

The importance of geochemical effects of containing aquifers on subsurface waters has been discussed in sufficient detail elsewhere (Hove 1976). A universally recognized quantitative measure of water chemistry, and hence of its chemical quality, is the amount of total dissolved solids (TDS) which are stated as ionic concentrations of various elements in parts per million (ppm). The rate at which the various ions are supplied to the water depends to a large extent upon the rate of solubility of the material forming the rock. An aquifer of predominantly calcareous composition with a substantial amount of $CaCO_3$, for instance, tends to yield water samples with relatively higher TDS values than those from a neighbouring one of a predominantly siliceous composition dominated by the more stable SiO_2.

A large number of boreholes have been sunk in the various sedimentary rocks of the Kenya coast. TDS concentrations in water samples from these boreholes have been plotted in statistical fashion (map 2, after Hove and Ongweny 1973), and show most of the salinity values to be over 1 000 ppm. A substantial number exceed 3 000 ppm and thus show that most groundwaters in this area tend to be highly saline. This is borne out in table 3 where the Middle Duruma Series attains average values of about 5 000 ppm. From map 2, it is clear that values of 10 000 ppm or more are not uncommon. A notable exception is the Upper Duruma Series where the water is non-saline, and shows why for a long time until fairly recently, the Mazeras Sandstone was Mombasa town's most important source of water. This, together with comparatively high yields, has made this formation the most promising aquifer of the coast.

Ca, Mg, Cl, HCO_3 and SO_4 concentrations are characteristically high in the Lower-Middle Duruma Series where the mean maximum values (rounded for



Map 2. Total dissolved solids concentration in parts per million.

Table 3. Salinity of water samples from some boreholes in sedimentary formations of the south Kenya coast

Rock type	Borehole no.	Depth (m)	Salinity
Lagoonal sands	C38	83	Brackish
Aeolian sands	C1722	65	Fair
Fossil coral reef	C48	62	Saline
Marafa Beds	C1046	?	Saline
Upper Jurassic shales and limestones	C173	130	Saline
Mazeras Sandstones	C609	103	Good
Mariakani Sandstones	C1101	160	Very saline (salts about 5 000 ppm)
Maji-ya-Chumvi Beds	C934	?	Very saline (salts about 5 000 ppm)

Source: Caswell 1953.

Table 4. Mean maximum values of selected ions in three formations (in ppm)

Mean maximum values	Ca	Mg	Cl	HCO_3	SO_4	SiO_2
Lower-Middle Duruma Series	350	200	4 000	800	1 000	<50
Coral Reef and Breccia	200	100	>1 000	300	150	30
Quarternary sediments	100	50	300	200	500	30

convenience) have been computed as shown in table 4. As previously noted, the succession in this part of the series is characterized by the development of evaporites. The impervious shale bands or strata occurring in these rocks have the significant effect of confining the water to nearly horizontal permeable strata for relatively long periods of time during which comparatively large concentrations of dissolved solids enter into solution.

The Red Magarini Sands represent early Pleistocene coastal dunes and constitute a highly permeable formation resting on a seaward-dipping surface of impermeable Jurassic strata. Subsurface flow therefore takes place towards the younger Quaternary sediments so that, coupled with the shallowness of the deposit, only small amounts of water can be retrieved from these sands. The water is reasonably fresh and potable but the ferruginous nature of the sands may locally contain objectionably excessive concentrations of Fe ions. Thus TDS values may be low but both the Fe_2O_3 and SiO_2 contents of the water tend to be higher than usual.

The Coral Reef and Breccia (early Pleistocene) is also highly permeable and yields hard but generally potable water, hence the numerous wells and boreholes. It is a fairly productive aquifer, next to the Duruma Sandstone, even though the yields tend to be small Fresh water is obtained from shallow boreholes since contamination from sea water increases with depth. TDS values of fresh water generally range up to 2 000 ppm but they may in certain localities exceed this amount. Mean maximum values of selected ions in this formation are indicated in table 4.

Contemporary and younger Quaternary sediments have more variable potential for groundwater than the Coral Reef formation. The chemical quality is also variable. This variability may largely be attributable to the substantial variety of depositional environment, to variable geochemical nature of the sediments and proximity to the sea. TDS values normally do not exceed 1 000 ppm but they can be as much as 15 000–20 000 ppm where there is encroachment from sea water. Geochemical factors are exemplified by the abundance of SO_4 ions in the gypsiferous aquifer at Roka near Malindi. Closer to the shoreline, a salinity gradient exists as shown in table 5.

Table 5. Salinity gradient at the Roka aquifer

Water quality description	TDS value (ppm)
Fresh water (at top)	$<1\,000$
Brackish water	1 000–10 000
Salty water	10 000–100 000
Brines	$>100\,000$

This progression with depth from brackish waters to brines can be largely attributed to gradually increasing mixture of the fresh water with NaCl-rich sea water. In table 4 mean maximum TDS values of fresh waters from these sediments are shown.

Statistical analysis of some hydrogeochemical data from coastal Kenya

Hove (1976) has made an attempt to portray the statistical (frequency) distribution of TDS values in groundwater samples from the sedimentary aquifers of the Kenya coast (figs. 1–3). This was also done for Ca and Mg which are among some of the most interesting cations (figs. 4–9). Considerable positive skewness is reflected in the distributional patterns of most of the major ions like Ca and Mg. This is an indication that, even though there is a substantial proportion of high TDS values (more than 1 000 ppm), smaller values are generally more prevalent. This observation conformed to the Vistelian law of geochemical processes (Vistelius 1960). According to Vistelius, the tendency for smaller ionic concentrations in a water-bearing rock to occur most frequently depends to a great extent upon the hydrogeochemical processes involved in the supply of these ions from aquifer to water.

A second major indication is the tendency of the distribution to unimodality. Only in figures 4 and 9 are there distinct implications of minor modes. Modal values were also computed for samples from the three major rock groups of the area (table 6). These values confirm the view that despite the occurrence of large concentrations, smaller concentrations of dissolved solids occur most frequently.

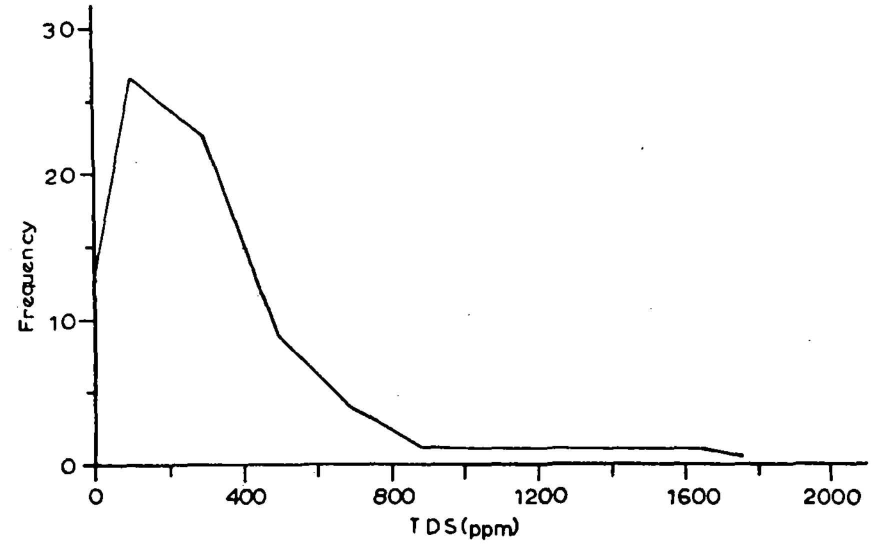


Figure 1. Frequency distribution of total dissolved solids in groundwater samples from sandstones of the Duruma Sandstone Series.

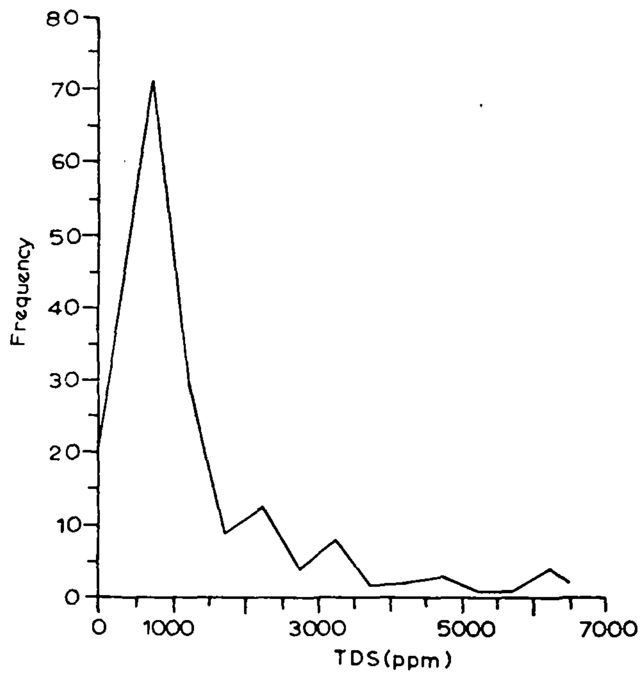


Figure 2. Frequency distribution of total dissolved solids in groundwater samples from the Pleistocene-Recent Coral Reef sediments.

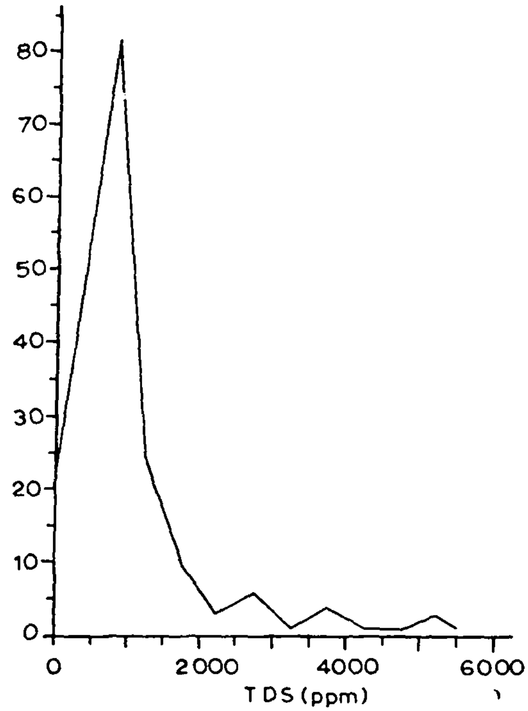


Figure 3. Frequency distribution of total dissolved solids in groundwater samples from Quaternary sediments

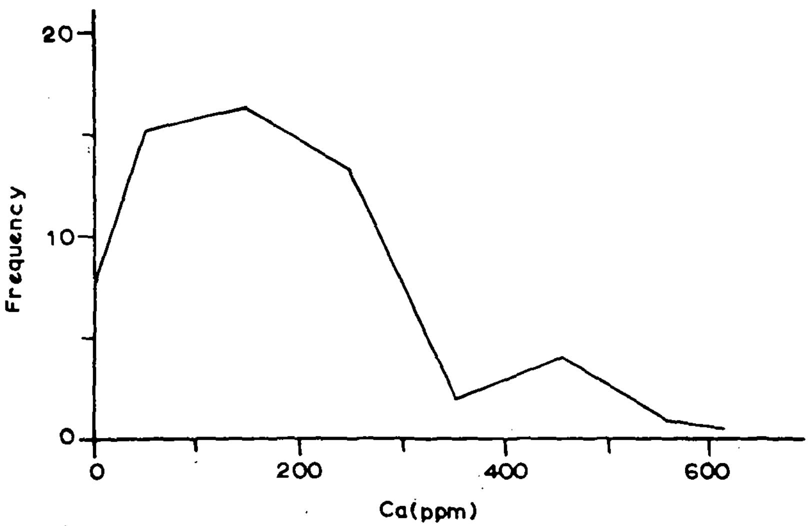


Figure 4. Frequency distribution of calcium in groundwater samples from sandstones in the Duruma Sandstone Series.

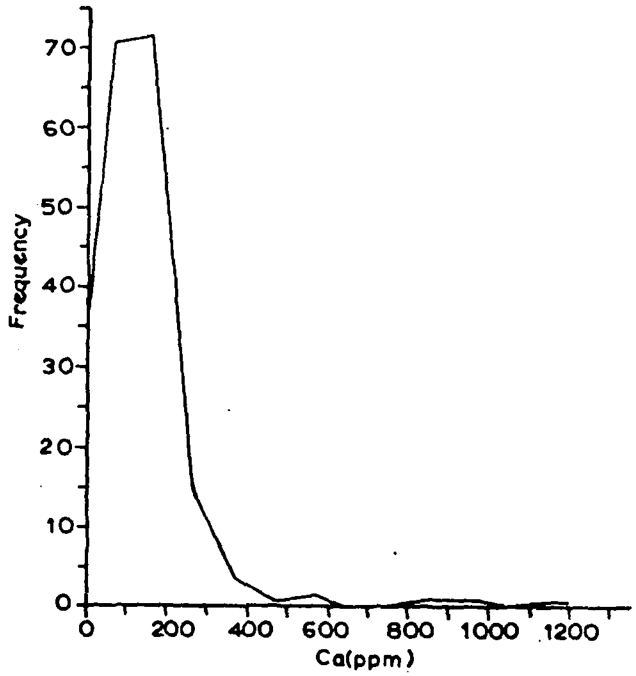


Figure 5. Frequency distribution of calcium in groundwater samples from Pleistocene-Recent Coral Reef sediments.

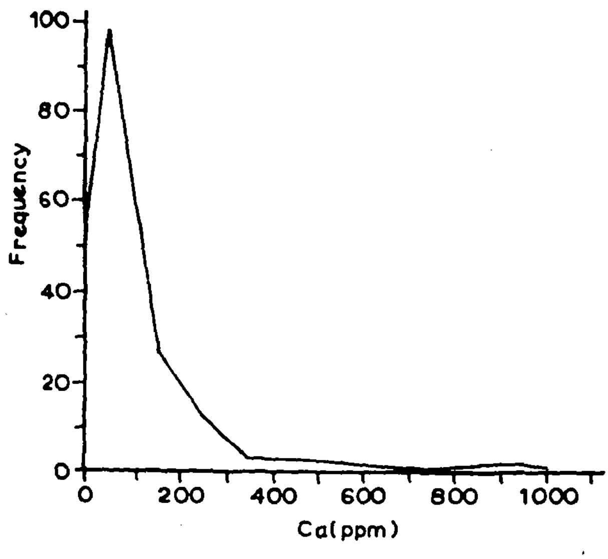


Figure 6. Frequency of calcium in groundwater samples from Quaternary sediments.

The normality/log-normality of ionic distribution was tested on a cumulative frequency basis (figs. 10–12) for TDS values from one group of coastal sediments—the fossil coral reef and breccia. The values were plotted on log-probability scale and all appear to be more or less straight lines, which is a reflection of log-normally distributed concentration values. This observation is in conformity with the log-normal laws of geochemistry advanced by Ahrens (1954, 1957a, b). Therefore, at least as regards the major chemical constituents, the trend is towards log-normality rather than normality.

On the basis of these observations, it is reasonable to assume that the Ahrens

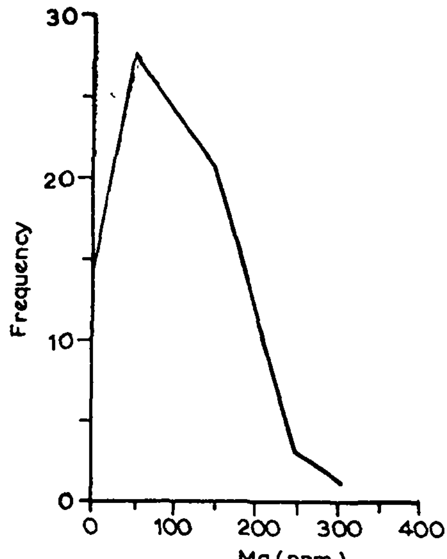


Figure 7. Frequency distribution of magnesium in sandstones of the Duruma Sandstone Series.

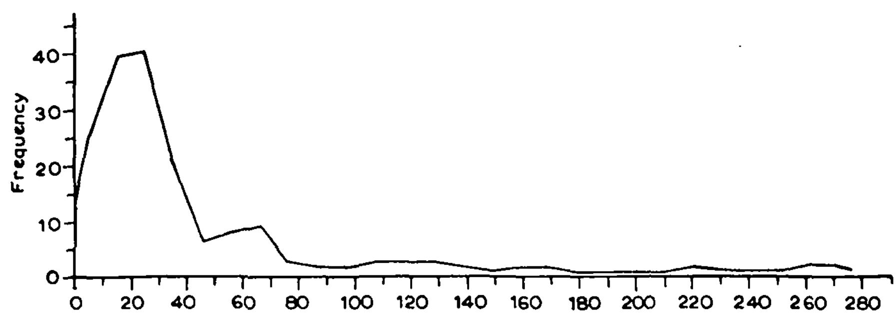


Figure 8. Frequency distribution of magnesium in groundwater samples from the Pleistocene-Recent Coral Reef sediments.

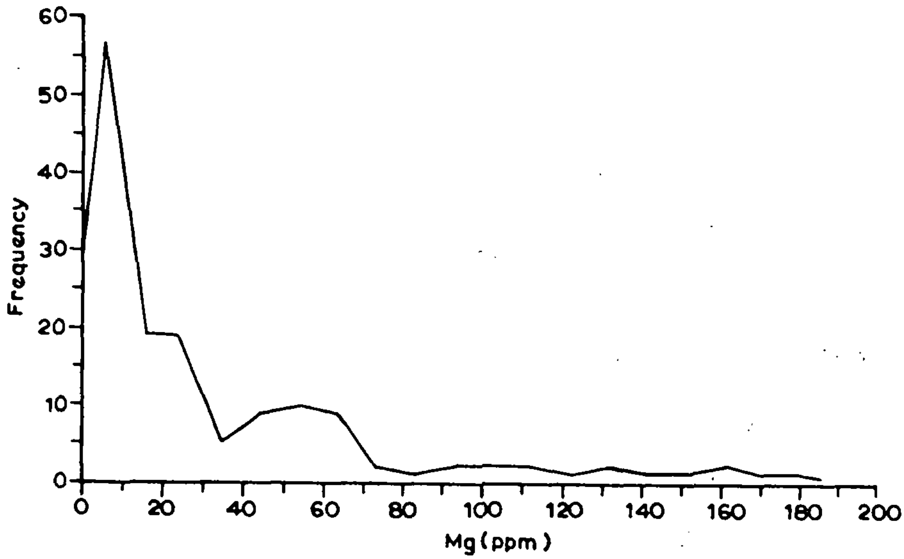


Figure 9. Frequency distribution of magnesium in groundwater samples from Quaternary sediments.

Table 6. Modal values of selected ions from the three major rock groups

	TDS	Ca	Mg
Duruma Sandstones	750	50	5
Fossil Coral Reef and Breccia	750	50–150	20–25
Other Quaternary sediments	100–300	50–250	50

laws can be extended to ionic distributions in groundwaters associated with aquifers whose constituent soluble materials are the source of most of the substances which have gone into solution in the water.

Correlation was also attempted between concentration values of Ca and Mg ions (in ppm) from several groundwater samples with values of content (in %) of the same elements in rock samples from aquifers where the water samples were obtained (fig. 13). The plotted values, particularly those for Mg, are close to straight lines and thus portray a positive correlation. Correlation coefficients (product moment correlation coefficients) were also computed for the same sets of data and came out with values of 0.606 and 0.691 for calcium and magnesium respectively. It is significant that the correlation is clearly portrayed as positive.

The positive relationship demonstrated above most probably reflects a similar relationship for most of the other chemical constituents. It is perhaps also a fair indication of the geochemical effects of the aquifers in question.

Applications to agricultural and domestic use

It is largely upon hydrogeochemical sample data that water quality, and its usefulness for certain purposes, can be determined. The criteria applied to agricultural and domestic as well as industrial uses have been proposed by Hern (1959), Todd (1959), Davis and de Weist (1966), the WHO (1971), and other authorities. They have suggested what they consider to be upper limits or tolerable quantities of certain substances or elements in solution.

Now that certain mean concentration values have been acquired for TDS, Ca, Mg, Cl, HCO_3, SO_4 and SiO_2 in groundwater samples from the various aquifers of coastal Kenya, it is possible to demonstrate how, in groundwater resource planning for the area, hydrogeochemical sample data of this kind can be used to determine the chemical quality, and hence the suitability or potential utility, of waters from aquifers found in the area.

Application to agriculture

TDS concentration values in groundwater samples from the Lower-Middle Duruma Series (5 000 ppm or more) indicate high salinity values and, therefore, unsuitability of the water for either irrigation or watering of stock (particularly dairy cattle). The Mg and Cl contents (up to 200 and 400 ppm respectively) are too high for most agricultural purposes. Those for HCO_3 and SO_4 (up to 800 and 1 000 ppm respectively) indicate a quality which is too poor for both irrigation and stock.

Samples from the Fossil Coral Reef and Breccia generally have TDS concentrations which are comparatively low (up to 2 000 ppm) but are still high enough to reflect poor quality. Nevertheless, this water is not altogether unsuitable for irrigation and should cause no apparent harm to stock. Its Cl, HCO_3 and SO_4 contents ($>$1 000, and up to 300 and 150 ppm respectively) do not, however, render it completely recommendable for all agricultural uses.

Quaternary sediments other than the Fossil Coral Reef and Breccia generally yield fairly fresh waters from shallow depths. TDS concentrations range up to 1 000 ppm but can exceed 10 000 ppm at lower depths where the water may locally be contaminated by sea water. The SO_4 contents (up to 500 ppm) may be somewhat disturbing because the very high values from the gypsiferous beds have been included in the computation of the mean value. The Ca, Mg, Cl, HCO_3 and SiO_2 concentrations are largely less than 200 ppm so that uncontaminated waters from those sediments can be regarded as suitable for most agricultural purposes.

Application to domestic use

Although there have been no definite or apparent signs that water from the Lower-Middle Duruma Series is harmful to human health, it is not recommended for drinking or household use without preliminary treatment. The TDS,

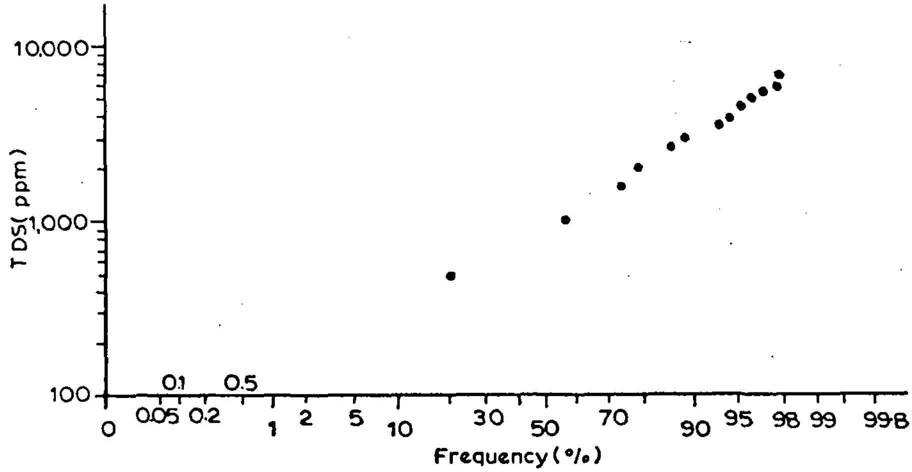


Figure 10. Frequency (cumulative) distribution of total dissolved solids in groundwater samples from Pleistocene-Recent Coral Reef sedimeent.

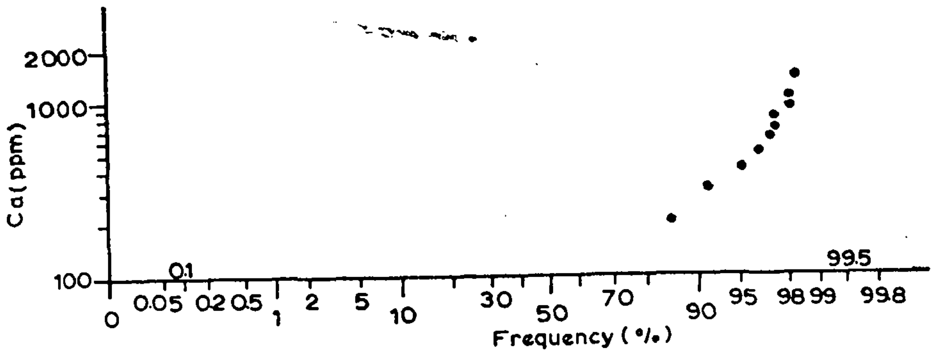


Figure 11. Frequency (cumulative) distribution of calcium in groundwater samples from Pleistocene-Recent Coral Reef sediments.

Cl_2, HCO_3, SO_4 and SiO_2 contents, for instance, far exceed the permissible limits for most household purposes.

The concentrations of TDS, Ca, Mg and SiO_2 in groundwater samples from the Fossil Coral Reef and Breccia are tolerable for most domestic uses but those of HCO_3 and SO_4 make it barely so. That of Cl certainly makes it unfit for drinking even if it may be fairly suitable for other household purposes.

Samples from Quaternary sediments other than the Fossil Coral Reef and Breccia, if uncontaminated, indicate acceptable limits of dissolved substances, particularly as reflected in the figures for TDS, Ca, Mg, HCO_4 and SiO_2. However, objectionable amounts, say for example the SO_4 amounts in samples from gypsiferous basins, may occur locally.

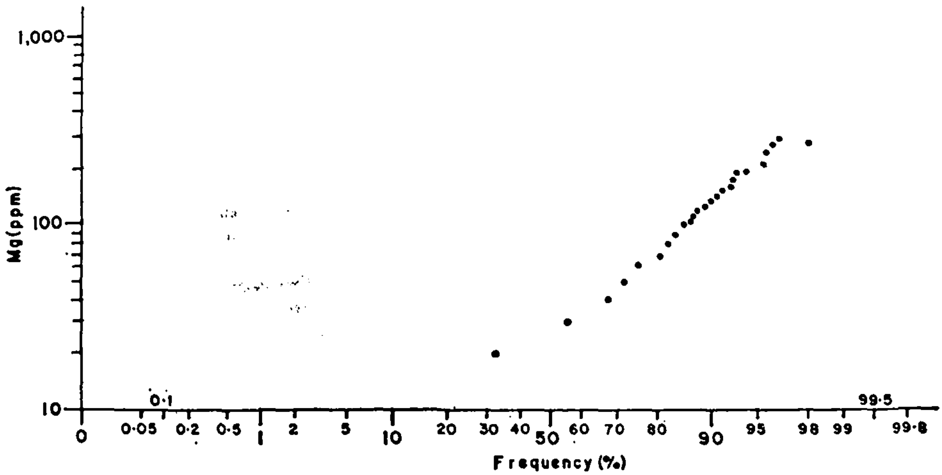


Figure 12. Frequency (cumulative) distribution of magnesium in groundwater samples from Pleistocene-Recent Coral Reef sediments.

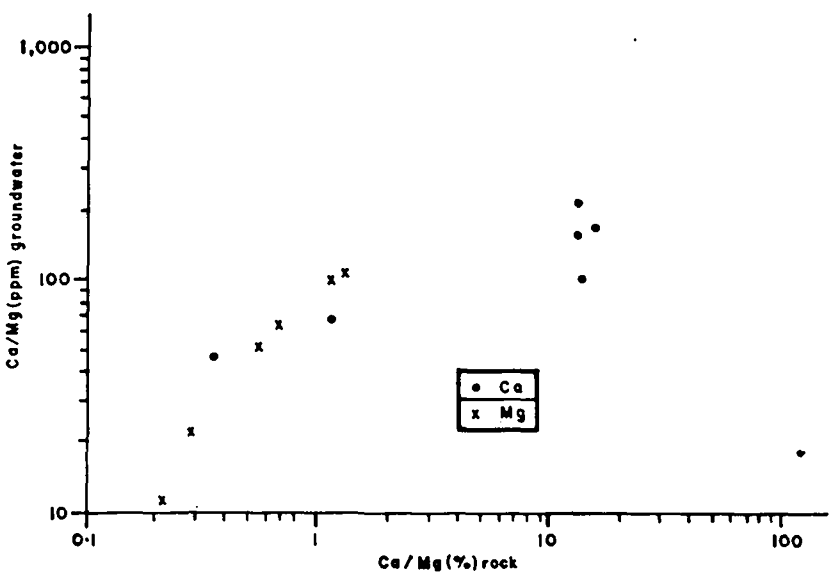


Figure 13. Relationship between calcium and magnesium content (median values) in groundwater samples and content (median values) of the same cations in rock samples from various sedimentary aquifers of coastal Kenya.

Conclusion

The principal factors of groundwater chemistry are largely geochemical ones. The materials constituting water-bearing rocks, if of different chemical composition and solubility rates, react differently to hydrogeochemical processes involving solution. Therefore sedimentary aquifers showing differences in lithology, mineralogy and cementing materials generally contain waters of different chemical quality as has been proved in samples from the Kenya coast. Hydrogeochemical sample data may be used to determine water quality and potential utility of the water for various agricultural, domestic and industrial purposes.

Sedimentary aquifers of coastal Kenya generally yield hard water but there are differences in the degree of hardness. These differences are largely attributed to differences in the geochemical character of the aquifers. The Lower-Middle Duruma Series yield water with high TDS concentration values, hence the tendency to excessive hardness. Rocks of the Jurassic system also tend to yield excessively hard water. They, and also those of Tertiary age, are not important aquifers. The major potential of the Duruma Sandstone Series lies in the Upper Duruma Series where the Mazeras Sandstones constitute a permeable and productive aquifer which yields relatively soft water. Other aquifers with potential are of Quaternary age and include the Coral Reef formation and other Pleistocene-Recent sediments. Locally, however, these young sediments may yield hard unpotable water.

An attempt has been made to show the use of hydrogeochemical data derived from the chemical analysis of groundwater samples from this area for determining the potential utility of these waters in agriculture and for domestic purposes. This can be done for any other part of the country where the character (quality) of groundwater resources is not sufficiently known. The value of this approach is that fairly objective conclusions concerning the chemical quality, and therefore utility, of such resources can be made on the basis of data from relatively few groundwater samples.

Acknowledgements

The data used in this paper were obtained from the Water Department, Nairobi, where a large quantity of unpublished information on boreholes throughout the country is available. A substantial amount of relevant hydrogeochemical data were originally obtained from the Government Chemist, Nairobi, by Mr G. S. O, Ongweny. Mr F. Wanyoike drew the maps and diagrams.

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ANALYSIS OF CHEMICAL POLLUTION IN SOME KENYAN WATER SYSTEMS WITH SPECIAL REFERENCE TO LAKE NAKURU

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Abstract

Analysis of pesticide residues in Lake Nakuru fish and algae has been undertaken and is reported. Similarly, analysis of copper, iron and zinc in the Lake Nakuru water is reported. The half-life of DDT in the Lake Nakuru area was found to be 120 days in the open field and about 200 days in the half-shaded field. This is possibly the shortest half-life time known. Chemical pollutants in the coast area, Kerio Valley and River Nzoia are reviewed.

Introduction

The analysis of chemical pollutants in Kenya has been carried out by various groups and individuals. However, the results of most of these analyses are not known. Consequently the state of the environmental quality in Kenya has been very ill defined. In fact there are very few laws that define environmental quality. The lack of such laws has brought several crises in Kenya. The most critical in my opinion is the increasing destruction of our coastal beaches by oil spills from the big oil tankers. I collected one of the crude oil cannon balls from Likoni Beach recently and I display it and its purified product here. I also believe that most of you who have visited the coastal beaches have had the experience of the black grease that sticks to the feet at every step and is very difficult to clean with soap and water. In view of the importance placed on the tourist industry, it is a pity that no corrective measures have been taken to eradicate this pollution. The technology for preventing oil spills is continuously changing. However, the present technology can succeed only if the law enforcement officers apply the necessary law available for combating oil pollution.

Another instance where the enforcement of corrective law is lacking concerns the chemical pollution created by the paper, coffee and sugar industries. The paper industry has a history full of dead rivers all over the world. In the United States, this industry is credited with the death of most rivers in the Tennessee and Mississippi valleys, although credit must be given to the same industry for the research it has done in improving its own technology. At present, the technology for combating chemical pollution coming from paper industry is very well understood. However, most of you who have visited Webuye recently will probably not forget the stench that hangs over that town. Furthermore, the industry remains a potential threat to the river Nzoia and Lake Victoria ecosystems. The awful smell is mainly sulphur dioxide which mixes with moisture in the air to form sulphurous and sulphuric acids. All three irritate the respiratory systems and at higher concentration can cause death gradually. Yet in Kenya, in spite of the known dangers associated with these industries, there is no law that seeks to contain their chemical pollution aspects. Similarly, the sugar and coffee industries in Kenya have been major polluters as their effluents are poured freely into the waterways, and there is very little control of these effluents.

Apart from the above industrial effluents there are other inorganic compounds which have become potential threats to the ecosystem balance in Kenya. These include fluorspar, calcium fluoride, cement and asbestos. The fluoride ion, which is formed upon the dissolution of fluorspar, when in a concentration greater than 0.8 ppm (mg/l) in drinking water will affect the bone systems of all animals and make them soft, and will also hydrolyse most peptide bonds. The ultimate result of fluoride poisoning is death. Although the formation of fluoride ions from the dissolution of calcium fluoride results in very low concentrations of the anion, this factor alone should not be emphasized without taking into account the effects of bacteria on salts under anaerobic conditions. The control of fluorspar dumping in the water systems needs to be made tighter if damage to the ecosystem is to be averted. The high particulates emission from cement and asbestos factories are objectionable because of their effect on the respiratory systems. The technology for controlling these emissions is again very well known but not enforced in Kenya.

Analysis of chemical pollution in and around Lake Nakuru

In recent days the threat to the Lake Nakuru ecosystem by the production of copper-oxy-chloride (Copal Co.) has been greatly exaggerated by the national newspapers. Our analysis (Wandiga 1977, unpublished data) of the Lake Nakuru water has revealed that the concentration of copper (2–8 mg/l), a major inorganic poison, is far below the threshold limit. However, we have not analysed the mud from the lake which may contain a higher concentration of copper than the water.

On the other hand the threat to the Lake Nakuru ecosystem by organic pesticides has concerned us for a long time. Kenya, unlike the United States and most European countries, places no restriction on the use of DDT, Toxaphene (to control ticks on cattle) and other insecticides. These and other pesticides form a potential threat to both the human population and wildlife. The potential threat of pesticides on wildlife is most serious in places where agricultural run-off can contaminate groundwater or streams and where pesticides are sprayed on crops that may be eaten by wild or domestic animals.

Because of the shallowness of Lake Nakuru and its being the habitat for the enormous flocks of flamingoes and other animals, it faces the greatest danger of pesticide pollution. The concern for the lake resulted in a study of chlorinated hydrocarbon residues by Koeman et al. (1972). Samples from several species of birds and fish were collected and analysed for DDT, DDE, DDD, dieldrin, and endrin. The results ranged from 0.001 to 0.064 mg/g. Again, in 1972 Prof. C. A. Sleicher (personal communication) of our department analysed the chlorinated pesticides residue in copepods (*Lovelula* sp.) and found gratifyingly low concentrations of DDT (0.003 mg/g) and DDE (0 007 mg/g). His analysis of the algae and mud samples from the lake gave no detectable DDT or DDE. The low level of pesticide residues found in these studies suggests that these insecticides disappear more rapidly at Lake Nakuru than in temperate climates where the lifetime of DDT has been reported to be 16 weeks for surface application in England (Wheatley 1965) to 30 years for forest soils in Canada (Dimond et al. 1970). A mean value of 10 years is generally accepted (Edwards 1966).

To test the rate of disappearance of DDT in Kenya soil, a field test was begun on 1 October 1972 and completed on 30 August 1975 (1064-days). Two small plots on the Baharini Wildlife Sanctuary of 2.5 m by 2.5 m were sprayed with water emulsion of commercial DDT (about 80% of the p-p′ isomer), at the rate of 2 lb DDT per acre or 1.3 g per plot. No DDE or DDD, the principal metabolites of DDT, was detected. The half-life of DDT on the exposed plot was found to be about 120 days, or 0.3 years, which is far lower than any previously reported value other than the 16 weeks value reported by Wheatley (1965). If the 1064–day point was ignored, the best estimate of half-life was about 100 days for the exposed plot and about 200 days for the partially exposed plot. These values show that the concern for the spraying of DDT in Kenya is much exaggerated, particularly when these pesticides are sprayed in open fields which are not grazing lands. However, the spraying of these pesticides to fields which are close to waterways poses a great threat to the users of the water.

Chemical pollution from other areas

The concern for pesticides in Kenya is not restricted to the Lake Nakuru area alone but extends to all inland water systems including Lake Victoria. For instance, analysis of one sample of bass (fish) from Lake Victoria by the University of Stockholm indicates that a wide range of chlorinated hydrocarbons is present in the lake and calls for further monitoring. The following figures were obtained: (in ppb) DDT, 0.02; BHC, 0.06; heptachloroepoxide, 0 07; aldrin, 0.04; dieldrin, 0.13; HCB, 0.03; PCB, 0.04 (Jensen and Odhiambo 1977).

Another source of great concern in Kenya is the pollution of the water systems by spillage of the human wastes into the waterways. In fact, today schistosomiasis (bilharziasis) and to a lesser extent leishmaniasis remain two of the major health problems in the tropics. In Kenya, it is estimated that one out of every five people suffers from schistosomiasis. The devastating effect of schistosomiasis is exemplified by the resistance to the Kano irrigation plan by the inhabitants of the area. Other examples come from the endemic nature of the disease in the Aswan Dam area and the reported death and exodus of surviving Chinese farmers from rice growing areas between the middle and lower Yangtze River valleys and to the south during the three decades before 1960. Every major irrigation scheme in the tropics has brought with it the blessings of increased agricultural productivity and the scourge of schistosomiasis. The rural development of underdeveloped countries in endemic regions is slowed by this disease. As yet, it has proved unfeasible to eradicate molluscan intermediate hosts, to prevent infection of these aquatic snails by schistosome larvae hatched from eggs present in the faeces of infected people or indigenous animals, or to immunize people against this disease. The only alternative is effective planning of irrigation schemes and chemotherapy. The management of the environment would be greatly enhanced if in Kenya today there were comprehensive laws dealing with all aspects of environmental management.

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FOREST WATER YIELD AND USE: A KENYAN PERSPECTIVE

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Abstract
The impact of forest and forestry practice in Kenya on water resources is discussed in detail. Watershed management in the high rainfall, high elevation forests and water problems encountered in lowland afforestation are covered. The interplay of vegetation cover and soil stability is discussed in relation to soil water balance. Finally the impact of arid land afforestation and dedesertification practices on underground water table and microclimatic amelioration is discussed.

Introduction
Forests are Kenya's most valuable natural resource, not only because, in contrast to all other natural resources, they are renewable, but also because the forest resource affords certain goods and services which are vital to the survival of the country. Unfortunately, the great majority of people look to the forests for the goods they provide in the form of wood for timber, pulp, paper, fuel and to a lesser extent foods, and forget that the services we obtain from these forests are even of greater importance. Forests, and only forests, have noticeable impact on the properties of the earth's surface which influence climate, for example reflectivity, heat capacity and conductivity, available water and dust, aerodynamic roughness, emissivity in the infrared band, and heat released to the ground (Wilson 1970). This article highlights only one of the services we obtain from forests—the impact of the forests on available water.

There are two operative generalities involved in the forest–available water interrelationships. First, it has been amply proved that open surfaces like deserts and grasslands have higher albedo than forests (a unit increase in the earth's albedo will cause a decrease in average surface temperature of 0.85°C). The increase in albedo results in a decrease in rainfall. Thus, deforestation on a large scale can result in droughts and desertlike conditions. Secondly, forests regulate the water through springs and rivers in dry seasons.

In dedesertification programmes, the establishment of forests in one form or another is often the goal. What is often forgotten by such afforestation planners is that trees require large amounts of water in order to grow. A closed forest vegetation is more extravagant in water use than say a field of maize or any other crop. Without irrigation, therefore, arid land afforestation schemes can only result in lowering the undergound water table. Let us now examine how these principles apply to the Kenyan situation.

Kenya forests as a factor in land use planning

Only one-third of Kenya's land base has sufficient precipitation for agricultural development. The remaining two-thirds of the country is mainly scrub and semi-desert. Kenya's forests cover an area nearly 2 million hectares in extent which amounts to about 3 %. About 1 800 000 ha of Kenya's forest is on gazetted government land managed by the Kenya Forest Department while the rest is under private or county council ownership. The top management policy of the Kenya Forest Department is the management of national forests for water catchment. The bulk of these forests is situated on the slopes of high mountains and ranges, e.g. Mt Kenya, Mt Elgon, Cheranganis, Mau Escarpment, Aberdare Range, etc., although there are extensive lowland forests like Arabuko-Sokoke and Kakamega forests. The high elevation forests are the catchments for the country's major rivers—Tana, Nzoia, Yala, etc.

In the recent past there has been a dangerous trend of excisions in the national forest estate. Some of the excisions have been the result of organized and legal political-agrarian pressures while increasing amounts of excisions have been for illegal farming and settlement. The rate at which Kenya's forest area is being reduced is so alarming that it calls for a reestablishment of an ecologically sound land-use classification and policy. Four categories are conventionally recognized in land use classification (Rehm 1975):

1. Land capable of maximum agricultural and forestry output.
2. Land suitable for agricultural and forestry use but which needs to be extensively cultivated because of modest yields.
3. Land suitable only for forestry.
4. Land unsuitable for any commercial utilization.

Categories 3 and 4 would normally be on the steep slopes of high mountains where intensive and extensive cultivation is difficult. Such forests play the important role of water catchment for rivers and springs and have always been conserved by the government for that purpose. What is rather disturbing in Kenya is that people are overlooking the basic principles on which the decision to create and conserve the forest estate was based. People find it 'very profitable' for example to grow maize extensively in the Kakamega Forest. What they do not realize or choose to disregard is the fact that the result of such deforestation in catchment areas will be great losses of water yield control and that the nation has to pay a greater price somewhere else as a result of devastation of catchments.

Watersheds and their management

The water budget

The equation for water balance in a catchment area is $P = E_t + F + S$ where P stands for total precipitation, E_t stands for evapotranspiration, F for stream flow and S for underground water seepage. Past catchment research in Kenya's highlands has indicated that S is very small as compared to F and could reasonably be ignored in the equation (Pereira and McCulloch 1962). Thus water yield from catchment forests can be represented as $F = P - E_t$.

Calculations
One hectare millimetre of water is equivalent to 12 000 litres. The catchment areas above 2 000 m receive an average annual rainfall of 1 150 mm. Therefore, 1 ha receives about 13 800 000 litres of water per year.

In an experiment to determine the evapotranspiration demand of a single *Eucalyptus grandis* growing in riparian condition in the Aberdares catchment area, it was found that a single mature tree uses about 15 litres of water per day (Dyson, personal communication). Under optimal growth spacing there will be about 1 480 such trees per ha.

E_t per ha $= 15 \times 1\,480 = 22\,230$ litres/day
which works out to 8 113 950 litres/year/ha;
$F = 13\,800\,000 - 8\,113\,950$ litres/year/ha
$\simeq 5\,686\,000$ litres/year/ha.

In Kenya, there exist well over 1 million ha of forests in catchment areas which result in an annual water yield of $5\,686\,000 \times 10^6$ litres.

It is important to stress that it is in the *control* of this water yield in the form of steady streamflow and riverflow throughout the year that forests prove superior to any other vegetation type cover. Replacement of forests in the catchment areas by pasture grasses for instance will result in a reduction in E_t and therefore an increase in F, but the flow will be erratic causing floods in the rainy season and the drying up of streams and rivers in the dry seasons.

The impact of forest management on water yield
Out of the 1 800 000 ha of gazetted national forests, only about 300 000 ha are under compensatory plantations with fast-growing exotic softwood monocultures. Water catchment research at Kimakia has provided data which indicate that the replacement of the indigenous bamboo forests and tall montane rain forest by monocultures of *Pinus patula* and *Cupressus lusitanica* has little or no effect on the total amount of water yield and on the control capacity for that yield. The management policy of compensatory planting, therefore, appears to be compatible with the original water catchment ideals.

On these same grounds I challenge the recent decision by the Kenya Forest Department to authorize extended agro-silvicultural practices whereby gazetted forest land is cleared of indigenous forest flora and planted with wheat or maize for 3 years before planting the tree crop. Not only does this practice entice the others to eat into the national forests land illegally but, if practised on a large scale, can also result in deregulation of streamflow causing flooding and drying up of streams.

In general, other management systems like road building, logging systems, etc., disturb negligible proportions of the forest area and can be assumed to have little impact on forest water yield.

The influence of silvicultural practices on water yield

The water consumption of a forest stand depends on:

1. Transpiring leaf mass,
2. Density of the stand,
3. Age and species composition,
4. Soil properties, and
5. The local climatic factors.

It has been found by several workers that there exists a linear relationship between streamflow increase and the amount of reduction in forest stand basal area. McMinn and Hewlett (1975) reported the relationships for temperate climate as shown in figure 1.

The current Kenyan practice for compensatory plantation requires that about 1 480 seedlings per ha be outplanted and that as these grow and mature, several thinnings be effected to reduce the number of trees per ha to about 250 in keeping with space requirements. The intermediate and final basal areas of these monocultures are lower than for the indigenous forest cover and theoretically should result in increases in run-off in the initial periods of plantation establishment. What is important to realize, however, is that under a sound silvicultural practice like the shelterwood method the yield and flow should be

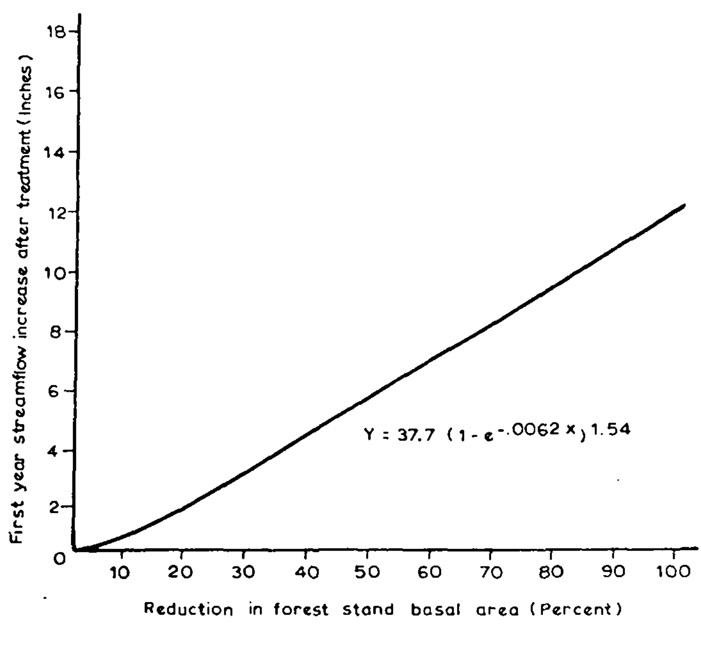

Figure 1. First-year streamflow increase related to reduction in forest stands (from McMinn and Hewlett 1975).

stabilized over the whole catchment area even under compensatory plantation forestry.

There exists the other problem of the overexploited catchment forests. The Upland Forest of Lari Forest Reserve, the Mau Narok Forest Reserve, Cherangani Forest Reserve and Kakamega Forest are good cases in point. In some of these areas the basal area has been reduced to such low levels that flooding is a certainty. There are two possible fronts of combat:

1. Move in with monocultures or
2. Gradually build up the basal per ha by enrichment planting.

The second option is obviously the more ecologically desirable.

Water use problems in marginal rainfall lowland forests

Low elevation forests of Kenya include Ndoto Range Forest, Mathews Range Forest, Leroghi Forest, Nyambeni Forest, Mbooni Hills Forest, Upland Forest of Karura, Ngong and Langata, Taita Hills Forest, Shimba Hills Forest, Arabuko-Sokoke Forest and Kakamega Forest. Apart from the Kakamega Forest, all these lowland forests experience precipitation of under 1 000 mm per year. Ecologically these forests are very fragile and, therefore, there is a need for strict conservation measures. Apart from Kakamega Forest, these lowland forests only serve as catchments to seasonal streams and rivers which dry up in the dry season. These forests occur typically in areas with shallow underlying impervious rock and therefore are very prone to heavy flooding. Devastation of these forests results in heavy soil erosion. In some areas like Machakos this trend of events can easily lead to the creation of desertlike conditions. The valuable surface soil lost and the subsequent heavy silt loads in the adjoining rivers are features very familiar in these drier parts of Kenya. In these areas, forests are vital for the prevention of soil erosion and only to a minor extent are they valuable for water yield.

Afforestation schemes in these areas face peculiar water problems. The marginal rainfall of about 1 000 mm is usually less than the evapotranspiration demand which in these hot areas amounts to 1 000–1 500 mm per year. All in all these lowland forests experience a water deficit on a yearly basis. Economy in water use therefore becomes important in afforestation programmes in areas like Arabuko-Sokoke. The silvicultural objective boils down then to ensuring that as much as possible of the available water be used by the growing tree crop and not by weeds. Practices like weed-free plantation establishment, zero-tillage silviculture, and branch mulching to reduce surface evaporation should be tried.

Arid land afforestation and dedesertification practices

About 60% of Kenya receives rainfall under 750 mm per year and can be declared arid. In these areas, rainfall is unreliable and is often confined only to a few weeks. Due to the hot climates prevailing in these areas, potential evaporation levels are often as high as 2 000 mm per year. By arid land, I refer to areas receiving 300–600 mm of rainfall per year while real deserts receive 0–300 mm of rainfall per year (both situations occur in Kenya of course). There is little disagreement as to the fact that trees rather than agricultural crops should be the vegetation with which to conquer these arid lands and deserts. However, there is a very common misconception that a forest vegetation, once established in these arid lands, will dramatically increase the amount of local rainfall. As a matter of fact nothing of the sort should be expected. If anything, successful establishment of a forest vegetation in the Turkana desert will do little more than cause a slight increase in the relative humidity in the forest locality.

Furthermore, as has already been stressed, trees, more than any other vegetation type, are big spenders of water and this water has to come from somewhere. Trees survive better in desert and arid lands because they have deep roots that can penetrate to a depth of 10 m or so to reach underground water tables. Intensive forest plantations in these arid zones is only likely to result in lowering the water table and thus driving the arid conditions from bad to worse. For this reason, it is important that only a small proportion of the land area be placed under trees in these dry regions. Strip and net planting arrangements involving areas not exceeding 5%–10% of the land area would be the most desirable practice since the strips would provide the services of arresting soil erosion, buffering inhabitants from sand-laden winds, provision of shade and timber while at the same time economizing on use of underground water.

When large masses of water are present and irrigation is feasible, then tree establishment in the arid areas by irrigation should be attempted. Under such hot climates a tree will consume about 200 l of water per day (Achtnich 1975). This amounts to some 300 000 l per day per ha. If desalination protocol is also feasible, this is not an unreasonable quantity of water to supply to arid area within 200 km from the ocean.

Conclusion

Kenya has a very limited forest base which is ecologically stable to provide catchment services for years to come. Conservation of this small forest base is the cheapest and ecologically most sound method of ensuring that enough water in controlled amounts is available for our generation and those that follow us. A no-nonsense policy will however have to be adopted in the custodianship of this small forest base in order to avoid losing even the little we have.

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INSECTS OF MEDICAL AND VETERINARY IMPORTANCE ASSOCIATED WITH WATER RESOURCES AND SOME ASPECTS OF THEIR CONTROL BY WATER RESOURCE MANAGEMENT

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Abstract

Various insect species associated with water in East Africa are vectors or carriers of human and animal diseases. Five groups are primarily involved, namely, *Culicoides* (Ceratopogonidae), blackflies (Simulidae), horseflies (Tabanidae), mosquitoes (Culicidae), and tsetseflies (Glossinidae). A brief outline of their life cycles, preferred habitats and distribution in East Africa is given, as well as a description of the types and prevalence of the diseases they transmit. There are large areas of natural lakes, rivers, streams and swamps all over East Africa which have never been appreciably altered by man and which form good breeding places and habitats for harmful insects. Countless ordinary human activities such as farming, house building, road building and watering of cattle, wildlife or humans require water supply and drainage and thus influence the number of harmful insects that thrive in their immediate environs. A conscientious water engineer or administrator who is aware of these facts will always find ways of reducing the availability of breeding places and habitats for disease-carrying insects. Keeping the banks of all bodies of water steeply sloping and clear of vegetation both within the water and along the banks, cutting and filling water reservoir or water course banks to avoid creeks or meanders, channelling areas of swampy ground, and regular damming and periodic flushing or ditches, streams and small rivers, are some of the well-proven ecologically sound methods of water management for the reduction of harmful insect populations.

Introduction

The subject matter of this paper sets out to draw attention to the widespread importance of insects that are associated with water as vectors or carriers of diseases of humans and livestock in East Africa. Specific reports on particular insect problems that exist in East Africa in connection with water resources and their management have been given by several authors including Parsons (1954), Buxton (1955), Clover (1967), Williams (1968) and Hopkins (1952a).

Insect species

The insects of medical or veterinary importance which are directly associated with water in East Africa are all true flies or Diptera. Their females require blood from a vertebrate animal as food for the development of eggs. Five groups are primarily involved, namely, *Culicoides* (Ceratopogonidae), blackflies (Simulidae), horseflies (Tabanidae), mosquitoes (Culicidae) and tsetseflies (Glossinidae). It will not be possible to discuss all the features of these insects' biology, but suffice it here merely to outline their life cycles, preferred habitats and distribution in East Africa, and give a brief description of the types and prevalence of diseases they transmit. At the end I shall outline certain well-proven, ecologically sound, methods of water management for the reduction of such insect populations.

Culicoides (Ceratopogonidae)

Culicoides are very small biting flies (length 0.6–5.0 mm) which breed in damp soil and open shallow standing water containing a high concentration of organic matter (Lubega and Khamala 1976). The larvae feed on humus in the top few millimetres of earth and organic matter in water. Development takes 3–5 weeks depending on the species. It is when large expanses of unflooded damp soil occur, such as marshes along water courses, in mangrove swamps, around dams and ponds, and along the sea-beach tideline, that production of these flies can reach annoying levels during certain seasons. Biting rates of over 2 000/hr have been reported by Hopkins (1952b) for *C. grahamii* Austen in West Africa.

The female *Culicoides* feed crepuscularly, i.e. at dawn and dusk. Their bite causes intense irritation and burning which continues for a few minutes, but with more susceptible victims, the pain lasts longer and the affected parts swell up into large weals. In many parts of Africa certain species, notably *C. austeni* (Carter, Ingam and Macfie), transmit the parasite *Acanthocheilonema perstans* Sharp, which is a worm responsible for a benign human blood disease known as filariasis. This disease exists in many parts of Uganda, western Kenya and northeastern Tanzania (Highton, Phipps and Nelson 1963). *Culicoides* are also vectors of two serious virus diseases of livestock, namely bluetongue and African horse sickness (Du Toit 1944; Price and Herdy 1954; Foster, Jones and McCrovy 1963). Both diseases are endemic in East Africa, and in a preliminary survey of the epidemiology of bluetongue in Kenya by Walker and Davies (1971), *C. schultzei* (Enderlein), *C. magnus* De Meillon, and *C. imicola* were shown to be involved.

Blackflies (Simulidae)

The Simulidae are small flies (length 1–5 mm) that breed always in running water. The eggs are deposited on vegetation overhanging the water or on stones, twigs, or logs beside or just beneath the surface. The larvae of most species attach by their tail to submerged surface, usually in a semi-sheltered position where eddies of the current will supply planktonic food. Larvae of *Simulium neavei* Rouband and related species regularly attach to the legs of freshwater crabs throughout their growth (Williams 1968).

These species are common in the fast-flowing streams of many East African highland districts. When fully grown, which may take weeks or months depending on the species, temperature, and food supply, the larvae turn to pupae attached to the same substrate. The adult fly emerges after several days, rises to the water surface, climbs vegetation, dries itself and flies away.

Female blackflies inflict extremely painful bites and certain species always prefer the human blood. Worms of the genus *Onchocerca* are transmitted by various *Simulium* flies. The species *volvulus* causes the disease called onchocerciasis in man. This disease is prevalent in certain mountainous areas of East Africa, where it is transmitted by flies of the *S. neavei* species complex, particularly *S. woodi*. Rates of human infestation are over 50% in some areas and at least over 300 000 people in Kenya are thought to be infected.

Human onchocerciasis is a chronic condition in which irritation and toughening of the skin and perhaps small swellings on the groin and trunk are the most noticeable effects. Progressive debilitation of the patient may occur over many years and ocular complications may eventually cause blindness. No effective therapeutic drugs are available as yet.

The disease has been controlled by eradication of *S. neavei* from streams in certain limited foci around Kakamega in Kenya by adding DDT to the headwaters. In Uganda, as well as large areas of west and central Africa, onchocerciasis is transmitted by the species *S. damnosum* Theobald which does not attach to crabs in the larval stage and which breeds often in larger rivers. The larvae are particularly abundant among boulders.

Horseflies (*Tabanidae*)

The Tabanidae are the least significant group under discussion although they definitely warrant inclusion. There are many species, ranging in size from 7 to 15 mm in length. Most of them usually attack wild animals. They are frequently encountered by man when in the vicinity of such animals as cattle and often enter the windows of a slow-moving vehicle after mistaking it for a potential host.

The eggs are deposited on vegetation near water and larvae may be found in many types of mud or wet sand beside streams, ponds, dams and ditches, each species having its own preference. Larvae are predatory, feeding on worms, molluscs and insects, and may be cannibalistic. Growth and metamorphosis take several months or a year, the pupae being formed at a rather higher, drier and hence safer level in the soil.

Horseflies of the genus *Chrysops* are vectors of the human disease loiasis in West Africa and the Congo. The disease is caused by worms of the species

Loa loa (L) which survive for many years in man causing fluctuating tissue swellings, lymphatic disorders, and sometimes damage to the eyes. Although loiasis is unknown in East Africa at present, there are several species of man-biting *Chrysops* occurring throughout Uganda, Kenya and in the northern and southern highlands of Tanzania (Oldroyd 1952) which might well be able to set up transmission. Other diseases that can be transmitted by horseflies are anthrax, tularaemia and trypanosomiasis, but no concise information on these in East Africa is available as yet.

Mosquitoes (*Culicidae*)

Culicidae are undoubtedly the insects of greatest general importance in the present context. Bristowe (1946) emphasized the disease transmission value of insect vectors when he stated: 'in the world as a whole more premature deaths are probably brought about annually by the direct and indirect results of insect bites than from any other cause.' He might as well have added that in the tropical and subtropical regions, mosquitoes are the principal offenders. They are fragile and familiar insects found almost wherever water exists. It seems unnecessary to describe their life history here except to point out that all species have aquatic larvae. Most species can undergo one life cycle in under 2 weeks, and each female mosquito usually produces over 100 eggs every 2–4 days. There are well over 300 species of mosquitoes in East Africa, of which less than 10 are known to be of medical or veterinary importance. Many more species are a nuisance when biting, but are not good disease vectors for physiological or behavioural reasons. The taxonomic division of mosquitoes into two groups, anophelines and culicines, also serves to distinguish between malaria vectors (anophelines) and malaria non-vectors. Representatives of both anophelines and culicines transmit a variety of filarial worm diseases, notably elephantiasis caused by the worm *Wuchereria bancrofti* (Cobbold) of man, as well as many virus infections, relatively few of which have been properly investigated medically. Mosquitoes of the genus *Anopheles* breed predominantly in open waters, namely, swampy areas, streams, ponds, marshes, pools, dams, and river margins. There are two main vectors of malaria throughout East Africa: *gambiae* Giles, which favours small collections of water such as ground pools of rainwater, wet footprints, freshly flooded ditches and burrow pits; and *funestus* Giles, which tends to breed at the margins of older water such as swamps, dikes and rivers, whenever some emergent grasses, hedges, or other foliage provide shelter for the larvae. Rice fields and similar activities with shallow standing water provide an ideal situation initially for *A. gambiae* breeding, followed by conditions suitable for *A. funestus* as the level of vegetation rises. Culicines of the genus *Culex* breed in virtually all types of water, although by far the most significant species in East Africa, *C. pipiens fatigans* Wiedmann, is restricted to domestic conditions where it breeds in water sponge pots, tanks and barrels, old tins and pots, and most abundantly in flooded latrine pits. This species along in urban coastal districts of East Africa, together with *A. gambiae* and *A. funestus* in rural areas, is probably responsible for the majority of elephantiasis transmission. Rates of human infection with this disease are as high as 20% in many coastal areas of Kenya and Tanzania (W. Hauserman, Rural Aid Centre, Tanzania, personal communication).

Other culicines of the genus *Aedes* are the vectors of certain viruses and filariae, but their relevance is limited in the present context since they breed mostly in small water collections in tree holes, leaf axils, coconut shells, etc.

Tsetseflies (Glossinidae)

The last group, the Glossinidae, is not primarily dependent on water or damp soil for breeding in the manner of the previous groups. However, one important species, *Glossina palpalis* Austen, characteristically frequents heavy vegetation along the margins of streams, rivers and lakes. These flies are painful biters and are one of the vectors of sleeping sickness, particularly the form caused by *Trypanosoma gambiense* Dulton (Gambian sleeping sickness). Flies reproduce and multiply slowly, the eggs hatching within the mother fly and larvae being extruded singly when nearly fully grown. They pupate soon afterwards among dry stones or sand. At best, a female fly produces 3–10 larvae over 10–12 days. Gambian sleeping sickness is an occupational hazard for fishermen, boatmen and water carriers working in endemic areas, particularly near overgrown parts of lakeshores. The principal affected areas, are around lakes Albert (Mobutu Sese Seko) and Edward (Amin Dada) and the Nile in Uganda, northeastern Lake Victoria in Kenya and the northern and southern parts of Lake Tanganyika in Tanzania.

Any conscientious water engineer or administrator who bears in mind the preceding facts will doubtless find commonsense ways of reducing the availability of breeding places and habitats of disease-carrying insects. It is not difficult to plan all water supply, irrigation and drainage works bearing such aspects in mind. However, large areas of natural lakes, waterways, and swamps exist all over East Africa which have never been appreciably altered by man. Between these extremes we have the countless ordinary human activities such as farming, house-building, cattle, wildlife or human watering, and road building, each requiring its own water supply and drainage, where the operators can themselves directly influence the numbers of harmful insects thriving in their immediate environment. Some very broad generalizations can be given regarding the most effective physical means of minimizing insect breeding. The paramount rule is to keep the banks of all bodies of water steeply sloping and clear of vegetation both within the water and along the banks. If no weeds grow in the water then mosquito larvae are more exposed to predacious insects and fish. Special 'larvivorous fish' of the genus *Gambusia* and others can even be introduced to water for the purpose of consuming mosquito larvae Absence of vegetation along banks reduces the availability of resting places for all insects within easy access of the water. The cutting back of vegetation for a belt of 10 m wide is of particular value against *G. palpalis*. Keeping banks steeply sloping and relatively smooth minimizes damp soil areas suitable for the larvae of Ceratopogonidae and Tabanidae.

Such rules apply as much to small ditches and streams as to larger ponds and reservoirs. Whenever natural customs are employed in construction of reservoirs or water-courses, they should be straightened by a process of cutting and filling. Not only does this avoid the creation of creeks or meanders, but it shortens the shorelines and should steepen the banks. Areas of swampy ground in any location should be drained by channelling even if flooding is inevitable during rains. The regular damming and periodic flushing of ditches, streams and small rivers at weekly intervals can be of great value for washing away mosquito and *Simulium* larvae and silt where horseflies and *Culicoides* might breed.

The use of chemical insecticides is indispensible in districts with a high human population, where vast numbers of insects may otherwise build up if blood-feeding is easy. It must be remembered, though, that most insecticides are also toxic to man and should not be applied to drinking water or food crops prior to harvest. Certain formulations of DDT added to the headwaters of streams are the only proven means of adequately controlling Simulidae. *Anopheles* mosquito larvae are often easily controlled by spraying an insecticide film into the edges of water surfaces. Two commodities for this purpose on sale in East Africa are Malarial and Flit MLO.

It requires courage and cooperation by the water, health, veterinary and entomology authorities to work well together on these matters. Often it is simpler to construct waterworks without consideration of disease implications. Many other engineering activities, such as road construction, should similarly be undertaken always with a view to avoiding the creation of unnecessary dams, flooded burrow-pits, and so forth. Throughout East Africa there is a shortage of competent advisors to study and report on such aspects when required. I must point out that the Department of Entomology at the University of Nairobi is trying to fill this gap by training competent medical and veterinary entomologists for the whole of East Africa and Africa at large. Meanwhile, although our staff is still small, we are always willing, in principle, to help where possible by giving consultant advice. Those of us who view these problems from the scientific angle can see the benefits accruing to the population as a whole if abatement of insect-borne disease features on the agenda of all water workers.

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WATER DEVELOPMENT AND THE INCREASING INCIDENCE OF MOSQUITOES AND SCHISTOSOMIASIS IN KENYA

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Abstract
Of late many areas of Kenya have been experiencing increasing infestation by mosquitoes with varying disease transmission capabilities. Schistosomiasis is also on the increase. The presence or absence of water development projects in relation to these increases is discussed, with emphasis on irrigation schemes. Recommendations for action to be taken when planning and implementing such projects are made.

Introduction
Kenya is mainly an agricultural country, a large part of which is dry. It has been observed that it is not the scarcity of water resources but the failure to fully exploit the existing ones that accounts for the low productivity of some of the drier regions. During the past two decades, some major irrigation schemes have been implemented, notably Hola, Mwea-Tebere, Perkerra, Ahero and Bunyala. These will continue expanding. Development plans envisage other irrigation sites at Taveta, Masinga and West Kano. In the same way dams have been built for electric power generation and to provide water for towns, piped water has been supplied to towns from boreholes and rivers, wells have been built as domestic water sources, as well as plain water-harvesting catchments for trapping rain storm water.

Where tap water is unavailable, household water is stored in metal tanks and drums, open cement tanks (*mbirikas*), or earthenware containers, and proper sanitary facilities are usually lacking. Now that we have a new Ministry of Water Development, we can expect more widespread water projects aimed to cater for agriculture and other needs. All water harnessing from utilization through disposal activities is associated with major public health problems arising from environmental modification. Water is a requisite for the breeding of mosquito disease vectors which are the most common vectors of water-borne human diseases. The coming of new water projects will therefore be accompanied by an enormous nationwide intensification of the problem, unless appropriate scientific planning and action are undertaken prior to and after implementation of the same.

Mosquitoes

The life cycle of mosquitoes comprises the following stages: egg, larva, pupa, and adult, in that order. The first three are aquatic, and the terrestial adults are responsible for disease transmission. Different genera and species have evolved preferences for different kinds of water for breeding and also specific and varying vectorial capacities for different mosquito-borne diseases. This will be highlighted by our four most important species. *Anopheles* spp. breed in clear water and the two most important ones in the transmission of human malaria in Kenya are *Anopheles gambiae* and *Anopheles funestus*. They are also responsible for bancroftian filariasis transmission, especially at the coast; their importance in this aspect seems to be superseding that of *Culex pipiens fatigans*. A dramatic increase in their numbers is always in evidence at new irrigation schemes, whose canals, paddies, and drainages they promptly locate for breeding. Suffice it here to quote the results of a survey carried out jointly by the Arthropod-Borne Virus Epidemiology Unit and the Medical Research Council at Mombasa village, in Ahero Irrigation Scheme and in West Kano (Kano II), an adjacent area proposed for future irrigation; between October 1972 and January 1973, a total of 6 774 *A. gambiae* and 1 667 *A. funestus* were caught in Mombasa village, whereas only 46 *A. gambiae* and 18 *A. funestus* were caught in the non-irrigated Kano II. This is a clear indication of marked population increase in the two species as favoured by irrigation. The usual succession of large numbers of *A. gambiae* followed during its decline by a peak population of *A. funestus* when rains fall also occurs in irrigation schemes. This is by reason of *A. gambiae* preference for breeding in open clear water as against *A. funestus* preferring shaded clear water (shade provided by vegetation during rains and by crops, e g. rice plants on irrigated lands). This means that in so far as there is water in the irrigation system, *Anopheles* mosquitoes will be present, unless control measures are undertaken, of course.

Culex pipiens fatigans is an important vector of bancroftian filariasis and is often associated with man, especially poor man. People who migrate to our irrigation schemes and settle in the new villages or towns that develop thereof are often the poor lot. Their settlements lack proper sanitary facilities and therefore pit latrines, open drainage canals, soakage pits, and sometimes open disposal lagoons spring up. These polluted waters are ideal breeding sites for *C. p. fatigans*. This mosquito will therefore flourish all the year round as such water is continuously present. Such situations also exist in towns and villages away from irrigation schemes where low income and/or traditional ways may be predominant. Thus, this mosquito may be called a pest of the poor—indeed, bancroftian filariasis has always been described as a disease of the poor. However, *C.p. fatigans* is extremely adaptable and in towns with proper sewage disposal systems, it breeds in improperly cared for septic tanks and lavatory flush tanks, finding its way through minute cracks and crevices. Or, it will deposit eggs in lavatory bowls and these develop in the septic tanks after flushing.

Otherwise the young adults fly out through open ventilation pipes. Whether *C. p. fatigans* is found transmitting disease or not, it is a major pest of man. It breeds in large numbers and loss of sleep and blood through its bites causes an overall reduction in the productivity of a people in any infected area, thereby inflicting a form of economic injury. The rapid increase in the number of small towns and settlements without proper water supply and therefore lacking entomologically sound sewage disposal systems is the mainstay of the nationwide dispersal of this species.

Aedes aegypti is a well-known vector of yellow fever the world over and has been incriminated as a transmitter of many other anthropod-borne virus (arboviral) diseases. It flourishes in two forms, a dark outdoor (peridomestic and forest) form known as *Ae. aegypti formosus* and a lighter indoor (domestic) form, *Ae. aegypti* type form. Strictly, this mosquito will not be established in an area by the development of water projects like irrigation as in the case of *Anopheles*, but the relevance of discussing it is that, where it occurs, e.g. in the Coast Province, the type form invades and breeds in water containers and storage tanks mentioned above which are in use due to lack of domestic tapwater facilities. Water development towards this facility will therefore minimize infestation by *Ae. aegypti* (which will breed in any clean temporary water during rains, e.g. tree-holes, coconut stems, derelicted tyres and all sorts of water receptacles, banana leaf axils, etc.).

Further, seepage of irrigation or even dam water may result in marshes or swamps in surrounding areas. These act as breeding grounds for such mosquitoes as *Mansonia* spp. which are arboviral vectors. Indeed, all the mosquito species mentioned above may act as vectors of one or several viruses causing disease in man, although mention has been made only of the most important common diseases they currently transmit/can potentially transmit to man in this area.

Lack of domestic water in dry areas such as North Eastern Province and along the coast has led to the digging of wells on both communal and individual bases. These act as breeding sites and also as aestivation centres for mosquito larvae and adults—these creatures are especially happy in such habitats where the wells have been abandoned.

Plain water-harvesting catchments are best displayed at two places at the coast. In Wasini Island at the Pemba Channel on Kenya's south coast, such a catchment is the only source of water, and residents are wise to store it in large *mbirikas* and other containers lest the reservoir goes dry. A similar catchment is found at the cashewnut factory in Kilifi. One may rightly conclude that large-scale water projects such as irrigations and dams are primarily important in the creation of large *Anopheles* vector populations whereas lack of clean domestic tapwater results in *Ae. aegypti* infestation; and that poor waste water disposal associated sometimes with no tapwater facility situations results in *C. p. fatigans* infestation.

Schistosomiasis

Of Kenya's human population of 14 million, well over 4 million are believed to be infected with schistosome worms. There are two forms of human schistosomiasis in our country: one visceral, caused by the helminth *Schistosoma mansoni*, common throughout the country, and one urinary, caused by *Schistosoma haematobium*, commonest at the coast. Schistosome eggs occurring in large numbers in various human organs are responsible for the disease. Those passing through organ walls are excreted in the stool in the case of *S. mansoni* (and also *S. japonicum*, which does not occur in this country) and in urine in the case of *S. haematobium*. In this way, the disease is spread. The maturation cycle of schistosomes in the human body and the clinical picture of the disease they cause are beyond the scope of this paper.

A brief schematic representation of the vicious cycle of human schistosomiasis infection, which is self-explanatory, and basically the same for all three schistosomes, is shown in figure 1.

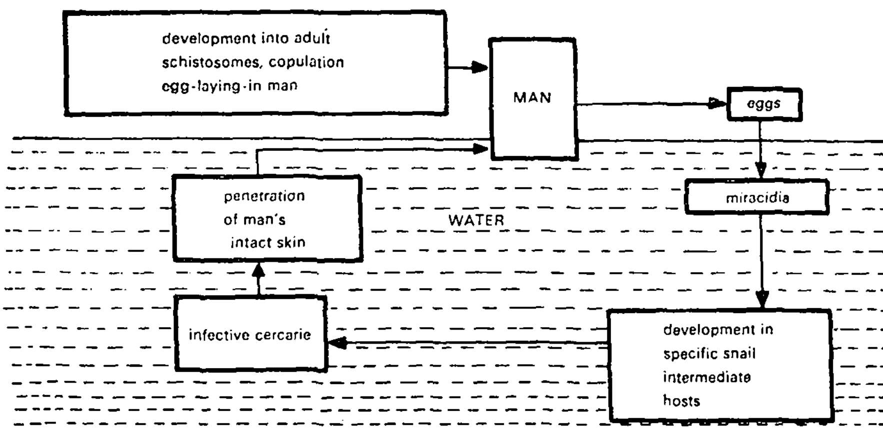

Figure 1. Cycle of human schistosomiasis infection.

Water is therefore a requisite for the completion of the parasite's life cycle and therefore man is infected through contact with cercariae-infected water. Also, the miracidia must find the appropriate snail species in which their species will develop—locally *S. mansoni* develops in snails of the genus *Biomphalaria* and *S. haematobium* in certain *Bulinus* spp. Twelve snail species have been identified as actual or potential vectors in Kenya.

Experience has shown that dams and irrigation schemes create favourable aquatic habitats (incorporating water and plants, e.g. water lilies and cultivated plants) for snail breeding. Snails, either infected or non-infected, easily invade such water into which they or their eggs may be carried by water-loving birds and other agents. Once established, they get involved in the cycle outlined above.

Table 1. ***S. mansoni*** **infection in primary school children**

School	*S. mansoni* infection (%)	
	1963	1977
Mathangauta	18.6	18.8
Murubara	11.0	48.6
Kirogo	3.2	14.8
Gathigiri	25.9	35.1
Nguka	29.0	36.8
Thiba	0.0	51.0
Karaba	0.0	3.2
Mutithi	1.2	14.0
Karira	6.9	64.0

We may cite the Mwea-Tebere Irrigation Scheme where an area survey in 1956 before scheme implementation indicated no infection. Table 1 shows results of *S. mansoni* infection in primary school children as per the Ministry of Health and Housing annual report, 1963, while the scheme was still developing. These are contrasted with the current results obtained in a September 1977 Division of Vector Borne Diseases (D.V.B.D.) survey of primary school children within the scheme by R. K. Munyi (personal communication). These show that despite the snail control measures undertaken over the years, the degree of infection simply gets even higher to date. Water projects therefore continue to play a major role in the increase in worm load per person and also in the total number of infected people as a whole. In irrigations without snail control, the disease status, whether previously endemic or not, always tends to hyper-endemicity because the frequency of man's contact with water is necessarily very high.

On the other hand, where clean tapwater is unavailable and proper sanitary and recreational facilities are lacking, the infection cycle is easily maintained through permanent and semi-permanent rivers and dams. Contact with water occurs variously, e.g. when fetching water for domestic use, when washing body and clothes or when swimming. Traditional customs affecting sex, age and social status are contributory factors in epidemiology. For example, swimming in such water is common for children, and water is normally fetched by women. Siongok et al. (1976) found an overall *S. mansoni* prevalence of 82% with a 98% peak in the 10–19 age group in a village in Machakos. Studies continue in Machakos (*S. mansoni*) and Kwale (*S. haematobium*) districts and it is hoped that results will be useful in planning large-scale, even nationwide control campaigns in future.

What happens

Here it is worthwhile to briefly take a look at the general trend in events which occur locally at the implementation of a new irrigation scheme in order to understand best how water development boosts mosquitoes and bilharziasis due to lack of prior study and planning. This is what has generally occurred in our irrigation schemes. Man moves in, either as a tenant in the scheme or a job-seeker. New villages and/or towns spring up in which hygienic standards are lacking (our peasant populace is generally poor). Plenty of dirty water builds up around. Relatives and friends keep visiting. Mammals in search of food or those variously associated with man such as *Rattus rattus* invade the area. During the month of August 1975, Smith and Highton (1975) trapped 323 rodents within Hola Irrigation Scheme and only 17 on the Tana River bank, 25 near a village, and 6 in the arid bush—all near but outside the scheme. Domestic animals, including chicken, may get introduced. For the love of water and in search of food, various birds come in. Bats, too, may come in.

Mosquitoes start flourishing in the irrigation water as well as in refuse and stored (household) water. The initial mosquito population comes in variously—transportation by man, presence before irrigation, invasion from surrounding areas. Snails get introduced, by birds, by river transportation, etc. Man, resident or visitor, comes infected with malaria, filariasis, bilharziasis, or some arboviral diseases. Animals and birds, domestic or wild, may carry arboviruses and possibly schistosomes, but more often the former. Mosquitoes biting man, animals and birds may transmit disease agents from man to man or from animals/birds to man, depending on the local situation. Improper disposal of human faeces and urine propagates infection of snails with schistosomes; man gets into irrigation water as farming requires and continues getting infected. Cycles involving animal and bird diseases also occur.

Recommendations

Once water projects are conceived, it is most important to carry out detailed studies of the area and the people to be involved in order to assess the potential health risks that may result because it is unrealistic to implement a project that will bring ill health to those whom it is meant to benefit. Such a study comprises such disciplines as biology, technology, sociology, economics, and even politics. Apart from agriculturalists, it must bring in geologists, meteorologists, hydrologists and other engineers, sociologists, economists, and above all, entomologists, malacologists and parasitologists. The disease vectors already present in the area and surroundings and the possibility that others could be introduced, the potential animal and bird reservoirs of the disease and the degree of different infections in the people likely to come in should be studied in relevant detail. Research must be done on building low-cost hygienic villages with proper sanitation (i.e. ventilation pipes covered by mosquito-proof rust-resistant gauze) for the people away from the dams and irrigations where they will work. Such strategies are already being realized in Kenya. Examples are the proposed Kano II (West Kano) irrigation project and the proposed Masinga irrigation scheme where the Division of Vector Borne Diseases of the Ministry of Health has already been actively screening vectors and disease agents in collaboration with the Tana River Development Authority.

Once studies have been done, infected humans should be treated for the disease they may carry prior to settlement. Treatment drug problems exist, however, and parasites, e.g. malaria-causing plasmodia, may become resistant to drugs after continued or irresponsible usage; there is also no suitable schistosomicide as yet.

In this connection, it is important to keep disease transmission at zero or insignificant levels after project implementation. This can best be done by careful vector control and control methods which have been determined during prior studies. Usually, integrated vector management is best—it aims at keeping vector populations at levels at which disease is not transmitted. For example Fescon (Shell Chemicals molluscicide) has been used successfully at Ahero, and also at Mwea-Tebere where over 77 000 *B. pfeifferi* were collected in a random survey in 1967 and less than 4 000 could be found in 1973 following regular use of the molluscide. It is economical and non-toxic to fish at recommended dosages and could be used alongside *Gambusia affinis* which is mosquito larvivorous. And this fish could be supplemented with house residual sprays. Health education of the ordinary people is a vital aspect of vector management which needs strong implementation; arising from it, certain aspects of legislation could become increasingly important.

Continuous surveillance of all vectors and the parasites they transmit is also important and must be carried out throughout the existence of the scheme to avoid disease epidemics. Also, control measures must be periodically assessed to ensure safety to the environment and that they do not eventually become useless on their targets. Indeed, to quote Professor T. R. Odhiambo (1975), 'we should cast our minds for a more scientific method, which recognizes that insects are not simply targets, but are biological entities with complex ecology, behaviour and physiology, entities that have a complex genetic potential which enables them to evolve beyond a particular situation; and entities which occupy an important place in the natural order of things.'

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ENVIRONMENTAL HEALTH ASPECTS AND FLOOD CONTROL IN BUNYALA LOCATION, BUSIA DISTRICT, WESTERN PROVINCE, KENYA

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Abstract
The environmental health aspects of Bunyala Location have been shown to depend largely on a number of related factors of which the most important are the almost perennial flooding of the greater part of the location from the Nzoia River and the influence of the Yala Swamp east of the location.

In 1967 a dike was constructed from Makunda to Sikhokho, north of Kholo-khongo, on the south bank of the Nzoia River. This construction proved useful in preventing the flooding of the immediate areas north of Lugare; and farming and cattle grazing were reported to be successful in these areas. It might appear that a continuation of the dike construction following the Nzoia River to Lake Victoria north of Bunaba would reduce the flooding of the areas below the south bank of the river. It was observed that considerable flooding was also experienced in the areas of Bukoma, Debani, Eburemia, Bujwane and Mudembi on the north bank of the Nzoia River. The construction of dike running along the north bank of the Nzoia River appears to be a solution to solving the problem of flooding in these areas. Dike construction in Kenya has reached a high level of technology and is economical. But for this to be successful it would have to be coupled with a proper irrigation system which would ensure the drainage of the area previously affected by flooding.

The environmental health disorders reported in Bunyala Location are many and include cholera, malaria, schistosomiasis and gastrointestinal diseases. Lack of proper sanitation appears evident in most of the areas, although water wells and a few pit latrines have been constructed in some places. The fact that the major part of the location is flooded during May to June and August to October of every year contributes greatly to the high incidence of environmental health disorders reported in the location. In order therefore to improve the environmental health conditions in the location, it is logical to consider undertaking flood control measures. The people of Bunyala Location have presently embarked on the drive to raise money for the Bunyala Flood Control Project, which is estimated to cost Ksh 10 million (1976 pricing). Since the people are mostly fisherfolk/agriculturists, the result of carrying out flood control projects would create better alternatives of occupation which

would alter their way of life and enhance their economic potentialities. Associated with any flood control measures would be programmes mounted to ensure good sanitation (adequate numbers of water wells, septic tanks/pit latrines and refuse depots) and to provide health education in the location.

Introduction

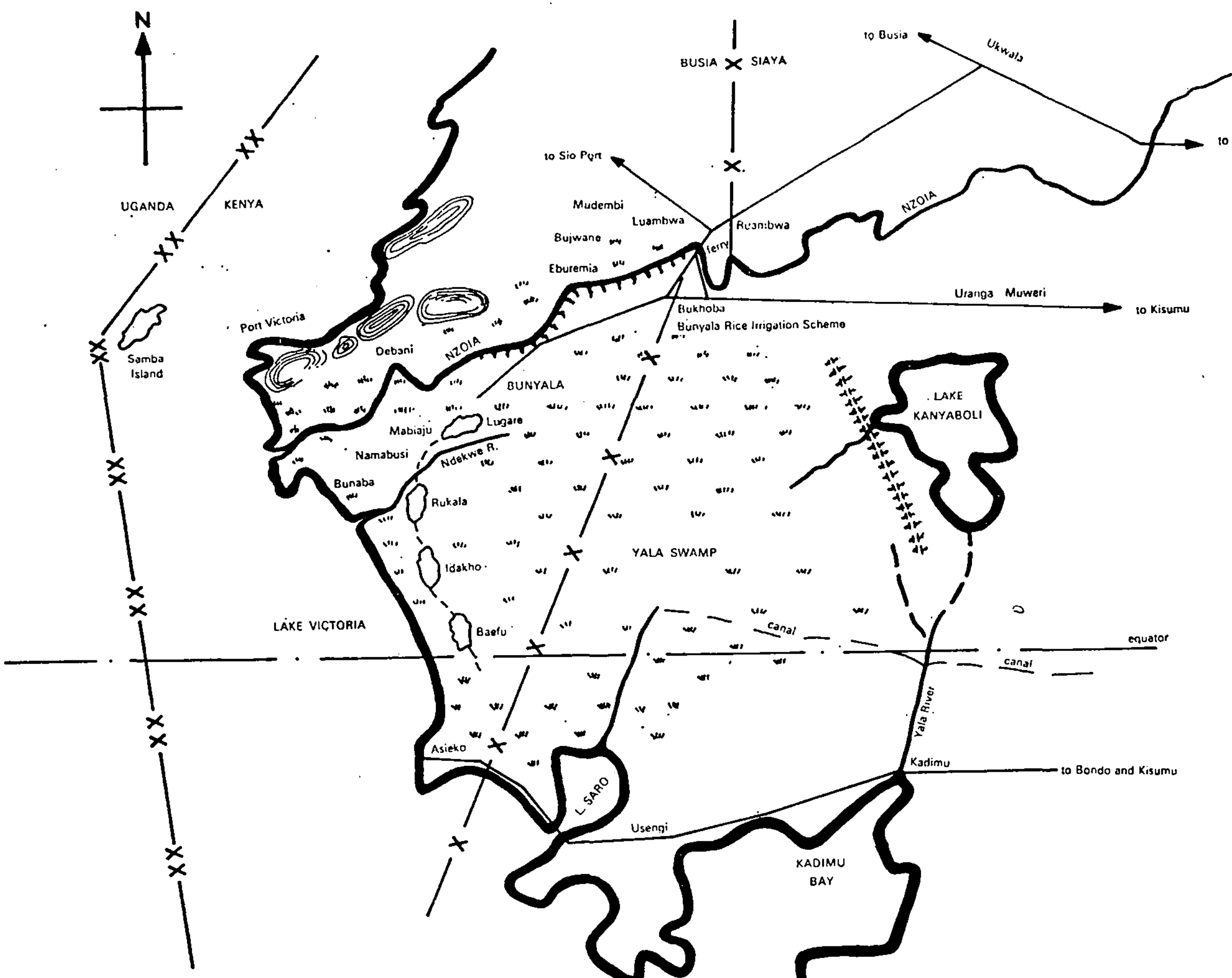
Bunyala Location is situated in Busia District of the Western Province of Kenya. It is bounded on the west and south by Lake Victoria and on the east by Yala Swamp which extends into Siaya District of Nyanza Province. The Nzoia River runs through the northern part of the location and discharges into Lake Victoria, south of Port Victoria (see map 1).

Two main rainy periods are experienced in this location, May to June and August to October. The heavy runoffs into the Nzoia River from the contributing tributaries during the rainfall spells have resulted in the general flooding of practically the whole of the location. The recession of the floods continues for several months after the rains. The floods of September 1975, as reported, did not dry up until January 1976. The flooding of Bunyala Location during some months of the year is recurrent and dates back to the early sixties when it was believed that the creation of the hydroelectric project at Jinja in Uganda caused the level of Lake Victoria to rise by some 250 cm. Since then river gauge data have shown that the lake water level has fallen by 100 cm as of 1975 with slight fluctuations and an equilibrium is presently expected. The flooding of the location brings about various problems of a health and economic nature. Among these is the general lack of environmental sanitation which for many years has created endemicity of malaria, cholera, schistosomiasis and other water-borne/water-related diseases in the location. Furthermore the general flooding of the location disturbs harvesting and crop production in the areas. It is reported that the location has not had a successful harvest of maize, sweet potatoes and other crops during the last 10 years.

Since 1975, the Ministry of Health has undertaken emergency measures to prevent and eventually stamp out cholera and related diseases from the Lake Victoria basin area. Large sums of money have been spent on curative and preventive measures. Water wells have been sunk and provided with hand pumps to ensure the availability of safe drinking water, and pit latrines have been built in the areas affected. These measures are reported to be adequate during the dry seasons of the year. However during the periods of flooding in the location, the sanitary facilities are submerged and sanitation becomes practically non-existent. The physical and geographical features of the location thus appear to be factors responsible for the inability of the Ministry of Health to eradicate cholera and related diseases.

Method

In June 1976 the author carried out field visits to Bunyala to assess the environ-



Map 1. Bunyala Location.

mental health aspects and flood control in the location. The first field visit route was from Kisumu through Kombewa, Bondo, Usengi, to Osieko in Bunyala Location. Visits to some dispensaries, subhealth centres and health centres were made to identify the patterns of reported environmental health disorders of the areas of Siaya and Busia districts. The available sanitary facilities, water supply, excreta disposal methods and refuse collection and disposal methods in these districts were also studied. The second field visit route was from Kisumu through Yala, Siaya, Boro Muweri, Uranga, Bukhoba, Makunda to Lugare. A guide was hired at Lugare and another at Mabinju and the party proceeded by foot through the flooded areas to the swamp islands of Namabusi, Rugungu, Rukala, and Idokho. Canoes were used to cross two portions on the route between Lugare and Rukala. The sanitary facilities available in these areas were also studied. The third and fourth field visit routes were from Kisumu through Ukwala to Ruambwa. The author and a guide then proceeded on foot through Luambwa to Mudembi and Eburemia on the north bank of the Nzoia River, and then through the swamp to Port Victoria.

The lack of usable motor roads and accommodation in Bunyala Location and the importance of obtaining thorough on-site impression and information of the conditions and facilities which obtain in the location made it necessary to start all four field visits from Kisumu, the nearest town with suitable and adequate accommodation. Considerable time was spent on the long treks on foot through the swamp and flooded parts of the location visited.

Observations

The problems of environmental health in Bunyala Location are many. Of primary importance was the outbreak of cholera in the area in 1974. The areas of Kisumu and Siaya districts were equally affected. Visits to health institutions in Kombewa, Akala, Mayuanda and Bondo in Siaya District showed an apparent recurrence of cholera. In effect 15 positive cases were treated in Bondo health centre from 17 May to 4 June 1976. It was observed that most of the areas visited in Siaya District were dry and water supply appeared to be scarce since flowing streams and rivers in these areas were not many.

In the villages, markets and towns visited in Bunyala Location, there were abundant untreated flood waters which were easily accessible to the people. This more than anything appeared to have been responsible for the few cases reported in this area since March 1975. At the dispensary in Rukala, 216 patients were treated (as suspects) for diarrhoea from 24 March 1975 to 4 June 1976. A surveillance team located in Lugare worked incessantly throughout the location on cholera control activities. Apart from cholera, the problems of malaria appeared great in the location. Evidence of this disease was shown by the spleens of the children living in the location which were considerably enlarged. A few dips to identify the larvae of anopheline mosquito in the flooded areas, and a few catches of adult mosquitoes (anopheline) in the huts confirmed the presence of this disease in the location. The records of suspected malaria cases did not however show any laboratory test for the identification of the parasite. There appeared also to be a problem of schistosomiasis in the location. A few snail specimens were collected but these were not identified as vectors. However, from discussion held with the people of the area, this disease may also be common.

The above environmental health diseases observed appeared to be endemic as a result of the continual flooding of most of Bunyala Location. The floods appeared to contribute greatly to the lack of sanitary facilities noted in the location.

Water supplies

During the outbreak of cholera in 1974, the villages of Namabusi, Rukala, Lugare, Mabinju, Idokho and Baofu were heavily affected (see map 1). Water wells for safe drinking water were sunk in these areas. These are properly cased and provided with locally manufactured hand pumps. The well construction consisted of precast concrete segments cast on site and driven into the ground. In some villages the number of water wells appeared too small to cater for the needs of the people; and untreated flood waters supplemented the total quantity required. The water wells in most cases are located on high ground and should provide safe water supply for the greater part of the year. However, it has been reported that during the floods of August to October 1975, most of the wells were submerged and were therefore unusable. Of secondary importance is the fact that some of the hand pumps, especially in Mabinju, were stolen and resold across the river in Port Victoria, thus rendering some of these water wells unusable.

Excreta disposal method

The construction of water wells in Bunyala Location in 1975 was undertaken mainly from funds released by the Ministry of Health. Few funds were however made available for the construction of pit latrines for excreta disposal. Efforts to encourage the people to construct pit latrines proved unfruitful. In fact it appeared that the social beliefs and taboos of the people did not allow for the provision of any safe excreta collection and disposal system. Furthermore pit latrines were found to be difficult to operate in the location during the flooding periods.

Since pit latrines are cheap to construct, the surveillance team assisted the people in self-help projects to construct a few pit latrines in operation in the location. Galvanized drums, empty petrol drums, and other types of empty drums have been used for the pits. These are cut open at both ends and driven into the wet ground. The pits are built up with a concrete slab with a chute, and the structures are housed in mud walls and thatched roofs. The provision of an adequate number of pit latrines would no doubt solve most of the gastro-intestinal disorders prevalent in the location for the greater part of the dry periods of the year. It is doubtful however whether this method of excreta disposal would be adequate during the periods of great flooding. The use of septic tanks may appear to be a better method of excreta disposal.

Refuse disposal methods

The refuse disposal method throughout the location is by individual collection which is followed by open dumping. In some cases the refuse is collected into pits and later burnt. A few villages where cattle are kept carry out composting of the refuse with cow dung.

WATER-RELATED DISEASES

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Abstract
Water is the colourless, tasteless and odourless compound of hydrogen and oxygen. For a long time it was regarded as a blessing to man but recent analyses have revealed that water is man's enemy as well. Certain diseases of man are transmitted only through water, particularly unmanaged water systems. These are typhoid fever, paratyphoid fever, cholera, dysentery, guinea worm, malaria, filariasis, onchocerciasis, and trypanosomias. Certain infections of the skins, eyes and intestinal tract may also be caused through contact with unhygienic water.

There is a deficiency of rainfall over extensive areas of East Africa which warrants water conservation. The reservoirs that hold the water unfortunately provide ideal grounds for the development of water-borne disease agents. The engineer's role in constructing such reservoirs is indispensable but must be well incorporated in the work of the doctor, biologist, chemist, administrator and the social worker.

Ill health is one of the most wasteful elements which a sanitary engineer properly incorporated in control or eradication programmes of water-related diseases would significantly help to reduce.

Introduction

Except in times of floods, water is generally regarded as a blessing to man. However, for generations man has held this indispensable commodity in esteem without suspecting it to be one of the major contributors to his sufferings. Recent analyses reveal that water is playing a double game on man. Human progress has been hindered and innumerable lives have been lost and continue to be lost, especially in developing countries, through illness caused by water-related diseases.

Definition of water-related diseases

The term 'water-borne disease' is indiscriminately used by some health authorities as if it were synonymous with water-related diseases. The term 'water-related diseases' encompasses all diseases whose prevalence is dependent on the absence or presence of unmanaged water.

Classification

In the old literature of sanitary engineering, attempts were made to classify diseases whose origin or life cycle of transmitting agents could be traced to water, but all attempts came up with proposals which were cumbersome and difficult to understand. It was not until 1973 when a study of the prevalence of diseases connected to water in East Africa was carried out that the scope of these diseases was magnified and a simple detailed classification was formulated. In this classification water-related diseases are categorized in four distinct groups:

1. Those for which water acts as a positive vehicle for the infecting agents are 'water-borne'.
2. Those infections that decrease as a result of the abundance of water are 'water-washed'.
3. Those whose infecting agents have an essential part of their life cycle that takes place in aquatic animals are 'water-based'.
4. Those infections spread by insect vectors that breed in water or lie in ambush near water to bite their victims are 'water-related insect vector'.

The above division conveys at a glance the idea that quality, quantity and the general management of water in various bodies and systems must be considered equally during any control or eradication programme of any of the water-related diseases.

Table 1. A classification of infections diseases related to water

Water-borne	Water-washed	Water-based	Water-related insect vector
Classical:	*Intestinal:*	*Per cutaneous:*	*Life cycle in water:*
Typhoid	Gastroenteritis	Urinary schistosomiasis	Malaria
Cholera	Ascariasis	Lactal schistosomiasis	Filariasis
Leptospirosis			Onchocerciasis
Non-classical:	*Cutaneous:*	*Ingested:*	*Habitat near water:*
Bacillary dysentery	Leprosy	Guinea worm	Sleeping sickness
	Otitis externa		
Amoebic dysentery	Louse-borne typhus		
Tularaemia	Louse-borne relapsing fever		
Paratyphoid	Skin sepsis		
Infective hepatitis	Chronic skin ulcers		
Enteroviruses	Trachoma		
	Conjunctivitis		
	Scabies		
	Yaws		
	Tinea		

Water-borne diseases

Water-borne diseases are those infections that are transmitted by way of the pathogen getting into the human body through ingestion when drinking contaminated water. The sources of these diseases are carriers. A carrier is one who has recovered from the clinical symptoms of a disease but still continues to discharge infectious bacilli in faeces. The organisms are in that case no longer pathogenic to the carrier, but are capable of producing enteric disorders when they reach the intestinal tracts of healthy persons. In times of epidemics, faeces of the sick and the convalescent are the main source of danger. A few of the diseases commonly diagnosed in East African clinics include:

1. Typhoid fever is classical water-borne, thus a low dose of pathogen is enough to cause illness. It is a disease of the small intestine, caused by *Salmonella typhi*.
2. Paratyphoid fever is non-classical water-borne. For the susceptible host to catch it, he must take in organisms in a large dose. Unlike typhoid it is caused by *Salmonella paratyphi* which is also responsible for food poisoning.
3. Dysentery is a non-classical which attacks the large intestine and is caused by *Shigella* generally found in polluted water.
4. Cholera is a classical water-borne killing disease and is caused by a comma-shaped bacterium known as *Vibrio cholerae*. There are two types of cholera: classical and El-tor. For a long time, classical cholera was regarded as being more virulent than El-tor but recent findings suggest that they are equally dangerous, especially when El-tor shows epidemic tendencies. The micro-organism multiplies in the gut contents but does not invade the blood stream. The incubation period ranges from a few hours to 48 hours and the disease is characterized by profuse diarrhoea during which the victim passes the so-called rice water stools. This causes the pH of the body to become acid so that the patient starts vomiting. Both diarrhoea and vomiting lead to dehydration and within a short time the patient collapses and dies. It is worth noting that although *V. cholerae* are extremely virulent, they are short lived in water, especially where the temperature is different from that of the human body.

Water-washed diseases

Water-washed infections are those of the intestinal tract and skin which may be significantly reduced following availability of adequate water. Thus a water-washed disease may be defined as one the prevalence of which varies inversely as the volume of water used for hygienic purposes increases.

Water-washed diseases are of two main types:

1. Infections of the intestinal tract. These include diarrhoeal diseases which are important causes of morbidity and mortality, especially amongst children. These water-washed enteric infections also include cholera, bacillary dysentery and other diseases already mentioned under water-borne. Clearly these diseases are also faecal-oral in their transmission route and are therefore potentially either water-borne or water-washed (Feachem 1976). Any disease that is transmitted by the pathogen passing out in the excreta of an infected person and subsequently being ingested can be transmitted

either in a truly water-borne route or by an almost infinite number of other faecal-oral routes, in which case it is susceptible to hygiene and is therefore water-washed. Recent investigations have shown that diarrhoeal diseases, especially shigellosis, decrease with the availability of water and with the volume of water used but do not appear to be associated with the microbiological quality of the water.

2. Infection of the skin and eyes. These include bacterial skin sepsis, ulcers, scabies-fungal infections and eye infections, e.g. trachoma. In the case of these diseases, water acts as an aid to hygiene and cleanliness and its quality is unimportant. It is the quantity used for washing rather than the quality.

Water-based diseases

Water-based diseases fall under two categories: those that get into the host via the skin (per cutaneous) and those that get into the patient through ingestion. Water-based diseases are directly connected to the activities of the hydro-engineer and lack of foresight on his part plays a part in the spread of these diseases. The incidence of schistosomiasis (bilharziasis) is on the upward trend due to the extension of irrigated areas (irrigation channels) and building of fish ponds, water dams and man-made lakes.

The transmission of the guinea worm is exclusively through water supply. It is a long subcutaneous worm that flourishes in the human leg. The mature female body lies beneath the skin with its genital pore underlying a sort of blister near the ankle. When the water splashes over this, especially when the host is drawing water from a traditional source, the blister bursts and a huge number of larvae are released with a good chance of reaching the source (well or pool). They are taken up by cyclops, small crustaceans that are found in many small water bodies, and the larvae develop in the new host's body. Subsequently when water is taken from the source it may include the cyclops and since they are very small, they are readily ingested through drinking or sometimes through bathing in infected water.

Water-related insect vector diseases

Malaria, filariasis and onchocerciasis are some of the common diseases in East Africa that are transmitted by insects that breed in water, while trypanosomiasis (sleeping sickness) is transmitted by the tsetsefly which bites near water.

Water sources in East Africa, the geographical position of East Africa relative to that of the Amazon forest in Central America and the equatorial forests covering Zaire and the Congo should mean abundant rainfall. But due to local climatic factors, East Africa suffers from a deficiency of rainfall over extensive areas. To East Africa therefore, water conservation, storage and distribution are of paramount importance for general development and economic progress. The bodies of water vary from relatively small ponds used for fish breeding and livestock watering to large man-made lakes (Lake Kenyatta) used for water supply, irrigation and production of power (electricity). These reservoirs unfortunately provide ideal grounds for breeding all sorts of water-related disease agents.

A water-related disease control and eradication programme in East Africa

At various water-related institutions in East Africa, the role of the civil engineer (public health engineer) is overlooked. The establishments reflect a general practice of combining chemotherapy and insecticiding or molluscrciding. The author feels that chemotherapy and mollusciciding or spraying are inadequate because of the following reasons:

1. There is a lack of completely satisfactory drugs easily administered over a short period of time free from side effects and producing a high rate of parasitological cure.
2. In traditional society the customary practices of land tenure, right of usage and inheritance lead to fragmented scattered holdings amongst the agricultural tribes. The nomadic groups on the other hand roam the arid and semi-arid areas in adjusting their movements to availability of water and pasture. This results in the population of about 35 million scattered over an area of 1.67 million km^2. It is difficult if not impossible to reach the whole infected population.
3. In case of schistosomiasis, trypanosomiasis and onchocerciasis a certain number of positive cases exist for which chemotherapy is contraindicated.
4. Many patients who start treatment fail to complete it because whenever there is death and it happens to be attributed to the treatment the deceased received, other patients are scared off so the programme irrevocably comes to a halt. In several cases patients are put off by the long distances they must walk to the nearest clinic.
5. Research laboratories in East Africa have proved that several water-related diseases are stored in the anthropoids. Cattle also act as reservoirs of *Trypanosoma rhodesiense*. Thus human treatment does not overcome the problem of animal reservoir hosts.
6. Occupation, habits and even attitudes towards water play a major role in the prevalence of water-related diseases. Fishermen, swimming boys, housewives drawing water from rivers, pools or unprotected springs, collecting reeds from swampy grounds for making baskets or washing household items in running streams or stagnant waters are contantly exposed to all sorts of water-related diseases. So are school children who generally walk barefoot and wash their faces and legs in the rivers they cross while on the way to schools.
7. A detailed survey by the Ross Institute, U.K., has revealed that pathogens are becoming resistant to new drugs after a short while in use. The Kenya Ministry of Health Report (1966) states, 'No attempts are made to eradicate malaria because of fear of resistance to chloroquine.'

8. Diseases connected with poor living standards, e.g. scabies, can be reduced and even eradicated only by improving living conditions and encouraging the use of more water. Drugs used in chemotherapy campaigns in such cases are a waste.
9. An outbreak of a killer water-related disease like cholera in East Africa where the majority of the people live in squalid conditions could hardly be suppressed by chemotherapeutic measures.
10. There is a lack of funds and personnel to implement programmes on a large scale.

Molluscicides and sprays (insecticides)

In case of schistosomiasis the ability of snails to return towards and even swing beyond the original degree of abundance when the use of molluscicides is discontinued is unfortunately undeniably a characteristic of chemical control. A good example of this was observed on sugar farms in the Lake region of Tanzania when Crossland (1963) carried out snail control measures that appeared to have succeeded; but after a short time, Bradley observed resurgence of the snails. Recolonization is influenced by the removal of the complex of parasites and predators. Thus the removal of those animals, plants or both which might seriously influence the capacity of snails to increase under natural conditions releases natural controls. Resistance of this sort applies to the control measures where insecticides, herbicides and all sort of sprays are used. There are also no ideal molluscicides and sprays which would remain effective in the medium at low concentration for a prolonged period of time. They should be non-toxic to man and his livestock, and they must be innocuous to fish and wildlife. Copper sulphate which is extensively used as a molluscicide is not stable. When dissolved in local water, it soon precipitates into a form of insoluble copper carbonate (Kenya 1966). Although control of insect vectors gives good results by spraying combined with chemoprophylaxis, the effect of this treatment is reduced and sometimes nullified by immigrants coming from zones where the disease is endemic. Vast areas of land are involved in the control of trypanosomiasis, filariasis, onchocerciasis and malaria, and spraying over large tracks of land that include thick forests can be very costly and even impracticable.

Large volumes of water like Lake Victoria and some of the big rivers of East Africa and the swamps around them are some of the reservoirs of these diseases. Lake Victoria is well known to be the source of *Biomphalaria choanomphala* host. Effective mollusciciding of large water areas is not possible and even if it were, applying molluscicides on Lake Victoria should be condemned because the lake is the second largest freshwater body in the world. Mollusciciding the lake would adversely affect people of East Africa, the Sudan and Egypt.

In view of all these points, for any control or eradication programme to succeed, chemotherapy, chemical controls (sprays and molluscicides) and environmental engineering must be combined in the right proportions. It is very important too for experts managing the schemes to try to understand the way of life of the people involved as regards their tradition, culture, beliefs, habits and occupation. If these are not considered while planning any scheme, there is a negative attitude from the inhabitants and this is likely to adversely affect the scheme. Many schemes in developing countries, though well manned and financed, have failed this way.

Engineering techniques against water-related diseases

Most of the water-related diseases are transmitted by agents which undergo a life cycle. Engineering measures should be applied in such a way that the cycles are broken. The engineer's contribution should be carefully studied on the following basis:

1. Site
2. Water supply
3. Excreta disposal
4. Solid waste disposal
5. General drainage
6. Design and construction.

Site. This includes (a) siting of villages or homesteads with reference to the polluted sources or insect vector breeding points, (b) setting aside areas to be covered with ponds, pools and dams, and (c) demarcation of the areas for control of diseases. In each case a reasonably accurate contoured demarcation map of the area concerned should be prepared. On it the existing streams, ponds, swamps, ditches and all other points that hold water should be clearly marked.

Control area. Many control programmes appear to be concentrated on small areas regardless of the fact that the sources of the diseases are outside those areas. It is the view of this paper that an effective economic control programme should be planned on a catchment or basin scale rather than isolated areas. The basin may be subdivided into upper, middle and lower zones. The exercise of control measures should be started in the upper division. This eliminates refeeding of the controlled area by surface runoff and flooding streams and rivers. Here the question of limited finances dictating the area to be covered arises. However, the diseases or their agents return sooner or later. In several cases, it may be advisable to let nature take its own course, rather than have control programmes which eventually result in unmanageable situations after spending much energy, time and money.

Siting of water bodies. The bodies of water to be conserved vary from small ponds to large man-made lakes. A feasibility study looking into levels of water at various times of the year, swamping effects on the adjacent grounds, and the general role of the new water body in hosting water-related diseases must be well analysed. Flooding effects on the upstream area is of great importance.

In constructing any dams, ponds, etc., the entire basin should be thoroughly cleared of all vegetation before inundation takes place.

Siting of villages and homesteads. Careful consideration should be given to this item when preparing layout plans for any development projects in irrigated areas or new towns, villages and even homesteads. Residential houses should be built on sloping terrain that allows the rain runoff to flow to rivers or constructed drains. They should be built away from polluted or infected swamps and rivers. Thick woods are usually ideal places for tsetsefly habitat and mosquitoes. A watch should be kept on clear mountainous streams for they provide ideal grounds for breeding of *Simulium* fly agents of onchocerciasis.

Water supply

Several water-related diseases can be reduced and even eliminated by providing or improving water supplies. Health benefits from water supplies are the same both in the urban and rural areas, especially for the urban population that relies on carried water. Prof. D. Bradley has written, 'An African housewife gets up in the morning and soon begins to fetch water. She walks through the thicketed savannah to the water source. This is the habitat of tsetseflies and she is exposed to their unpleasant bites and the risk of sleeping sickness. She reaches the water source in a valley bottom and has to wait her turn. This is the habitat of disease-bearing mosquitoes and of different tsetsefly more efficiently transmitting sleeping sickness. The stream contains snails transmitting bilharziasis if it is sluggish or breeds the vector of onchocerciasis if it is rapid or may contain guinea worm larvae if it is a mere muddy hole. She collects the water, which today bears a highly diluted load of human excreta and may contain typhoid bacilli or hepatitis virus. She returns past the tsetseflies to her home.' He continues, 'She prepares the family's main meal. The scarcity of water discourages the washing of hands before the meal and makes washing up after the last meal perfunctory. Some decayed food might be left on utensils. Some unboiled water is drunk by her thirsty family who pick up the germs from it. Two days later, father falls sick, the cattle are not tended properly and the cotton is not planted, later in the year there is no money for school fees since not only was the harvest small but part of the available cash had been spent on the medicine.' This story appears exaggerated in case of a single housewife yet it conveys a fair picture of more than 95% of East Africans that rely on carried water.

The following health gains, among others, will result from the provision of a more reliable water supply:

1. The frequency with which an East African housewife (drawer of water) is exposed to sources of water-related diseases will be reduced considerably.
2. A lot of time and energy are saved. In agricultural communities these are transferred to cultivation of crops while in pastoral and urban populations

that rely on carried water, they are spent on household work. Both ultimately have health gains.

3. Availability of water is conducive to using more of it. It is hypothesized that there is a diluting effect on gastrointestinal diseases by using large quantities of water. Several cutaneous diseases are drastically reduced and even eradicated by a simple washing exercise.
4. There would be more leisure time for the housewives. It is regrettable that several authors on this subject think that time released from water drawing is passed gossiping. To these authors an East African housewife without the duty of water drawing is a gossip. This is not true.
5. With improved water supplies, there would be a felt reduction in the prevalence of diseases discussed above, thus savings on staff and drugs and health expenditure in general.
6. Economic expansion is inevitable in an area with a water supply. Waste lands are reclaimed and a higher yield per acreage is realized on the lands relying on natural rains. Healthier livestock and higher milk and meat products are conducive to proper nutrition which in turn leads to great reduction in gastroenteritis and all maladies due to malnutrition.
7. Water development improves the economic position of a community, so much so that usually there is sufficient money to buy medicines, mosquito nets, boots and to build recreation facilities. A rich community can afford a higher quality and quantity of water.

Excreta disposal

Disposal of human excreta is very important in the control of water-borne, water-based and to a certain degree insect vector-related (filariasis) diseases. By providing effective water-borne sewers for densely populated urban areas the general nuisance of excreta is removed and life cycles of water-related disease agents are broken. In the rural areas pit latrines are very effective if they are built down the slope from the underground supplies (wells). If the proper direction of flow of groundwater is not well established, pit latrines could contaminate the underground water supplies and therefore be a mechanism in water-related disease transmission.

Drainage

Antimalarial drains to eliminate insect vector breeding grounds near human residences bear the name of the purpose for which they were first constructed. Because of the multiple role they play in reducing schistosomiasis, filariasis and trypanosomiasis and even diarrhoeal diseases (where pools are used as water sources) this paper considers the most appropriate name for these drains is environmental sanitary drains. They are economical only in densely populated areas.

Solid waste removal

Collection and removal of solid waste that includes metal scrap, old tyres, tins and broken pottery is very important for the reduction of yellow fever.

Design and construction

Design, selection of building materials and workmanship should be so strictly looked after that seepage under the dam wall is eliminated or adequately drained. Irrigation channels and drainage ditches should be given suitable gradients, be free from unnecessary bends, be designed and maintained so as to avoid pool formation in corners, junctions, dead ends, inlets and outlets. Bridges and culverts should be constructed in an endeavour to reduce contact between man and water which might be infected. Road plans should be such that the road drains are prolonged to discharge their waters in places where the water will not become a public nuisance.

Conclusion

Ill health is one of the most wasteful things in East Africa and people in poor health stop contributing to the labour of a family or community. Children attending schools lose their lessons and their parents have to take them to outpatient clinics thus wasting time that should have been otherwise utilized. Poor health leads to poor work and a lot of time wasted. As a result, there is less harvest, unsatisfactory school results from children and the general community socioeconomical well-being is adversely affected. A sanitary engineer properly incorporated in control or eradication programmes would contribute much in alleviating these human sufferings.

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GROUNDWATER DEVELOPMENT IN KENYA

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Abstract
This preliminary paper describes the background of the country's groundwater development as a source of water supply. It examines the various aspects of groundwater and the shortcomings, and suggests projection proposals for the future.

Introduction
The development of groundwater in Kenya, which dates back to 1927, has received considerable attention in the last 50 years, primarily because of the relatively low cost of groundwater, the short and inadequate supply of surface water resources, as well as the inherent advantage of subsurface resources over surface waters, particularly for domestic and stock water supply. Many of the borehole sites were selected in a haphazard manner. To date some 4 600 boreholes with an average depth of about 106 m have been drilled. Drilling is mostly by the percussion (cable tool) method. The quantity and quality of water is localized and is dependent mostly on hydrogeological factors. There are 54 monthly observation boreholes, and another 100 are monitored yearly. All available data of these boreholes are computerized in a data bank. The water resources are controlled under the provision of the Water Act (Cap. 372 of the Laws of Kenya).

Importance of groundwater
Groundwater reservoirs have been significant because of their ability to store usable water, especially during the dry years, in the perennially water deficient areas of eastern, southwestern and northern Kenya. Because surface water in rivers, lakes and streams and soil moisture is vulnerable to evapotranspiration and progressive depletion between regular rains, groundwater is the most reliable source of water in the arid and semi-arid areas of Kenya.

Natural sources of groundwater discharge are springs, seepage areas, lakes and base flow of perennial streams which have been used by man since time immemorial. Due to lack of surface sources, groundwater from hand-dug wells has been used at Kenya's coast, northern and northeastern areas for many centuries, mainly for domestic and stock use. However, the beginning of any significant development of groundwater was only possible in the late 1920s due to the introduction of borehole drilling technology and motor-driven pumps.

Available data, information and recent groundwater development indicate that groundwater is widely though not uniformly distributed in the republic. As a result of this, many groundwater reservoirs, most of which contain several water-bearing aquifers of varying thickness, exist in Kenya, but their extent, depth, and the quantity and quality of the water in them are not known. Some of these groundwater reservoirs contain far more water in storage than the volume that flows through them. This flow-through volume is the renewable resource, or the subsurface phase of the hydrologic cycle. However, many of these parameters will be known only as knowledge is acquired in the course of exploration, developing and withdrawing water from them. It can therefore be postulated that the potable water stored underground has very great potential which is readily available for use through proper investigation, development and management.

Groundwater development

The history of groundwater use in Kenya goes back many centuries. As use of this water increased, people in many water deficient and agricultural areas relied on boreholes. In the past, groundwater development did not have a scientific background. The selection of boreholes was influenced by such indications as, for example, that a certain place had an underground river because it was always green, or that there was a small spring or a depression, or by dowsing (the use of a Y-shaped stick). These methods had their advantages and disadvantages.

Scientific groundwater investigations started in the late 1920s to help develop water supplies for domestic and livestock use and for the railroad. By the end of 1930 through to 1940, groundwater development extended to the arid and semi-arid areas. During the late 1960s the subsidy scheme (now insurance grant) was introduced to cover dry or unsuccessful boreholes intended for agricultural or livestock development. As a result the number of boreholes has increased every year (fig. 1). Groundwater resource investigations are very closely related to the country's development, and history of these investigations and water development strongly reflect the general characteristics of the country's development patterns.

Geology

The geology of Kenya, though complex in detail, can be simply divided into four basic units: the metamorphic crystalline rocks of the Basement Complex, the Tertiary and Quaternary Volcanics Series, and the Sediments. The Sedimentary units range in age from Upper Paleozoic to Tertiary. The first three cover about 90% of the surface area of Kenya and each of subequal area coverage, i.e. about 30%. Rocks of the fourth unit occur in narrow bands in the southeast and the northwest of the country. The rocks of the Basement Complex, mainly Precambrian, occur in two main structural regions and are composed of granites and metasediments. The Paleozoic is represented by Carboniferous-

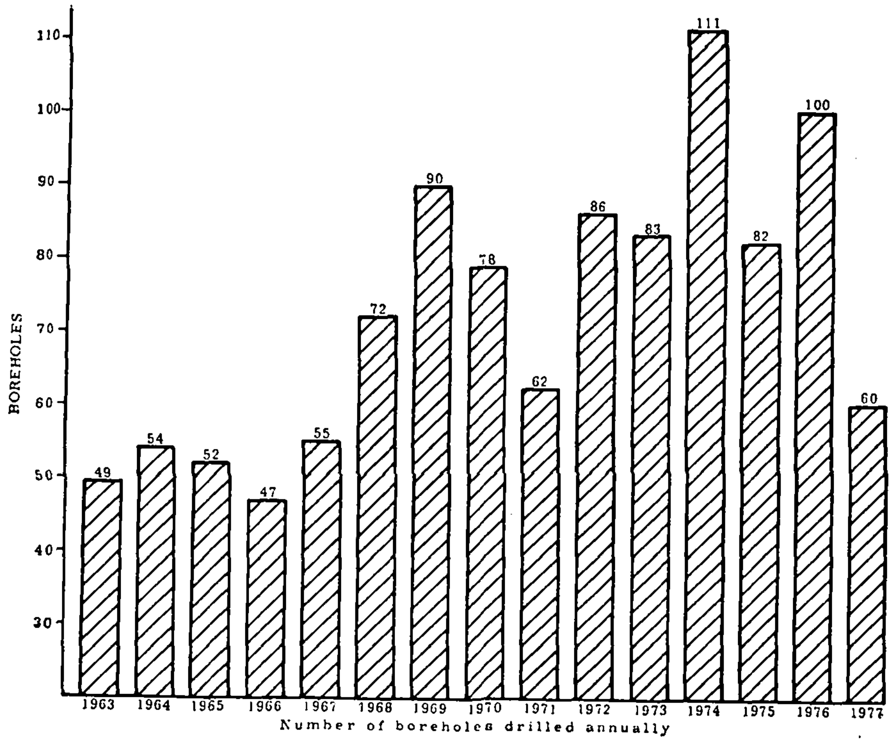

Figure 1. Number of boreholes drilled annually.

Permian, composed of Duruma sandstones and grits. The Mesozoic occur in areas representing different basins which account for their distinct fauna. Tertiary and Quaternary volcanics occur mainly in the Rift Valley, the central part of the country and north of 2°; they are composed of phonolites, basalts, trachytes and tuffs. Quaternary sediments cover most of the eastern part of the country and consist mostly of sands.

Occurrence of groundwater

The source of all water is rain which is not uniformly distributed in Kenya. Precipitation varies with the amount of rainfall, time, space and to a large extent the geology. The Precambrian and to a great extent Paleozoic and Triassic rocks, on account of the low permeability of their aquifers, do not produce continuous water table or confined aquifers. Groundwater found in them is local and is influenced by vertical and horizontal faults, fissures and the degree of weathering. It accounts for about 30% of the total groundwater used in Kenya. Borehole yields are generally low and do not exceed 10 m^3/h. The average depth is 122 m. The quantity and chemical quality is localized and is dependent more on hydrogeological factors. In most cases the water is mineralized with up to 1 000 ppm.

The Jurassic and Cretaceous sediments are generally permeable and could therefore be potential aquifers. Groundwater studies for their development are now being carried out as a major source of water supply and to establish their potential, quality, quantity, and extent. These parameters are presently not known. The Quaternary and Tertiary volcanics are highly potential but are highly variable in their water-yielding properties. Their groundwater issues form alluvial and lacustrine deposits interbedded with the impervious lavas and tuffs. Due to faulting localized water tables occur in the Rift Valley. The depth of boreholes ranges from 91 to 304 m. High yields in excess of 27 m^3/h have been obtained. The quality of water in them is generally good. In localized cases, however, high fluoride concentrations, i.e. 24 ppm, are known. As a result of volcanic activity in the Rift Valley, hot groundwater and in certain areas stream are found in the boreholes. Studies have already indicated potential for geothermal energy.

Quality

Although the two main criteria for quality description of the groundwater resources are the total dissolved solids (WHO allowable 1 500 ppm) and fluoride content (WHO allowable 1.5 ppm), a full chemical analysis was not always carried out in the past. And as a result the water quality of many of the boreholes was classified by taste. Now a more comprehensive analysis is always carried out (appendix 1). About a third of all boreholes have been chemically analysed.

The chemical quality of water is localized and is dependent more on hydrogeological factors. Based on these hydrochemical data, a preliminary water quality and fluoride map of Kenya is being compiled. These data also show that the water quality is generally good apart from some localized zones of high fluorides. Much of the groundwater resources of the North Eastern Province have total dissolved solids of 10 000 ppm or more. In some parts along the coast, freshwater floats on saline water in Tertiary-Quaternary sediments, and thus the salt water intrusion into the mainland may present a future problem in the coastal groundwater development.

Uses

Groundwater finds ready application to industrial, livestock, irrigation and domestic uses, and the choice is dictated by lack of an adequate source and/or financial considerations. Based on the borehole use, groundwater is mainly used for domestic and stock use. Agriculture and industry take second and third places respectively. Efforts to obtain exact figures of water used for each of the above purposes have not been successful because of many reasons. About 99 % of all the boreholes are not metred. Present groundwater demands indicate that the use and priority for groundwater will continue to be the same for a long time to come.

As the demand for water in the country grows, an increasing percentage of this demand will be met from groundwater. To meet this increased demand, a proper scientific approach of the qualitative and quantitative evaluation of aquifer systems and dynamics and a better understanding of their role in the total hydrological environment is a must. This plus many other inherent problems not yet foreseen present a big challenge to those in water resources development and management. Research is also needed in the study for use of brackish water for useful purposes, i.e. transforming the vast dry areas for the benefit of man. In order to achieve our objectives in the exploitation and use of groundwater resources, the coordination of all those involved in its different aspects is necessary.

Conservation

Considering the total number of boreholes in the country today and their annual abstractions, groundwater reservoirs all over the country are under-developed, particularly in the uninhabited or sparsely inhabited areas where boreholes have been drilled for domestic and stock supplies. In these reservoirs, the natural equilibrium, the inflow (precipitation) and outflow (abstraction), is presumed to be unaffected by the negligible withdrawals. On the other hand, the exploitation of a known reservoir is marked by successful development of large-production boreholes, increased number of boreholes and increased rates of pumping. This ought to be checked and controlled. Conservation of aquifers should keep pace with groundwater development. The Nairobi Conservation Area is a case in point. This area covering some 380 km^2 was defined in 1953 after a long-term localized water table depletion was recorded. The area is divided into seven hydrogeological zones (table 1). Monthly rest level measurements are taken in 54 observation boreholes and 100 boreholes on an annual basis. Presently there are some 600 boreholes in the Nairobi Conservation Area. Although the exact groundwater abstraction is not known, available data give a daily abstraction of about 100 000 m^3.

Table 1. Nairobi Conservation Area: hydrogeological zones

Zone	Area (km^2)
Kamiti	53.4
North Eastern	196.0
Spring Valley	27.5
Kabete	11.5
East Langata	66.8
West Langata	17.9
Karen	6.5
Conservation Area	379.6

Conclusion

For various reasons groundwater was not considered as a potential source of water supply, but now it is proving more and more a major potential source of water not only for today but for tomorrow. It is common knowledge now that an asset virtually unexploited in this country is the large quantity of groundwater available from storage in the aquifers. Much of it can be used in urban and rural areas, during droughts and for reclamation. These aquifers will then be replenished seasonally in periods of normal recharge.

Our knowledge of the groundwater resources is very deficient because the most important groundwater parameters, potential, quality, quantity, annual recharge and abstractions, are not known. The direct relation between effective management of groundwater resources and proper land use requires the training of local manpower and necessary research into the groundwater resources as well as how easily and cheaply it can be exploited.

Appendix 1

Sample No:
Source:
Date of Sampling:

Date Received:
Submitted by:
Purpose of Sampling:

PARAMETERS		RESULTS			
pH	pH units				
Conductivity (25°C)	μS/cm				
Permanganate value	mg $KMnO_4$/l				
Turbidity	J.T.U.				
Colour	mg Pt/l				
Iron	mg Fe/l				
Manganese	mg Mn/l				
Total hardness	mg $CaCO_3$/l				
Total alkalinity	mg $CaCO_3$/l				
Calcium	mg Ca/l				
Magnesium	mg Mg/l				
Sodium	mg Na/l				
Potassium	mg K/l				
Nitrate	mg N/l				
Nitrite	mg N/l				
Ammonia	mg N/l				
Total nitrogen	mg N/l				
Chloride	mg Cl/l				
Fluoride	mg F/l				
Sulphate	mg SO_4/l				
Ortophosphate	mg P/l				
Total phosphorous	mg P/l				
Total suspended solids	mg /l				
Dissolved oxygen	mg O_2/l				
Temperature	°C				
Saturation					
CO_2	mg CO_2/l				
BOD_5	mg O_2/l				

COMMENTS:

WATER RESOURCES AND SOIL CONSERVATION: THE KENYAN SITUATION

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Abstract
Only about 4% of the land area in East Africa reliably receives more than 1 200 mm of rainfall a year. More than half the area is unlikely to receive as much as 600 mm in four years out of five. It is imperative, therefore, not only to conserve what little water there is in the drier areas but also to make the best possible use of the limited resources of the high rainfall areas.

In Kenya, it is clear that effective soil conservation measures, upon which water conservation ultimately depends, are long overdue. This paper highlights some of the current problems of water resources that planners face with ever-increasing pressure on the land.

Introduction

Only about 4% of the land area in East Africa reliably receives more than 1 250 mm of rainfall per annum (Russell 1962) and land with vegetation is likely to use at least this amount, given that there are no physical restraints on transpiration and evaporation. It is this area within which the major perennial streams rise and, hence, on which the densely populated areas depend for domestic water supply, electric power and water for agriculture. Kenya's situation is summarized in figure 1, which shows the percentage of land area receiving an average mean annual rainfall of less than given amounts. It will be noticed that only 26% receives more than 625 mm, which is conventionally taken as the boundary between areas of medium agricultural potential and low agricultural potential (Brown 1963). Twelve per cent could be classed as of medium agricultural potential and 14% as of high agricultural potential. Of the latter, about 3.6% is gazetted forest.

These figures are approximate and they do not take into account rainfall reliability. They serve, however, to emphasize how critically small is the area where rainfall will exceed actual evaporation and thus guarantee recharge. Without recharge, the dry season flow of the major rivers will be affected with far-reaching consequences for agriculture and industry. In the drier areas, rain-fed agriculture is marginal because of the great variability and low reliability of rainfall. Supplementary irrigation and water supplies are dependent upon the dry season flow of the rivers and on groundwater. Both of these sources

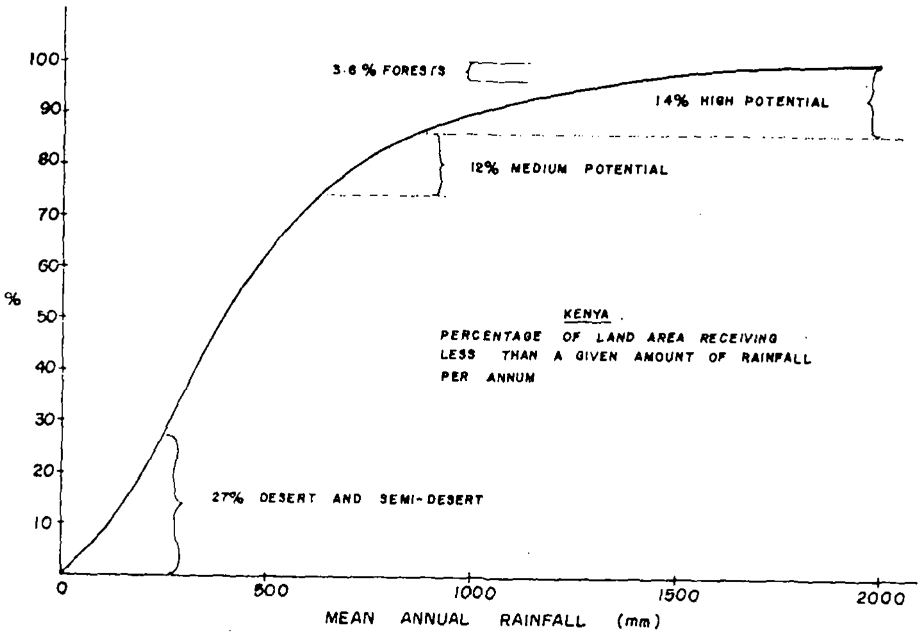

Figure 1. Mean annual rainfall in Kenya.

are themselves dependent upon the efficiency of recharge. Thus, it can be seen that one hydrological process above all, infiltration, can control the status of a nation's water resources. Rainfall that does not infiltrate to recharge soil and groundwater storage runs off, taking with it valuable soil and plant nutrients. The faster it runs off, the more catastrophic flooding can become until it is impossible to harness these high flows for man's needs. Indeed, destructive floods are not only a threat to life and property, but also a threat to water development projects. Dams can be breached and reservoirs silted up in a single storm. During the floods of 1961/62, it is estimated that the Kalundu water supply reservoir at Kitui lost a quarter of its storage capacity in 6 months. Subsequently, in the wake of bad land management and drought, the Kalundu reservoir has completely silted up, necessitating an additional expensive water supply which the country can ill afford.

Kenya's prospects for continued agricultural development are clearly dependent upon the efficient use of all her water resources. Ultimately, conservation of water resources is indivisible from conservation of soil. With the prospect of sufficient funds becoming available for the first time to initiate coordinated and large-scale soil and water conservation measures, it is opportune to stress the interdependence of the two major natural resources, so that planners, politicians and farmers have a clear idea of what the government is trying to achieve, and why it is vital for future agricultural development.

In the past, soil conservation measures were often misinterpreted and much good work such as that started by ALDEV (Min. Agriculture 1962) has gone to waste. With population pressure now stretching Kenya's resources, and with a large part of the country composed of delicate ecosystems, particularly in times of climatic stress, the dire consequences of failure to continue and improve conservation measures cannot be overemphasized.

This paper is intended as a simple, objective statement of some of the important and controversial issues concerning resources in different regions of Kenya. The broad classification of land potential has been used for simplicity, although it is recognized that the terms high, medium and low potential for agriculture are not strictly defined nor do they coincide with the accepted ecological zones (Pratt, Greenway and Gwynne 1966).

Hydrological cycle and the water balance

The hydrological cycle is a well-known concept, which underlines the continuity and cyclic nature of the flow of atmospheric moisture into surface and groundwater storage, into streamflow and ultimately into oceans and lakes, from which it returns to the atmosphere by evaporation. The water balance is an attempt to quantify the flux of water in the individual processes of the hydrological cycle, so that calculations can be made of the unknown variables, or of those that are difficult to measure. While it is unnecessary to detail the many physical processes involved, it is useful to examine the broad outline of the cycle, so that its interdependence with soil conservation can be seen. Given that the input to the cycle (rainfall) cannot yet be easily modified by man, the crucial process is that of infiltration, which has to be maximized. Evaporation, transpiration and residual runoff into the oceans are all losses which have to be minimized. How these are interrelated is set out in table 1, and it can be seen that the soil conservation practices are basically all aimed at increasing infiltration and conserving water.

Only one conflict arises. It has been demonstrated in many countries, including Kenya, that trees use more water than shorter and aerodynamically smoother vegetation. In terms of minimizing evaporative losses, therefore, it could be argued that conservation forests do just the opposite. There is no evidence that montane forests have anything other than a minor effect on total precipitation in the high rainfall areas, but it is self-evident that a deep-rooting, evergreen forest will use more water than annual crops or even short-rooted grass, particularly where evaporation of intercepted water becomes a measurable term in the water balance.

At the same time, trees are by far the best ground cover to stabilize soil, increase infiltration and protect steep slopes from erosive rainfall. With the possible exception of well-maintained tea plantations or rigidly controlled mixed forestry and sheep farming, forestry, both indigenous and plantation, is the only permissible land use in the vital recharge areas of the highlands.

Table 1. Interdependence of the hydrological cycle and soil conservation

Process/key factor	Guidelines for conservation optimization
Rainfall:	
Erosivity	Protection of soil by complete ground cover
Frequency/duration	Reducing reflectance (?)
	Weather modification (?)
Infiltration:	
Soil porosity	Maintenance of high organic content
	Prevention of compaction by overgrazing
	Breaking up of surface crust and hard pans
Surface horizon depth	Prevention of physical removal by terracing and improving ground cover
Topography	Terracing to reduce slope angle and length
Storage:	
Soil moisture storage	Maintenance of soil depth, structure and humus content
Groundwater recharge	Maintenance of high infiltration rates
Evaporation:	
Interception losses	Use of aerodynamically short crops where effect is critical to water balance
Open-water evaporation	Monomolecular films on reservoirs, covered storage and efficient irrigation systems
Transpiration	Clean weeding, use of xerophytic species
Streamflow:	
Surface run-off	Increase of infiltration, decrease of slope and protection impermeable areas (i.e. roads, paths, school playgrounds)
Flood flow	Increase of surface storage and decrease of surface run-off
Base flow	Increase of groundwater recharge
Sediment transport:	
Wash load	Decrease of surface run-off and maintenance of ground cover
Bed load	Reduction of stream velocity by attenuating flood flows, i.e. balancing reservoirs
Soil erodibility	Prevention of soil degradation by applying conservation guidelines

The steady increase in mean annual flow in major rivers over the last 30 years, e.g. Tana at Garissa, could be attributed to the excision of forests in the upper Tana and change in land use to subsistence agriculture over large parts of the catchment. While this might appear a beneficial effect at first sight, the increase in water yield has to be balanced against the enormous accompanying loss of nutrients and fertile top soil and the decrease in groundwater recharge. It is estimated that on average, over 12 million metric tons of suspended sediment are transported past Garissa every year. Even taking into account that the deep red loams developed on the Tertiary volcanics give good yields in spite of continued loss of top soil, it is clear that accelerated erosion of this nature will not only lead to the eventual decline in agricultural production but also create severe siltation problems in reservoirs and at abstraction points downstream. The following sections briefly review the major characteristics of the hydrology of the three agricultural potential regions in Kenya with recommendation as to water resources planning and soil conservation.

Areas of high agricultural potential

The areas having more than 900 mm of rainfall on average comprise the eastern coastal belt, the western shores of Lake Victoria and the highlands flanking the Great Rift Valley including the residual volcanoes of Mt Elgon and Mt Kenya. The highlands, developed for the most part on the Tertiary volcanics, have deep red soils which support the important cash crops of tea and coffee together with the maize and bean subsistence economy of large numbers of small-scale farmers. It is these areas on which the perennial rivers such as the Tana, the Athi, the Sondu, the Mara, the Nyando, the Ewaso Nyiro and the Endo/Kerio rise. Thus, large areas of drier climate are closely dependent upon land-use practices in this region. The coastal strip is largely self-contained but in spite of promising groundwater yields there is still a measure of dependence upon the Sabaki (Athi) River. Western Kenya is similarly fairly self-contained with theoretically sufficient surface water resources to meet most development projects.

The three areas have the densest population in the country and the highest rates of population growth. Although it is possible to estimate the likely demand by the year 2000 and compare it with the total surface water resources (WMO 1973), the conclusion that surface water availability is not critical in these areas ignores the great expense involved in exploiting a large number of small rivers and, particularly in the case of the highlands region, ignores the necessary provision of compensation water to downstream users. Thus, although it is estimated that only 10% of the 95% runoff (i e. the runoff which is likely to be exceeded 95% of the time) will be required for domestic use in the year 2000, not all of the runoff is available by any means. At the same time, the number of competing users for the same water is likely to increase. It does not take into account either the proportion of water lost by pollution—either industrial or by soil erosion—or the proportion of high flows which cannot be utilized because of their destructive power. It is obviously extremely difficult to forecast the likely demand as a proportion of available water for any time in the future. What is certain, however, is that we are likely to underestimate demands and since this is the only region where rainfall reliably exceeds evaporation and transpiration, it forms a resource bank which we cannot afford to deplete.

Examining the land-use practices existing in the region at present and the degree of soil erosion reveals several disquieting features. It is now well known from the EAAFRO series of catchment experiments that both plantation forestry and plantation tea have a minimal effect on the streamflow regime of the highlands if the land-use change is carried out under good management. The higher parts of the water catchments do not pose a threat, therefore, to our water resources. Lower down, however, there is a region of intensively cultivated land which is characterized by an almost total disregard for sensible soil conservation measures. Thus, steep slopes are cultivated for annual crops without terracing, stands of protective trees are removed without replacement, unprotected paths lead directly downslope and little or no attempt is made either to protect the soil surface or to replace lost nutrients.

On any soils other than the well-structured red volcanic soils, such land-use practices would have been disastrous years ago. Sediment yields of rivers such as the Thika, Sagana and Tana are estimated to have been nearly 600 metric tons km^2/annum by 1965 and this does not take into account bed load or the sediment delivery ratio. Erosion from the individual fields must have been at least 10 times that figure and cultivation has intensified since that date. Apart from the serious loss of top soil into the rivers, accelerated erosion of this nature affects groundwater recharge and peak flows. Unfortunately, since 1961, the hydrological regime of the rivers seems to have changed in character with a notably greater incidence of high and low extremes in response to climatic factors. Thus it is not easy at the present time to show conclusively that there is a decrease in dry season flow and an increase in flooding which can be associated exclusively with accelerated erosion. For instance, although the Nyando River in western Kenya has experienced six major floods since 1960, there appears to be no statistical justification for assuming that the high incidence of flooding is a result of changes in the runoff characteristics of the catchment, although a subjective appraisal would suggest that it is.

In summary, the high potential areas have enough surface water to satisfy domestic needs by the year 2000 given that the needs have not been grossly underestimated. In view of the importance of these areas as a source of perennial streams and groundwater recharge, however, soil conservation measures must be stepped up to ensure adequate recharge, to prevent surface runoff and to reduce the dangerously high silt loads in the rivers. The planting of deep-rooting crops such as tea should be encouraged, while any future intensification and expansion of cultivation should take place only within guidelines set out by the Ministry of Agriculture. In this context the encroachment on existing forests by illegal squatting will endanger the water supplies of downstream users and should be recognized as an antisocial and wasteful act akin to the wanton felling of forests for charcoal without replanting.

Areas of medium agricultural potential

These areas are much harder to define. Originally taken as those areas having between 25″ (625 mm) and 35″ (875 mm) of rainfall, they correspond broadly to ecological zone 4, together with the drier portions of ecological zone 3. Much of the region is productive rangeland with a potential for dry farming, i.e. cultivation of drought-resistant crops. Potential evaporation exceeds rainfall for most of the year, however, and rivers are seasonal except for those originating in the high potential zones. According to the WHO survey (WHO 1973) the domestic demand by the year 2000 will exceed 50% of the 95% runoff in areas having perennial streams. Elsewhere, water supply is dependent upon surface water dams and groundwater. Under these conditions, water conservation is a strict necessity and yet it is this region which suffers most from pressure on the land due to high human and animal populations. Basement Complex metamorphic rocks are the predominant parent material and the soils developed on these are generally thin and sandy with little resistance to accelerated erosion. Overgrazing due to cultural traditions and scant regard for the variation in carrying capacity of the land with effective rainfall has led to the denudation during dry years of large areas of communal land while adjacent large-scale enclosed ranches have been able to remain productive because of the lower stocking rate. On the slopes, abandonment of terraces and intensification of cultivation have led often to the complete removal of soil down to the exfoliating granitic gneiss bedrock.

Sediment measurements from these areas are sparse although the Kalundu River near Kitui has a calculated suspended yield of 550 metric tons/km^2/annum. The rate of bed load transport is estimated from the rate of sedimentation of the Kalundu reservoir to be of the same order. Similarly, the Maruba Dam near Machakos received a combined suspended sediment and bed load of about 1500 metric tons/km^2/annum and has lost more than half of its original storage capacity since 1958. Apart from the disastrously high erosion rate inferred from the above figures, the loss of infiltration capacity on these soils has led to a drop in groundwater level and decline in yield of existing boreholes. The laying bare of large areas has also led to severe flash flooding—one such flood breaching a harambee dam at Kitui township. Numerous examples exist of the silting up of small dams to the extent that surface reservoirs are completely uneconomic without accompanying soil conservation.

At the present time, land adjudication has made great strides in certain parts of the region. This has had the effect of encouraging farmers to take conservation measures seriously—albeit from motives of self-interest but ultimately to the benefit of the whole community. With efforts being made by the Ministry of Agriculture to improve extension services in areas of Machakos and Kitui districts and to work out a system of incentives for conservation works, there is every hope that the present impetus will not be lost. The grazing lands, however, show little sign of improvement even following this year's good rains. In spite of the remarkable powers recovery of degraded rangelands demonstrated by ALDEV and others, many parts of Kitui such as the Tiva River catchment and parts of Machakos District such as Kalama have lost so much soil that even partial recovery must be impossible without strong government intervention.

The prospects for water development within the medium potential zone, therefore, are closely tied to soil conservation. Surface water reservoirs, groundwater wells, subsurface dams and rock catchments are all affected by the low infiltration, rapid runoff and heavy silt concentrations which characterize this zone. Future agricultural development may well be dependent upon the provision of adequate water supplies and under the present circumstances the latter may be very difficult indeed.

Areas of low agricultural potential

With rainfall less than 600 mm, rain-fed agriculture becomes extremely marginal. Rangeland potential is good under strict management but such areas are highly susceptible to misuse through overstocking. During periods of climatic drought in the past, denuded areas would be abandoned and allowed to recover while nomadic herdsmen sought alternative pasture. Population pressure and restriction on movement now lead to famine conditions being felt more and more frequently.

Water supplies in such areas are seasonal wells in sand rivers, perennial streams from wetter regions and groundwater. The latter includes springs which emerge on the lower slopes of the mountain masses of northern Kenya such as Marsabit, Nyiru and Mt Kulal. These are often vital sources for sedentary groups as well as nomadic tribes and whereas the upper slopes of the mountains traditionally provided dry season grazing, there is a tendency now for grazing to continue the whole year round. Encroachment on the summit forests is commonplace and concern is felt that destruction of these high forests will lead to an eventual failure of the basal springs.

Elsewhere, ground cover is sparse, soils are poorly developed or absent and there is little to prevent severe erosion when the infrequent convectional storms bring intense rainfall. Improvement of water resources in these areas will be impossible without enormous efforts to increase vegetation and, hence, infiltration. Here in the realm of desertification so little is known about the interaction of climate and the ecosystem that one can only hope that the current plans for action against desertification will lead to feasible guidelines for future development. Unfortunately, for reasons to be described below, the prospects of any immediate improvement are remote and rural water supplies in the low potential areas will continue to present almost insuperable difficulties.

Use of the perennial streams which flow through the low potential areas are the most promising source of future supplies. Multi-purpose reservoirs such as the proposed Turkwell Dam could well provide water supplies for a large area. Schemes like this, however, are critically dependent upon protection of the catchment areas if siltation and dry season yield problems are to be avoided. Minor irrigation schemes, as on the Turkwell River, also rely on soil conservation measures in the catchment. Years of labour can be lost through damage produced by flash floods. How long it will take to reverse the accelerated erosion and create a more stable system, however, is still a matter for conjecture.

Priorities in conservation planning

Soil and water conservation are expensive programmes. The more severe the environmental degradation, the more costly the remedial measures. Already in Kenya, some areas such as part of Baringo District are not worth reclaiming in view of the high cost and low national priority. The highest priorities are clearly those areas of high unit value to agriculture and where water conservation has the most far-reaching consequences. These areas are primarily the high potential areas and those small outliers of high rainfall within the medium potential zone which yield perennial streams. Here, not only are soil conservation methods less costly but the return in terms of increased water resources and agricultural production easily justifies the expenditure. Logically, the medium potential zone comes next in anticipation of future agricultural expansion and in an effort to prevent further loss of potentially productive land through erosion. Within the zone, areas of greatest population pressure, such as Machakos District, must take precedence but areas experiencing particular difficulty, such as Kitui following a 7-year dry spell, should also see early remedial action.

The low potential areas, although they exhibit examples of spectacular erosion and dire water shortage, must unfortunately come last in spite of the extensive publicity being given to desertification. In the first place, so little is known about the physical processes here that no clear guidelines will be forthcoming in the near future as to the remedial measures which lie within limited financial resources. Secondly, the return on such investments does not justify using funds which could do so much in areas of higher population. It is certainly worthwhile investing in research in the drier areas so that when funds are eventually available a plan of action is ready. At the present time, however, effective action on a national scale is only possible at the expense of effective remedial measures elsewhere.

Conclusion

The foregoing comments have outlined the relationships between the hydrological cycle and soil erosion to emphasize how closely soil and water conservation are linked. Conservation problems are essentially those of increasing infiltration by completely covering the ground with vegetation or terracing to reduce slope. Already it can be seen from the quoted suspended sediment data that not only are the fragile Basement Complex soils suffering accelerated erosion but the rich red volcanic soils of high potential regions are also being lost. With the present renewed interest in the environment, it is sincerely hoped that effective legislation, coordinated action and a sound judgement of priorities will at last begin to swing the balance in favour of resources conservation. If not, there seems little prospect for continued economic growth in the agricultural sector given the present rate of population expansion. Remedial measures are well known, well documented and have been used for centuries in countries faced with similar problems of population growth, soil erodibility and rainfall erosivity. If not for sound economic reasons, it should now be a matter of national pride that Kenya refuses to allow her precious soil and water resources to disappear into the Indian Ocean.

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WATER RESOURCES PLANNING IN THE TANA RIVER BASIN

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Abstract

The Tana River Basin represents a major contributory sector within the Kenya economy. Already on the river there are substantial commitments to public water supply, hydropower and irrigation, each of which is rapidly increasing its demand on the strictly limited water resources of the Tana Basin. To a certain extent the requirements of these various water-user sectors are in conflict with each other, and therefore the Tana River Development Authority finds itself working towards a global development strategy which will maximize overall benefits.

A mathematical computer model of the Tana Basin has been developed to allow river management schemes to be analysed rapidly, and to a depth and complexity that would be quite impossible by manual calculation. As a result of the authority's planning, a major river regulating reservoir is about to be constructed in the upper reaches. This reservoir will greatly enhance the development potential of the river basin.

Introduction

The Tana is Kenya's largest river, with a catchment area approaching 100 000 km² comprising regions of widely differing nature and development potential. The river is fed from perennial streams rising on the well-watered slopes of Mt Kenya and the Aberdares, and it eventually flows into the Indian Ocean at Kipini, having traversed almost every climatic and ecological zone in the country. The river is approximately 1 000 km long, with no perennial inflow for the last 500 km. The Tana Basin (fig. 1) represents a major contributory sector within the Kenya economy. It contains some 20 % of the national population, a large proportion of the country's rain-fed agricultural production and much the greater part of its potential for irrigation development. Furthermore the Tana River is the only major source of hydroelectric power within Kenya. This paper describes how the Tana River Development Authority is reconciling these vital and often competing demands on the strictly limited water resources of the Tana River.

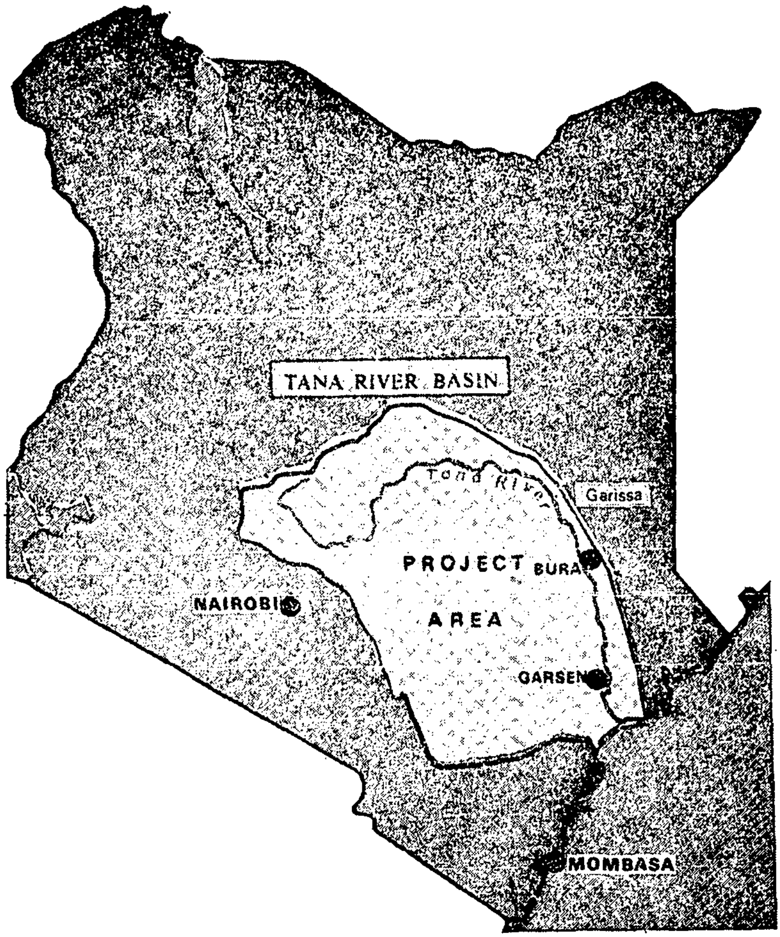

Figure 1. The Tana River Basin area.

Tana River Development Authority

Recognizing the importance of the Tana Basin, and the need for coordinated planning of its development, the government established the Tana River Development Authority (TRDA) by Act of Parliament in 1974. The authority is a statutory board, responsible to the government through the Ministry of Water Development. TRDA functions under the control of an executive chairman, supported by technical staff. It reports to a board of members made up of representatives of the government, private industry and other interested organizations. Under the terms of the Act TRDA is to advise the government on all developments within the Tana Basin. In practice this means that it plans, coordinates and monitors projects, and maintains an important liaison between the government, the private sector and development agencies. TRDA is not normally responsible for the execution and operation of works, as this falls within the province of the appropriate undertaking (e.g. East African Power and Lighting Co., National Irrigation Board, Water Department, etc.) but where a development crosses normal institutional boundaries the act provides for the authority to assume the role of executing agency. This occurs, for example, in the development of multi-purpose projects such as the Upper Reservoir, which is referred to below.

Demands on the Tana River

There are three major demands on the water resources of the Tana River. They are:

1. Public water supply
2. Irrigation
3. Hydropower

Broadly speaking these are at present in competition with each other, as the bulk of irrigation and public water supply abstractions occur upstream of the hydropower stations. With these prior abstractions increasing every year there is a gradual but steady depletion of hydropower potential. Furthermore, on certain tributary systems, the base flow is already insufficient to sustain even the currently proposed water supply and irrigation abstractions without increased local storage. In this situation of growing competition for strictly limited water resources, the TRDA's comprehensive planning role is crucial if the development potential of the Tana Basin is to be fully realized. To appreciate how this is to be achieved it is now necessary to consider the above demand sectors in rather more detail.

Public water supply

Public water supplies are regarded as a priority demand on the river system which must and can be met. The Tana River supports not only its own in-basin population, but also the rapidly growing Nairobi demand, although the city is in fact well outside the catchment. It is anticipated that all future Nairobi supplies will be derived from tributaries of the Tana, thus increasing the export of water from the river basin. In considering future demands from this sector one may conveniently take year 2000, by which time the government has pledged to provide all Kenyans with an adequate domestic supply. By this time current projections indicate that the population supplied by the Tana will have tripled, and the actual water requirement will have increased fourfold over present levels.

Irrigation

The subject of irrigation within the Tana Basin is covered by J. K. Kimani (published in these proceedings), and therefore will only be mentioned briefly here. Irrigation within the Tana Basin falls within two basic categories: First there is the upper Tana irrigation. It utilizes the tributary waters and is basically required to supplement an inadequate rainfall pattern. Second, there is the lower Tana irrigation. This draws water from the mainstem river for what is essentially total irrigation of the arid land expanses downstream of Garissa. In the Middle Tana, where the hydropower potential lies, there is little prospect of large-scale irrigation due to the broken nature of the country and the relative remoteness of the area. There are significant differences between the two categories of irrigation described above (see Kimani 1978) but from the point of view of water resources planning, perhaps the most important difference is the position of the prospective irrigation areas relative to the hydropower reaches. Some of the advantages of upper Tana irrigation must be offset by the fact that it depletes the power resources of the river, whereas lower Tana irrigation, occurring as it does below the hydropower stations, is not directly in conflict with them. There is therefore an element of trade-off between the lower Tana irrigation and hydropower, and upper Tana irrigation. It is part of TRDA's role to achieve a reasonable balance between the two.

Hydropower

The Tana River possesses virtually all of Kenya's hydropower potential. There are already two major hydroelectric stations on the river: Kindaruma, 44 MW; Kamburu, 84 MW; and a third, Gitaru, 142 MW, is nearing completion. Together with some minor stations on the tributaries, they represent approximately two-thirds of the national generating capacity. The remainder of Kenya's power requirement is met by importation (30 MW) and thermal generation (140 MW). The imported component is fixed, and therefore all expansion on the rapidly growing interconnected system is currently taken by hydro or thermal stations. Thermal stations burn imported oil and are expensive to run. There is also a locational problem in that they are best situated at the coast whereas the centre of demand is 500 km away in Nairobi. In time there is the possibility of geothermal generation in the Rift Valley, which would obviously be another low-running cost energy source like hydropower, but at the moment it is not sufficiently proven for commercial operation. Consequently there are strong reasons for further development of the hydropower resources of the Tana, where there are sites for perhaps another six major generating stations (fig. 2). However the commitment of such a large portion of the national generating capacity to the single unregulated river carries with it the risk of severe dislocation of power supply in the event of a drought. Consequently hydrological factors loom large in assessing the future development of the hydroelectric resources of the Tana River.

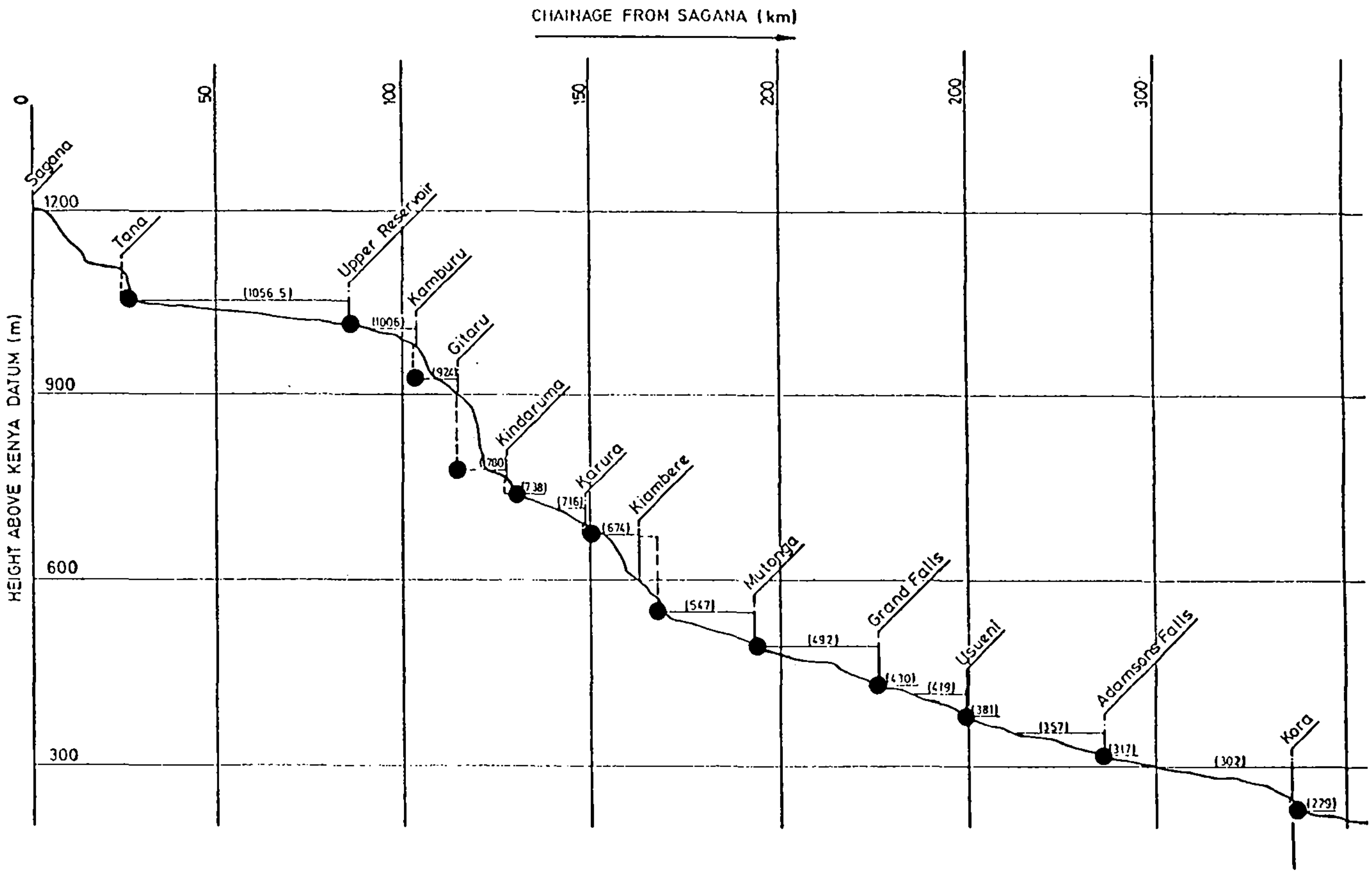

Figure 2. Existing and possible hydropower developments in the middle of the Tana River.

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The river basin simulation model

A planning agency such as TRDA, when faced with a variety of interacting demands on the unstructured geography of a river basin, finds itself with a complex task. It is easy enough to recognize in broad terms the connection between the various demand sectors, but it is very difficult to quantify the relationship. Before rational development plans can be made, answers must be found to a wide variety of questions. What, for example, would be the cost to the power system if large-scale irrigation was fostered in the upper Tana? What would be the consequences on lower Tana irrigation? What is the opportunity cost of water abstracted to supply Nairobi? Where should the river be reservoired? How big should the reservoirs be, and how can they best be operated for optimal benefit? These are the types of problems that require a large amount of data handling and computation. In order to assist in this task a mathematical computer-based basin simulation model has been developed. The main purpose of the model is to allow river management schemes to be analysed rapidly, and to a depth and complexity that would be quite impossible by manual calculation. In this way a broad pattern of alternatives can be examined, and subsequent decisions based upon sound quantitative data.

The general nature of the model

The model takes the form of a computer programme that reproduces all of the essential features of the Tana River Basin, thus allowing the performance of the river system to be 'simulated' under any defined pattern of future demands (e.g. public water supply, irrigation and power demands) and under a wide range of possible future engineering developments (e.g. the introduction of a new reservoir or hydroelectric station). In this way, the programme allows the user to evaluate what the detailed effects will be of any future change in either the demands on or the engineering of the river or the national electrical system. The computer programme characterizes the river system as shown in figure 3. In particular it recognizes:

1. Five main tributary systems (Thika, Sagana, Thiba, Mutonga and Kazita)
2. The mainstem Tana River
3. Nairobi water supply abstractions (from the Thika)
4. Public water supply abstraction (on each tributary)
5. Upper Tana irrigation abstractions (on each tributary)
6. Lower Tana irrigation abstractions
7. Reservoirs with live storage — Upper reservoir
   — Kamburu
8. Reservoirs with no live storage — Gitaru
   — Kindaruma
   — (Kiambere)
9. Power stations, variable head — Tana

10. Power stations, fixed head
— (Upper reservoir)
— Kamburu
— Gitaru
— Kindaruma
— (Kiambere)

Schemes shown in parentheses are not yet built and therefore can be included or ignored by the programme.

The simulation of the river system

As already indicated, the programme is capable of simulating the operation of the river system at any future stage of development. Thus, it might be required to simulate the behaviour of the river under the conditions that are expected to pertain in, say, 1990. Accordingly, estimates of all water and electrical demands as projected for 1990 are prepared and incorporated into the programme as data. Similarly, data are input describing the capacities of the reservoirs, hydrostations and alternative power sources corresponding to the level of development projected for the year. The programme then automatically simulates the operation of the river system and produces results describing the behaviour of the river under these conditions. These show:

1. The degree to which it proves possible for the river to meet the required public water supply and irrigation demands.
2. Whether the national energy demand can be met with adequate reliability; what part of the demand can be carried on the hydrosystem and therefore the loadings on other energy sources.
3. The best way to operate the major reservoirs on the system with detailed information on reservoir levels and regulated flows.

The programme achieves this by 'routing' water down the tributaries, deducting the public water supply and upper Tana irrigation abstractions, passing the net flow into the mainstem river, and on through the various reservoirs and hydrostations, thence into the lower Tana, where further irrigation abstractions are taken, and thus eventually on to the delta region. This routing of water flows down the river is conducted on a monthly time interval.

Anticipated river flows

Now, although it is hopefully possible to project what the various demands will be in, say, 1990, there is no way in which it is possible to predict what the actual river flows will be in that year. It may prove to be a very wet year, or a dry one, or most probably something in between. For this reason, it is necessary to simulate the same 1990 demand and engineering conditions on the river under the complete range of natural flow conditions that might reasonably be anticipated. This has been done by routing down the river (i.e. through the programme) the whole of the historic natural flow record for the Tana and its tributaries. In practice, reliable records are available, and have been used, for the period

1947 to 1971 (the post-1971 record having been omitted for other reasons). These 25 years of past river flow records are taken as a reasonable indicator of the general long-term natural behaviour of the river, containing, as they do, examples of severe droughts and peak floods as well as more average conditions. Thus, briefly, in order to simulate the behaviour of the river system at any future stage of development:

1. Data are input to the programme describing the expected levels of water and electrical demands and the proposed installed reservoir and generating capacities.
2. The programme simulates the behaviour of the river system under a wide range of possible natural flows (e.g. the 1947–71 historic flow record).
3. Results are output for this same hydrological range and, in particular, for drought, flood and average conditions.

The Upper Reservoir Scheme

Planning is not an end in itself, but merely a means to an end. Therefore it would be inappropriate to finish this paper without mentioning tangible developments. Perhaps the best example of this is the Upper Reservoir Scheme, which is the largest water resources project currently being undertaken in Kenya. Since the inception of TRDA it has been apparent that the development potential of the Tana River is severely constrained by the seasonal nature of its flow pattern. The hydrology is bimodal, with two shortish flood seasons a year and two rather long dry periods. It is the dry season flows that ultimately limit the development potential on an unregulated river. At present Kamburu is the only significant reservoir on the river. However its useful storage is only equivalent to about 2 weeks mean flow, and consequently its value as a seasonal flow regulator is strictly limited. Therefore the present situation on the Tana could be summarized as follows:

1. Lack of water in the dry season precludes the planning of any new major irrigation development in either the upper or lower Tana catchments.
2. Development of needed public water supplies will only be possible at the expense of reduced hydropower production.
3. The further development of the hydroelectric power resources of the river is inhibited by a lack of security against drought conditions.

Overall concept

It is to overcome this virtual barrier to all further development that the Upper Reservoir Scheme is proposed. The reservoir will provide large-scale storage at the head of the hydropower reach of the river, thus making it possible to release water to increase the dry season flows through the hydropower stations and thence into the lower Tana for irrigation abstraction. Maintenance of these improved dry season flows in the middle and lower Tana is possible even with increased abstraction in the upper Tana, the apparent deficit being made good

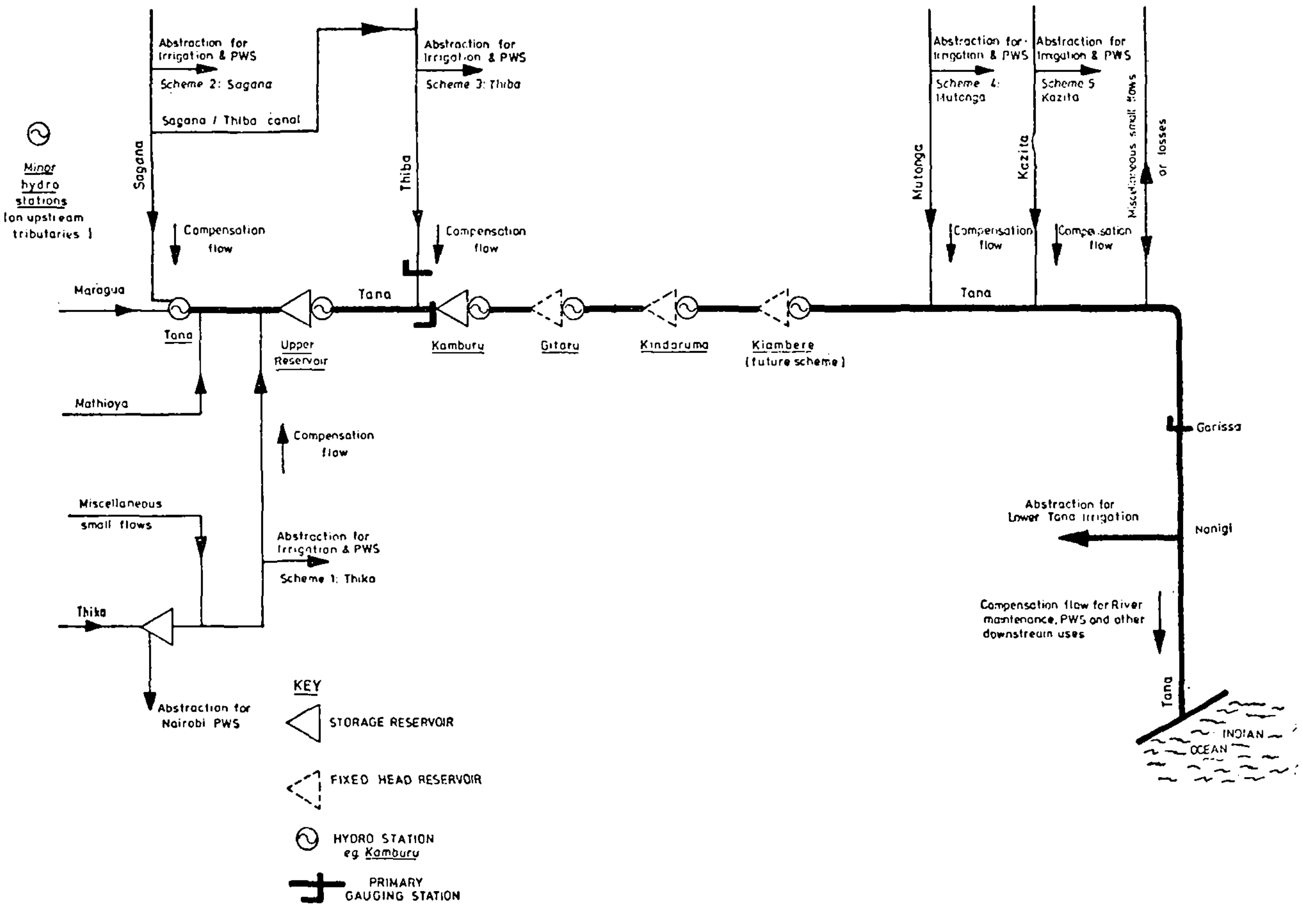

Figure 3. Schematic representation of the Tana River system.

by the impoundment in the upper reservoir of the previous flood season flow. The works comprise the construction of a major earthfill dam and ancillary structures, and also a hydropower station. Tenders for construction have recently been received, and it is anticipated that work on site will start early 1978 to be completed in 1981. Estimated cost is approximately US $150 million.

The upper reservoir will have a gross storage of 1 560 million m^3 which is equivalent to about 7 months of average river flow at the site. About 90% of this volume will be available as live storage. The reservoir will stretch back some 45 km westward along the main river valley, and in addition there will be a major branch formed by the valley of Thika tributary where the impounded waters will penetrate south for about 15 km. At full supply level the surface area will be 120 km^2.

The planning of the Upper Reservoir Scheme of the Tana River has been one of the major concerns of TRDA over the past 3 years, for a project of this size can be evaluated only by taking a total-basin approach to planning. In assessing the benefits of the scheme it has been necessary to consider in detail its impact on the major water-user sectors described above, and in this task the mathematical model has proved invaluable. When the upper reservoir is complete this same programme will be used to establish reservoir operating rules, on a year-by-year basis, to ensure optimal benefit taking into account the needs of all interested parties. The scheme is being undertaken by TRDA on behalf of the government. The works are being jointly funded by the governments of Kenya, Germany and Great Britain, and by the European Development Fund of the EEC. When completed the Upper Reservoir Scheme will be a major component in the water resources development of the Tana Basin and a significant contributor to the wealth of the country as a whole.

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IRRIGATION POLICY FOR KENYA

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Abstract
In Kenya, 80% of the country, where about 2 000 000 people live, receives an annual rainfall below 750 mm. In these arid or semi-arid areas, food is short and agricultural production can be improved, made regular or developed only by irrigation. All over the country, the maximum catchable run-off is 14×10^9 m^3 of water per year (5% of the rainfall). But the average water requirement for one hectare to be irrigated comes to the large quantity of 10 000 m^3 per year. Therefore, according to the available water resources, the maximum irrigable area in Kenya is 1 million ha, i.e. only 2% of the total area that would require irrigation.

Faced with this scarcity of water, irrigation, which is the human activity most consumptive of water, must be brought in Kenya to a high standard of water efficiency. Existing traditional irrigation methods, resulting in a low water efficiency, must be improved and modern systems must be developed, especially water conveyance through lined canals and pressurized pipes, and sprinkler and drip irrigation. Compared to surface irrigation with unlined canals without storage, the same amount of water can irrigate three times as much area under sprinkler irrigation and five times under drip irrigation. And with drip irrigation, water of relatively high salinity can be used to produce good crops.

IRRIGATION DEVELOPMENT IN THE TANA BASIN

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Abstract
The drainage basin is a convenient physical unit within which water can be planned. In the Tana Basin, attempts are being made to allocate the scarce water resources among community water supply, irrigation and hydropower. Irrigation development in the Tana Basin aims at achieving the following objectives: raising productivity of existing rain-fed agriculture, bringing arid lands into production, creating employment opportunities and redressing economic imbalances among regions and communities within the country.

Without regulation, the Tana River can irrigate the existing 21 300 ha plus a further 6 600 ha in the upper basin without affecting hydropower generation. Below the hydropower reach, irrigation of 14 500 ha is possible. With installation of the Upper Reservoir, an additional 21 800 ha in the upper and 23 000 in the lower Tana can be irrigated. Irrigation development is, however, constrained by a number of factors. Physical factors such as soils, topography and proximity to a source of river water determined the sizc of irrigable area. Land tenure systems influence the pace as well as institutional framework for irrigation development. Since irrigation projects are expensive in terms of capital and skilled manpower, a real choice exists between improving rain-fed agriculture or developing irrigation. This may partly explain why irrigation development in the Tana Basin is often seen in terms of external aid.

Introduction
The drainage basin is a convenient physical unit within which the size of the water resource can be estimated and allocated among competing use sectors, namely public water supply, hydropower generation, irrigation, wildlife and perhaps navigation. The planning exercise within the Tana Basin aims at assigning the level as well as pace of these water-based developments in a way that reflects the high opportunity cost of Tana water to the economy as a whole. C. R. Head (1978) has indicated how the Tana River Development Authority seeks to resolve demand conflicts arising from the three major use sectors. The aim of this paper, therefore, is to give an overview of irrigation development potential and prospects within the Tana River Basin. At the outset, let me point out that out of the 10 million ha within the basin, only a maximum of 2% is considered irrigable. The rest is excluded on grounds of broken topography or unsuitable soils.

The case for irrigation

More than 70% of the basin population resides in less than 15% of the basin area where rain-fed agriculture is feasible. However with increasing demographic pressure in the wetter areas, there has been inevitable population overspill into the low potential, ecologically fragile zones. By regarding water as an essential crop input (alongside fertilizers, crop protectants, etc.), irrigation development in the Tana Basin aims at achieving the following:

1. Raising the productivity of existing agricultural land by supplying irrigation water during the months when rain is inadequate. The crop yields are not only increased, but the growing cycle is more often shortened. Hence crop output per unit area and time is enhanced.
2. Bringing unproductive land in the semi-arid areas of the basin into production by making water available in areas where rain cannot support agricultural production.
3. Creating employment opportunities by incorporating into the cropping programme high value, labour intensive irrigated crops.
4. Taking the benefits of economic growth to areas (more often rain-deficient zones) that are lagging behind the rest of the country.
5. Attempting a redistribution of economic benefits by making the poorest members of society (often found in marginal semi-arid areas) productive through provision of irrigation water and associated crop inputs.

Irrigation development strategy

Unregulated river

Without regulation, the Tana River is capable of irrigating the existing 21 300 ha and a further 6 600 ha in the upper catchment, without detrimental effects on hydropower generation. In the lower Tana, however, discharges downstream of the hydropower reach, plus contribution from the Mutonga and Kazita tributaries, permit irrigation of a maximum of only 14 500 ha.

Regulated river

The installation of the upper reservoir, however, will change all this. Irrigation opportunities will rise by a quantum of 21 800 ha in the upper catchment and by 23 000 ha in the lower Tana Basin, over and above what is possible with the unregulated river flow.

Phasing of irrigation development

Current irrigation plans envisage simultaneous irrigation development in the upper and lower Tana catchment, subject to the maxima set by the unregulated river flow. With the completion of the upper reservoir in 1981/82, development tempo will accelerate until by the turn of the century nearly all the irrigation opportunities arising from the reservoir will be exploited.

Factors that constrain irrigation development

Physical factors

The great diversity of soils, topography and climate at times makes it extremely difficult to get the right combination of conditions that permit irrigation development. Where irrigation water is readily available, the soils may be saline or alkaline or the microrelief too uneven. In other cases, the soils may be too permeable, indicating a need for adopting comparatively more sophisticated, if not more expensive, delivery methods. Where the land is flat and the soil has attractive physicochemical properties, irrigation water can only be commandeered at a forbidding price.

Land tenure and institutional factors

Much of the lower Tana Basin is either state or trust land. The government can therefore acquire it easily for development into irrigation schemes. Infrastructural services are, however, rudimentary and the cost of providing them substantially inflates the total project bill. In the upper basin, most of the land consists of smallholdings, held under individual title. While extinction of individual rights, through compulsory acquisition and payment of compensation, is technically possible this approach is politically undesirable. Irrigation development in this part of the basin will, therefore, entail superimposing an irrigation system on existing holding layouts and land rights. Where holding sizes are large, and for practical reasons, only a portion of the holding can be irrigated, the cost of supplying and administering irrigation water will be unnecessarily high. On the other hand, infrastructural services are normally present and relatively little cost and effort need be directed to this aspect. The lower Tana is amenable to large centrally organized projects. The upper catchment is not. Creating the right institutions to implement and manage irrigated agriculture on individually owned smallholdings is a problem that has yet to be resolved. The immediately planned 100 ha Kibirigwi Pilot Project, in the upper catchment, embracing 250 smallholders will perhaps provide guidelines regarding the appropriate institutional arrangements.

Capital and skilled manpower

Irrigation systems are perhaps the most expensive forms of agricultural development since they exact a comparatively heavy toll on the country's most scarce resources, capital and skilled personnel. At times, a real choice may have to be made between devoting these scarce resources to improving rain-fed agriculture or using them for creating costly irrigation projects. It is perhaps for this reason that irrigation development in the basin is always conceived within the framework of external aid and expatriate personnel.

Summary

I have given an outline of the irrigation component in the Tana Basin. With this form of agricultural development, there is always a time lag between plans and their implementation, between implementation and attainment of sustained production. I am convinced, however, that the waters of the Tana River will in the coming years play their role in contributing to the wealth and welfare of the rural people, either by making the existing cultivated land more productive or by bringing new land into agricultural use.

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THE SUPPLY OF WATER TO RURAL AREAS OF KENYA FOR DOMESTIC PURPOSES

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Abstract
At the present time the Rural Water Supply Programme with its goal of water for all by the year 2000, and the Self-Help Water Programme are largely run as a two separate entities. The paper argues that there is a need for proper coordination and amalgamation of the two in order to avoid wastage of scarce financial resources and bring the year 2000 goal closer to reality. A possible method of achieving this is put forward for consideration and adoption as a pilot study prior to making a final decision on the matter.

Introduction
Rural water supply schemes currently being implemented by the Water Department can be categorized by the two methods of approach adopted. In the first, the government's Rural Water Supply Programme, the contribution from the people of the area is generally minimal, whilst in the other, the Self-Help Water Supply Programme, the community's contribution is expected to be much greater. Both approaches are undergoing significant changes arising from the greatly increased scope and costs now being contemplated in single projects. Little real forward planning or consideration has until now been given to the likely consequences of these changes, either to the need for a redefining of the goals or (to date) to the possible advantages of coordination or amalgamation of the two approach methods.

Background
The first Rural Water Supply Programme (RWS 1) commenced in 1970, being funded jointly by Kenya and by the Swedish aid organization, SIDA. Prior to the introduction of this programme, rural water supply schemes were generally small in size and basic in concept and design. These point schemes can be categorized as local authority water supplies, WHO/UNICEF water supplies and self-help water projects. They numbered some 1 640 in 1972.

At present, a significant proportion no longer function, particularly those that relied on pumping By the early 1970s local authority and WHO/UNICEF involvement in new design and construction had been largely phased out and replaced by the RWS programmes controlled by the Water Department. The scope of the initial proposals for the RWS programme and the ongoing self-help programme differed depending upon the part of the country involved. It may be helpful to categorize them into two regions, 1 and 2. Region 1 consists of the more populated, generally humid areas of Western and Nyanza Provinces, parts of the central rift area of Rift Valley Province, Central Province, western parts of Machakos, Embu and Meru districts in Eastern Province and the coastal and southern areas of Coast Province. In this region, self-help schemes were springing up to satisfy the needs of small communities, institutions, and similar 'point' needs. Treatment was rarely included. In these same areas, the RWS programme proposed to go a stage beyond this to encompass trading, market and rural centres and their immediate surrounding areas and to provide a potable water supply. Region 2 encompasses the rest of the country and in this region there was little self-help involvement in water supplies due to the scattered nature of the people, the nomadic nature of the way of life and subsistence levels of existence. In these areas the RWS programme was itself mainly concentrated on potable 'point' supplies to small communities and centres.

During the past 6 years, the situation in region 2 has not changed significantly except in the much greater distances now being considered for the conveyance of water to the small centres. However, in region 1, in the more populated, wealthier parts of the country, a very different water supply picture is rapidly emerging. Self-help projects, costing tens of millions of shillings and including treatment, are being put forward covering whole divisions. Such intensive large projects are also becoming the rule for the RWS programme and recently a project covering the major part of a district and costing millions of pounds has been actively promoted. If such projects go ahead, they will impose such a burden on the department's already overstretched operations and maintenance branch that the presently very restricted O & M involvement in self-help schemes directly controlled by the department must cease.

Any major development programme should be dovetailed into a master plan framework if uneconomic and inefficient solutions are to be avoided. The larger the individual development schemes in advance of such master planning, the greater the risk of introducing solutions that are later shown to be nationally undesirable and financially inefficient. As Kenya's national master water-plan studies are only just commencing, it is clearly inadvisable to embark on major projects that may later be shown to be inappropriate. Under these circumstances, to proceed along present lines and using present methods, it is argued, must lead to frustration with consequent waste of time, effort and finance.

Operation and maintenance

The problems being faced by the operations branch have been dealt with in a recent paper and so will just be summarized here (Farrant 1976). They arise from lack of permanent skilled manpower at all levels, both technical and professional, and a shortfall in finance compounded by inadequacy of revenue tariffs and unsuitable, inefficient methods of revenue collection and control. Whilst it is to be hoped that workable solutions to alleviate these problems will be instituted, it is likely that at best deterioration can be halted followed by a very gradual improvement. It is therefore of great importance that the situation is not aggravated by the construction of projects that are ill-conceived, inappropriately designed or poorly constructed.

Impact of the RWS programme and human motivation and involvement

Notable features lacking in the RWS programme to date are any sustained attempts to motivate or involve the people, the recipients of the scheme, in the planning, design or construction states; to identify the real social needs and constraints present in rural Kenyan society; to determine the best groupings for water supply systems; and to educate the people, particularly the women, in the responsibilities that go with receiving a piped potable water supply. Instead, technically feasible, possibly alien solutions have been imposed by engineers, generally non-indigenous, who, unable to identify with the people they are supplying, proceed on the assumption that the people's response will be that experienced in the rural areas of industrially advanced nations. The shortcomings of such an approach are now being realized and efforts are underway to try to rectify the situation (Saunder and Warford 1976). These commenced approximately in 1975 with the employment of engineering consultants to evaluate the Rural Water Programme during its first 6 years. In addition to the engineers and economists employed on this evaluation, a consultant social anthropologist was seconded to the team at the request of the Water Department. The report produced made very clear the total lack of appreciation of any health benefits of such supplies, and that the decision of whether or not to leave the traditional source for the new supply was one of convenience only. Another consequence of the study has been the embarkation upon a major rehabilitation programme for both RWS schemes, the older county councils and WHO/UNICEF water supplies. (See IDRC 1975; Mbithi 1976.)

Financial contribution and community enthusiasm

It is frequently noted in rural water supply literature that the probability of project failure is much greater in cases where the recipient village is not outwardly enthusiastic about the project. No matter how badly (in the opinion of an external appraiser) a village needs a better water supply system, if the population itself does not perceive the value of the system, the usage rate will be low, system maintenance and local administration will be inadequate, and vandalism could be a problem. After a study of the available relevant literature, and drawing on the author's own experience in three self-help projects (two domestic water supply and one irrigation) in Uganda together with several government-funded rural water supply projects constructed in Uganda between 1969 and 1972, a change in methodology is proposed for project testing.

Proposed methodology

From the foregoing, the problem is considered to be twofold. There are, first, the constraints imposed by beliefs and behavioural patterns of the scheme recipients, and second, those imposed by financial considerations and skilled manpower shortfalls in operation and maintenance. Dealing first with the problem facing operation and maintenance, the technical constraints, the single biggest problem is pumping—the difficulty of training a person or persons from the locality in the correct operational procedures, together with the cost of producing power, and the maintenance of the pump and motor. Secondly, there is the problem of efficient treatment plant operation and, in particular, the more complex control operations and the testing of quality and for residuals. With the present relatively high time preference discount rates prevailing, least cost technical solutions favour a low intital investment–high running cost solution, rather than a high initial investment–low running cost solution. This leads to a preference for a pumped supply with short trunk main, rather than a gravity supply requiring a long trunk main. To cater for this in the decision-making process, taking into account the operation and maintenance situation as described, requires a socioeconomic analysis rather than a financial analysis. This is best achieved by recourse to shadow pricing, possibly using a shadow discount rate. As neither criterion has been computed for the civil engineering sector in Kenya, other temporary alternatives must be utilized. Weighting factors and balancing discount rates have both been considered, and the latter is preferred as it is not as sensitive to total project costs as are weighting factors.

The problem with either method is that the initial decision on the various acceptable values to favour the lower running cost solution are necessarily value judgements. However, provided the schedule of decision-making values is drawn up on a consensus of informed technical opinion, the decision-making processes become both realistic and consistent. The use of such a decision-making technique will result in a reduction of the total number of projects undertaken for a given amount of capital finance. It is however more desirable to have three successfully run water supply schemes rather than four of which one is operational, one totally non-functional and the remainder run on an intermittent basis. Such a selection procedure by no means rules out pump alternatives but will reduce their number, especially in remoter areas, when alternatives exist. The second part of the problem of technical origin, the treatment works, still remains, although investigations into 'simpler-to-operate' treatment processes, such as slow sand filters, upward flow filters, and self-contained package units, possibly maintained under maintenance contracts, are being undertaken. Also under review is the provision of off-river raw water storage by damming a nearby main river tributary to reduce the need for chemical coagulation prior to sedimentation and to be able to avoid abstraction of high sediment loads during flood flows. Finally, the whole question of how far the emphasis should be on quality as against quantity is being reconsidered. Where treatment has been provided so far the intention has been to provide whenever possible potable water supply to WHO standards. However, to supply limited quantities of a high-quality product via communal water points with a high risk of repollution during transfer to individual households is of doubtful value.

A problem of major significance is however that involving the preferences and attitudes of the rural population of Kenya. The author, through his own experiences, the available literature and discussion with a social anthropologist, would postulate the following proposals. They are especially relevant when considering larger schemes supplying water over one or more locations and less appropriate for the 'point' water supply schemes in region 2. Such schemes in region 1 should not be categorized as either RWS or self-help but should rather provide for both government inputs and local efforts on a *harambee* basis. At the same time the combination of the two inputs needs to be carefully planned so that the self-help input of labour is separate from and follows on after the completion of the basic supply system installed by the contractor or departmental labour. The intention should be that upon completion of the self-help section of the project, water is immediately available to the self-help group concerned:

A self-help labour input that is not seen to be directly productive is far more difficult to organize. A further problem, already apparent, is the placing of the communal water point in such schemes. Whilst there is no evidence that the response to a part-individual, part-communal water-point supply will evoke the type of response indicated elsewhere there is also no evidence to support the belief that the rural womenfolk in East Africa enjoy social gatherings around the communal water point. Indeed a preference for private family sources, even when collecting from a naturally occurring water source, is apparent (White, Bradley and White 1972). Finally, there is a problem in that since the people in the upper parts of a large scheme do not readily identify with the people often many kilometres away, they act in a selfish way even when they are able to appreciate that the consequence of their actions is lack of water for others. Whilst the charging of a water rate based on quantity consumed and marginal cost pricing would probably provide a solution, such a pricing system would not only be repugnant to the rural consumer who often considers water to be a gift of God, but is also beyond the ability of most supply authorities to enforce even in urban societies of developed countries. Bearing these points in mind, the following is suggested:

1. The government's RWS programme would be responsible for the design of the entire scheme and for the construction of a bulk supply system consisting of offtake, raw water gravity main and/or a pumping station or stations and pumping main, treatment work, a primary balancing contact-storage tank, the primary bulk supply distributary system and draw-off balancing tanks.

Commodity aid of the type currently being offered by the Netherlands could usefully assist here.

2. Self-help involvement would be for community or group reticulation systems that would start from the appropriate draw-off balancing tank.
3. There would, however, be involvement by the people from the conception of the scheme, to make them aware of what was proposed and to indicate the need for and areas of their direct participation. Their advice and suggestions should be actively sought to help them identify with and support the proposed scheme.
4. The initial problem of such a procedure, namely the identification of the self-help group or community that could be expected to come together as a unit and work together, could be overcome by consideration of:
   a) Natural geographic boundaries,
   b) Traditional boundaries,
   c) Administrative boundaries, and
   d) Calling local meetings.
5. Having identified and then enumerated the population of each community group, the bulk supply main alignment would be planned, as far as practicable, to pass nearby or through the highest parts of each community areas.
6. The community's draw-off balancing tank would be located so that the whole of the community group could receive a reticulated supply by gravity, and the tank size would be sufficient to balance out the fluctuations in demand throughout the day from a constant or average inflow from the bulk supply main thereby ensuring that each community would receive its designated quantity of water.
7. To prevent excessive abstraction by any one community each balancing tank would be fed from the bulk supply main via an adjustable flow restriction device set to pass no more than the design flow for the community supplied. Each tank inlet would be fitted with a ball valve and each tank outlet with a sluice valve. In this way not only would a fair apportionment of water between the various communities be achieved but the size of the bulk supply main would need to be only slightly in excess of that required for average flow, say 1.25 times instead of 2 to 3 times, as with many of the present systems.
8. Thus the additional financial cost of a number of balancing tanks would be largely offset by the reduction in pipe costs, and, using shadow prices, could well prove to be economically cheaper, as balancing capacity could be constructed as required and not many years in advance as is the case when it is incorporated into the buried pipeline.
9. As far as possible, no individual connections would be provided off the bulk supply main. Where they were unavoidable, because of special circumstances of location or for institutional supplies, they would be allowed only for an

internal building supply, would be metered, and would require an individual balancing tank.

10. Self-help involvement on a community basis would commence at the point of the community draw-off balancing tank outlet sluice valve.
11. Communities would be assessed on their ability and willingness to meet the costs of their reticulation system. The richer communities would be expected to contribute sufficient cash for the purchase of all reticulation pipes and fittings and to supply labour for installation under artisan supervision provided by the department.
12. The medium income and poorer communities would be expected to contribute only a portion of the necessary capital together with all unskilled labour inputs. Such groups would receive the balance of capital required for material purchase via the EEC microproject scheme or similar aid financing. The EEC scheme enables up to 50% of the cash input to be met by the EEC up to a present maximum of 750,000/- per project provided that the community can provide up to 30% of the input required in a combination of cash and labour.
13. Individual connections and/or communal water points would be a community decision. All communal water points would be fitted with Fordilla or similar control taps that require the operation of the tap handle or button in a downward movement to release a preset volume of water. Such taps should also be considered for schools and other institutions. It would, of course, be necessary to educate the people in the method of operation of such taps prior to inauguration of the scheme.
14. Excessive abstraction by a few members of a community supplied in this way would result in an insufficiency only within the community who would be expected to impose their own penalties on the greedy few, or otherwise resolve the problem by collective decision. Alternatively, Fordilla type taps could be fitted to all individual connections.
15. Each community group would be charged on the basis of the water consumed by the community as recorded at the metered inlet to the draw-off balancing tank, the charge being spread uniformly throughout the community or on a two-tier system with one charge for individual connections and another lower rate for those using communal water points. Collection could be annually after the harvest with the responsibility given to a person or persons selected by the community.
16. In instances where one or more communities within a supply area could not be provided with a gravity supply from the primary balancing tank a booster pump would be unavoidable and would be the department's responsibility. The most likely location of such a community would be at the upper end of a supply system. The booster pump would therefore probably be located at the primary balancing tank and would pump water via a trunk main to the communities balancing tank located above the

community so as to supply the community by gravity from their balancing tank.

17. In the rare instances where a hill community further down the supply area needed a boosted supply, an initial draw-off balancing tank would be required at the bulk supply main and a secondary balancing tank above the community again interconnected by an untapped trunk main.
18. Whilst manual starting of the booster pumps would be needed, each pump should be fitted with a low and high pressure cut-out—the former in case of rising main burst, and the latter for ball-valve closure at the upper balancing tank.

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CONTROL OF SOIL EROSION IN RURAL AREAS OF TANZANIA

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Abstract
The soil erosion problem in various parts of Tanzania is discussed. Factors that affect the source of eroded soil are enumerated, stating therein the different types of erosion. Steps to be taken to alleviate the problem are outlined. Research needs on the subject, both in data collection and in the development of mathematical models, are highlighted.

Introduction
Soil erosion is a complementary process of sedimentation, both involving a complex interrelationship of multiple factors influencing the detachment, transportation and deposition of soil particles. The erosion process noımally begins when raindrops strike the surface of the soil and soil particles detach themselves from the rest of the mass by the explosive character of the impact. Detachment by runoff primarily occurs when the flow concentrates and exceeds the critical tractive force for the existing soil condition, which can be obtained from Lane's (1953) diagram, connecting the critical tractive stress to the mean diameter, d_{50} mm, of the particle. Unless the soil surface is protected by vegetation and mulch, these raindrops can detach tremendous quantities of soil for transport by splash or run-off. Further, the detachment and splash transport capabilities of concentrated run-off increase downslope, as the flow acquires greater mass and velocity, cohesive soils getting more easily transported than detached by rill flow. Rill erosion is literally sheet erosion and it implies the non-sheet locational selective removal caused by run-off detachment. The soil thus eroded is the source of much of the sediment transported to rivers and reservoirs, which was once considered primarily as the farmer's problem, in view of its decreasing the potential productivity of cropland. The problem is now recognized by the soil conservationists, the irrigation engineers, the ecologists and the town planners alike, as it engulfs their interests in their respective fields of operation. Eroded soil incidentally is the nation's largest pollutant of surface waters. To have an understanding of the gravity of the situation (Meyer 1971), it may be cited that a loss of only 0.1 inch of soil over an area of 1.60 km^2 amounts to more than 1 000 tons of deposited sediment. Although the above loss works out to be under 2 tons/acre, erosion of many times this rate frequently occurs

from cropland that is not properly managed and rates a few hundred times this quantity may occur from long bare slopes, such as new construction sites.

Historical perspective of soil erosion in Tanzania

The importance of soil conservation in Tanzania has been recognized even at the beginning of the century (Berry and Townshend 1973), in the dry savannah forests and due to nomadic grazing of the Maasai and Mangati. Since the 1930s, one of the major interests of the government has been soil erosion, which was by then gaining prominence in international scientific circles. The two main problems had been the overcrowded mountainous areas and the overstocked pastoral areas in the plains. By the early 1940s, the country was witnessing continued expansion of soil conservation measures in the regions of Dodoma, Singida, and Shinyanga, where the problem was acutely felt. Although in the 1960s the soil scientists of the ministry highlighted the need to conserve soil and train the technical staff to implement the schemes, the problem was not viewed in its right perspective and there was a lag in the implementation programme. However, with the Arusha Declaration of 1967 and the implementation of the *ujamaa* concept, the intensive utilization of rural areas for the settlement of expanding populations and the increased production of food and timber, forming a part of the 'self-reliance' programme, have made it necessary for the authorities to have a new outlook on the problem of soil erosion and the need to implement effective conservation measures.

Erosion problem in various parts of Tanzania

There is no uniformity of opinion amongst officials and scientists concerning the severity, importance and economic consequences of soil erosion in Tanzania. It partly reflects the lack of reliable quantitative data on erosion and sedimentation. Regular quantitative data collection was undertaken in Tanganyika (mainland Tanzania) in 1933 at Mpwapwa and continued over 5 years. The too few and limited recordings could not throw much light on the problem, even under limited conditions. Temple (1972) gave a history of conservation policy and practice in the Uluguru Mountains, selected for the representativeness of the area's largely deforested mountainous area. While discussing the above, Fleming (1974) cites an example of erosion by landslides, mud flows and mass movements, from the Mgeta area of western Uluguru Mountains, wherein a single storm over an area of 20 km^2 caused an estimated 0.27 million m^3 of soil to erode by landslide activity in a 1-hour period, and compares this loss to an estimated 10 000 m^3 of soil due to sheetwash over a period of 4 years. Prior to these occurrences, soil erosion by landslides was not mentioned as a menace, perhaps because of the lack of thoroughness or due to these having been attributed as terminal phase of man-induced accelerated erosion. The original capacity of Kisongo reservoir in the Arusha region in 1960 was 121 000 m^3, but its capacity by 1971 had been reduced to 71 700 m^3, i.e. a reduction of

59.6% of original capacity. If this fast rate of sedimentation is maintained, the reservoir will have completely filled with sediments by 1983, although the increased capacity might possibly lead to decreased sedimentation rates, thereby slightly increasing the useful life of the reservoir.

The Department of Agriculture in its report on Luguru cultivators and their land use stated that they were destroying land due to inadequate fallowing practices, excessive burning and exposing cultivated soil on steep slopes to sheetwash. It is reported that the local people are endeavouring to produce crops on clayey subsoil underlying a surface layer of 2 to 3 inches of immature surface soil. It is further claimed that large areas of abandoned land, not recovered even after 40 years, were common, as per Savile's (1960) statement. In the Imagi catchment of the Dodoma region, sheetwash dominates; 14.6% of the catchment is subject to severe sheet erosion and 9.2% suffers from combined sheet and gully erosion, as per 1960 estimates. Originally, the dam on Imagi was to supply 136 000 m^3 of water to Dodoma town every year. Some conservation measures were taken up in the catchment, including sand traps to arrest reservoir sedimentation which to some extent arrest rapid deterioration of the capacity of the reservoir.

Suspended sediment concentration/discharge relationship or rating curve has been used in many studies to characterize the suspended sediment production within the drainage basin, in its natural state. Despite the limitations of the rating plot and its characterization of the response of the catchment under natural conditions, an attempt made by the author and Masawe (1977) on the Great Ruaha River at Mtera to obtain the cumulative annual values of water and sediment discharges versus days in a year expressed as per cent of total revealed that 50% of the total annual sediment transport took place as per 1960 data in 9% of the total time, i.e. in about 32 days, and the same amount during 1959 and 1957 was carried in 15% and 22% of the time, i.e. in 54 and 80 days respectively. The study indicates that as time progresses, more sediment is flowing in fewer days. Further, the plot between annual sediment yield (mm) versus annual precipitation (mm) revealed that the rate of erosion is highest (3.5 mm) over the drainage basin for a mean annual rainfall of 350 mm. The annual sediment production over a given drainage basin is however dependent on such variables as climate, soil type, land use, and topography, apart from the mean annual precipitation over the basin.

The above are but a few examples of the erosion and sediment problems in the country. Steps are being taken to tackle the problem in view of the increasing understanding of the same, both by locally educating the people as well as by the measures taken by the ministries concerned.

Factors affecting soil erosion

It should be noted that various factors and combinations of them contribute to the eroded soil on a given drainage basin. The slope steepness, length and shape, effects of rilling, rainfall intensity, infiltration capacity, soil detachability and soil transportability are but some of the influencing factors which deserve careful study. While nominal steepness of a sloping area is commonly used in the universal soil loss equation, where macroslope of upland areas is taken into consideration, several microslope influences, such as relief between crops rows, meandering of rills, and flow channels, also have their part to play. The universal soil-loss equation is expressed as:

$A = RKLSCP$, where
$A =$ computed soil loss per unit area,
$R =$ rainfall factor,
$K =$ soil-erodibility factor,
$L =$ slope-length factor,
$S =$ slope-steepness factor,
$C =$ cropping management factor, and
$P =$ erosion control practice factor.

Soil loss A per unit area is expressed either as an exponent of steepness (range 1.2–1.6) or as a quadratic in S of the type $A = a + b$, $S = cS^2$. The rainfall factor accounts for differences in rainfall intensity–duration frequency for different locations. The soil-erodibility factor K is a measure of intrinsic susceptibility of a given soil to soil erosion and is expressed as erosion rate per unit of erosion index for a specific soil, the value of K varying from 0.7 for highly erodible loams to less than 0.1 for sandy or gravelly soils. The crop management factor C varies for an individual crop with the stage of crop growth, which for maize may be 63% during its first month after seeding and only 26% as it approaches maturity. The erosion control practice factor P accounts for the effect of conservation practices such as contouring, strip cropping and terracing. While contouring reduces erosiveness of runoff by channelling it around the slope instead of allowing it to flow directly downslope, strip cropping with alternate grain and meadow strips has a P factor half that of contouring alone. Terracing, however, is the most effective conservation practice for decreasing soil erosion wherein the downslope runoff is intercepted which in turn effectively decreases the L factor by subdividing the slope.

Remedial measures to combat soil erosion

Activities affecting soil erosion in rural areas include deforestation to clear land for agricultural use, overgrazing and unsuitable cropping practices. Unplanned drainage and uncontrolled forest fires also contribute to soil erosion; unless the land management planners adopt necessary design criteria to control soil erosion, soil losses would take unlimited propoıtions. Conservation techniques to be adopted in a country should take into account social, economic and political impact on natural sediment processes. The feasibility of implementation of the methods should be viewed, in the light of the acceptance of the methods by the country's farmers and peasants. Some of the methods may fail, if they do not meet the legitimate interests of the people in particular and the country in general. Remedial measures should take into account the tolerable level of soil loss from land, quantity of solids acceptable in streams, physical, chemical and biological quality of eroded sediments. An understanding of the source of the eroded soil over sloping areas shall provide sufficient clues for the prevention of excessive losses at all points. Downstream sediment loads can be kept within acceptable limits by adopting practices that encourage deposition of soil eroded from upland areas, extent of deposition depending upon the sediment sources. Sediment's pollution potential with reference to chemical and biological pollutants is worthy of intensive study, as organic and inorganic amorphous constituents of the colloidal clays are carriers of soil-borne pollutants and nutrients. If these pollutants are concentrated at the soil surface, the raindrop impact will be more in dislodging the fine sediment. Plant canopies, plant residues and other surface mulches are very effective in minimizing the raindrop impact.

Research on erosion control

Recent research has helped in the better understanding of the subject as concerns the effect of rilling slope length, slope steepness, surface cover, rainfall intensity, infiltration capacity and the like on the sediment detachment and transport. Both experimental and analytical research on soil erosion have proved valuable in controlling the cost of conservation schemes. Analytical studies have revealed that slope shape (convex or concave) greatly affects the sediment yields from a sloping surface. For example, a concave shape produces less sediment than a uniform slope, as deposition occurs as the slope flattens and velocity reduces. Such equations as the universal soil loss equation, together with relevant data, have provided a useful mathematical tool for soil and water conservation research. Development of mathematical models has been promising and is affording greater precision in soil erosion studies.

Conclusion

1. Soil erosion, being a complex phenomenon involving many variables, needs intensive study, so as to understand the mechanics of detachment, transport and deposition of sediment.
2. The rural areas need particular attention in view of the recent trend in intensive utilization of such areas for settlement of expanding population in developing countries.
3. The conservation technique should be in conformity with the sociopolitical and economic goals of the country.
4. Both experimental and analytical approaches to the problem should be undertaken to expedite effective implementation of soil conservation practices.

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HYDROLOGICAL DESIGN STUDIES ON THE SINZA RIVER PROJECT AT UBUNGO, TANZANIA. PART 2: OPEN CHANNEL COMPUTATIONS

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Abstract
The Sinza River Project at Ubungo, Tanzania, involves the preliminary hydrological studies and subsequent design studies for the low-level dam, weir and spillway. This paper describes the open channel computations necessary to specify the inverts and major dimensions of the weir and spillway. Using backwater computations, water elevations and discharges through the weir and spillway have been determined.

Introduction

The Sinza River is a tributary of the Msimbazi River system which drains into the ocean in the vicinity of Dar es Salaam. At Ubungo, to the west of Dar es Salaam, a hydrological station was built on the Sinza River in the mid 1960s. During the rainy season of 1975, torrential floods completely washed away the existing low-level dam and measuring weir. Afterwards a survey of the area was taken and the staff at Ubungo Maji took geological drillings at the site of the proposed new weir. In addition the Hydrology Department did investigations to determine a design flood flow. A diversion spillway is being planned so that any future measuring weir will not be washed away by flooding.

Since the site is very close to two training institutions (Water Resources Institute and Faculty of Engineering, University of Dar es Salaam), it is proposed not only to renovate the existing hydrological station, but also to make it a complete outdoor hydrological laboratory consisting of dam, weir, spillway, flow measuring devices, experimental pumps and hydraulic rams, boreholes and pumps, including perhaps a small irrigation plot. The whole area offers an excellent site for nearby practical applications of the subject matter that students are studying. The entire project is feasible and within our present capabilities. UNESCO has also expressed interest in supporting this project as part of the expansion of the Water Resources Institute.

A previous paper (Schiller 1976) described the studies that were made within the Hydrology Department to determine the design flood at the proposed new hydrological station. The aim of this paper is to continue these hydrological studies and thus to lay the foundation for the final design and construction of the proposed low-level dam and spillway. The main design parameters that will be determined are the following:

1. Elevations and major dimensions of the low-level dam and weir.
2. Elevations and size of the diversion spillway.
3. State-discharge curves for both weir and spillway.
4. Composite operating curves for the hydrological station.

With the completion of these studies the hydrological analysis will be complete and detailed design and construction plans for the dam and spillway can begin.

Outline of procedure

The problem can be briefly stated as follows: The river hydrograph indicates that during the rainy season the typical flow is within the range of 0 – 1 cumecs. It is proposed to design the low-level dam and weir to pass a specified low flow. However beyond this limiting V-notch discharge, most of the excess flow will be diverted through the spillway (figs. 1–2). In this way the greater portion of flood flows will be diverted by the spillway and the low-level dam and weir will be prevented from damage. Operational curves for the station will enable us to determine what proportions of the flows are diverted for any given intake flow. The detailed steps in achieving the above objectives are as follows:

1. The criterion for the distance of the weir invert above the river bottom (*a* in fig. 2) was that it should be at least equal to the head of water flowing over the weir (Henderson 1966, p. 178). A reasonable value of limiting weir flow can be chosen from past records (0–1.0 cumec) and thus the elevation of the water at the weir X_1 calculated for the limiting V-notch flow.
2. Backwater calculations can then determine the corresponding water elevation at the site of the spillway entrance Y_1. To compute the backwater curves, the standard step method was used. The energy equation yields the relationship

$$L = \frac{(V_1^2 - V_2^2)/2g + y_1 - y_2}{S - So}. \tag{1}$$

In our case y_2 and $V_2 = Q/A_2$ will be known. A value of y_1 will be assumed. and from predetermined curves the values of A_1, V_1 and R_1 can be calculated. Average values of the reach can then be calculated as follows:

$$< A > = \frac{A_1 + A_2}{2},$$

$$< R > = \frac{R_1 + R_2}{2}.$$

An average value of S can then be calculated from

$$S = \frac{n^2 \quad Q^2}{< A >^2 < R >^{4/3}}. \tag{2}$$

Substitution of the above values in equation 1 will yield a value of L. If the value is not correct the procedure must be repeated in a trial and error.

3. The natural elevation at the spillway entrance is 101.80. By excavation (fig. 2) the entrance to the spillway would be constructed equal to the elevation Y_1, corresponding to the water elevation for limiting V-notch flow conditions.

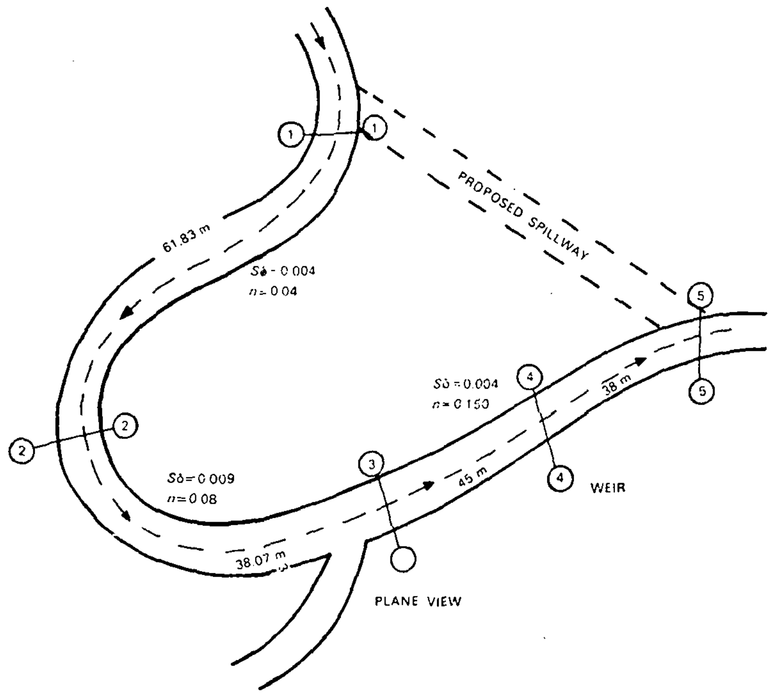

Figure 1. Project sketch.

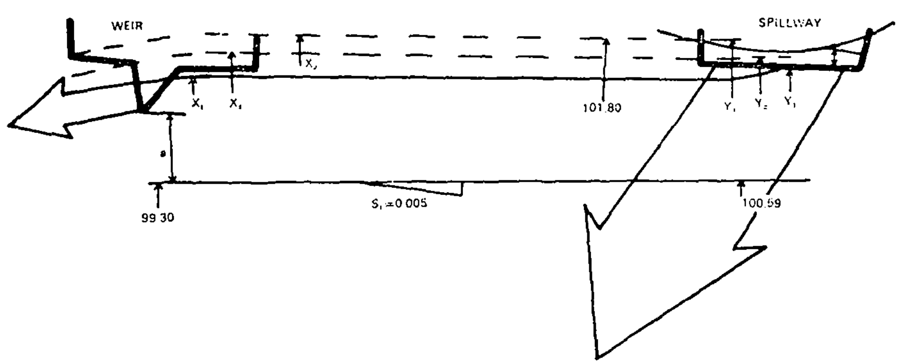

Figure 2. Longitudinal section.

4. The spillway will be designed to accommodate at least the 50-year flood. Using the criterion that for this flow through the spillway the head should be about 1 m, the width of the spillway can be determined. The relevant design equation here will be

$$Q = CLH^{3/2} \tag{3}$$

where $C \simeq 2.23$ for an approximate ogee-shaped spillway (metric units). The rectangular spillway entrance and ogee portion of the spillway will be cement lined. It is also envisaged that a smooth entrance will be built to deflect the flood flows into the spillway. A low-level sill across the riverbed may assist this and serve as a silt trap as well. It is anticipated that a stilling well and crest level gauge at the spillway will record the stage of the maximum flood.

5. It is anticipated that the weir portion of the low-level dam will consist of two portions. A 90° V-notch weir will accommodate the limiting V-notch weir flow. The governing equation for the V-notch weir will be

$$Q = 1.38\, H^{5/2} \tag{4}$$

where H = head in metres
Q = flow (cumecs).

A rectangular part of the weir will accommodate the excess flow that bypasses the spillway during the flood stage. The discharge through this portion will be given by:

$$Q = 2/3\, C_c\, (L - 0.2H)\sqrt{2g}\; H^{3/2} \tag{5}$$

where L = is the length of the weir and $C_c = 0.611$.
In the metric system of units equation 5 becomes

$$Q = 1.8\,(L - 0.2H)\; H^{3/2} \text{ cumecs.} \tag{6}$$

6. Knowing the stage-discharge relations for both weir and spillway, and using backwater computations from the weir to the spillway, it is possible to determine corresponding depths and flows at both weir and spillway.

Summary of results

1. A flow of 0.243 m^3/s was chosen as the limiting V-notch flow. For this flow, using eqn 4 the design head will be

$$H = \frac{(0\ 243)^{2/5}}{1.38} = 0.50 \text{ m.}$$

The invert of the weir was then situated 0.5 m above the riverbed, so that the depth at the weir cross-section was 1 m, with a water elevation of 100.80.

2. Backwater computations were then performed yielding the results shown in table 1.
3. The invert of the spillway should then be 0.25 m above the channel bottom which would be at an elevation of $100.59 + 0.25 = 100.84$ m. This would then require an excavation of $101.80 - 100.84 \simeq 0.96$ m (b) at the spillway entrance.

4. Using a design flood of 45 cumecs (Schiller 1976) and assuming a rectangular spillway with a design head of 1 m, eqn 3 gives a design length of

$$L = \frac{Q}{C \times H^{3/2}} = \frac{45}{2.23 \times 1^{3/2}} = 20 \text{ m}.$$

5. The width of the river cross-section at the proposed weir location is about 18 m (fig. 3). It was therefore decided to make the rectangular weir portion 16 m wide. A combined stage-discharge curve for the weir was constructed, using eqns 4 and 5 (fig. 4). Similarly, after the width of the spillway portion was determined its stage-discharge curve was plotted using eqn 3 (fig. 5).
6. It is necessary to relate the water elevations at the weir to the corresponding water elevations at the spillway entrance. This was achieved by successive backwater computations between the two cross-sections. The results of these computations are given in table 2.

   From this table, it can be seen that a reasonable height for the rectangular portion of the weir would be 0.6 m which would give reasonable freeboard (0.1 m) above the design flood (fig. 3). The temporary pond thus created would have only two outlets, the V-notch and rectangular weir and the

Table 1. Backwater depths

	Depth in metres
Section 4 (weir)	1.0
Section 3	0.82
Section 2	0.48
Section 1 (spillway)	0.25

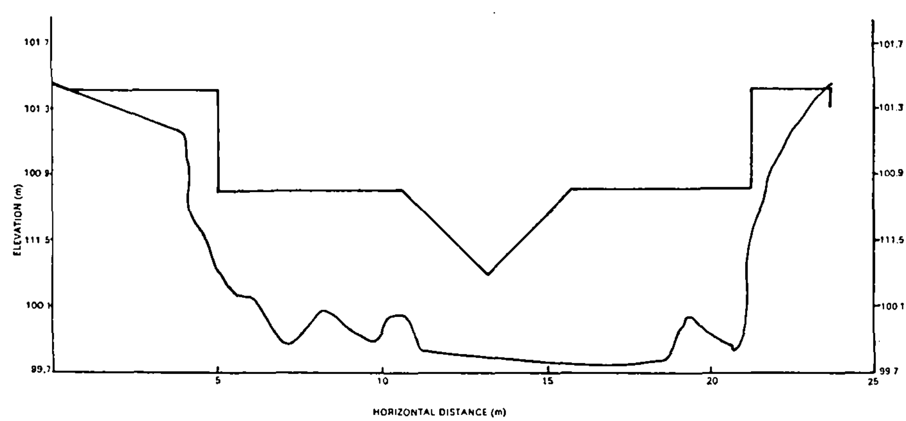

Figure 3. Cross-section of 4-4: weir location.

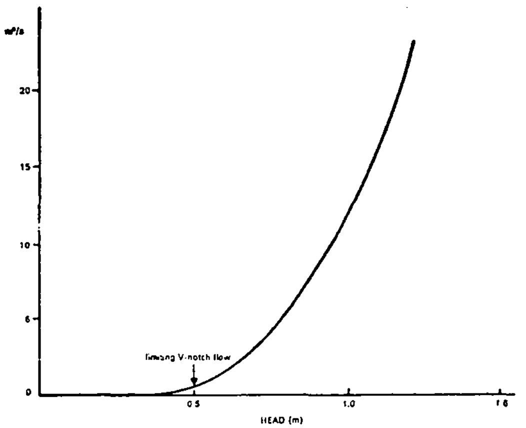

Figure 4. Stage-discharge curve for combined V-notch and rectangular weir.

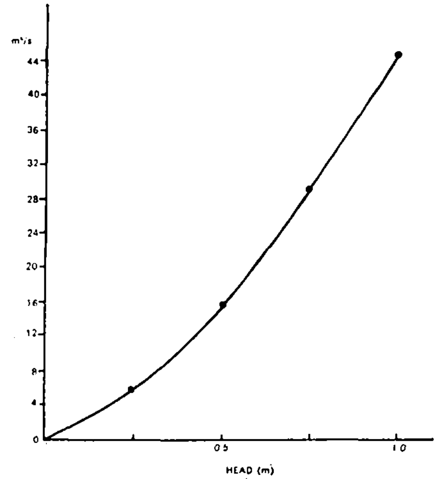

Figure 5. Stage discharge curve for rectangular spillway entrance.

Table 2. Corresponding water levels at weir and spillway

WEIR			SPILLWAY			TOTAL CHANNEL
Head (m)	Elevation (m)	Discharge (m^3/s)	Head (m)	Elevation (m)	Discharge (m^3/s)	Discharge (m^3/s)
0.50	100.80	0.24	0	100.84	0	0.24
0.75	101.05	3.83	0.6	101.44	20.73	24.56
1.0	101.30	10.36	1.0	101.84	44.60	54.96

spillway. The computed water surface profiles for the different flows, the corresponding elevations at weir and spillway entrances, and the corresponding discharges through weir and spillway as well as the total discharge entering the reach are plotted (figs. 6–8). The operating curves for the weir-spillway combination describe the proposed operating characteristics of the project over the entire expected range of flow conditions (figs. 7–8).

Discussion

As with all practical projects, the computations presented in this paper represent an idealization of the actual physical phenomenon. Approximations introduced in the computational procedure are the following:

1. The meandering effect on the river flow is omitted. Instead the reach was divided into approximately straight portions, and the backwater computations carried out step by step.
2. The simple standard step procedure was used in the backwater computations with an assumed velocity correction coefficient equal to unity. Plans are being made to check these computations by a computerized form of the more sophisticated Newton's iteration technique.

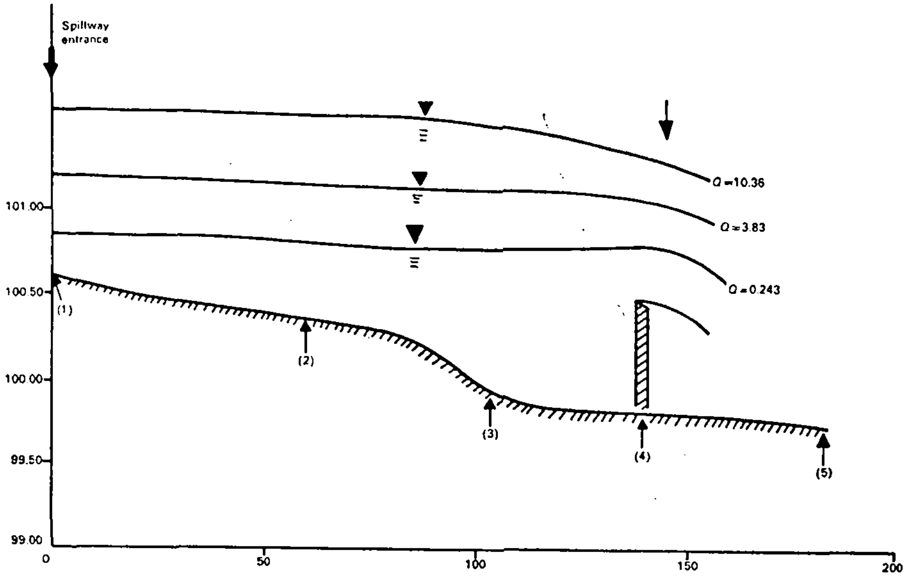

Figure 6. Computed water surface profiles.

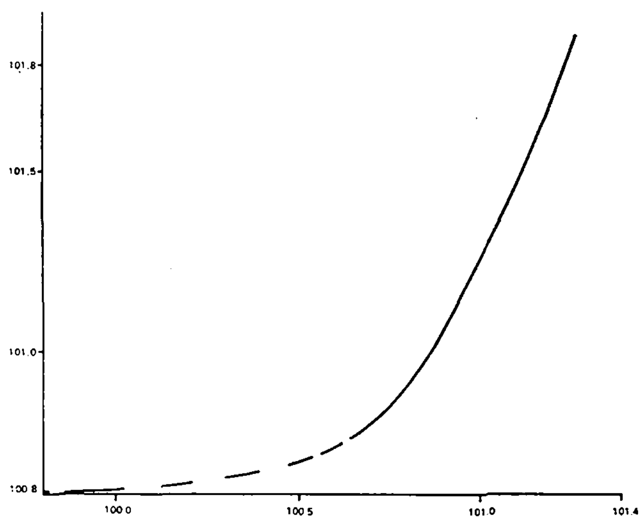

Figure 7. Corresponding water elevations at weir and spillway entrance.

3. The fact that there was a small tributary entering the reach was not specifically accounted for. This small tributary has a drainage area equal to about one-eighth of the total area. If it can be assumed that this tributary will contribute about one-eighth of the total flow, then most of its flow can be expected to pass over the V-notch weir. The backwater computations would still be approximately correct, but the incoming flow would be mainly diverted

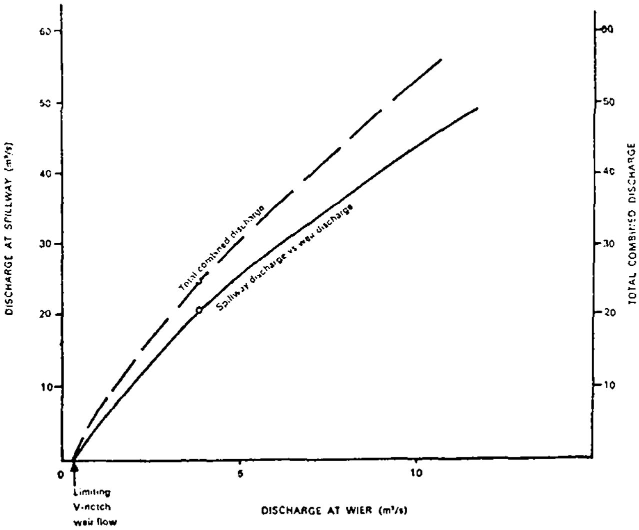

Figure 8. Corresponding discharges through weir and spillway.

through the spillway with only a small portion contributing to the downstream V-notch weir.

4. To gain more detailed information about the nature of the backwater curves the following modification could be made:
   a) Backwater curves can be computed for smaller increments of water elevation. This can be easily done with a computerized backwater computation procedure.
   b) Shorter reaches of river could be used. This would necessitate surveying additional river cross-sections.
5. The Mannings roughness coefficient for the three subsections was estimated from a knowledge of the physical characteristics of the river section. Complete flow information together with measurements of the water surface slope would make possible a more precise determination of the value of n.

Conclusions

The publication of this report marks the end of the hydrological investigations related to this project. The design flood and the basic parameters have been determined that will allow low flows to pass through the V-notch and rectangular weir and the major portion of larger flows to be diverted through a spillway. It is also strongly recommended that crest level gauges be installed at both the weir and the spillway so that peak flows can be recorded. The design parameters that have been determined are the following:

90° V-notch weir	
Invert elevation	100.30 m
Height	0.5 m

Rectangular weir portion	
Invert elevation	100.80 m
Width	16.0 m
Height	0.6 m
Spillway	
Invert elevation	100.84 m
Width	20.0 m
Height	1.0 m

Backwater calculations for a range of flows have provided the corresponding elevations and discharges for both the weir and spillway. Therefore not only design parameters but also operating characteristics for the scheme have been determined. What remains after this stage is the detailed design of the low-level dam and spillway. The data gathered from topographical and geological surveys at the site will be necessary for the next phase of work. These data are readily available. Following the completion of the detailed design, the final construction phase can begin. It is hoped that these last stages will soon be completed so that the proposed outdoor hydrological laboratory at Ubungo will soon become a reality.

Acknowledgements
Much of this work was conducted as a group project by the 3rd year hydrology students at the University of Dar es Salaam under the guidance of the author. The design flood studies were conducted by the graduating class of 1976, and the land surveys and open channel studies of the present report were conducted by the graduating class of 1977. All computations however have been checked by the author. One student, Mr. M. C. K. Msalali, adapted the computer programme of the Newton iteration technique for the Sinza River site. The author subsequently further revised the computer programme. The author also acknowledges the work done by another student, Mr. J. A. Ntupwa, who during his 4th term assignment coordinated the work of the staff from the Water Ministry at Ubungo. This group surveyed the area and produced a contour map.

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UNIT HYDROGRAPH DERIVATION FOR SMALL CATCHMENTS WITH SPECIAL REFERENCE TO KIZINGA BASIN

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Abstract
Methods of separation of recession limbs of surface and base flows from total hydrographs resulting from successive storms on small basins are discussed with special reference to Kizinga Basin of the Coast Region. The average daily rainfall over the basin is derived using the Thiessen polygon method, based on precipitation records from four stations. The effective rainfall is determined, after successfully separating the base flow component from total run-off. The unit hydrograph for the basin is determined based on data collected on three unit storms on the catchment.

IMPROVEMENT IN THE CAPACITY OF SETTLING TANKS FOR WATER AND WASTE WATER TREATMENT

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Abstract

Settling tanks are widely used all over the world to remove particulate matter suspended in the water. Their field of application includes water treatment, sewage treatment as well as certain industrial processes. These treatment units, which are of simple construction and are also easy to operate, are well suited to the conditions prevailing in the developing countries including the countries of East Africa. Furthermore, there is another advantage with them, and that is the great potential to increase their output by simple supplementary structures.

The increase in capacity can be 50% with a very simple arrangement and 4 or 5 times of the original capacity by fixing other still relatively simple structures. The paper reviews the presently known types of high rate settlers and how the existing settling tanks can be converted to suit to the high rate settling principles. Evaluation of the different high rate settling methods is also dealt with, and a recommendation is given as to which of the proposed alterations can be most beneficial in the different cases.

Introduction

From the second half of the last century, sedimentation as a method of removing particulate matter suspended in the water has been in wide use all over the world in the field of water and sewage treatment as well as in certain industrial processes. Sedimentation being of as great importance as it is, one cannot but wonder at seeing so many badly designed, ill-functioning and neglected settling tanks still in use everywhere in the developing countries; sometimes in the industrialized countries too. And yet the settling tanks described here are well suited to the conditions prevailing in the developing countries, including East Africa.

The main advantages of the use of settling tanks in developing countries are as follows:

1. Except when extremely large tanks are used, no mechanical equipment is involved.
2. The units are made mostly of relatively simple reinforced concrete construction.

3. Operation and maintenance of the tanks are relatively simple.

Adding to these advantages there are great possibilities of increasing the capacity of the already existing settling units according to the latest research findings on the subject. It is possible to achieve an increase of 50% with a very simple arrangement and a 4 or 5 times increase of the original capacity with other, still relatively simple supplementary structures.

Types of sedimentation tanks

There are several types of sedimentation tanks in use. The two basic ones are the fill-and-draw type, and the continuous flow type. Of these, only the continuous flow type is of great practical importance, as the fill-and-draw type is restricted to certain specific areas of the settlement of the water.

The main types of the continuous flow settling tanks are as follows:

1. Rectangular horizontal flow tank, which is the most widely used type in water and sewage treatment and also in industrial establishments.
2. Circular tank, used mainly in sewage treatment and by some industries.
3. Vertical flow tank, which again has two subtypes:
   a) Hopper bottom type, which is mostly used in water treatment, and as a humus (secondary settling) tank in sewage treatment.
   b) Flat bottom type, the use of which is restricted to water treatment.

Sketches of the different types are shown in figure 1.

Theoretical considerations

To understand the settling principles the best thing is to study the settling path of discrete solid particles in a rectangular horizontal flow basin. This gives a clue as to how to design effective settling tanks, and how to increase the capacity of existing ones. At first it was claimed that the governing factor in sedimentation is detention time, but this concept was proved to be wrong. It has been shown that efficiency of a settling tank depends upon surface area rather than detention time or flow velocity.

In fact it is easy to conceive that passing the same flow through a settling tank with half of the original depth (surface area remaining the same) doubles the flow velocity, yet only half of the vertical distance is there for the solid particle to fall and reach the bottom with the same settling velocity. Thus the particle (of the same size, etc.) will reach the end of the tank in half the time, but will as well strike the bottom in half the time (see fig. 2). This example demonstrates that though detention time was reduced and the flow velocity increased the efficiency remained the same, just as the surface area was kept unchanged. The above idea can also be used to explain the rising path of an oil globule, the only difference being that the direction of vertical movement is opposite to that in the previous case.

This concept, of course, is based on an ideal state of water and particulate matter, as follows:

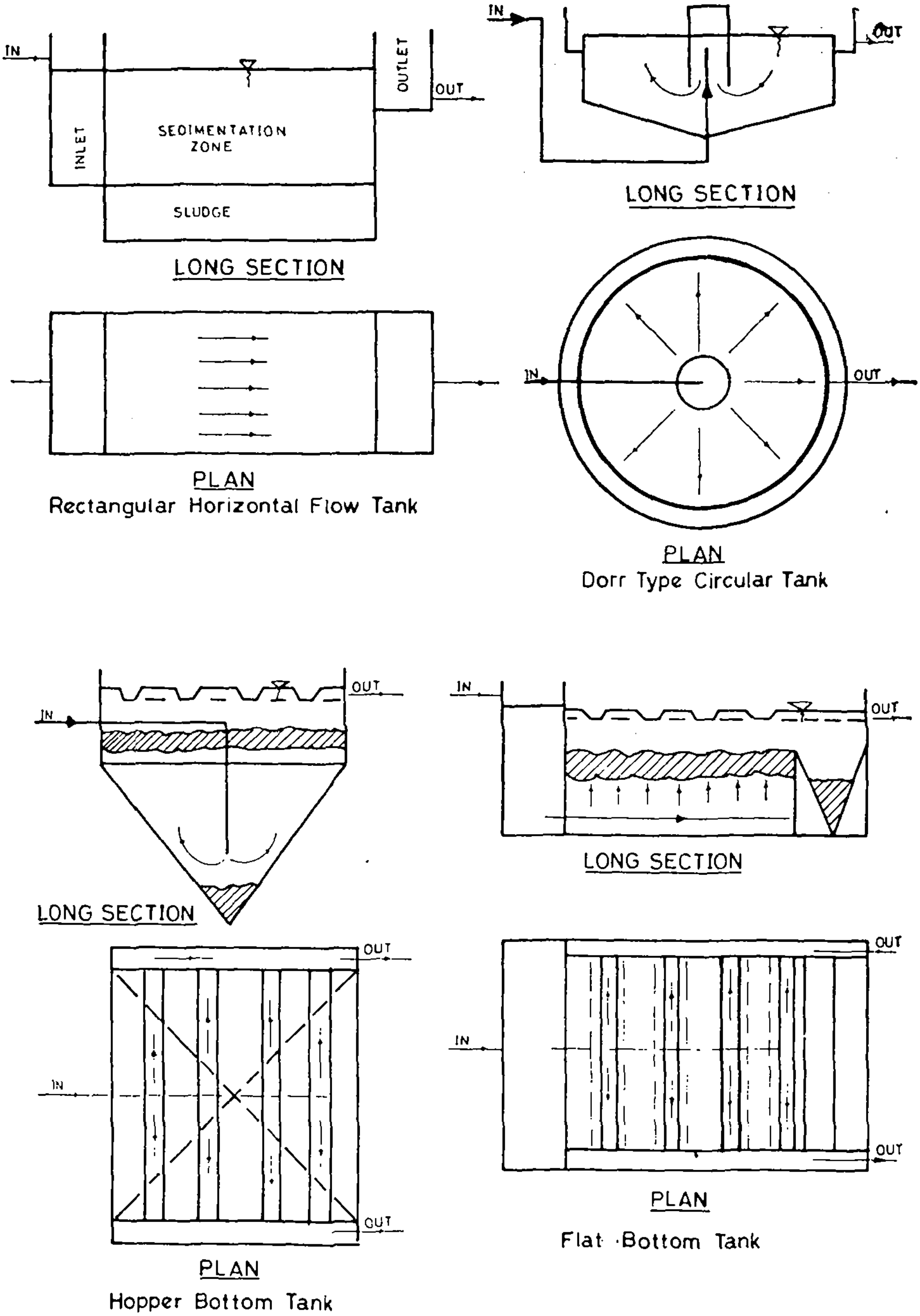

Figure 1. Different types of sedimentation tanks.

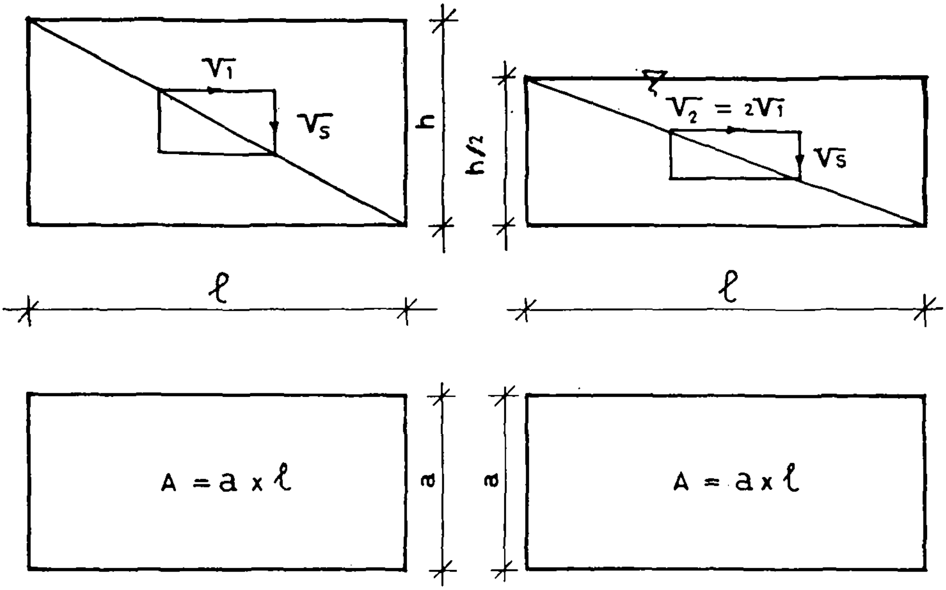

Figure 2. Settling at different water depths.

1. The flow does not exceed a limit at which particles once settled can be uplifted again. In fact the flow is laminar or close to that.
2. Distribution of water is such that all the tank (each small portion of the cross-sections) has the same load. Also there is neither turbulence nor density currents.
3. The particle concerned is a spherical discrete particle which will not agglomerate during settling, e.g. clean sand.

This is however not the case, and the process is far from an ideal one. So, while accepting that the basic factor behind sedimentation is the surface load we have to make provisions for the effects of other factors, for instance for the agglomeration of the particles due to coagulation. Hence, when making calculations to determine the size of a settling tank, we have to make sure that the surface load on the tank is not higher than the settling velocity of the smallest size particle we intend to remove, and further provision must be made for other effects, most of all for the agglomeration of particles.

Finding the settling velocity of a particle

There are mathematical formulae for computing the settling velocity of a particle of a given size, e.g. the Stokes's formula and Newton's formula, yet these formulae are based on an ideal state and are not of much use in the design practice. The approximate figures of settling velocity can be better acquired from textbooks.

The application of models to the settling phenomena

Modelling is quite common in solving the designing problems of many hydraulic structures. Flow under pressure in pipes and conduits, for example, can be well simulated in models, based on geometric similarity and on the same figure of Reynolds number. In this case even modelling by using air or gas instead of water is practised. But modelling the settling process which takes place in a settling tank is more complicated than the case mentioned above. Apart from hydraulic similarity, for which the Reynolds number is used, gravity forces also affect the settling. For these forces the Froude number, which refers to the stability of the flow, has to be taken into consideration. Still, if we consider the conditions of a good sludge blanket formation in a hopper bottom clarifier, we have to admit that the modelling of this particular problem is extremely complex, though not impossible.

Full-scale experiments

A great advantage with existing treatment plants is that the possibility of full-scale experiments is almost always granted. And of course full-scale experiments are the best to solve our technical problems. There is more than one unit in use at all the medium- or large-sized treatment plants and these are connected parallel, each having the same load which is a proportion of the total load. This system makes it possible to separate one of the identical units for full-scale experiments any time when there is doubt about the optimum solution to the alterations required. The reason why I insist on full-scale experiments is that the effect of the flocculation and the process of the agglomeration of the particles is hardly predictable today. This phenomenon, the agglomeration of particles, would require a greater height for the settling particles to let them collide during settling, and this is against our theory of the all-importance of the surface load. Hence the optimum solution to increase the capacity of existing tanks can best be achieved by full-scale experiments.

Proper inlet and outlet arrangements

Many of the existing settling tanks are working much below design capacity. More often than not the reason for this can be traced back to the inadequate or wrongly designed inlet and outlet arrangements. If this is the case, a decision should be made on how to alter the inlet and outlet structures to suit the modern principles of these simple hydraulics. Though these alterations do not result in the increase of design capacity, they do result in the increase of existing working capacity of the tanks. And in any case these alterations would have to be made before any further renovation of the tank would be considered. A common misconception in settling tanks and oil-water separators is the application of several vertical baffles crosswise to the flow direction. The purpose of these baffles should be to help in the settling process or in the floating up, but the effect is just the opposite. The more the baffles, the more local turbulence created, particles and oil globules which can be easily removed without baffles are just carried over and also these very baffles decrease the effective working capacity of the tank. Another problem with settling tanks, which contributes to the decrease in capacity and quality, is delay in desludging the tank. However, this problem can easily be overcome by more frequent cleaning of the tank, a task for which an unskilled labour force is always available in the countries of East Africa.

Providing multiple overflow channels (troughs) instead of one weir

There were suggestions earlier of recommended loads on overflow weirs and the idea of 'weir load' was introduced. But according to the latest research, even when the weir length is multiplied, by the application of overflow channels, it is the surface area that is increased. Figures 3 and 5 are examples of this system. Figure 4 gives an idea of what is really happening in such a system.

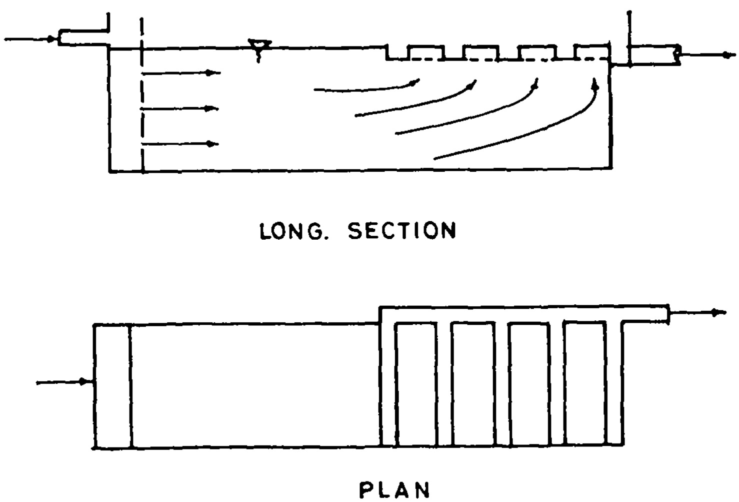

Figure 3. Lateral overflow channel.

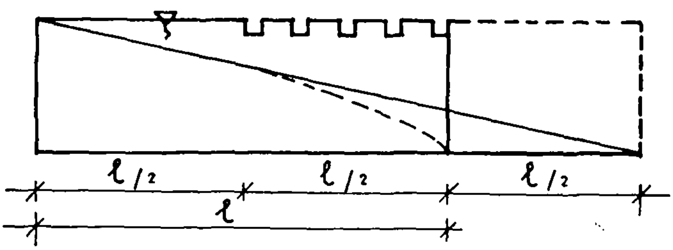

Fig. 4

Figure 4. Path of the settling particle when overflow channels are used.

The basic concept of the system can be summarized as follows. If troughs are provided on the second half-segment of a horizontal flow rectangular tank, a proportional quantity of the total flow is removed by each trough, gradually reducing the flow accordingly. And by so doing the flow velocity of the remaining part of the flow also decreases, gradually bringing about an even smaller surface load for the subsequent segments of the same size. (cf. Lee 1971.)

Theoretically, if the overflow weirs of the troughs are extremely close to each other, the gradual reduction of the flow may result in the doubling of the surface area of the part of the tank, where the troughs are fixed. That means that by providing overflow channels to the second half of a horizontal flow tank the increase in the capacity of the settling tank cannot exceed 50% of the original capacity of the tank. However, as the flow direction is modified and turned increasingly upward, the settling effect on flocculated solids will certainly improve further. Naturally this system cannot fit the oil-water separation field, where collection of the uprising lightweight material is the aim. In fact it cannot be advised for waters with significant proportion of floating material. So the system was revised in order to find out how best it can be adapted to waters where settleable solids and upfloating lightweight materials are present together. Figure 6 shows a system devised just for that. This kind of arrangement, however, has not been so popular compared with the previous ones in spite of the fact that theoretically it can provide a solution to the settling problem when floatables are also present. The reason for that is most probably frequent choking and the difficulty of getting the perforated pipe system cleaned.

Parallel plate and tube systems to increase the surface area of rectangular horizontal flow tanks

As has been mentioned before, the efficiency of a settling tank depends first of all upon surface area. It is also claimed that if the surface area is unchanged we can have the same settling effect with half or any fraction of the water depth in a rectangular horizontal flow tank. Consequently, it follows that by inserting one horizontal tray in the tank we will double its capacity. Yet there are other advantages of the tray settling system:

1. The flow pattern that is normally characterized by the Reynolds number is also improved, because of decrease in the hydraulic radius.

   $N_R = (VR)/\nu$ (the smaller the hydraulic radius the smaller the Reynolds number).

   Thus, by providing several trays or plates the flow becomes laminar which does not happen normally with horizontal flow tanks without plates or tubes. In fact laminar flow conditons or even $N_R < 250$ are recommended by many experts for high-rate settling.
2. Stability of the flow, which depends on the value of the Froude number, is also improved. This is because both the smaller hydraulic radius and the higher flow velocity help increase the Froude number, $N_F = V/(\sqrt{g}R)$, of which the higher is the better.

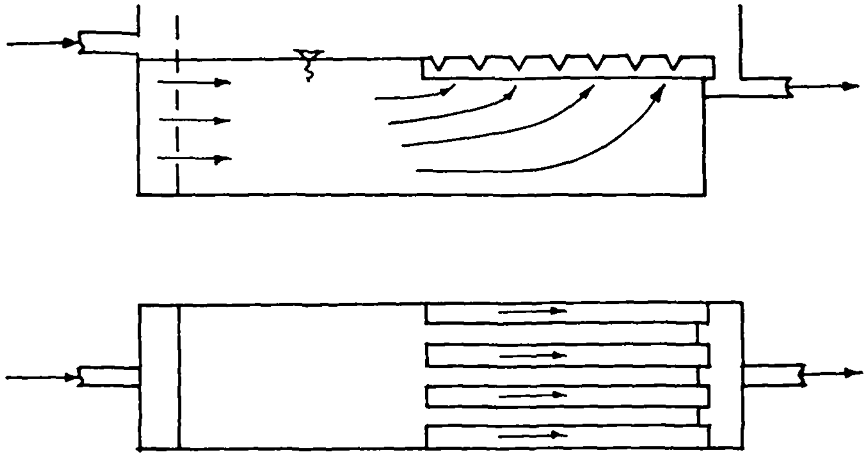

Figure 5. Longitudinal overflow channels.

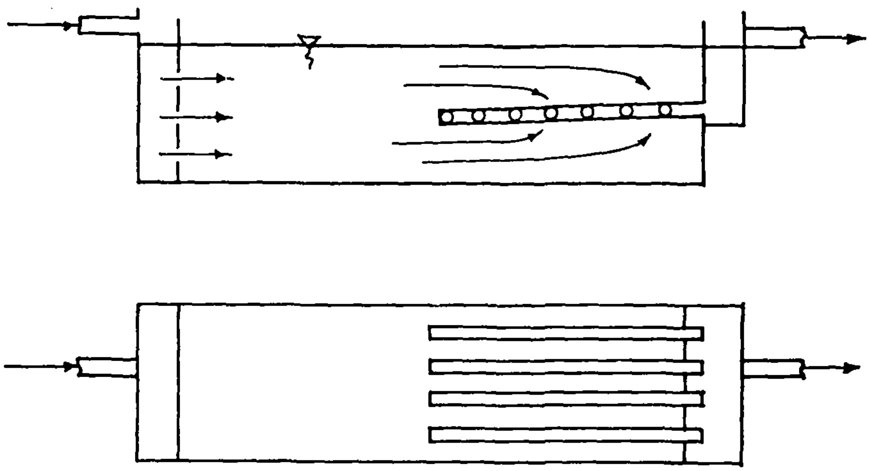

Figure 6. Perforated pipe water collection system.

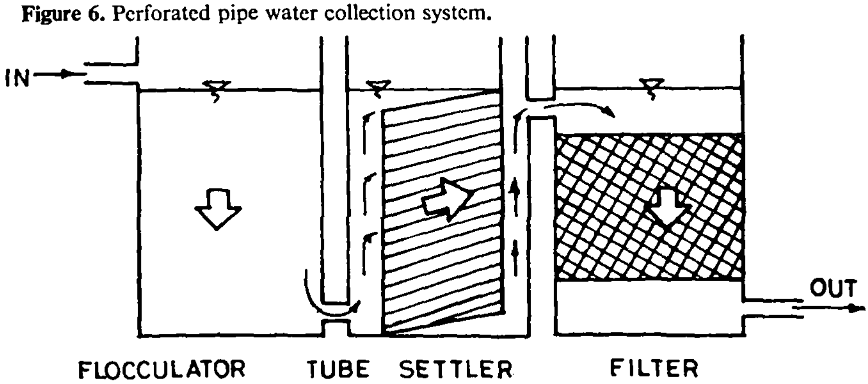

Figure 7. Application of the slightly inclined tube system.

However, there is a barely measurable negative effect as well. If the flow is laminar the flocculation effect is somewhat hindered, compaied with that of a turbulent flow.

It is apparent from the above that for the settling of discrete particles maximum effect can be expected with smaller diameter, horizontally set pipe system, when the settling path of the solid particle is smallest and the hydraulic radius also is the smallest possible. But unfortunately the removal of settled solids in such a system is extremely difficult.

Slightly inclined tube (plate) system

Figure 7 shows the application of this essentially horizontal ($\Theta \simeq 5°$) tube settling concept, as it was proposed by S. P. Hansen and G. L. Culp in 1967. As is shown on the sketch this type of tube settler can hardly be discussed separately from the preceding and following units in the treatment process. The main problem is that every time the cleaning of the tubes is required the whole settler has to be emptied, otherwise the removal of the settled solids from the tubes is impossible. Hence the efficiency of this system depends on how the filter backwash cycle can be coordinated with the cleaning of the settler by using the last portion of the relatively clean backwash water to refill the settler after its cleaning has been completed. This is a task that is very difficult to achieve with existing treatment plants. But apart from that, even the shape of a normal rectangular tank is quite different from the ideal one required for this process.

Steeply inclined tube (plate) system crosswise to flow direction

This is a very important high-rate settling concept and also theoretically the most refined of the tube or plate systems. Figure 8 shows the usual set-up of the tubes or plates crosswise to the flow direction, with an angle of inclination (Θ) of about 60° to the horizontal. $\Theta = 60°$ was chosen to best satisfy two opposing requirements: for good settling effect, the value of Θ should be as small as possible: for the effective sludge removal from the tubes (for self-cleansing) the value of Θ should be as close to 90° as possible, but minimum 60°. Hence the best compromise is $\Theta = 60°$. If efficiency depends upon surface area as it was claimed, then all that is required to calculate the capacity of this type of tank is to add the horizontal surface derived from the inclined plates (or tubes) to the original surface of the tank, and these will give the total surface to be taken into consideration. The projected surface area of one cell (as in fig. 9) depends upon $d \sin \Theta + l \cos \Theta$. Hence the projected surface area of one unit size square of the plate system comes to $(d \sin \Theta + l \cos \Theta) 1/d$, where $1/d$ stands for the number of cells in line. The above equation written in a simpler

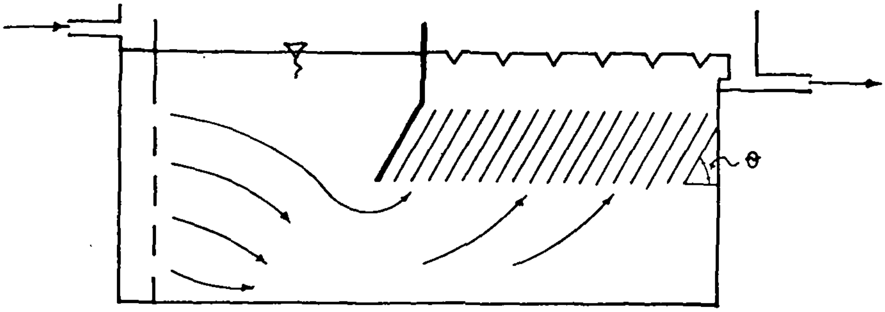

Figure 8. Steeply inclined plate system.

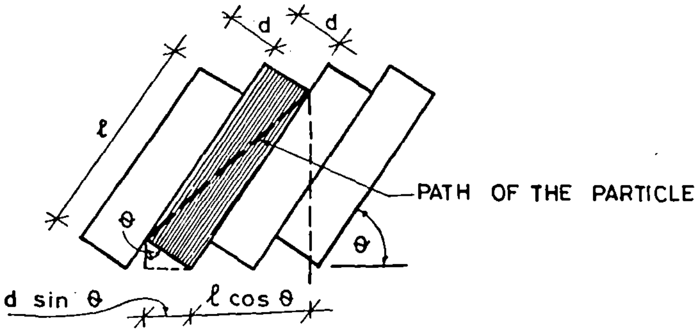

Figure 9. Flow pattern through the plate system.

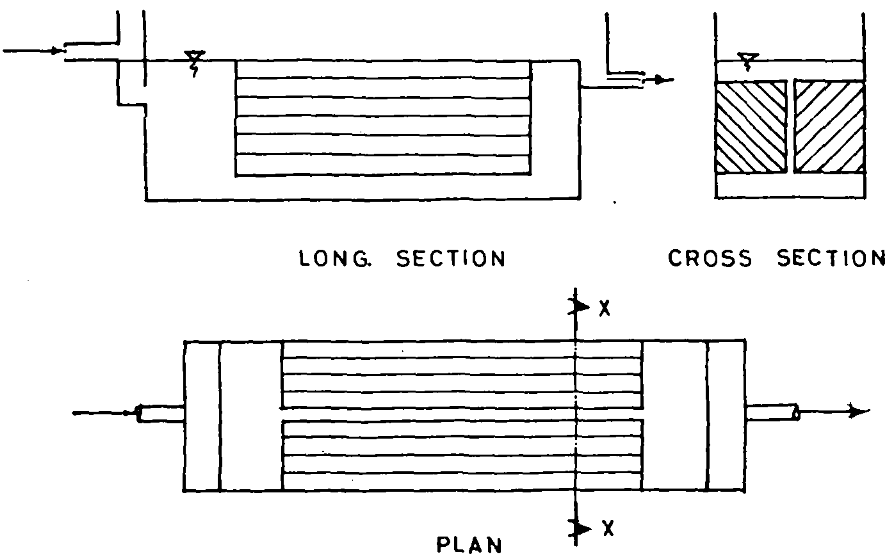

Figure 10. Shell separator.

form comes to $\sin\Theta + L\cos\Theta$, where $L = l/d$, is called 'relative length'. Since the surface area is increased by $\sin\Theta + L\cos\Theta$, the flow velocity through the original surface area can also be increased accordingly, and we still have the same surface load. That is, $V_o = V_s(\sin\Theta + L\cos\Theta)$. But when Yao (1970) analysed this system, he suggested that an efficiency constant S should also be taken into consideration for the different tubes or plates used. So the general formula came to

$$S = \frac{V_s}{V_c}(\sin\Theta + L\cos\Theta), \text{ or rather}$$

$$V_{sc} = \frac{S_c V_o}{\sin\Theta + L\cos\Theta} \text{ where}$$

V_o = flow velocity through original surface area,
V_s = settling velocity of particle,
S_c = critical value of efficiency constant.

The S_c value for circular pipes is 4/3; for square tubes, 11/8; for plates, 1. Consequently, any suspended particle with an S value greater than or equal to S_c is completely removed by the above system.

Relation of width to length ($L = l/d$)

The above formula was also used to find out the optimum economical relation of width to length in one cell. From theoretical considerations which have also been approved by experiments the efficiency of the system rapidly increased up to the figure of $L = 20$; above that figure, there was no significant improvement in efficiency. Hence the suggested ratio of l/d or relative length should be kept around 20.

Two questions still remain open: (a) What should be the depth under the tube-set in the tank? (b) How long should the first portion of the tank be, the one which is undisturbed? Pragmatic approach to the first problem requires a depth which ensures an access to the place under the tubes in case of cleaning And certainly some depth is required for the proper distribution of the flow to the tubes. But the most important thing is to provide detention time to make it possible for the upmoving particles to collide with the flocks falling down from the tubes. As for the length of the undisturbed section, it is recommended that this be kept for as long as between half and one-third of the total length, preferably closer to half. Treated water is collected with a trough (overflow channel) system above the tubes which ensures the uniform loading of the tubes. Technically, this water collection system is the same as what was discussed before, and is shown in figures 3 and 5. By that system the capacity of the existing tank can be increased 3. 4 or 5 times of the original capacity.

Steeply inclined parallel plates running along the length of the tank (Shell separator)
This system, the sketch of what is shown in figure 10, was first developed by A. W. W. Kirby (1964) of the Shell Company more than 20 years back as an up-to-date oil-water separator. In fact it is more than just that. This system improves the settling effect and the upfloating effect at the same time and does both things with about the same efficiency. The system had to be developed in such a way because it seldom happens that there is waste oil in the water without waste solids.

Apart from the oil industry this type of settling tank can be very useful in all the fields where settling is involved and the conditions (the size of existing tank, etc.) are not suitable for providing a system like the one discussed in the previous case. The increase in capacity of the existing tank is again related to the increase in surface area due to the inclined parallel plates, and it can be worked out accordingly.

It is recommended that the distance between two neighbouring plates be kept between 10 and 15 cm (these figures are based on experience). The *l/d* ratio does not seem to be so important in that case as it was in the previous one. As far as the distance between two plates is concerned, I am of the opinion that it should be kept greater than 10 cm not just for ease of cleaning, but to provide some contact time for the coagulated particles to agglomerate, as no undisturbed portion is provided in this type of settling tank. Cleaning of the tank can give us some problems also because the existing rectangular tanks, which we are going to alter, are normally of the flat bottom type. In this type the settled sludge does not accumulate as it does when hopper bottom segments are provided for sludge collection and concentration. Kirby's original idea was to provide a flexible suction hose along the bottom of the tank which is connected to a sludge pump and which can be slowly pulled along the bottom of the tank. The removal of the plates in compact steel units with a chosen length, the weight of which should not exceed a standby crane's capacity, has also been suggested by others. Lately, and mainly with smaller units, another system became popular in which the plates (again to limited length) are individually mounted on a rack system. If these plates are made of plastic to reduce weight, then they can be removed from their rack one by one any time the cleaning of the tank is required.

The case for circular (Dorr type) tank
These tanks, which are frequently used as settling tanks in sewage treatment, can also be fitted with a tube or parallel plate system to increase their output (See figure 11.) The idea is the same as before: by fixing the tube or parallel plate system the capacity is increased significantly, according to the total surface area in horizontal projection. Thus by keeping the usual surface load the flow velocity can be increased in the output. The *l/d* ratio should be kept again around 20, as it is with the same system on rectangular tanks.

Slightly inclined tube (plate) system
Though it may well be the most efficient of all presently known types of high rate settlers, as far as the settling effect itself is concerned, it still has its inherent problem with sludge removal. But let alone its setbacks, it certainly is not suitable to already existing settling tanks. Thus, it is not recommended for existing units.

Steeply inclined tube (plate) system crosswise to flow direction
This system seems to be the most beneficial to existing settling tanks. Always, when its use is not prevented by local conditions, that system can be recommended in water treatment as well as in sewage treatment. Increase in capacity can be 3, 4 or 5 times that of the original. Still the structures to be fixed are relatively simple and the whole system is easy to operate. If the expenses necessary for these improvements are compared with the costs of constructing three, four or five conventional settling tanks, this investment certainly is a very good one.

It should also be suggested that bamboo sticks cut to the proper size and fixed to an existing rectangular humus tank (of a sewage works) be used to find out optimum conditions for the improvement. Because of lack of experience this suggestion cannot be safely applied to water treatment unless the total separation of this particular experimental unit is ensured. Of course, the fixing of overflow channels over the top of the suggested tube system is a prerequisite to this experiment. I hope I will not be ridiculed if I go so far as to suggest that experiments be carried out to try the possibility of using bamboo sticks as tubes for the final structure of improvement. This certainly will not do much harm to the treated sewage effluent and can even be tried in potable water treatment. My suggestion is based on the good results gained in primitive waterworks where hardwood trays were used in certain parts of northern Europe. And as far as I know bamboo is also quite a durable material.

The usefulness of this proposition depends on how fast the decomposition of the bamboo takes place and how frequently the bamboo system requires replacement.

The use of Shell separator
In cases where the steeply inclined system mentioned above cannot be applied, the Shell separator may be very useful, in my opinion, in sewage treatment (for secondary settling only) as well as in water treatment. The increase in capacity can be triple or even more of the original. And the investment cost is not excessive. Cleaning may give us some problem but with small-sized units and necessary labour force this problem can be overcome, as mentioned above.

Tube (or plate) systems to circular tanks
The advantages of providing tube or plate systems to circular tanks are not so evident as they were in the case of rectangular horizontal flow tanks. However,

the application of this idea to circular tanks is not unusual and may be considered.

Hopper bottom tanks
The most important improvement to a hopper bottom tank can be the fixing of the Ives cone to the bottom of the tank (Ives and Hale 1970). Increase in capacity is from 1.6 to 2 times. Again it is a relatively simple structure and does not give us any more operational problems than we already had. The investment is certainly worth it.

Conclusion

As an overall conclusion naturally I am strongly in favour of these types of improvement, though I have to admit one disadvantage with them, that is, the use of mechanical scrapers is very difficult in horizontal flow rectangular tanks, once the suggested structures are fixed. However, fortunately enough, not many very large-sized settling tanks equipped with mechanical scrapers have been constructed in East Africa. Still even in that case desludging could be carried out by means of a special suction system instead of mechanical scrapers.

Improvements are being carried out on Nairobi City Council's plants regarding the above suggestions: (1) Conversion of our rectangular horizontal flow settling tanks to high rate settlers of the steeply inclined plate type (as per figure 8), at Kabete Water Works—construction is under way. (2) Multiple overflow channels, as in figure 5, on our rectangular horizontal flow tanks at Sasumua—construction is under way. (3) Fitting of Ives cone to one of our hopper bottom sludge blanket type clarifiers at Sasumua—as an experiment, construction will soon start.

Acknowledgements
I wish to pay tribute to Jorge Arboleda Valencia, an adviser of the Pan American Health Organization and the World Bank, who has given us a great impetus towards the conception and planning of our own improvement programme; also his lectures given to us about a year ago in Nairobi on water treatment, and his book *Teoria, diseño y control de los procesos de clarificación del agua* proved to be a valuable source of information for the realization of this paper.

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THE ROLE OF WIND-POWERED PUMPS IN WATER SUPPLY AND SMALL-SCALE IRRIGATION IN EAST AFRICA

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Abstract
An attempt is made to assess in general terms the potential for utilizing the region's wind resources for pumping water. While very few areas receive winds that are both strong and reliable enough to be called high potential areas, it is nevertheless possible to identify a considerable number of areas as having medium potential. A further positive factor is that in many areas the wind tends to be strongest in the dry season when most water is required. Minimum requirements for the utilization of wind power are suggested in relation to water supply and irrigation needs. The costs of systems using locally made wind pumps are compared with those using imported diesel pump units. It is argued that for small water schemes, the windmill is generally to be preferred on the basis of lower maintenance cost and potentially greater reliability. An important feature of the windmill is its comparative simplicity, which enables maintenance and repairs to be performed by local personnel. In social terms, it is claimed that this is an advantage since it encourages greater local involvement and responsibility.

Introduction
Where a reliable wind resource exists, it presents attractive possibilities for exploitation to meet a number of needs, not the least of which is the pumping of water. In rural areas the advantage is that it is a local source of power and can be tapped on the spot, thus not incurring heavy transmission costs as in the case of electricity. Compared to a diesel-powered pump, a wind-powered pump is sometimes more expensive to buy, but there are no fuel bills to pay afterwards, and maintenance is much cheaper also. The one disadvantage of using wind power for pumping is that the wind is not always reliable. Consequently this may necessitate extra expenditure in the provision of water storage to guarantee a supply over calm periods. This may not present many problems in the case of water supplies for human consumption or cattle, but in the case of irrigation it can be quite a critical factor.

After a period of decline in their use due to competition from small diesels, windmills are now making a comeback. Many orders have been placed by developing countries despite the fact that these or alternative designs could be manufactured locally at less than half the cost. This indicates that in general a considerable potential should exist for locally made wind pumps. It is considered that the advantage of lower cost equipment would make many proposed pumping schemes more economically viable.

Wind power as a resource

The power available in the wind depends on the following principal factors:

1. The cube of the wind velocity
2. The cross-sectional area exposed
3. The air density (depending on altitude).

This means that for a given size of power extraction device operating at a given altitude and with a given efficiency, the potential power output depends on the cube of the wind velocity. The precise wind velocity is therefore quite a critical factor: for example, the seemingly small difference between a wind velocity of 13 m/s and 10 m/s actually represents in power terms a ratio of over 2 to 1. This points to the need for obtaining fairly precise wind data before the wind-power potential of a particular location can be accurately assessed. It is clear that an average wind speed measured over a 24-hour period can give a realistic measure of wind power only if the velocity remains constant over the whole period. The more variable the wind speed, the more the actual power will be underestimated if we base it on a measured average. In the wind-power field what is required is a knowledge of the proportion of a given period over which the wind speed was between zero and 2 m/s, proportion between 2 m/s and 4 m/s, 4 m/s and 6 m/s, etc. In this way it would then be possible from a frequency distribution to determine which velocity band provides the most power. It would also indicate the relative probability of receiving winds at each particular velocity, thus revealing wind reliability.

At present those anemometers which are capable of providing such recorded data are rather expensive and the raw data they produce subsequently need a considerable amount of processing. A need exists for the development of a special purpose wind-power anemometer. Meanwhile wind-power engineers have to do the best they can with data of average wind speed, some of which have been recorded by instruments, and some of which have been based only on visual estimates.

The wind resources of East Africa

General

An outline of low-level wind distribution has been presented at the 11th Academy Symposium by Obasi and Rodhe (1974). Although the title of their paper referred to Kenya in particular, most of its contents deal with the East African region as a whole. Much of the original data are obtained from Findlater (1968) and other data by the East African Meteorological Department (1961, 1973) and the World Meteorological Organization (1973).

The general pattern over the region is governed by a large-scale pressure distribution associated with the monsoon system. In the areas around large lakes, particularly Lake Victoria, the lake breeze (daytime) and land breeze (night time) are sufficiently strong to form the predominant influence. A similar diurnal sea and land breeze system exists along the East African coastal strip, extending up to 30 km inland. Though these winds are not particularly strong they tend to be reliable. A third important feature is the diurnal movement of air in the areas around large mountains and mountain ranges due to alternate heating and cooling. In the daytime, anabatic winds are caused by warm air rising up the slopes, while at night katabatic winds are caused by cool air flowing downhill. Finally, on a more localized basis, there are sporadic winds resulting from differential heating of various types of land surface and from the passage of clouds.

Data available

As might be imagined, the most comprehensive and reliable wind data available relate to major urban centres and major airports. In general the data relating to the rural areas in which we are interested are far less comprehensive, consisting mostly of readings taken at 6-hourly or 12-hourly intervals. At best the data will have been recorded on a cup-type anemometer, giving an average wind run over the period. Frequently historic data are based on Beaufort-type estimates, which are obviously open to error. (It is the author's belief that wind-speed estimates taken in areas covered by acacia scrub, for instance, are frequently 20% below the true figure, leading to an underestimation of the wind power by as much as 50%.) From the point of view of wind-power utilization, therefore, the data available leave much to be desired. Until a thorough wind-power data collection programme is instituted, it will be necessary to do the best possible using average wind speeds. The best that can be done at present is to differentiate between high, medium and low potential areas in a general way and then within these areas to look at local features which could tend to have a magnifying effect on the wind velocity.

As yet no one appears to have done a thorough analysis of the wind potential of the region as a whole. In the individual countries, some work has been done by Van der Laak (1971) and Parkes (1974) in Tanzania and by Denton (1969) in Kenya. An attempt has been made by Chipeta (1976) at the University of Nairobi to assess Kenya's wind-power potential from available data as part of an M.Sc. project. Wind 'contour' maps were drawn on a monthly average and annual average basis. A few relatively high potential areas and a greater number of medium potential areas were identified. The area of greatest indicated potential was the Eldoret-Equator area which showed an annual average availability of greater than 100 watts/m^2. It was also thought that a similar high potential area exists in northern Kenya around Lake Turkana. The remainder of northern Kenya, the coast and Lake Victoria shores were considered to be of medium potential. Such conclusions can only be provisional, however, until more stations are established and more relevant data collected.

In talking about 'high' and 'medium' potential areas one has to bear in mind that these are only relative terms applying to the region. The author tentatively suggests the following designation:

High potential — annual average wind speed greater than 5 m/s (10 knots; 11.5 miles per hour).
Medium potential — annual average wind speed between 3.5 and 5 m/s.
Low potential — annual average wind speed between 2 and 3.5 m/s.

The above designation may be crude and inadequate, but it does serve initially to help point to areas upon which further attention should be concentrated. It also gives a guide as to the uses to which the wind can be put. Roughly speaking it would be economic to operate windmills for pumping drinking water in any medium potential area. For irrigation purposes, however, windmills would be certainly economic in high potential areas, but perhaps only marginally economic in medium potential areas (though this would obviously also be dependent on other factors such as the type of crops, etc.).

Economic aspects

Water supply for human consumption and cattle

Much of rural East Africa is characterized by low population density which tends to render only a few large piped water schemes economic. In most cases it is probably more appropriate to consider a multiplicity of water supply schemes serving small communities. Except where the water has to be obtained from deep boreholes, the net power requirement for such a community is usually quite small. For example the net energy required to lift 10 m^3 of water (10 000 litres) per day* from a depth of 30 m is equivalent to only 38 watts of continuous power, or say 50 W after pump efficiency is taken into account. This energy can be supplied over a daily 6-hour period by a prime mover which provides an output power of only 240 W (0.32 bhp) This sort of power output falls well within the scope of a windmill, and could be provided by a 6 m diameter machine operating in a medium potential area, for instance. On the other hand, 240 W represents a rather insignificant amount of power for a diesel or petrol engine. A small engine giving an output of say 1.5 kW (2 bhp) would have completed the necessary pumping in less than one hour per day, which results in the machinery being underutilized. Thus it is generally not very economic to use a diesel engine delivering less than about 3 kW (4 bhp) which is not being utilized for more than 2–4 hours per day on average. The

*It is normally accepted that this daily quantity is sufficient to serve the minimum needs of 1 000 people or 250 head of cattle.

fact that engines smaller than this are used illustrates the high price that people are prepared to pay for drinking water.

A comprehensive cost comparison between imported wind pumps and diesel pumps has been carried out in Tanzania by Parkes and Van der Laak (1976). Applications involving quite large powers were considered. The first cost of the imported windmills was found to be considerably greater than the equivalent diesel engine but this was balanced by the fuel costs and higher maintenance costs in the case of the diesel. The cost comparison showed that any relative advantage was fairly marginal and depended on the write-off periods assumed. However, when it is considered that the windmills could be manufactured locally at less than 50% of the cost of imported machines, this gives wind-powered pumps a clear advantage, especially in the 0–3 kW power range. The main imponderable in costing a wind-powered water supply scheme is the day-to-day reliability of the wind, since this determines the amount of storage capacity it is necessary to provide. However, it should not be too expensive to provide up to 10 days of strategic storage. In addition it is not too difficult to provide means by which the wind pump can be turned by hand if any extended calm periods occur.

Table 1. Estimated capital costs of small water supply scheme (10 m^3 per day) (Ksh)

	Wind-powered	Diesel-powered
Windmill (6 m dia)	8 000	....
2-5 bhp diesel	....	4 500
Base plate, pulleys, etc.	....	3 500
Pump	2 000	4 500
Pumphouse	....	1 200
Pipes, etc.	4 000	4 000
Tank storage	6 000	2 500
Concrete foundation	300	200
Total (excluding installation)	20 300	20 400

Water for irrigation

For irrigation the quantities of water demanded are very much larger than for drinking purposes, and the price per unit of pumped volume that can be afforded is much less. Consequently the costings relating to pumped irrigation schemes become much more critical, particularly with schemes of small size. Small pumped irrigation plots (less than 5 ha) appear to be economic only if high value crops are grown and the water does not have to be lifted more than about 5 m.

If the wind blows reliably at a speed of around 6 m/s for 8–10 hours per 24-hour period, then wind-powered irrigation is definitely feasible. In fact it fills a valuable gap between a half ha shamba irrigated by hand, and a 5 ha plot served by an engine.

Even with a plot size of 5 ha it can be argued that four windmills, say, are preferable to one internal combustion engine on grounds of mechanical reliability. Should the engine break down, then 100% of the pumping capacity is lost, and with it also possibly the crop. Should one windmill break down, only 25% of the capacity is lost. Again, the reliability of the wind itself is a most important factor since concrete tank storage for irrigation can add considerable capital cost to the scheme. Lower cost storage can be achieved by building a large storage pond or feeder dike provided leakage and evaporation losses can be kept small.

Examples of estimated costs

Table 1 shows estimated capital costs for a small water supply scheme lifting an average of 10 m^3 of water per day through a height of 30 m. Two sets of costs are shown, one relating to a system employing a locally manufactured wind pump, and the other a system employing an imported diesel pump set. It is assumed that the wind pump operates in an area of medium potential. It is also assumed that piping costs are reasonably small, and that tank storage is equivalent to 10 days of usage in the case of the wind-powered scheme, but only 3 days of usage in the case of the diesel-powered scheme. Installation costs are not included since these can be very variable. It can be seen that overall the equipment costs are virtually the same. (It must be pointed out, however, that the diesel engine in this case is underutilized.) When the recurrent costs are considered, however, the situation is very different. Table 2 gives estimated costs excluding any debt servicing. For simplicity linear depreciation of equipment is assumed over a 10-year period with the exception of the diesel engine. The greater running costs of the diesel-powered equipment arise principally from the extra (skilled) maintenance required and the fact that the diesel engine needs an operator who must be paid a wage for this part-time work. The figures quoted are obviously open to argument but clearly show the advantage of the wind-powered system.

It would also be appropriate to compare respective costs for a larger scheme in which the diesel engine, if employed, were not underutilized but would be operating closer to its capacity. Table 3 shows estimated capital costs for a scheme delivering 30 m^3 per day with the storage capacity increased pro rata. In this case the cost of three windmills is compared with the cost of the same diesel engine as before. This time the capital cost of the windmill-powered scheme is roughly double that of the diesel. Despite this it is observed (table 4) that the recurrent costs of the wind-powered scheme are considerably less, assuming a need does not exist for debt servicing. Even including a moderate

Table 2. Estimated recurrent costs of small water supply scheme (10^3 m per day) (Ksh per annum)

	Wind-powered	Diesel-powered
Fuel	....	800
Maintenance	400	2 000
Operator's wage	....	2 400
Depreciation*	2 030	2 470
Total (excluding debt service)	2 430	7 670

*Based on linear write-off over 5 years (engine) and 10 years (all other equipment) which is written off over 5 years.

Table 3. Estimated capital costs of larger water supply scheme (30 m^3 per day) (Ksh)

	Wind-powered	Diesel-powered
2 windmills (6 m dia)	24 000	....
2-5 bhp diesel	....	4 500
Base plate, pulleys, etc.		3 500
Pumps	6 000	4 500
Pumphouse	....	1 200
Pipes, etc.	6 000	6 000
Tank storage	14 000	5 500
Concrete foundation	900	200
Total (excluding installation)	50 900	25 400

interest charge on the cost of equipment, the wind-powered scheme still appears to have the advantage. It is clear, however, that as the output requirement increases, the relative advantage of the wind-powered system becomes less.

A similar comparison can be made in the case of equipment for small-scale irrigation. The main differences are that in the case of the wind-powered system storage costs could be greater, while storage is not necessary at all in the case of the diesel-powered system. Table 5 shows estimated capital costs relating to a 3 ha irrigated plot requiring a daily application of 250 m^3 (5 m lift). In the case of the wind-power option, two possibilities are considered: firstly one windmill operating in a high potential area, or alternatively three machines operating in a medium potential area, producing the same amount of output

Table 4. Estimated recurrent costs of larger water supply scheme (30 m³ per day) (Ksh per annum)

	Wind-powered	Diesel-powered
Fuel	....	2 400
Maintenance	1 200	3 000
Operator's wage	....	3 600
Depreciation	5 090	2 990
Total (excluding debt service)	6 290	11 990

Table 5. Estimated capital costs of equipment for 3 ha irrigated plot (in Ksh)

	Wind-powered		Diesel-powered
	high	medium	
Windmill(s) (6 m dia)	8 000	24 000	....
2-5 bhp diesel and base plate	....	....	6 500
Pump	3 000	6 000	4 000
Pipes	500	1 500	500
Tank storage	15 000	15 000	....
Concrete foundation	300	900	200
Total	26 800	47 400	11 200

Figures are based on one windmill operating in a high potential area or three in a medium potential area, producing the same amount of output.

Table 6. Estimated recurrent costs of irrigating 3 ha plot (Ksh per annum)

	Wind-powered		Diesel-powered
	high	medium	
Fuel	....	....	1 600
Maintenance	600	1 800	4 000
Depreciation	2 680	4 740	1 570
Total	3 280	6 540	7 170

See note for table 5.

(figures in brackets in table 5). Table 6 shows the corresponding recurrent costs, in which this time the operator's wage is omitted. (It is assumed that the operator's task is performed by the farmer himself or by his employee who already receives a wage.) The cost estimates suggest that wind power is marginally competitive in medium potential areas but could be very advantageous in high potential areas.

Conclusions

A preliminary assessment of the region's wind resources suggests that this source of power could find much more application in rural areas for small pumping schemes, both for water supply and for small-scale irrigation. Further data collection is necessary to assess wind resource more precisely. Windmills appear to be most highly competitive in the 0–3 kW (4 hp) power range. The simplicity of the directly coupled windmill and reciprocating pump makes it a simple item to manufacture locally, thus giving a cost advantage over imported machinery and saving foreign exchange. Because there are so few parts, it should also give a very high mechanical reliability. Its simplicity is a further advantage in that the technology associated with it is more likely to be understood and accepted by the rural population than is that of the diesel engine. It follows that local personnel will be more able and willing to service and maintain the equipment and regard it as their responsibility to keep it working. In relatively remote areas, the development of local skills in servicing can lead to considerable savings in maintenance costs. It is believed that when responsibility for equipment is accepted locally, rather than relying on a *fundi* to come out from Nairobi, this can be an important factor in rural community development.

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THE USE OF SOLAR ENERGY FOR GROUNDWATER EXTRACTION IN RURAL WATER SUPPLY

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Abstract
Solar pumps are based on the principle of a water heater in combination with a solar motor thermal cycle. The total system consists of:

- —a flat plate heat collector which collects thermal energy by heating water
- —a solar motor which transforms thermal energy into mechanical energy
- —a hydropump unit which uses mechanical energy (via hydraulic system or an electro-generator) to drive a submergible pump
- —a large storage reservoir with a water distribution system.

Solar pumps demand very high initial investments but require less maintenance and less skilled manpower to run than diesel-powered pumps, which make them more suitable for use in remote areas.

Introduction
To ensure satisfying water supplies to men and livestock, adequate pumping methods are required. A promising one is the solar motor pump which converts solar heat into mechanical energy which may then be used to operate a water pump. Solar energy has the great advantage of being free. However, it is a diffuse form of energy which with present methods of collecting and converting into a useful form requires considerable investment. In large parts of Kenya conditions for utilization of solar energy are favourable. Insolation is intense with total duration up to a considerable 3 000 hours per year (Moumouni 1972). Moreover the use of conventional energy forms has its disadvantages in remote areas. Both diesel fuel and electricity, whatever the source, are bound to be expensive due to high transportation and transmission costs to thinly populated areas (Tabor 1971).

Nothing would seem more logical than to make use of the abundant solar radiation, since an area of 1 m^2 can receive a maximum average amount of solar energy of 1 kW per hour. In many places the total energy received per year exceeds 2 000 kW. Nevertheless, solar applications with a useful efficiency are hard to realize. Capturing and concentrating solar energy in any quantity requires extensive apparatus, even for the direct conversion of the sun's electromagnetic radiation into electrical energy. The various possibilities for solar energy utilization may be grouped into three main systems:

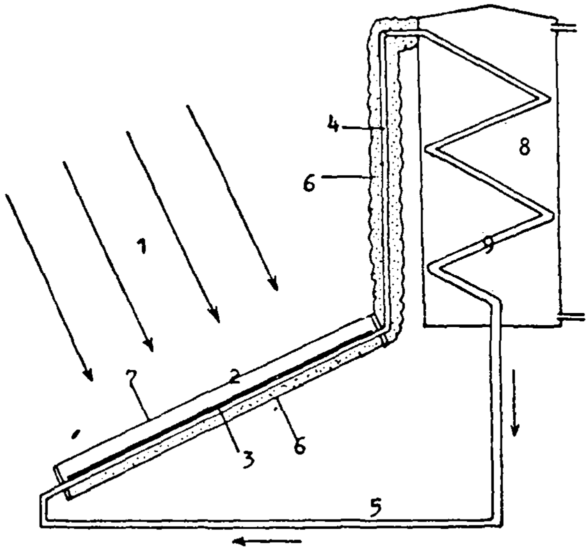

Figure 1. Principle of the indirect water heater with a heat exchange coil.
1—solar radiation
2—heat collector
3—blackened metal sheet with water pipes
4—hot water
5—water to be heated
6—isolating material
7—glass pane
8—hot water tank
9—heat exchange coil

1. The system of direct production of electrical energy. This system uses solar cells such as photocells and thermocells which function by means of semiconductors. The application of solar cells has been highly developed for use in spacecraft which obtain their electrical energy from solar panels.
2. The system of high concentration of solar energy. This category contains solar furnaces with some experimental vocation for technological research. To attain high concentrations of energy, large single or complex parabolic reflectors are orientated so that a large amount of solar radiation converges on a small surface. The reflector complex must be mounted on a complicated mechanism in order to follow the daily and seasonal movements of the sun, which renders it vulnerable and expensive to maintain.

   Apart from technical perfections, high focusing of solar energy also requires parallel solar rays which occur particularly under exceptionally clear atmospheric conditions.
3. The system with low or no concentration of solar energy. This system involves principles simpler to realize and thus lends itself to a greater variety of applications. The flat plate collectors of solar heat exchangers which collect solar energy without optical concentration can take advantage of both direct and diffuse solar radiation and thus absorb heat even under hazy conditions and slightly overcast skies. Existing applications include, among others, water heaters (the most widespread), desalination plants or solar stills, solar cookers, solar grills, and solar motors. Steam under pressure may also be obtained with the help of a low degree of focusing (Duffy 1972).

Principles underlying the solar pump

It is in this last group (3) that the possibilities for the solar pump are realized by means of a solar motor which receives energy from a water heating apparatus. The following explanation is based on the principle underlying the Masson-Girardier (1966) solar pump which was developed in the sixties in West Africa (Senegal, Niger, Upper Volta). A pump based on this principle will also soon be operating in Kenya, at Wajir. The solar pump (fig. 1) is based on the use of flat radiation collectors and consists of:

1. An assembly of flat plate heat collectors intended to heat water;
2. A solar motor which transforms thermal energy from the sun, brought on by the hot water, into mechanical energy;
3. A hydropump for withdrawing water, composed of a hydraulic system or an electro-generator powered by the shaft of the solar motor and a hydraulic or electric submergible pump in the well;
4. A large storage tank with distribution system.

The heat collector

In a flat tray (e.g. dimensions 210 × 110 × 10 cm) lies a blackened metallic plate (200 × 100 cm), on the rear of which are attached tubes through which water passes. The blackened metal plate absorbs solar energy and transfers it to the water in the tubes which consequently heats up. The pipes converge into a central system which unites the various heat collectors into a heat collector assembly of several tens of square metres. The flat tray is covered by a panel of glass resulting in a greenhouse effect, the glass being transparent to entering short-wave solar radiation but opaque to the larger wavelength radiated by the plate. The bottom of the tray is separated from the black plate and tubes by insulating material which prevents heat losses by conduction. All other exposed hot water conducting tubes are also insulated. The collectors are east-west oriented and sloped for the best position towards the sun. On an average, the heated water reaches temperatures of 70 to 80°C and the solar pump can work up to a maximum of 6 h/day. New types of collectors have been developed with a slight concentration of radiation which increases the temperature of the water and extends the working period of the solar pump.

Figure 2 shows the principle of an indirect water heater which uses a spiral tube to transfer the collected solar heat to the water in the reservoir. Similarly an indirect system such as this is used in the solar motor where hot water in the spiral tube heats a fluid in the expansion reservoir which then passes from the liquid to the gaseous stage. In order to guarantee good circulation of water in the heat collector system, a thermal siphon is installed. It makes use of slight temperature gradients to create the pressure necessary for closed circuit circulation.

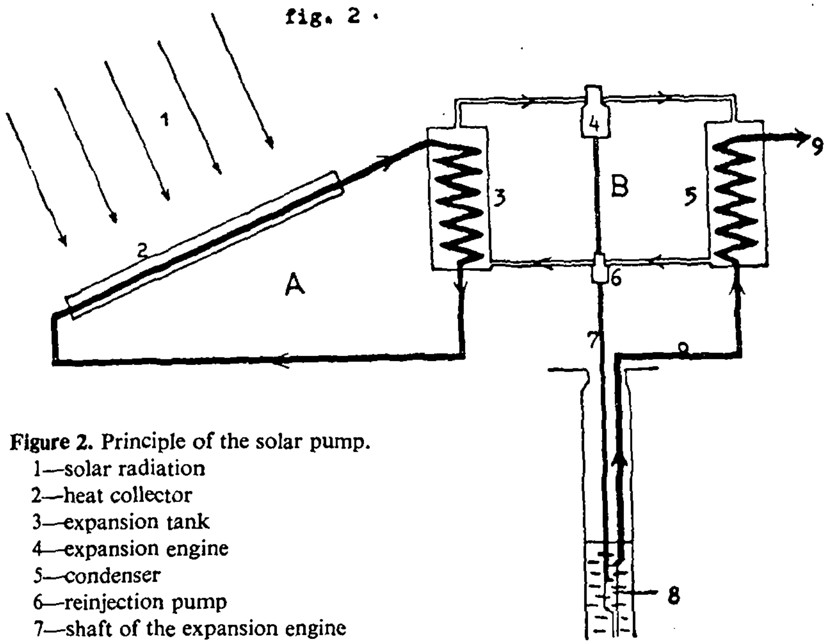

Figure 2. Principle of the solar pump.
1—solar radiation
2—heat collector
3—expansion tank
4—expansion engine
5—condenser
6—reinjection pump
7—shaft of the expansion engine
8—pump in the well
9—pumped water
A—heat exchange cycle
B—solar motor thermic cycle

The solar motor and its thermal cycle

The solar motor itself consists of a thermal cycle of expansion and recondensation of gas (see fig. 3). Hot water coming from the collector passes through the spiral in the expansion tank or heat exchanger, thus transferring its thermal energy to the expansion liquid (liquified gas). The hot gas which ensues under considerable pressure enters the cylinders of the expansion engine. In thus running the engine, the gas loses pressure while increasing in volume. The gas then enters the condenser where it is cooled and decompressed by the water which is pumped from the well. The gas, at reduced temperature and pressure, is then recompressed and reliquified by a small counterpressure or reinjection pump from where it reenters the expansion tank. This reinjection pump is mounted on the shaft of the expansion engine. The power produced by the solar motor E_p equals the power developed by the expansion engine E_e minus that which is used to run the reinjection pump E_c, or $E_p = E_e - E_c$. A maximum value of E_p can be obtained by an appropriate choice of gas. Likewise, highest values for E_e result from effective heating, while effective cooling gives low E_c values. Gases having the desired properties are chloromethyl and freon. However, commerical butane is sometimes preferred for the use in the thermal cycle, due to its easy availability.

The hydropump complex

The hydropump, which finally brings up the water, is driven by the solar motor, or, more precisely, by the expansion engine. It consists of a hydraulic system which runs a hydraulically controlled submergible pump, or an electro-generator which drives an electric submergible pump. The hydraulic system or the electro-generator are both driven directly by the shaft of the expansion engine. The advantage of the hydraulic or electric system is the absence of rotating or vertically moving shafts and rods. Equally avoided is the necessity of constructing the motor directly over the well. The pumped water passes through the condenser where it serves to cool the exchange fluid leaving the expansion engine. It continues to a storage tank which is preferably much larger than the pump's daily capacity. This assures a sufficient water supply for several days in the event of slowed or halted operation due to a cloudy sky, repair, or maintenance work. Distribution pipes from the tank supply drinking troughs for the animals and taps for the people.

Capacity of the solar pump

What is the capacity of the solar pump? For example the solar pump in Niger has a collector surface of 60 m^2 permitting it to bring up 6–7 m^3 per h at a hydraulic head of 12 m. Raising 7 m^3 of water at 12 m requires about the same energy as raising 84 m^3 at 1 m. With 60 m^2 of collector surface, this gives us an efficiency factor of 84:60 or 1.4 $m^3 \times$ m/h per m^2 of collector surface. This factor allows us to compare the efficiencies of various pumps in relation to their total collector surface, as indicated in table 1 (Nauta 1973).

Table 1. Capacities of some selected solar pumps

Place and date of installation	Collector surface m^2	Pumping capacity m^3/h	Hydraulic head m	Efficiency factor $m^3 \times$ m/h per m^2	Power at shaft hp/ $\times$ m/h	watt
Dakar (Senegal) 1968	88	6	25	1.7	1.3	970
Niamey (Niger) 1969	60	6–7	12	1.4	1.0	750
Ouagadougou (U. Volta) 1971	30	2.5	20	1.3	0.3	225
Chinguetti (Mauritania) 1973	88	8–10	20	2.3	1.5	1 200
Wajir (Kenya) 1977	77	5	25	1.6	1.4	1 045

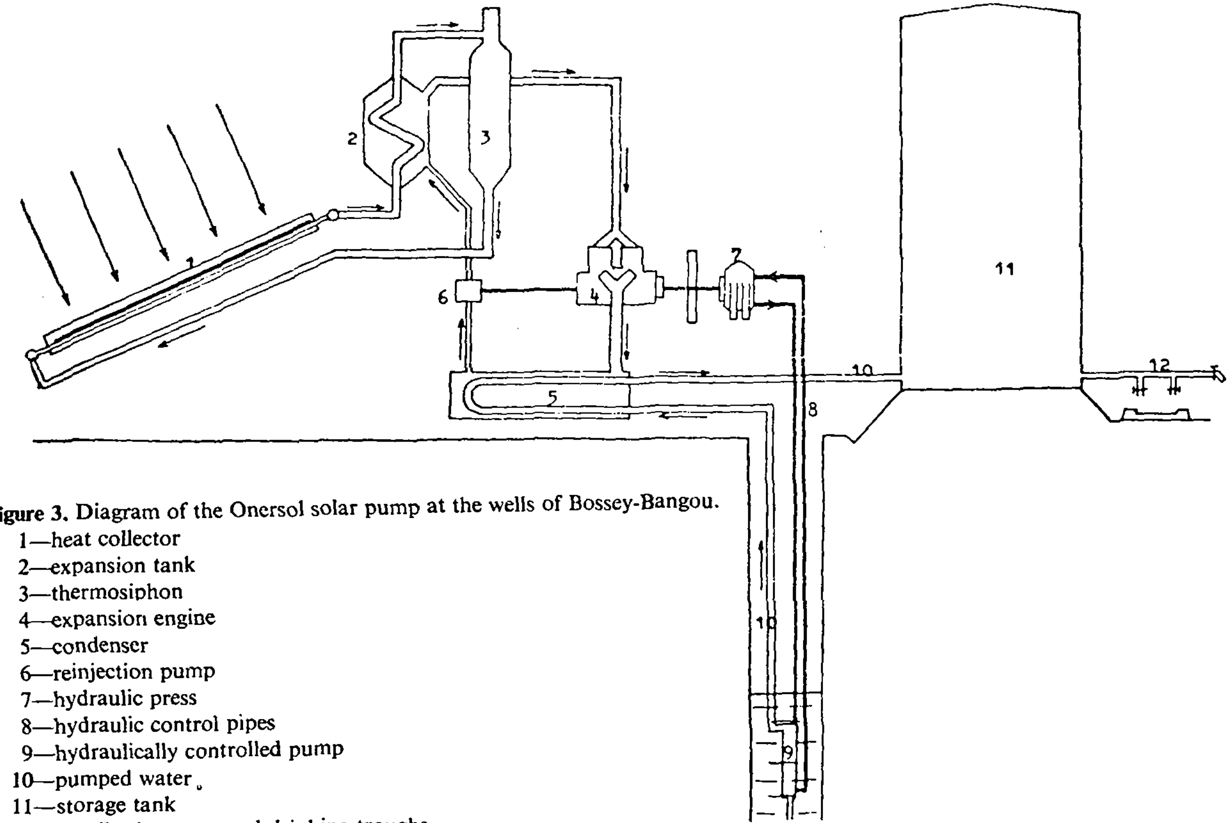

Figure 3. Diagram of the Onersol solar pump at the wells of Bossey-Bangou.
1—heat collector
2—expansion tank
3—thermosiphon
4—expansion engine
5—condenser
6—reinjection pump
7—hydraulic press
8—hydraulic control pipes
9—hydraulically controlled pump
10—pumped water
11—storage tank
12—distribution, taps and drinking troughs

Prospects for solar pumping

Presently, on the basis of experience with existing solar pumps, study and development is being carried out with a view towards larger and more efficient and integrated applications. By the use of new collector systems the banks of collectors can serve as a roof for a hospital, school, or hotel for instance. Thus the system can supply water for the establishment itself and for people and livestock in the vicinity, as well as provide energy for electricity generating and cooling or air conditioning for a hospital or a hotel. Consequently rather satisfying developments may be expected in the near future. Another interesting application will be that of a solar irrigation pump. Especially under conditions of good water availability under a low head, several hundreds of m^3 per h may be pumped and serve to irrigate large areas. Preparations for such projects are going on in Algeria.

Economic considerations

The author of this paper did not have the opportunity to go deeply into the economic aspects of solar pumping and has considered the limited value of many economic approximations. Consequently he asks the reader to view the following considerations as representing relative rather than absolute values. The reader should further be aware of a tendency of some adherents of solar energy utilization to present the case of solar pumping in a too favourable light, choosing to ignore certain less favourable aspects of it.

Investments

It is true that solar energy is free, but as has already been indicated, the price of gathering it is likely to be high and considerable initial investment must be expected. Solar energy is very diffuse, thus its capture is difficult and complicated. The application of solar energy has not yet fully emerged from the experimental stage, and mass production of components or their assembly is only developing slowly (with the exception of water heaters in certain countries). Increased demand will no doubt improve this mass production, resulting in significant lowering of prices. Valuable research could be done in the field of local assembly of solar plants and the local production of certain elements, like collectors, connection pipes, condensers and exchangers.

Operating expenses

The idea that the only cost of a solar pump, which uses free energy, is its installation is not entirely true. Maintenance is a less compelling necessity than with a diesel-powered pump, nevertheless special attention is required for certain parts of the system. The collectors have to be kept clean and leakproof. The isolation has to be checked regularly and repaired where necessary. The gas system requires regular checks on leakage and loss of gas. Moreover, once or twice a year, a general inspection and maintenance service has to be carried out by a specialist. These factors increase the operating expenses of the solar pump but are difficult to foresee and are seldom found in calculations determining the feasibility of solar applications.

Returns

The advantages of a mechanical pump in satisfying rural water demands are well known. Water supply to the rural population from pumped wells with clear and pure water is one of the main development objectives in many countries. Moreover, a steady water supply to livestock is of vital economic importance in pasture areas. A solar pump with a capacity of 6 m^3/h is capable of watering about 800 head of cattle per day or a rural human population several times as large, in view of which the value of such pumps should be obvious. Table 2 shows the approximate prices of five solar pumps, ignoring transport and assembly costs (Nauta 1973).

Table 2. Prices of solar pumps

Pump	Yield m^3/h	Efficiency factor	Year of price quotation	Approximate prices US$	Ksh
Ouagadougou	2.5	1.3	1972	23 500	195 000
Niamey	6	1.4	1972	34 750	285 000
Dakar	6	1.7	1972	36 250	300 000
Chinguetti	8	2.3	1974	47 500	390 000
Wajir	5	1.6	1976	60 000	500 000

A more telling indication might be the figures which Prof. Masson (1966) quotes for approximate prices of water per m^3 considering 10 years writing down, for motors, pumps, etc., manufactured in Europe and for collectors, pipes, and framework made locally (see table 3). For a comparison, electrical or diesel pumping in Kenya gives prices of water well below Ksh 1.

Table 3. Approximate prices of water per m^3

Niamey-type	Ksh 1.40 per m^3 (US$ 0.17 per m^3)
Chinguetti-type:	Ksh 1.16 per m^3 (US$ 0.14 per m^3)
Wajir-type:	Ksh 2.75 per m^3 (US$ 0.33 per m^3)

A proper appraisal of the practicality of solar pumps will not be possible until a sufficient number of them are operating and reliable estimates of costs and prices can be made. Moreover, once the manufacture of the various components has become standardized and locally realized, a better judgement on the feasibility of solar pumps will be possible.

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DESALTING OF WATER BY SOLAR ENERGY

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Abstract
The sun's rays have all along produced fresh water from salty sea water as a part of the natural hydrological cycle. Hardly any deliberate attempts to adapt this natural process for supply of drinking water were made until the last century. The solar still is widely adopted in various forms in arid and coastal areas and on islands where it is especially suited. Constraints of high initial cost, requirement of extensive land and practical problems interfering with its performance have limited the application of the solar still. More recent devices include the solar pond and more efficient methods of converting solar energy into electrical or mechanical power to operate more sophisticated desalination equipment. In the context of the meteorological and geohydrological conditions obtaining in Kenya, the use of solar energy for desalting water appears technically and economically feasible in the arid areas of Kenya.

Introduction
Providence employs nature to make use of solar energy to desalt sea water. Every day, over 1 000 km^3 of fresh water is distilled by the sun's rays from oceans and large bodies of water and despatched on clouds which are towed to their upland destinations by winds actuated mainly by sun rays on and around the globe. Part of the well-known 'hydrological cycle' comprises this familiar phenomenon on a staggering scale.

First attempts
Perhaps the first known attempt to utilize solar energy, in a manner similar to that of nature, was made in Chile, South America, where up to 19 000 litres per day were recovered from sea water flowing slowly over a channel having an area of 4 500 m^2. This plant is understood to have been operated from 1872 to 1912 (Taylor 1975). In 1938, C. G. Abott took a patent of 'solar distilling apparatus' in the USA. With slight modifications, W. S. Barnes took another US patent of 'solar water still' in 1945 (Girelli 1965). At the moment, solar stills operate in a number of countries, notably, Australia, Greece and Tunisia. Most of these stills have been installed within the last decade.

Kenyan experiments
The first experimental solar still in Kenya was set up at Kilifi during the 1950s.

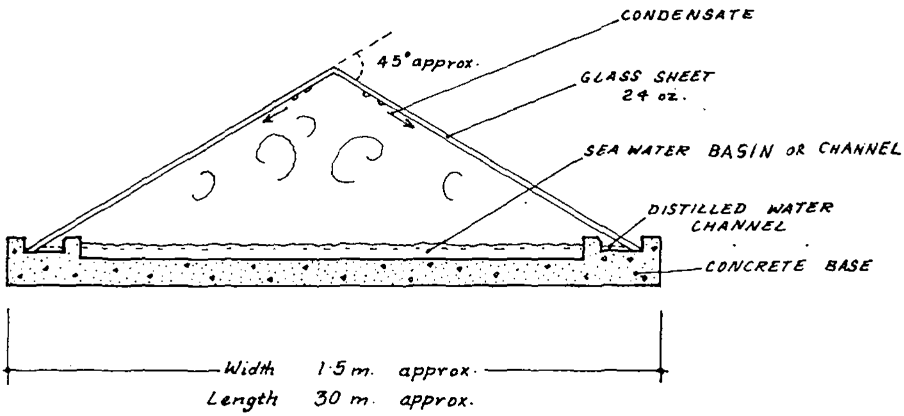

Figure 1. Solar still—section sketch.

The general principle of the working of this unit is the same as adopted in earlier attempts elsewhere and is illustrated in figure 1. Sea water charged into a shallow basin is evaporated by the sun's rays and water vapour condensed on the underneath of the glass sheets covering the basin. The glass sheets sloped laterally and deposited the condensate in fresh water channels running on either side of the sea water basin.

The Kilifi still produced a maximum of about 5 l/m^2 per day on clear days. A prototype used for Divisional Police Headquarters of Turkana was observed in 1959 to yield less than 2 litres per m^2 per day. This was not regarded as a success and the venture was dropped. Probable reasons for its poor performance are:

1. Inadequate temperature gradient between the evaporation trough and the condensing surface;
2. Loss of heat through the concrete base into the ground and through joints between cover plates, end plates and side walls;
3. Reevaporation of the condensate from the collecting channels.

Another experiment was carried out, some 10 years ago, at Lodwar using synthetic sheets in place of glass. The maximum yield was observed to be about 9 litres/m^2 per day. It was roughly worked out that overall cost of water from a plant producing about 5 m^3 per day was nearly Ksh 5.80 per 1000 litres, assuming 20 years economic life, 3% rate of interest on capital and 1½% of capital cost to be required for maintenance and repairs.

General principles

Distillation is not only the oldest, but in terms of established plants also the most productive of the processes of obtaining fresh water from saline waters. In fact, over 85% of the world's installed desalting capacity is based on distillation

(Taylor 1975). In this process water passes through the vapour phase and this distinguishes it from other processes. Performance of an evaporator plant is reckoned in terms of heat required to produce unit quantity of distillate. This is known as 'specific heat consumption' expressed in the number of kilocalories required per kg of distillate. Distillation plants generally perform well in this respect if proper care is taken for heat-transfer and heat-recovery in the system.

Solar energy can be more efficiently harnessed by the use of one or several of the following measures:

1. Focusing sunlight and heat waves by mirrors and/or lenses on thin sheets of water;
2. Arranging such mirrors or lenses to follow the position of the sun in the sky for several hours of the day;
3. Insulating the structures and tightly sealing the joints to prevent heat loss;
4. Absorbing heat over black surfaces to improve heat accumulation and transfer;
5. Preheating incoming water by heat of condensation, simultaneously cooling the condensing surfaces;
6. Preheating the feed to sea water channels from waste brine in a heat exchanger, thereby recuperating heat;
7. Screening the condensing chamber from the sun; and
8. Preventing reevaporation of distillate.

Application

The performance of a solar still depends more on available solar radiation than the mean ambient temperature. Wind has little effect on the process. The areas lying between the 30th and 40th parallels, both north and south of the equator, generally enjoy clear skies and are, therefore, more suitable for solar distillation than the areas nearer the equator. There are many isolated areas which are exceptions to this generalization such as the northeastern Brazilian state of Ceara lying between the equator and the 5th parallel where conditions for solar distillation are good (Taylor 1975). The best situations for the use of solar stills are where:

1. Fresh water is scarce or unobtainable, but saline water is available
2. Solar intensity is high and fairly uninterrupted
3. Population is sparse
4. Land is cheap
5. Fuel resources are meagre, and
6. Demand for water and energy is low, typified by absence of industry.

Such situations are frequently met on the coastal belts, in arid interior zones and over small islands.

Design features

The daily production of fresh water from solar stills varies from place to place and at the same place from month to month, and even day to day, depending mainly on available sunshine. The size of the still is often based on the average achieved in the least productive month. The area of the still can be worked out from the following expression (India 1975):

$$Q = 6.008 \times 10^{-3} \times S$$

where Q = output per 1 m^2 of still area in litres per day, and

S = insolation (i.e. total solar radiation, direct and diffused, incident on horizontal surface) in Langleys (i.e. gram calories per cm^2) per day.

The maximum level of insolation is commonly observed to be 600 gram calories per cm^2 per day. For successful operation of a solar still an insolation in excess of 300 gram calories per cm^2 per day is needed (Taylor 1975). Because of the corrosive nature of saline water, piping, pump impellers, etc., have to be such as to resist corrosion. Polyvinyl chloride (pvc) has very favourable properties for piping and stainless steel (although costly) is found suitable for impellers. Glass has often been used for still covers. Its high cost and brittleness have led to the search for a suitable plastic material which has not yet satisfactorily been completed, because prolonged exposure to sunlight has been found to affect the strength and/or transparency of plastics to a certain extent. Engineering considerations have to be given to operational details such as the provision of adequate slope for flow (1:50 to 1:100), a walkway for facilitating maintenance repairs and dust removal, proper sealing and insulation to prevent heat loss, etc.

Areas where solar distillation can be successfully applied are often attended by strong winds. The structural design needs to take care of this factor. Winds carry dust which can impair the performance of the solar stills by covering their covers and obstructing sunlight. Arrangements to keep the covers clear have to be thought of and provided. It is good practice to provide storage capacity considerably in excess of the usual for water supply system to balance the demand with the uncertainties of production from solar stills. The still covers are ideally suited for collection of rainwater falling over them. It has, however, to be ensured that such rainwater does not get into the fresh water storage without being properly cleared of suspended matter picked up from the surface of still covers and without being disinfected. Where rainwater is thus additionally collected it will be reasonable to adopt the average yield higher than the one expected in the least productive month, which is normally the wet month. Such an addition can be substantial as, for example, in an area of annual rainfall of 250 mm and assuming that at least 70% of it can be collected, the yield will increase by about 175 litres/m^2/annum which represents an increase of 17.5% over the average yield of 1 000 litres/m^2/annum expected from solar stills operating under field conditions.

Solar pond

The solar pond (fig. 2) is an artificial blackened bed pond, 1–2 m deep, in which convection is prevented by having a strong density gradient from the bottom to the top. The dense layer adjacent to the pond's bed is heated up and its temperature may rise even up to 96°C. The top layer remains near the ambient temperature. The hot layer near the pond's bed is extracted carefully without disturbing the remaining contents of the pond. The hot brine so extracted is passed through a flash evaporator. The water vapour from the evaporator is condensed by incoming sea water to produce the distillate whereas the concentrated brine is partly recycled and partly blown down. The cooling sea water is fed near the bottom of the pond together with the recycled concentrate. The top surface of the pond is flushed with sea water to correct for salt transfer by diffusion from the bottom and make up for surface evaporation losses.

Solar cells

Direct conversion of light energy into electrical energy is termed as 'photovoltaic' and the units employing this phenomenon are known as solar cells. The photovoltaic energy converters do not involve mechanical or heat energy. The maximum feasible efficiency for solar cells is of the order of 25%. The commonly achieved level is 11–15% (Wilson and Jones 1974). Solar cells

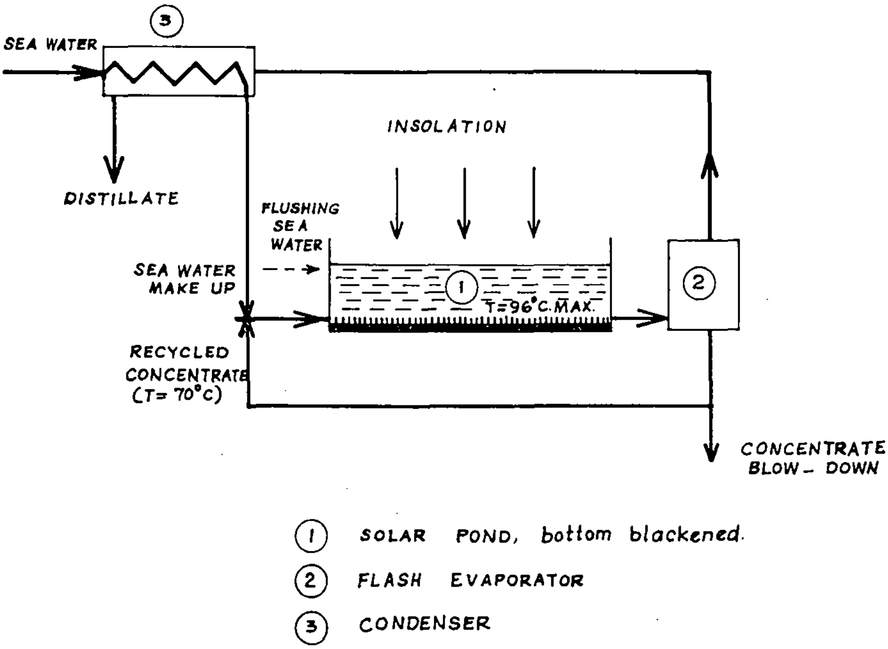

Figure 2. Diagrammatic sketch of a solar pond.

capable of generating up to 1 kW have been developed for space explorations. By coupling the solar cells with storage batteries, a continuous supply of electric power can be obtained. Solar cells have the additional advantage of being light in weight for the electric power produced and occupying very small volume, but their very high cost has stood in the way of their being employed in practice for anything other than space explorations where their advantages are especially favourable. The electric power generated with silicon-type cells costs nearly 8 times as much as it costs with cadmium-sulphide cells, even though the latter are only about 25% as efficient as the former. The electric power can be utilized for desalination in the usual manner. Flash distillation (multiple-stage) is particularly favoured in view of its low requirement of power.

Prospects in Kenya

With the exception of less than one-fourth of the total area, comprising the highlands in the west and centre and a narrow belt along the coast, Kenya receives less than 500 mm of rain a year (Kenya 1970). Several inland lakes—Turkana, Baringo, Magadi, etc.—have saline water. Scarcity of drinking water is, under these circumstances, experienced in a large part of the country which is arid, sparsely populated and industrially undeveloped. Provision of drinking water in such areas is expected to give relief to the population and stimulate economic activities. These areas enjoy bright sunshine for about 8 h or more per day throughout the year. Humidity is low. Relative humidity seldom exceeds 70% in the morning and is almost always below 40% in the afternoon (Kenya 1970). Air temperatures run high, with an average daily maximum close to 35°C. During March-April, when sunshine hours are the minimum, the isolation is nearly 500 to 550 gram calories/cm^2/day.

The use of solar stills is clearly indicated in Kenya, as the conditions are so favourable, especially for small communities where brackish or saline water is locally available and good quality water from conventional sources is available at considerable distance, say in excess of 15 km. The cost of desalination depends on many local factors besides the size of the plant and the process adopted. A survey conducted in 1962 by the United Nations Department of Economic and Social Affairs revealed that numerous areas were paying very high prices for fresh water from conventional sources—prices of US $2.50 per m^3 were recorded in a number of locations (Girelli 1965).

The cost of desalination of water for primary domestic use was reported to range from a low of US $0.39 to a maximum of US $4.38 per m^3 (Girelli 1965). The survey included 61 desalination plants with a total installed capacity of 77 000 m^3 per day. It is not intended to suggest that solar desalination will save tremendous amounts of energy or will be economic in comparison with electric or fuel-driven units in all cases. The point to be made is that transport (by pumping or haulage) from distant sources of water and the desalination processes developed for relatively large-scale plants are likely to be surpassed by the simple solar still in terms of economy and practicability, for providing drinking water to the numerous small communities, isolated institutions, range management schemes, ranches, missions, police and army establishments, etc., in the arid areas of Kenya which lie in the north, northeast and the inland side of the coastal belt.

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TOWARD MORE EFFICIENT WATER USE FOR CROP PRODUCTION IN KENYA

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Abstract
Water supply and not land area is the major limiting natural resource for crop production in Kenya. The most important water resource is rainfall, stored temporarily in the soil and used *in situ* by the crop. Crop water requirement is largely determined by weather conditions prevailing during the growth of the crop. The relationship of crop yield to water supply with water limiting is complex and a simple proportionality is not always realistic. Rainfall regimes in Kenya can be classified according to the degree to which potential evapotranspiration can be supplied from rainfall and according to the seasonal distribution of the wet months which can be bimodal or monomodal. Drought escape is a useful plant breeding objective for bimodal rainfall regimes but drought resistance, suitable for monomodal regimes, presents a more complex breeding problem. Generally crop management for high yields per hectare will also serve to maximize water-use efficiency. The greatest water-use efficiency in irrigation is often theoretically achieved by using less than optimal water over large areas of crop, though this approach is usually more costly for other inputs.

Introduction
The major limiting resource for crop production in Kenya is water and not the area of suitable land. Thus 72% of the land area receives less than 508 mm of rainfall in 4 years out of 5 (Griffiths 1972) and therefore cannot be used for crop production except with special techniques to concentrate rainfall onto smaller areas of cropped land or with irrigation. Nevertheless, crop yields are usually reported on a yield per unit area basis and rarely on a yield per unit of water. It will be shown that this is not too important an omission because the theory of assessing crop water requirements is well advanced and because improvements in yields per unit area usually also imply better water use. In order to grow a metric ton (tonne) of maize, at least 500 tonnes of water are required and for a tonne of wheat, the figure is nearer to 1 000 tonnes of water. Therefore, it is usually more feasible to grow field crops using rainfall that falls *in situ* rather than transporting these large quantities of water for use in irrigation. The major water resource for crop production in Kenya is therefore rainfall, which is stored temporarily in the soil profile and used *in situ* by the

crop. The efficient use of this resource requires an understanding of how crop water use is determined and how it can be 'matched' with rainfall.

Theory of crop water requirement

Of the water taken up by the roots of plants, by far the greatest quantity (at least 95%) is rapidly translocated to the leaves from where it evaporates to the atmosphere. Only a very small proportion is required by the chemical machinery of the plant or for cell hydration. Provided that the roots are located in moist soil, most crop plants are able to take up water at a sufficient rate to maintain growth under the atmospheric conditions to which they are adapted but if the soil becomes dry, this is no longer possible. The immediate result is both a reduction in photosynthesis because the stomata close and a reduction in cell division and growth because the plant tissue experiences a reduced water potential so long as water tends to evaporate more rapidly than it can be replaced. One or both of these will make inevitable a reduction in the capacity of the crop plant to develop its full yield and when carried to the extreme may cause the premature death of the plant.

Since it is difficult and usually unnecessary in practice to distinguish between evaporation of water direct from the soil and from the leaves, the two are usually combined in the term 'evapotranspiration'. The potential evapotranspiration E_t is therefore defined as the rate of evapotranspiration from an actively growing crop, of which the leaves completely cover the ground. Whether it is maize or potato or even forest or grassland is largely irrelevant provided that it has sufficient water and covers the ground. Many attempts have been made to estimate E_t from data normally collected at meteorological stations. The simplest approach is the evaporimeter pan, which is an open tank from which the evaporation of water can be measured with a correction for the addition of water by rainfall. Although widely used for practical irrigation scheduling, the pan is subject to rather unpredictable errors. Dagg (1969) was sceptical of the usefulness of pans under East African conditions. Of the many equations that attempt to relate potential evapotranspiration to weather elements, the most widely applicable is probably that of Penman (1948) or one of its subsequent modifications. As originally proposed, and still widely used, the approach was to estimate the evaporation from a water surface of large extent E_o for which data on radiation or sunshine duration, air temperature, humidity and windspeed are required. From E_o, E_t is empirically determined by:

$$E_t = fE_o$$

where f usually has a value between 0.6 and 1.0. In practice, the equation is usually used for periods of 7 to 31 days and the inputs are the means for the weather elements for the period in question. Woodhead (1968) gives estimates of Penman's E_o for many meteorological stations in Kenya.

Crop water requirement in relation to photosynthesis

The question 'Why do plants need so much water?' seems most satisfactorily answered by an understanding of the interrelated nature of transpiration and photosynthesis. The evolution from the aquatic to the terrestial habitat is still taking place and so far has been unable to provide plants with a system of absorbing carbon dioxide for photosynthesis without at the same time losing water from the large area of most tissue which must be in contact with the atmosphere. There are major differences in carbon assimilated per unit of water transpired between plants such as maize and sorghum which use the C4 pathway and the less efficient C3 species (Black 1971). These arise because C4 species use approximately the same quantity of water per unit time but fix up to twice as much carbon. There are major technical problems in transferring C4 characters to C3 species because of the lack of variation within species (Moss 1971) and the anatomical and biochemical chaos which results where hybridization is possible (Bjorkman et al. 1971). For the time being it is more fruitful to improve existing C4 species for other desirable characters and thus to use their improved water-use efficiency. CAM plants (Ting 1971) are potentially even more efficient but the only crops that have this type of photosynthesis are sisal and pineapple.

The appreciation of the interrelationship of photosynthesis and water use is essential to the understanding of the limitations of crops in low rainfall areas. There is a popular assumption that there must somewhere be a food crop that can be grown in these areas, if only the crop scientist would look a little bit harder. However, there is a severe limit to what conventional crop science can do to solve the problem. Improvements in crop production in dry areas (say less than 600 mm annual rainfall in Kenya) are possible by conventional means but they will inevitably be small, and the problem of erratic rainfall will remain. This is not the fault of the crop scientist. Until such time as research in the pure sciences offers practical solutions to the problem, the crop scientist must not be afraid to say that there is simply no prospect of a given area being able to support the projected growth of its human population in a bad year and to put the reality of this situation squarely before the politicians and policy makers. The situation is exactly comparable to that operating in the dry rangelands as acknowledged by Pratt and Gwynne (1977:40). Neither crop science nor range science can do more than offer a breathing space within which the problems of human populations must be faced. Any final solution lies in untying the knot between photosynthesis and transpiration and the probability of availability of such a solution is not high.

Crop water requirement in relation to crop duration

Because E_t per day is so little dependent on the crop, the total water requirement of different crops is largely a function of their duration. Thus an early maturing crop requires less water in total, not because it uses less per day but because it requires water for fewer days. The matching of crop duration with the rainfall season is the key to high and consistent yields in areas with poor rainfall and therefore to the efficient use of water in these areas.

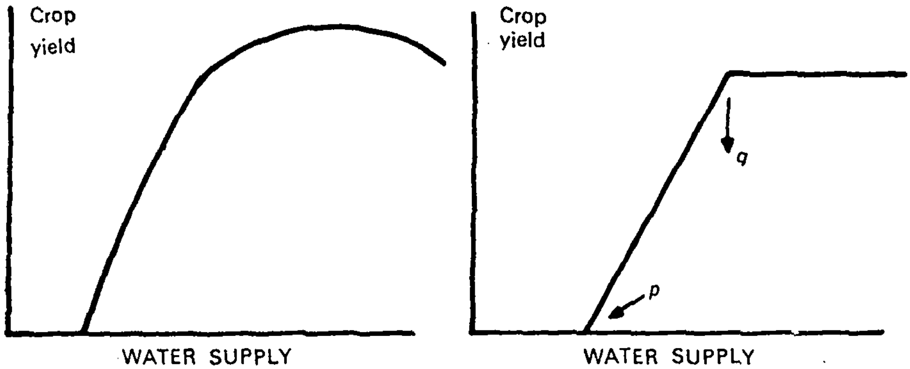
Crop yields with less than optimum water

Provided that adequate water is available at all times of the crop's life to supply E_t, the water use is estimated by E_t accumulated over the growing season and the yield will depend on other factors such as the genotype of the crop, the inherent fertility of the soil, the weather factors other than those determining the water balance and management factors such as timeliness, weed, pest and disease control and fertilizer use. If water is inadequate to supply E_t, then actual evapotranspiration E_a will inevitably fall below E_t and if this condition is sustained, yield will suffer. This is the situation where water supply is limiting. An excellent and worldwide review of the many attempts to relate crop yields to water supply is given by Stanhill (1973). Perhaps the most successful depend on the principle of water budgeting, where the input of water by rainfall or irrigation is compared with the loss of water by evapotranspiration during short periods (4–15 days) through the life of the crop. A reservoir of limited capacity is considered to be available from soil moisture storage so that excess water from one period can be stored until a later period in which rainfall is deficient. It is of vital importance that such water budgets take account of the bad years as well as the average years.

To calculate a water budget is fairly simple; the yield which will result from a given relationship of supply and demand is usually the greater uncertainty (Fisher 1974). De Wit (1958) has suggested, and subsequently many have used, a simple relationship in which the ratio of actual yield Y_a to potential yield Y_p is equated to the ratio of actual to potential evapotranspiration, accumulated over the growing season:

$$Y_a/Y_p = E_a/E_t \quad \text{or} \quad Y_a = (Y_p/E_t)\, E_a.$$

This seems to work very well where the yield that is important is the total production of the above-ground parts, as in herbage production. It may also work for seed crops where the discrepancy between supply and demand is evenly distributed through the growing season. It works for wheat in the N. Negev and Lakish region of Israel but not in the Bet Shean Valley and the Jordan Rift (Shalevet et al. 1976). It certainly does not give a satisfactory prediction for maize in conditions such as those which apply in the Eastern Province of Kenya where, in a poor season, the crop may receive reasonable rainfall for perhaps 20 days but is then subjected to severe drought and fails to produce a cob. Under these conditions, even a ratio of 54% for E_a/E_t results in zero maize yield (Fisher 1974) instead of the 54% of potential yield predicted by the de Wit assumption. Conceptually, the relationship appears to be some-



Figures 1 (left) and 2. Conceptual relationships of crop yield with water supply.

thing like what is shown in figure 1 which can for practical purposes be approximated by the step function of figure 2.

The crucial requirement is to put values on these axes for the various crops and varieties, but there is very little information available for Kenya. According to the de Wit assumption, the intercept (point P of fig. 2) is located at zero. For maize in the Machakos area, the intercept using 3-month rainfall has been estimated as 175 mm for an extremely early maize (Taboran), 215 mm for the local medium maturity maize (data of Dowker 1971) and 203 mm for Katumani Composite B (Fisher 1974). The minimum water requirement for maximum yield (point q) should coincide approximately with the accumulated potential evapotranspiration unless the rainfall is badly distributed so that water runs off or drains away. For the Taboran maize, it is about 320 mm and for the local type about 360 mm. An estimate for Katumani Composite B was 250 mm but this seems to be based on rather scanty data from unusual seasons (Fisher 1974).

A classification of rainfall regimes in Kenya

Rainfall regimes in Kenya need to be classified for crop production purposes according to two criteria. The first criterion is the degree to which the regime can be considered wet or dry. Probably the best index of wetness is the available water index (AWI) of Woodhead (1970) which estimates the percentage of the potential evaporation accumulated over the year which can be met from rainfall. It takes account of the possibility of excessive rainfall in wet months being lost to drainage below the rooting zone. For the purpose of annual crops as opposed to rangeland it is convenient to use an average value of potential evapotranspiration E_t and $2/3E_o$ is suggested. Otherwise the calculation is as in Woodhead (1970). AWI is a continuous variable and any number of categories could be defined according to the purpose for which the classification is required. For present purposes, I shall simply consider a regime with AWI $> 60\%$ as wet and one with AWI $< 60\%$ as dry. The second important criterion is the seasonal pattern of the rainfall; there are two basic regimes in Kenya, one with

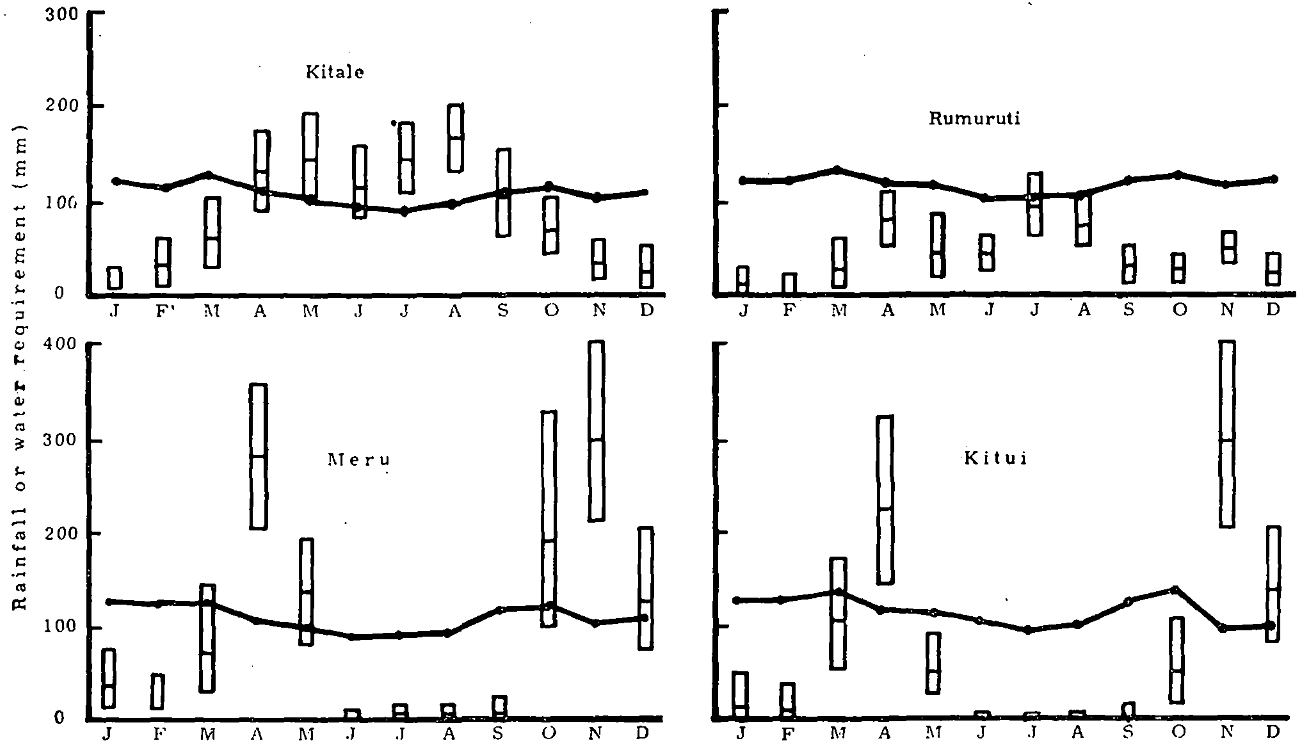


Figure 3. Rainfall regimes and water requirement: wet monomodal, Kitale; dry monomodal, Rumuruti; wet bimodal, Meru; dry bimodal, Kitui. The upper and lower extremity of each bar represents R_{25} and R_{75} and the dividing line is R_{50}. Water requirement shown as a graph is 2/3 E_o, according to Penman as given by Woodhead (1968).

Table 1. Examples of the classification of rainfall regimes for crop production in Kenya

Category	Wet monomodal	Wet bimodal	Dry monomodal	Dry bimodal
Example	Kitale	Meru	Rumuruti	Kitui
EAMD ref. no.	88.35008	89.37000	89.36001	91.38000
E_t from	88.35001	*	89.36001	91.38000
ΣR_{50} mm	1 020	1 174	503	883
ΣE_t mm	1 283	1 280	1 373	1 351
Drainage mm	100	299	0	152
AWI%	72	68	37	54

R_{50} is the rainfall likely to be exceeded in 50% of years. It is usually less than the arithmetic mean. Maximum assumed soil moisture capacity is 100 mm.
*Interpolated between Kathiga (90.37038) and Nanyuki (89.37022) assuming linear relationship between monthly E_o and altitude.
$E_t = 2/3\ E_o$ (Penman) in all cases and E_o is from Woodhead (1968).

a single long rainy season each year, situated mainly within and to the west of the Rift Valley and at some parts of the coastal strip, and the other with two much shorter seasons to the east of the Rift Valley (see map of Griffiths 1972). The latter could be subdivided into one regime where the April rains are heaviest as around Nairobi and another where November rain predominates as in many parts of Eastern Province.

Table 1 and figure 3 give four examples of regimes typical of the four categories now defined. Kitale, a wet monomodal regime, has R_{50} in excess of E_t continuously from April to August with September above the requirement in almost 50% of years. This gives a 6-month growing season, ideal for long-maturing maize genotypes. The dry monomodal regime is represented by Rumuriti, which has no month in which R_{50} exceeds E_t though July comes quite close. The period April to August is wetter than September to March. With rather dry intervening months of May and June, this regime requires long-maturing genotypes of a drought-resistant crop. The water-use pattern of late-maturing sorghums (Kowal and Andrews 1973) with its peak late in the crop's life is ideal for this environment. Maize has insufficient drought resistance. Wheat is useful at higher altitudes with a bare fallow to conserve and store rainfall falling before planting (Poulsen 1973). Although the annual AWI is only 37%, this monomodal regime has some advantages for cropping purposes over a bimodal regime with similar AWI because the probability of complete failure is much lower in the long though somewhat intermittent season.

Meru with AWI = 68%, typical of the wet bimodal areas, requires a very different type of crop production system from Kitale because early maturing crops are required and are planted twice each year. Medium maturity maize, potatoes and beans do well. Unlike Kitale, there are several months each year when rainfall is considerably in excess of E_t which means that measures to prevent runoff and conserve moisture for the drier months are essential if efficient use is to be made of rainfall. The variation of rainfall in the wet months is also greater at Meru than at Kitale. The growing seasons are from around the middle of March (the actual date varies from year to year) to June or July with the crop using stored water in the later months and from mid-October to January or February. The regime at Kitui is very similar except that the season is even shorter with only one and two months in the April and November season respectively when R_{50} exceeds E_t as compared with two and three months at Meru. In this environment, the variation from year to year in the rainfall occurring in each season is critical. Any assessment of crop production potential needs to take account of the bad year as well as the average one. Very early maturing crops are essential such as Katumani maize, early sorghums and millets and early cowpeas or beans. An alternative strategy is to plant long duration crops in October or November, to be harvested after the April rains. Not many crops can withstand the drought except pigeon peas and cotton which become quiescent during February and flower and fruit after the April rains. The long dry season from June to September effectively prevents this strategy from being applicable to April-planted crops.

Drought escape and drought resistance: the breeding problem

A drought-escaping crop is one that is capable of developing at such a rate that by the time the rains end, it has completed those developmental stages that are most sensitive to water stress (Salter and Goode 1967). The theory of drought escape in Eastern Province has been well described by Dowker (1963 and 1971), Dagg (1965) and Russell (1968). It requires a combination of a genotype of suitable duration with optimal management practices, particularly early planting and timely weeding. Inevitably, an early maturing genotype has a lower potential yield, though it may realize this potential more frequently. Even with these, the chance of complete crop failure for maize in the Eastern Province is by no means negligible (Fisher 1974). The main reason for this is the very considerable year-to-year variation in the duration of the rainfall season as is apparent from figure 3.

The strategy appropriate for monomodal regimes within which short dry periods may occur requires drought resistance as opposed to drought escape. The duration of the crop is still important because too early a maturing crop will not develop the maximum possible yield. Emphasis also needs to be placed on the crop's ability to maintain high yields even if subjected to a number of weeks of drought during its growing season. The most useful feature is a deep and intensive rooting habit for maximum exploitation of the soil moisture reserves. Characteristics of drought resistance in the ecological sense, other than deep rooting, are not necessarily of value in crop plants because they almost invariably require a reduction in photosynthesis and cellular growth in order to conserve water. They may ensure survival but they do not necessarily ensure production. Drought resistance is a far more complex characteristic than drought escape and is not yet satisfactorily defined in the crop (as opposed to the ecological) context. It therefore represents a far more complex plant breeding problem than does drought escape and the only sure solution at present is simply to breed for high yield under drought conditions.

It is frequently suggested that the ideal plant for dry areas would be both drought escaping and drought resistant. There are however major practical objections to combining the two. This is because most drought resistance mechanisms require some quiescence during dry periods with good ability subsequently to resume growth and development without permanent injury. In contrast, the drought escape mechanisms require the rapid completion of the plant development and there is no value in quiescence unless rainfall is resumed before death occurs, an unlikely event in the bimodal environment. Even an improved rooting habit is not altogether compatible with drought escape because it necessarily requires the greater diversion of resources into the roots, a situation which may be tolerable in a long duration crop but is quite serious in a short one. A more fruitful policy is to examine the rainfall regime in each area and then to breed for that strategy which is best suited to the regime. This was done by Dowker (1963) for Eastern Province and has resulted in the Katumani Composite series of drought-escaping maize varieties, which, though they still fail occasionally, represent a big improvement for the Eastern Province farmer over any maize available to him before 1965.

Water-use efficiency and crop management

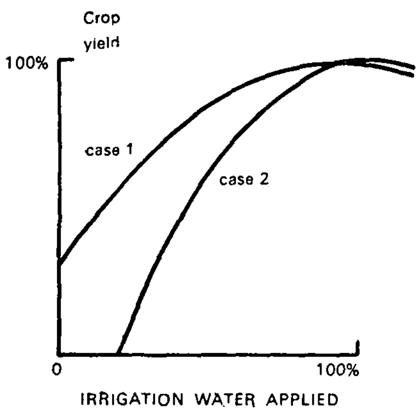
As a broad generalization, good management increases yield much more than it increases water use. This follows from the physical nature of water use because the crop will transpire near to its potential limit irrespective of management, but much can be done to increase yield. This is illustrated by wheat data from semi-arid USA where yield and water use were measured over a range of nitrogen fertilizers (table 2).

Table 2. Effect of nitrogen fertilizer on yield, water use and water use efficiency of wheat

Fertilizer	kg/ha	N	0	62	268
Grain yield	t/ha		1.41	3.06	3.67
Water use	mm		250	300	345
W.U.E.	kg grain/t water		0.56	1.02	1.06

Source: Brown (1971).

The highest rate of fertilizer increased yield by 160% but water use by only 38%, giving a considerable gain in water-use efficiency. The higher water-use efficiency applies equally if an improved variety of comparable duration is substituted, if weeds, pests and pathogens are controlled, if timely planting is observed and if optimum plant densities are used. Because timeliness is so important, improved technologies to enable small farmers to prepare their land before the rain begins and to weed rapidly and effectively are vital complements to the new varieties now becoming available. For maize in most parts of the country, the important improvements are early planting, early weeding, phos-



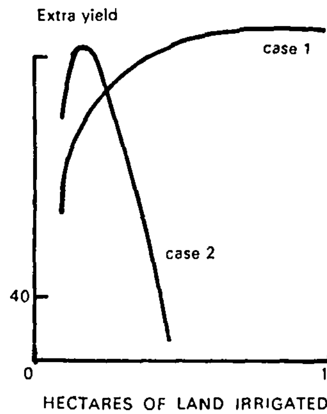


Figure 4. (left). Response of yield/ha to irrigation water applied.
Figure 5. Effect of irrigating larger areas with a fixed volume of water.

phate fertilizer and nitrogen fertilizer in that order. Although optimum plant densities are important for pure stand maize, much of the crop is grown in mixture where less than the recommended density can give higher total returns if combined with suitable densities of the interplanted crop (Fisher, unpublished data).

The efficiency of water use for irrigation

Irrigated farming differs from rain-fed in that both water supply and yield are to some extent under human control. Nevertheless, the most important principle remains that of doing everything possible to maximize yields per hectare because this usually implies maximum water-use efficiency. The only exception would be to accept some yield reduction in order to spread limited quantities of water over a greater area of land. Figure 4 shows possible yield-water relationships. The situation for supplementary irrigation where some yield can be realized using only rainfall is shown by case 1. Where this situation applies, the greatest efficiency of water actually applied to the field is always achieved by spreading the water available over a greater crop area than that which could be irrigated if optimum water were used on limited land. A diminishing return does however set in (fig. 5) and in practice inefficiencies associated with developing larger land areas for irrigation will mean that a compromise point must be reached. Small-scale inexpensive irrigation schemes for stabilizing crop yields in areas of erratic rainfall could certainly make use of the principle of a little water over a large area. Case 2 is the situation where the majority of the crop's water is supplied by irrigation (as in the dry season) and a minimum application has to be made in order to get any yield at all. For the curve shown, intercepting the axis at 20% of the theoretical optimum water requirement, greatest efficiency is achieved by irrigating 1.9 ha of land with 53% of the optimum water which gives an increase in total yield of 23% over irrigating 1 ha with 100% of the optimum water.

These cases can form the basis of a discussion of water-use efficiency of Kenyan irrigation. The largest organized schemes are those growing rice at Mwea and Ahero. Rice is something of a special case because it does best with complete flooding for most of its life cycle. It is therefore an extreme example of case 2. It is unlikely therefore that there will be much benefit from spreading the water over large areas. Otherwise the most important irrigated crop is coffee. Except at the margins of the coffee areas, where trees would die in a bad year without irrigation, case 1 applies. Coffee estates with limited water available, unless at the margins, would reap greatest benefit from spreading the water over as large an area as possible. The yield response in coffee shown by controlled irrigation trials is not at all dramatic. Vegetative growth is certainly improved but not necessarily yields (Fisher and Browning, in preparation). It could well be that many coffee growers are irrigating because the trees appear droughted but are not in fact getting much yield response, or could get their response using much less water, more strategically.

Irrigation of vegetable crops either for the urban fresh markets or for export by airfreight is becoming increasingly important. For these perishable products, growers with irrigation aim to produce in the dry season when prices are good or to meet the requirements of the winter market in Europe. For dry season production, case 2 would almost certainly apply and the area of vegetables may well be limited by water supply. In addition, the maintenance of quality standards, especially for export, may require near optimum water supply on limited areas.

Major irrigation development is envisaged for the lower Tana Valley. The rainfall is low so that for most crops, case 2 will apply and near optimum water will be needed on fairly small areas. Nevertheless, there is a tendency in irrigation design to assume rather uncritically that greatest water-use efficiency is achieved by optimum irrigation of small areas. It is important that in the economic appraisal of such developments, the alternative of spreading the water available over greater areas be at least examined. It may be that the long-term economic optimum is somewhere between the biological optimum of say 60% of the theoretical water requirement on 167 units of land and the minimum cost solution of 100% of the water requirement on 100 units of land.

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WATER AND RURAL DEVELOPMENT

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Carruthers says, 'Improved water is not a sufficient input to ensure any benefit except the obvious amenity benefit' (Carruthers 1973). He thinks that a mix of factors is required. 'For all other benefits complementary inputs are essential.' We can agree that this is usually the case and that the benefits assumed to follow in health and agriculture frequently have not occurred (White, Bradley and White 1972). But we must not bend so far in the new direction that we need prolonged physiotherapy to regain our balance.

This was brought home to me whilst collecting information last November in Embu District (Scotney 1976). Kyeni Sublocation has an extensive water supply reticulation and over 1 200 individual connections. At the higher end near the Mount Kenya forest reserve, in the tea and coffee growing high-income area, the most obvious benefits are the amenity benefits. Perennial streams have always made good water reasonably accessible. At the lower end, which would not have received its few communal water points and individual connections but for the revenue expected from the high-income area, the results were striking. Five years had seen a revolution. Firstly, people have moved in and population has increased so that attendance to Kasafiri Primary School has quadrupled. Secondly, large areas of bush have been cleared for cultivation—principally maize and beans. *Matatus* ply the feeder roads. The price of land—if you can get a piece—has risen steeply. By contrast, the adjacent sublocation, Gichera, just across a shallow valley, continues as before. Cattle and goats wander through the unimproved bush. Poor traditional-type houses are widely dispersed and the basic subsistence level of the people is obvious.

It is not soils and rainfall only which have encouraged rapid development in this section of Kyeni. The economic advance, especially through coffee receipts, the resourcefulness and optimism of the Embu people, the continuing educational influence of schools, churches, political and local leaders are all factors in the development of Kyeni, but all are equally available for Gichera. The most obvious difference is that the difficulty experienced in obtaining any reasonable quantity of water in the dry season has largely been removed in the Kyeni case. In the whole area there is no tradition of well digging, and roof catchments are unknown; that is, alternative sources have not been explored or utilized. When certain preconditions are met it does seem, contra Carruthers, that water can act as a catalyst that precipitates development. Can we distinguish situations in which water improvement can bring benefits greatly exceeding outlay?

The *absence* of readily available water right through the year seems to be one of those preconditions. In that case when the Ministry of Water Development, selects 'high potential, medium potential and low potential' (Kenya 1976) areas solely on the criterion of rainfall it is looking in the wrong direction, unless it is using 'potential' to refer not to development but to revenue collection! 'Readily available water sources' indicates that only limited change will occur if there is introduction of piped or other improved supplies. For *development* potential attention must be directed to areas handicapped by limited water resources. Hence the impetus leading to irrigation schemes. A second precondition for disproportionate benefits to follow water development is the way of life, attitudes, capacity for initiative and innovation of the people involved (White, Bradley and White 1972). The man who has made a precarious investment in grade cattle will desire adequate, readily available water of good quality. But what is to be done for the man who wants water for his seed bed or shamba? In Kyeni and elsewhere I have found some of the most energetic and forward-looking *wananchi* were secretly and, of course, 'illegally' using piped water for vegetable gardens and high quality crops.

A water authority must at some stage direct its attention to areas of economic difficulty. Some may prove to be the very areas where cost-benefit ratios will be most satisfactory. Secondly, a resource of value, though often overlooked, is the attitude of the people. In these same areas the community response may be so important that with local support more can be accomplished quickly and at low cost than anywhere else. But we have to be able to both assess possible community response and to work with it. There is an insidious danger in using phraseology which implies that 'the government' or 'the ministry' is 'providing' water for people. We all know where water originates! But such expressions tend to obliterate considerations of payment. People recognize, or should recognize, that they either pay directly or pay indirectly through government revenues. Secondly, such expressions make a false distinction between people, that is citizens, and their government, the instrument they have endowed with authority to serve their needs. No country can afford to encourage passivity in its citizens. Kenya in its watchword *harambee* is committed to the opposite policy.

Questions of payment and of citizens' responsibilities become urgently relevant when the enormous and widening gap between water supply revenues collected and increasing recurrent costs is appreciated. VIAK (1977), in its evaluation report, mentions: 'In only two of the twenty-three schemes studied in the Rift Valley does the revenue due have the potential to cover the direct Organisation and Maintenance costs . . . . Thirteen of the Rift Valley schemes have the potential of recouping less than twenty per cent of the direct O and M costs in revenue due.' Even under the most favourable circumstances, to meet both capital and recurrent costs on present schemes would require water charges for individual connections of not less than sh 39 per month. No conceivable overseas or other assistance can obviate the need for involving people in the improvement of their water supplies. The relevant question is: How can people play their part in the planning, the work and maintenance of water supply provisions, and how can they be educated to use water conservatively and effectively? To have some responsibility for care of equipment and for payment according to their ability to pay are, alike, essential.

At present the Ministry of Water Development is seen by many people as an outside agency making decisions from its own purely technical and often incomprehensible information. It is also seen as promising much but frequently failing to provide supplies as reliable as traditional sources. Nevertheless, people have dug trenches for pipes, made *harambee* collections and also advance payments. Sometimes their disappointment has been intense. Why must they make further payments when the supply is unreliable? Why, having paid for a pipe from the road to his shamba, does the farmer, in time, discover that until it crosses his boundary the pipe is not his; that he has, in fact, made a present to the government? These and many other sources of misunderstanding and frustration can be resolved only if there is a very different relationship between staff of the ministry and *wananchi*. Retraining of staff is essential. (Most would welcome an opportunity to move towards community cooperation and respect.) Even more important is an approach towards community involvement and cooperation in water planning and water improvement, that is a change of methods in water supply. Fortunately, there is an example of this method from another part of the world. In Colombia the Ministry of Health has since 1972 been developing a system where after discussions and consultations the community and ministry enter into a contract, the ministry providing the water in bulk and other assistance, and the community accepting all other responsibility (Instituto Nacionâl para Programas Especiales de Salud 1975).

In Kenya the first necessary steps may be to adopt a more comprehensive approach to water provision. In all countries in the world, wells play a part. Rural families prefer a hand pump to a long walk with a *mutungi* or *debe*. For many, a piped supply is an economic impossibility. The trend towards hygienic permanent houses follows the choice of *mabati* roofs. *Mabati* roofs (corrugated iron sheets) prepare the way for a run of gutters and a low-cost storage tank. PVC-lined catchment tanks and basins, windmills, hydraulic rams and other technological innovations are opening a new world of possibilities (Burton 1973). An addiction to pipes and expensive diesel-driven pumps will prove a debilitating habit. People want to be involved in, and to have some control over, their own water supplies; they want to be consulted, participate in and share responsibility for those amenities that affect their daily lives. A great opportunity is in danger of being lost. 'Development', if it is to have meaning, must be development of people. People learn by doing, cope with responsibility by being handed responsibility. Working together with people in the *harambee* spirit we can help them to achieve a better way of life. Friendly cooperation, by pooling our knowledge and experience with their initiative and will to progress, can accomplish more than any divided effort. Costs will be manageable—benefits continual.

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A CATALYST FOR THE IMPLEMENTATION OF SELF-HELP WATER PROJECTS

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Abstract
CARE has found that its position as an international private voluntary agency has enhanced its ability to coordinate with the government and the people in the self-help effort. This can be seen from CARE's ability to coordinate with the various ministries as well as to encourage the people of a community in their self-help efforts. CARE hopes to instil in the communities it assists a pride in their project so that they will continue to maintain it. CARE tries to act as a catalyst between the government and the community to see that the community receives the proper guidance and assistance in implementing the scheme. CARE could not have this ability if it were not for the cooperation and commitment of both the local leaders and the government to see that these projects succeed. So we would like to emphasize that this effort to assist self-help water projects has been a joint one and we hope it will continue to grow and progress in this pattern.

Introduction
The purpose of this paper is to explain the role CARE (Cooperative for American Relief Everywhere) has played between the government and communities in developing their capabilities to both implement a scheme and see that once it is installed it is maintained by the community. Also because of the fact that CARE projects are located in various parts of the country, we have learned many lessons about self-help activities as they particularly relate to these areas which may be useful to those trying to assist self-help projects.

CARE as a coordinator
Since 1975 CARE has been working closely with the Ministry of Water Development in its efforts to assist these schemes. The Ministry of Water Development provides CARE with all survey and design information on the schemes CARE plans to assist. Over the last 2 years CARE has managed to begin coordinating efforts between the Ministry of Water Development, the Ministry of Housing and Social Services and the Ministry of Finance and Planning in order to improve CARE's capabilities of identifying self-help water projects. CARE has chosen to work with these three ministries because they have the necessary

initial information CARE needs before it visits a project. The Ministry of Housing and Social Services is directly responsible for seeing that the self-help input actually does exist in these schemes. The community development officer and his assistants are responsible for assisting with any organizational difficulties a community might have upon embarking on such an effort. They also keep records of the self-help labour and cash raised for materials by the community. The Ministry of Finance and Planning, through its provincial planning officers, know which schemes have been approved by the district development committees (DDCs), for instance. Usually these officers can provide CARE with sufficient information to begin inquiries into a project. This coordinating effort has been done on the provincial level mainly because the officers there are aware of the projects which have been designed and those which have requested additional assistance from government implementation. A list of such existing projects is worked out in each province approximately once a year and then CARE can begin its selection process.

CARE site selection criteria

It should be noted here that all district and provincial officials concerned with these ministries have CARE's initial selection criteria which are used to refer sites to CARE. These are as follows:

1. Each project must be a rural self-help water supply project primarily for domestic consumption.
2. Each project must be a government priority project, approved by the district and provincial development committees.
3. Each project must be technically feasible; that is, there must be a complete survey and design report, including drawings and materials list, approved by the Ministry of Water Development. The design report must contain all necessary technical data as well as take into consideration future growth of population, institutions, etc.
4. Community involvement is imperative. Each project must have a self-help committee and be registered with the community development officer. The committee should have collected funds, purchased materials, and initiated construction on the advice of officers of the Ministry of Water Development.

CARE's selection process is based on these criteria and follows from the initial discussions with provincial officers to the projects themselves. The CARE engineer visits a scheme with the Ministry of Water Development officers to determine if all design and materials information is correct. If this is the case the scheme is then visited by the CARE project coordinator to determine the community's organizational and self-help commitment. CARE basically has a strategy of assisting self-help water systems if they are financially viable because this generally increases the probability that the system will be used and properly operated by a community. In order to determine a community's financial viability, several factors are considered: self-help input in the form of materials, cash, labour, or land, and the agricultural potential of the area. The self-help input is considered in relation to the total estimated cost of the scheme. The agricultural potential is considered in relation to the existing infrastructure and design of the scheme. A project in a high potential agricultural area is usually designed in such a way that the community is expected to make a sizable input in labour, cash and materials. We would expect this project to have a well-organized management committee and for the community to be actively involved in the scheme. This is usually the case in many parts of Central Province, where communities have been implementing self-help water projects at an increasingly successful rate. In many of these projects, one finds a management committee that has established a membership fee system that all members pay to the scheme. This membership fee assures the member that once the system is installed he will have the right to connect pipes to his home. The fee is used to purchase major capital items for the first or second phases of the scheme. *Harambee* fund-raising meetings are held in these areas as well; however, the main means of raising capital revenue is usually the membership fees.

In a medium potential agricultural area the projects are usually designed more with accessibility in mind; in some cases the community is very well organized and in others it is not so well organized. If the community has made the initial efforts to begin the scheme and has not made a large cash input, CARE will still consider the scheme for assistance once the community has completed some structure. This is the case in many settlement areas and in a few marginal areas where most projects hold *harambee* meetings in order to raise funds for the scheme. The self-help labour input is usually larger than the cash input, but the community is willing to hold as many *harambee*s as necessary to complete construction of the scheme. In some of the other medium potential areas where leadership has been a problem it may take a community a period of years to begin initial implementation of the scheme once the design is complete. CARE is willing to provide these communities with enough time to get the scheme under way. Usually if the community can finally manage to begin the scheme then CARE can provide it with some assistance.

In many low potential areas the community is dependent upon members of the community living outside of it to contribute to the scheme. In a place like Kitui, CARE would expect any cash or labour effort made by a community to be quite small. However, if the community shows enough interest and makes an effort to implement the scheme then CARE will consider assisting the scheme. Many schemes in areas like Kitui or Narok are dependent upon the DDC and organizations like CARE for most of the cash/material input. The community is willing to provide all labour and if they can show how they can pay for the operating costs then CARE is willing to consider assisting the scheme. Of course even with a self-help water project people in dry areas will still have to travel some distance to get water, but it will be more accessible than it presently is.

Capital per capita cost

This knowledge of the areas being served by a water supply is also related to the estimated capital per capita cost of the scheme. Most of the projects assisted by CARE have a capital per capita cost ranging from Ksh 16 to 240. This capital per capita cost is used in relation with the agricultural potential of the area to determine the financial viability of the scheme. If the scheme has a low capital per capita cost then the community has a very good chance of completing implementation of the scheme. A high capital per capita cost is usually found in areas where the agricultural potential is high and the communities can afford to make sizable inputs in the scheme.

Implementation process

The CARE project coordinator visits the scheme with the community development officer who works directly with the project committee. The committee's ability to organize and operate the scheme is assessed according to the aforementioned criteria. If CARE decides to assist the scheme then the implementation of CARE materials begins. The implementation process is a combined effort between CARE, the Ministry of Water Development and the Ministry of Housing and Social Services. CARE orders all materials requested and delivers them to the site. Then the CARE engineer works with the district water officer and the community development officer in order to see that the implementation of CARE materials proceeds in an orderly fashion. The district water officer provides all technical advice and supervision to the project committee, while the community development officer and his assistants see that the self-help labour element is present. In many instances the community development assistants work with the local administration, chiefs and subchiefs, in a combined effort to see that all CARE materials are installed.

Once CARE materials are provided to a scheme, CARE's role with the community does not end. CARE continues to visit the scheme to offer it encouragement and tries to assist the scheme if there are any problems in its operating process. CARE encourages these self-help water projects to set up a fee system in order to raise revenue to pay for operating costs. Different methods are used to collect these fees. In some of our projects, for example, where there are communal water points a charge per *debe* of water of 10 cents is collected. At other systems with individual connections, families pay Ksh 10 to 15 per month. In other areas near Nairobi, meters have been installed by the residents and they pay the management committee a fee each month. Most project management committees modify their rate charge system as they get more members and have to pay for diesel or oil. In the case of gravity flow systems, which are usually quite large, a set fee is established for all consumers to pay monthly. The CARE engineer makes frequent visits to the projects assisted to see that they are still operating and that all equipment is being properly maintained.

CARE also considers reassisting a scheme if the community has shown the initiative to continue working on the project. A self-help water project is a long-term investment, which CARE realizes, so if the community is committed to the scheme CARE will continue to take an interest in the project.

INFORMATION AND DOCUMENTATION, THE CHALLENGE OF THE FUTURE

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Abstract
This symposium again illustrates the enormous task that research workers are faced with, by the rapid evolution of the scientific world. More scientists in the world are constantly producing more papers, reports, publications data for the use of fellow researchers. It is already an avalanche—the information avalanche. But the danger exists that valuable information is not received in the third world because it is misdirected or is hindered by unnecessary expenses. An appeal is made to strengthen the information structures in libraries, archives and documentation centres at all levels.

Introduction
The attention given to the success of the East African Academy's annual symposia is a clear indication of the need of close communication between researchers and technicians in this area. We are aware that no one discipline can any longer look at a problem *ceteris paribus*, that is excluding other parameters of influences. Research has become a management task, where the environment of a project with all the influencing factors has to be carefully observed and taken into consideration. And here the real and frightening difficulties arise. How do we go about staking out the boundaries of influence of a project—how far, how narrow? Which are the influencing disciplines? What effect does a project have on its environment? What experience is already available? Has research on the same subject already been carried out? Where are data and information to assist and back up the given tasks? These are questions over questions having a definite influence on quality and success of a project. Nowhere in the world are these problems more pressing than in East Africa and the answers are not very far.

Factors influencing the problem
Since the beginning of the last century humanity has stepped up its evolution at a constantly accelerating speed. One of the factors and probably the most important one that sparked off this development was Gutenberg's invention of printing by movable letters in the 15th century. This opened the way for the distribution of ideas and expressions of the human brain in quantity never

before thought about. It enabled such scientific revolutionists as Galileo to tear down the walls of centuries of dogmatism. Communication improved rapidly through increased supply of information.

It is this newly discovered force of information of which it has been said that for the first time a non-physical but yet definitely measurable value was established as an element of nature (Ganzhorn 1969) or as the German physicist and philosopher C. F. von Weizsaecker put it: 'Today physics urges us to define three basic units: material, energy and information. Philosophically I tend to the supposition all three finally could be traced to a common root which by the name Information is still named markedly.' The fantastic progress of science and technology which began with the 19th century can easily be brought into combination with the improvement of information methods. And this is certainly true with the learned community. Whereas in 1850 the world had about one million scientists, this number had grown to 10 million by 1950 (Lutterbeck et al. 1972). Today we have to accept the fact that the number doubles every 15 to 20 years and by the year 2000 there may be 100 million. About 90% of all sientific workers in the history of mankind live today. What is even more important is their productive capacity. The annual output is awe inspiring. The greatest medieval library known held 1 500 books. The Lenin Library in Moscow contains 20 million and the Library of Congress not many less. At the beginning of the 10th century about 35 000 book titles were known. Now we have about 35 million, but other estimates go up to 75 million, even 300 million. About 100 000 scientific journals publish up to 20 million articles per annum. Whereas daily newspapers in 1800 produced scarcely 2 million copies there are at least 300 million today—daily. In addition about 200 000 patents, 300 000 research reports, a million industry papers and conference reports, and uncounted government, parliamentary and university papers are being churned out annually.

In total it is estimated that at least 60 million (up to 300 million) printed pages are produced annually. We have to realize that scientific information according to discipline doubles every 7–8 years, in some even every 3 years. Today in some fields it is not even possible for the individual scientist to follow the secondary literature, be it reference books or abstract journals. According to UNESCO the number of published references in some of the most important services increased as follows: Nuclear Science Abstracts from 1948 to 1961 ca 1600%, Biological Abstracts from 1947 to 1961 ca 400% and Chemical Abstracts from 1953 to 1961 ca 450%.

Faced with such figures and developments one might be frustrated and feel like giving up. The end would then be that research would be done over and over again, thus creating enormous losses to the economy and public welfare. This finally would lead all scientific work *ad absurdum*. The above picture was based on figures and facts collected in the industrialized world. The situation could be even more frightening since the sources cited are about 10 years old.

This is the situation where libraries and conventional methods can no more cope single-handedly with the requirements of day-to-day work. Today's mode of communication in the scientific community is through symposia, conferences, reports or through articles in professional journals. The development is too rapid to wait for the bound textbook to be published (fig. 1).

A new science has evolved calling itself information science (in the West) or informatics (in socialist countries). Its tools are documentation, data banks, reprography and computers to cope with the mass of information which is mounting at an ever-increasing rate. The UN family of agencies are actively engaged in setting up specialized information systems, in particular with a view to aid the developing countries. This is true especially in the most vital areas such as agriculture (FAO–AGRIS), nuclear science (IAEA–INIS), industrial information (UNIDO II), education, and information science. Other national, international and also commercialized services cover practically the whole field of human knowledge. To name a few with relation to our symposium:

Chemical Abstracts
Biological Abstracts
Medlars
STAR—Scientific and Technical Abstracts
ISI—Institute for Scientific Information
Excerpta Medica
SCI—Science Citation Index

At this juncture, one may ask the big questions: 'Where are the specialized centres to deal with this kind of information and to cooperate with the international systems?' Although efforts have been made in some countries to organize a structure and cooperation among existing information institutions such as libraries, special libraries, documentation centres and archives, as yet, little has come out of it. Take this present example, water resources. Information has to be collected from a wide range of different disciplines with outwardly little relation—geology, geography, geophysics, medicine, biology, agriculture, chemistry, mining, sociology, jurisprudence and what not. Who is able to concentrate on collection of latest development information which have relation to our central theme if not highly specialized organizations or centres? It is a fact that most countries in this area hold more information in their centres than is commonly known. The problem lies in cooperation and coordination. Here all of us carry a substantial load of responsibility since as producers of information we are consumers as well (fig. 2).

Discussion

Is it not a paradox that while in industrialized countries, scientists, planners and administrators are on the verge of frustration about the mass of information which is about to overwhelm them, here in the so-called third world this urgently needed, most precious and not so costly raw material is hardly if at all available.

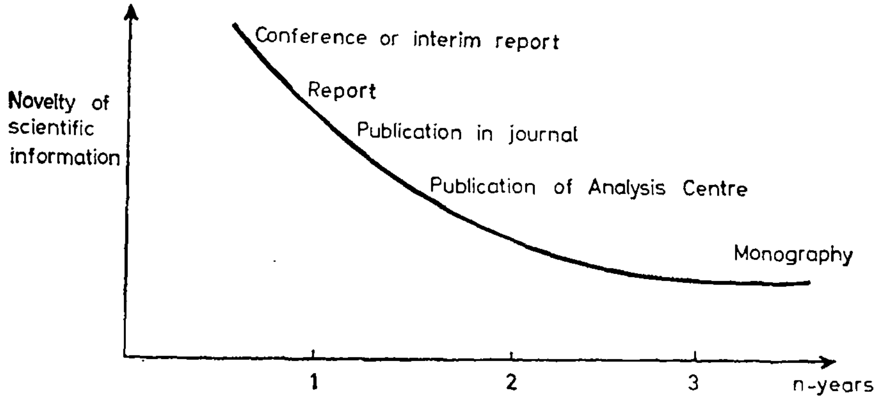

Figure 1. Communication time for various scientific media.

And all that is needed is some organization, some sticking together of heads to find what and where documentation should be arranged. Coordination between the important sections of information work, libraries, documentation and archives, and the wealth of knowledge from all the world is at your disposal. We have put for display some important international information sources. They are by no means comprehensive but it shows where one might look if the necessity arises. There is no need to call too loud for government involvement and regulation. As I have already said, as producers of information we are consumers as well and our responsibility lies on either side. However, the government has to be involved in the overall organization, the by-laws, the appointment of a focal point in the UNESCO/ICSU's UNISIST system. But first and foremost it is we the consumers who should press for the improvement of the information situation. There can be no genuine development without a well-organized information structure. And this means:

1. Installation and strengthening of documentation centres where up-to-date information is indispensable for useful work. And this should be in
2. Research and development (R & D)
3. Technical work
4. Government development planning
5. Development finance.

Improvement of services of libraries and their holdings is essential. This means the reorganization or introduction of legal deposit and library laws in various countries, organized interlibrary lending systems and the improvement of government surveillance responsibilities. Archives should not be just graveyards for historical documents but research reports and other valuable data and facts should be prepared for easy accessibility. The process of obtaining permission to make use of government records should be made less vigorous.

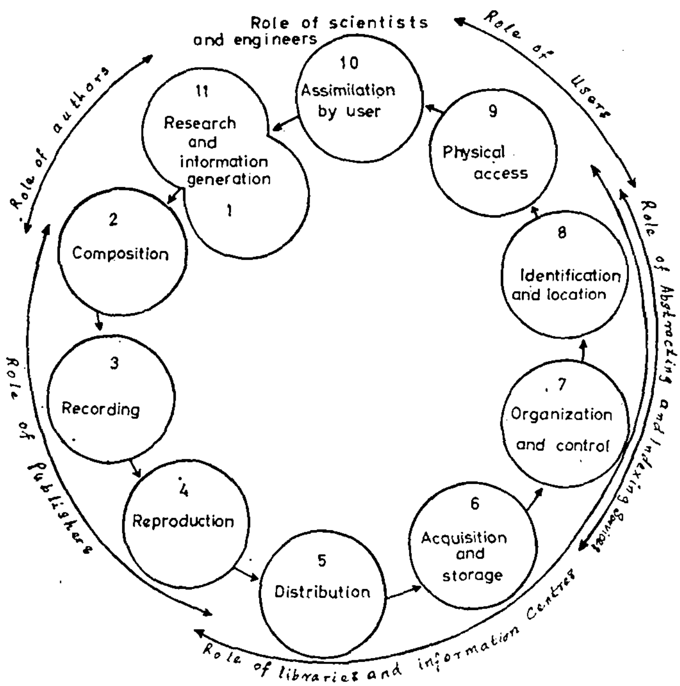

Figure 2. Scientific and technical information transfer. *Source:* D. W. King, Statistical indicators of scientific and technical communication 1960–1980 (National Science Foundation 1976).

After all—why do authorities always have to hide behind a smoke-screen of secrecy? It would appear particularly important to create a national information and documentation centre under the guidance of the highest possible authority. This centre should be responsible for the coordination of all the information centres in the country, be declared the national focal point in the sense of UNESCO's UNISIST science information community. This centre would be responsible for rationalizing the accessibility of scientific journals and papers, maintaining a union catalogue and a catalogue of journals available in the country. And it should be responsible for the professional questions of librarians, documentalists and archivists as there are standards, training and supply of manpower. Information science and information institutions may be regarded as the intellectual logistics of scientific work. The better you support them the better you will be supported by them.

Abbreviations used:

FAO-AGRIS	Food and Agricultural Organization–Agricultural Information System
IAEA–INIS	International Agency for Atomic Energy—International Nuclear Information System
UNIDO II	UN Industrial Organization Industrial Information
ICSU	International Council of Scientific Unions
UNISIST	Programme of International Cooperation in Scientific and Technical Information

WATER RESOURCES IN KENYA: A BRIEF BIBLIOGRAPHICAL SURVEY

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Abstract

1. There is sound official awareness in Kenya of the need for water development which is consistent with the objectives of the United Nations.
2. However there is a need to intensify national efforts in assessing the availability of water resources.
3. Consequently there is need for effective documentation of available literature and for the dissemination of the same. This necessitates regular recording and publishing.
4. It is desirable to educate the public on modern utilization of water in order to avoid waste and pollution. This makes it necessary to study the traditional social habits of people so as to enable the government to sell new attitudes to them.

Water is a crucial requirement for agricultural and industrial development apart from being basic to human and animal life. The United Nations Organization has placed great emphasis on the development of water resources and will continue to do so. For instance, 1965–75 was declared the International Hydrological Decade by the United Nations Educational Scientific and Cultural Organization (UNESCO) while more recently during the United Nations Water Conference at Mar del Plata, Argentina (14–25 March 1977), the participants resolved that 1978–88 be declared the International Water Resources Development Decade. Among items earmarked by the conference for emphasis during the decade are:

1. Assessment of water resources,
2. Regional and international cooperation, and
3. Public information, education and training.

Kenya, which was a significant participant in the said United Nations conference, is well aware of the wider needs for water and has demonstrated this awareness by creating a cabinet portfolio for water. In view of the above, it seems important to the author of this paper that a few points which are consistent with the resolutions of the said conference and which merit attention here in Kenya should be highlighted. It is on these highlights that the appended bibliography is based.

Assessment of water resources

The UN Water Conference observed the following:

> To improve the management of water resources, greater knowledge of their quantity and quality is needed. Regular and systematic collection of hydrometeorological, hydrological and hydrogeological data needs to be promoted.

Elsewhere in the report of the conference it is recommended that countries should:

> Establish a national body with comprehensive responsibilities for water resources data, or allocate existing functions in a more coordinated way, and establish data banks for systematic collection, processing, storage, dissemination of data in agreed formats and at specified intervals of time.

In the effort to compile the list below on water resources, it became apparent that while some considerable work has been put into the determination of the quantity of water resources in Kenya, the available information is not stored in any systematic manner nor is there any comprehensive record that could be used to trace material that is in hand. Much of the existing information is in the form of working papers which often did not get published. It would not be surprising therefore if this lack of systematization led to duplication of work or inadequate official advice.

It appears desirable therefore that the authorities concerned in this matter should consider as a matter of priority making provision for a documentalist who would compile lists of work done and work in progress and for the publication of these lists regularly. Further, it is desirable that project papers should at least be registered so as to facilitate follow-ups.

It was found out in the course of compiling this bibliographical list that funds for publishing were often limited or simply not available. Perhaps, along with provision for a documentalist, funds should be made available to facilitate simple binding of available material which could initially be published in cyclostyled form.

In order to facilitate international cooperation in the financing of water development projects, the United Nations Conference on Water Development recommended that developing countries should, by 1980, compile an inventory of investment needs in the field of water resources and determine the relative priorities of these needs. It is therefore even more urgent that data relating to water resources be organized to facilitate the determination of equitable priorities, which would subsequently be used to shop for funds from abroad.

Regional cooperation

As in the case of internal development of water resources, proper data are necessary for the development of shared water resources such as the waters of Lake Victoria. Availability of data in this field would facilitate peaceful and fair sharing of benefits as well as the cost of development. Further, it seems from the mood of the United Nations Water Conference that the development of shared water resources is likely to receive warmer attention among the international assistance agencies. It is therefore important that documentation of joint water development be given serious attention.

Public information

The United Nations Water Conference has recommended that in implementing water development projects, the local people be involved through their labour and other forms of material contribution. In Kenya where the spirit of *harambee* is already well established, the people do not need to be persuaded to cooperate. Where a water project is aimed at human consumption, it is particularly important that the public be educated on fair use of communal water facilities in order to avoid waste and possible pollution. While part of this objective can be achieved by way of rules and regulations, it is believed that through a process of education the public can be helped to cultivate a sense of responsibility on the use of water and this sense of responsibility would finally become self-perpetuating as it will be passed down from parent to child. It should be emphasized, however, that sound public information for water development can be feasible only if suitable data on water and the people are available.

A LIST OF SOME PUBLICATIONS AVAILABLE IN NAIROBI

Foreword

In compiling the following list the author relied very heavily on information available in the United Nations Information Centre, the Ministry of Agriculture and Ministry of Water Development libraries. A little time was spent in the UNESCO library and information was received that the library at the United Nations Environment Programme (UNEP) also had considerable material on water resources. Because of the limited time and because most of the material examined was scattered and uncatalogued, it has not been possible to give full citation of the publications listed. It will probably be necessary to spend some more time on the job in order to produce a complete bibliography.

It will be seen from the list that a lot more has been done to assess the extent of water resources in Kenya since independence and the inauguration of the International Hydrological Decade (1965–75) than before. It is also significant to note that during the same period, considerable attention has been directed towards the development of water supplies in urban centres and to some extent in the rural areas. It appears from the list that quite a lot of the country still remains to be surveyed although one cannot be too sure about this as it is probable that some vital reports of restricted access were not reached by the compiler.

It is also apparent from the literature available that little or nothing has been done to determine the attitudes of *wananchi* towards modern methods of water utilization, such as large-scale irrigation, and the effect of these methods on patterns of human settlement. In order that it may be possible to appeal to the public for cooperation in the new development approaches, it seems desirable that this kind of study be undertaken.

Acknowledgements
I would like to record my gratitude to the deputy librarian in the Ministry of Agriculture, the librarians of UNESCO, UNIC and UNEP and to Mr Classen, Head of Resources Branch, Ministry of Water Development.

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3	Current Sewage Disposal Methods and Problems
4	Design and Selection Criteria for Community Water Supplies
5	Water Pollution Control
6	Water Legislation
7	Groundwater Resources in Kenya
8	Recommendations on a National Programme for Sewage Disposal
9	Selection and Design Criteria for Sewerage Projects
10	Recommendations on Administration and Organizational Structure for Water Supply and Sewerage Development
11	Manpower and Training Requirements
12	Ten Year Development Programme for Community Water Supply
13	Ten Year Development Programme for Sewerage
14	Preliminary Design of Ngariama Water Supply
15	Preliminary Design of Ngong Sewerage Scheme
16	Surface Water Resources in Kenya
17	Final Report

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INDEX

Printed by Printing and Packaging Corporation Limited, Likoni Road, P.O. Box 30157, Nairobi