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WATER SUPPLY

Proceedings of the
Conference on Rural Water Supply, 5-8 April 1971,
University of Dar es Salaam,
Tanzania

Edited by

Gerhard Tschannerl

PREFACE

This volume should be seen as the second one in a series on rural water supply in East Africa. It contains the Proceedings of the Conference on Rural Water Supply in East Africa held 5-8 April 1971 at the University of Dar es Salaam. The earlier volume contains the Proceedings of the Workshop held 17-19 December 1969, also at the University. Although the workshop was intended to be preparatory to the conference, the papers which were presented at the 1969 Workshop hardly overlap with those of the recent conference. The 1969 workshop was held soon after the governments of Kenya and Tanzania had committed themselves to vastly accelerated water supply programmes, and the meetings concentrated mainly on reports on field research, health, and the work of the different governmental, international, and volunteer organizations.

The developments which took place between the holding of the 1969 workshop and the 1971 conference shifted the attention to other topics. The following might be seen as some of the principal advances. The role of the water development departments of the respective governments increased to such an extent that the efforts of other agencies, although important in their own right, have receded into the background; the need to take health factors into account when designing water supplies has been recognized in principle, with a corresponding adjustment in design of newer projects; ways and means are now being worked out in the attempt to come to grips with the enormous task of implementing the gigantic water supply programmes; the preparation of master plans for water development has begun.

The conference concentrated therefore primarily on planning and policy issues, and on studies in hydrometeorology and hydrology as the most fundamental one of the required inputs for water development plans.

We wish to acknowledge the help received from many people in the University of Dar es Salaam and the Ministry of Water Development and Power, both before and during the conference. Special thanks go to Len Berry, the former Director of BRALUP, to Ulf Riise for taking on a sizeable share of the organizing work, and Pu-Chin Waide for serving as administrative assistant to the Conference. We also wish to acknowledge the generous grant received from the Ford Foundation which covered most of the costs of the conference, including this volume.

G. Tschannerl
August, 1971

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IV. DESIGN AND IMPLEMENTATION

by
Gerhard Tschannerl

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Largely because of the topography and geology of East
Africa, water is not readily available from traditional sources
215 in the rural areas. It must often be fetched from several miles
away; a 3 to 5 mile distance from the house to the water source
is not uncommon. Even then the quantity of water available
in the dug hole or well might be very low, and in some areas
229 there is a severe water quality problem.

As a consequence, the quantity of water used for domestic
241 purposes is relatively small; the per capita daily consumption
in Tanzania averages only about 15 litres.[1] There is strong
evidence to suggest that this is inadequate from the health stand-
245 point. The long distance which has to be covered to fetch the
water takes up a lot of time - adding to the already heavy burden
on the women - and consumes a lot of physical energy. The
251 generally low quality of the water itself, due to bactereological
and chemical pollution, has an adverse effect on health.

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Comparing the water availability in the three countries
of the East African Community, the situation appears to be similar
261 in Tanzania and Kenya, where the whole range of problems - quantity,
quality, and convenience of location of sources for domestic water
267 supply - is present, but not necessarily always occuring together.
Uganda is by and large more fortunate with quantity and location,
275 but has to deal with severe quality problems.

Recognizing that the welfare of the rural population urgently requires the provision of improved water supplies, and hoping that the provision of these supplies will be a driving force for economic and social development, the countries of East Africa have given rural water supply a high priority in their national development plans.

The Kenyan government aims at providing water supplies through communal outlets in all parts of Kenya within the next 20 years, and at installing house connections for the entire population in the 10 years after that. To achieve this, the Five-Year Development Plan provides for an increase of available funds for capital outlay from 10 million shillings in 1969 to 38 million shillings in 1974.

The Water Development Department of the Ministry of Agriculture is in charge of all aspects of rural water development, including the design of schemes and the preparation of a master plan for the 30-year period. As a further boost to water development, an Interministerial Committee on Rural Water Development was set up in 1969.

Tanzania has recently shortened its period within which to provide an improved water supply to all the people in the country from 40 to 20 years. The budget allocation in the Second Five-Year Plan for water development and irrigation is 187 million shillings, or 6.8 percent of total development expenditure.

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[1] This figure is approximately the average of the results from several water supply studies. They are listed in "Water Development Tanzania", BRALUP Research Paper No.12. In comparison, the per capita daily domestic water use in USA is about 300 litres, 80% of which is disposed of as waste water.

The investment in rural water supply during fiscal 1970/71 reached 19.1 million shillings, which represents a 35% increase over fiscal 1969/70.

The importance attached to water supply in Tanzania found expression in the beginning of 1971 by the creation of the new Ministry of Water Development and Irrigation Division (Ministry of Agriculture) and the Water and Drainage Division (Ministry of Lands) and will to some extent regulate the Tanzania Electric Supply Company. One of the tasks to be undertaken by the new Ministry is the preparation of water master plans for each of the Regions.

Research on Water Development has been one of the main activities of the Bureau of Resource Assessment and Land Use Planning (BRALUP), University of Dar es Salaam, ever since its inception in 1967. Closely cooperating first with WD&ID and now with the Ministry of Water Development, BRALUP has conducted and sponsored a number of short-range and long-range research projects on rural water supply. This includes research on (1) design criteria, quantity and quality of water to be supplied, location and frequency of standpipes, and population forecasts; (2) hydrologic studies (flow simulation, small catchment characteristics, sediment transport); (3) project selection and planning (standardization of procedures, cost curves, computer use); and (4) the role of water in integrated planning (regional development plans, settlement patterns, land use, soil erosion, transportation, etc.)[1]

In line with BRALUP's interest in water studies, a Workshop on Rural Water Supply in East Africa was held in December 1969 at the University of Dar es Salaam; it was organized jointly with the Economics Research Bureau, University of Dar es Salaam.

The Objectives of the Workshop were as follows:

(1) to acquaint the participants with the various existing programmes of research and implementation on rural water supplies in East Africa;

(2) to identify common problems faced by the participants;

(3) to compare ideas and experiences dealing with these problems; and

(4) to set out the major issues for deliberation at the 1970 East African Conference on Rural Water Supply.

A number of papers were presented at the 1969 workshop and a list of recommendations drawn up, which have been published as BRALUP Research Paper No.11. The topics of the workshop were: field research, health, technical aspects, implementation, community development, and planning. One of the recommendations arising out of the workshop was that a follow-up conference be held because a number of unsolved questions had been raised which needed further attention.

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[1] A list of BRALUP publications is given in the back of this volume.

Consequently the Conference on Rural Water Supply in Tanzania was called for 5–8 April 1971 under the joint sponsorship of the University of Dar es Salaam and the Ministry of Water Development and Power. Some 120 delegates participated, most of whom came from Tanzania. They were affiliated with a variety of governmental, academic, international, and private institutions.[1]

The diversity of institutions which were represented was perhaps one of the most fruitful aspects of the conference, as delegates discussed each topic from a variety of viewpoints depending on their background and the kind of institution they served. That led to a better understanding of the different roles that institutions had to plan in regard to water research planning, design, implementation, and operation. Such discussions took place, for example, between regional water engineers who might be keenly aware of day-to-day problems, university researches who might be enthusiastic about what long-term research can offer, and consultant engineers who might concentrate on bringing in the experience gained from other, not always partinent, situations.

The conference was divided into four main themes: planning and policy, health, hydrology and meteorology, design and implementation. Because of a greater number of papers submitted and the considerable interest in the subject, the theme called planning was sub-divided into master plans, planning procedures, and the broader context of planning. The programme of the conference called for the presentation and discussion of papers under the different themes, followed by several workshop sessions for closer discussion in interest groups. The discussion groups also drafted recommendations which were approved at the last session by the conference as a whole.

The remainder of this introduction is an attempt to highlight some of the main points raised during the conference. Any such summary is naturally biased towards what its author finds the most striking and important in the context of his own work and background, and cannot do justice to the various contributions made by the participants. As a partial remedy, the papers which were presented at the conference are printed in this volume in their entirety,[2] and some of the points raised during discussions found their way into the final recommendations of the conference.

Planning - Master Plans

While the decision of the governments of Tanzania and Kenya to prepare master plans for water development found wholehearted support, some words of caution were raised as to the nature and method of preparation of such plans.

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[1] See the list of delegates

[2] Three out of twenty-three papers presented at the conference could not be included in this volume, for the reason either that the author had withdrawn it or that it was not available by the time the proceedings went to print.

The principal advice was about the provision of flexibility and choice in the plans. Kates gave a number of examples to show how present estimates, aims, and projections might change within the next 20 years, and how the master plan should lend itself to periodic revisions to take account of these changes. The process of arriving at these plans also must make it possible that the important choices be made by those who should make them. This point was also stressed by the Minister of Water Development and Power in his opening address, who went even further to say that most decisions, even if they seem entirely in the realm of engineering or economics, have a political content which must be dealt with by politicians because they are the ones responsible for policy matters.

Data needs and how they might be fulfilled are discussed by Berry and Conyers. They stress an integrated approach to planning, whereby water development is only an integrated approach to planning, whereby water development is only one of many develbpment aspects, all of which must be considered together. Agriculture, settlement programmes, cattle marketing, all influence the demand for water with different uses, and are in turn closely affected by water schemes. Plans should therefore be drawn up for all of these jointly, rather than for each of the activities in isolation.

In the course of the discussion, the Principal Secretary of the Ministry of Water Development and Power, Government of Tanzania, explained that the first task of the teams preparing master plans is to assess the quantity, quality and location of the available water, as well as the likely water demand for the different uses. Teams from other countries will be invited to prepare these plans (except for Dodoma Region which the Ministry itself has already taken up), but their work should be limited to factors which can be measured and studied in some systematic way, he continued. Socio-economic and political factors should not be decided by the teams, whose task in that respect would be to provide the relevant information with which such decisions can be made by the right persons in accordance with national policy.

Planning - Policy

Burton offered some reflections on the desirable level of investment in water supply. He suggested that Tanzania is presently in the first phase of a long-term programme, during which the provision of minimal water requirements, primarily for reasons of health and social welfare, is the main objective and requires heavy government expenditure. He maintains that in the next phase the increased income of the beneficiaries will enable them to finance further investments in improved water supply themselves, so that government expenditure for this investment will diminish. Burton's analysis brings the old argument of "water supply as a social service to be provided free of charge to the people (Tanzania's policy)" versus "water as an economic good for which people should be asked to pay (Kenya's policy)" in a new perspective.

Impact studies of rural water supply provide vital information for the establishment of policy. One important item, about which not enough is known, are the actual benefits from rural water supply. Heijnen and Conyers compared a list of categories of benefits which are generally assumed to arise from rural water supplies with the evidence available for each case, and found supporting evidence for only a few categories of supposed benefits.

Planning - Procedures

Harlaut presented a functional division of the planning and design process according to the nature of the work involved and according to what body (local or central) should carry it out. This gave rise to a lively discussion, which emphasized that maintenance, of schemes must be an integral part of that process and must be considered already at the different design stages of a project. Another point emphasized was the importance of feeding the results from the scheme back into the design process. There was disagreement about whether design engineers should take the time to carry out that lengthy task.

A project selection procedure which differs from that advanced by Kates was presented by Tschannerl. It relies on expressing the characteristics of a project in the form of a mathematical model, and on some special properties of such a formulation in order to arrive at a preliminary selection of projects to be implemented in one time period for which a specific budget allocation has been made. The speed of that computation allows the exploration of many alternative policies and alternative projections for the inputs (such as future population or crop specialization)

Health

One of the highlights of the conference was Bradley's brief summary of what is known about the effects of water supply on health. He outlined the relationship between water quantity and quality on the one hand, and the occurrence of different diseases on the other. The supporting evidence that he presented suggests that a significant improvement in health can be reached only through the provision of household connections. Questions were raised from the floor about the cost of carrying out the studies which would furnish more conclusive evidence on that relationship and whether this expenditure would be justified. Questions were also raised about the cost of house connections as compared to communal taps.

Hydrology and Meteorology

The long distance between rain gauges makes it difficult to study rain showers. Based on some previous experiments, Morth computed several hydrological measures of storms in Tanga Region: intensity, frequency of occurrence, and spatial distribution. Nieuwolt analysed the causes for rainfall variability in Zambia. The nedd for more precise and reliable data for meaningful hydrometerologic studies was strongly emphasized in the course of the discussion.

Project plans must often be made on the basis of scarce data. Bear, Issar, and Litqin gave a detailed description of how they dealt with such a situation in their work on the preparation of water development plans. They give a method for supplementing scarce data with other, related, data, which is an example of how existing data of various description can be used optimally for the analysis of a particular water resource problem.

Hasan discussed different forms of artificial groundwater recharge which have/been successful in the Sudan, and suggested that recharge should be more closely considered in East Africa.

The successful design of a permeable dam for flood control and groundwater recharge was discussed by Raikes. This kind of structure, he maintained, is ideally suited for countries like Tanzania where storms are usually of high intensity and short duration.

Design and Implementation

Design criteria for water supply projects were discussed at some length. Harlaut proposed specific design criteria for some project inputs, such as design horizon, water quantity per capita per day, and storage capacity. It was pointed out during the discussion that some of these criteria should vary with the type (and scale) of projects and their geographical location. The need for further research, especially into consumption data, was raised. Manpower training, and specifically procedures for recruitment and promotion of certain levels of workers, was discussed at some length.

Two specific design suggestions were made. Bateman proposed a low-cost method of building rainwater catchment tanks based on experiments in Botswana and Swaziland, and Van de Laak introduced a wind-powered pump as suitable way of lifting water under certain wind conditions. The latter also stressed the need for better wind data as a prerequisite for feasibility studies on the use of wind power.

Self-help for building schemes is important to reduce government expenditure and for the mobilization of the people. Matanga and Mayerle reported on the experience with self-help schemes in Lushoto District. Having achieved a good degree of success in the construction of schemes with self-help labour, they analysed the reasons for possible failures and suggested some remedies. Similar to the earlier discussion on design criteria, it was again pointed out that no generally applicable standard for self-help could be established. Results of experiments on the friction coefficient in SIMBA plastic pipes were reported by Todorov.

Conclusion

The conference, together with the 1969 workshop, had a rather unique character, being focussed on the very specific topic of rural water supply in East Africa, and bringing together people from all sorts of institutions. It fulfilled a great need in that regard, and has perhaps provided the push to continue this interchange. With developments in water supply in East Africa happening at such a rapid pace, the focus of attention might soon shift to other topics from the ones emphasized in the conference, but as the 1969 workshop made an important contribution at the time it took place, the 1971 conference dealt with some of the key issues in water development in East Africa at this time.

TEXT OF THE OPENING ADDRESS GIVEN BY THE MINISTER FOR WATER DEVELOPMENT AND POWER, DR. W.K. CHAGULA, AT THE CONFERENCE ON RURAL WATER SUPPLY IN EAST AFRICA AT THE UNIVERSITY OF DAR ES SALAAM ON 5TH APRIL, 1971

Mr. Chairman, Your Excellencies, scholars, ladies and gentlemen:

It gives me much pleasure to have been given this privilege of addressing you at this opening session of this international Conference on Rural Water Supply in East Africa.

First of all, I should like, on behalf of the Government of the United Republic of Tanzania to extend to you all a very warm welcome to Tanzania. It is my sincere hope that the exchange of views and ideas among yourselves during the Conference, while you are also enjoying the intellectually stimulating atmosphere of this beautiful Campus of the University of Dar es Salaam, will make this Conference the success that we all believe it should be.

In most developing countries which are really serious about the development of their peoples, the vast majority of whom live in the rural areas, rural development, in all its various aspects, is being implemented very energetically within the limitations of manpower and material resources which are usually some of the constraints which developing countries encounter in the implementation of their development programmes. One very essential aspect of rural development in East Africa, including Tanzania, is the provision of water to rural areas. In fact, without the provision of adequate and wholesome water supply to our rural areas there can hardly be any rural development in East Africa. This, apart from causing a stagnation in our rate of economic growth, would undoubtedly aggravate many of the problems of rapid and unplanned urban development, particularly unemployment and crime. Stated positively, the provision of safe and sufficient water to our people in the rural areas will lead to greater productivity through:

(i) the resulting reduction in illness and general debility;

(ii) the saving of effort and time previously expended on non-productive transport of water;

(iii) the reduction in the medical bill facing each family and the nation as a whole;

(iv) the possibility of stabilization of settlements in which small industries and such social services as schools and health centres could be established;

(v) the use of irrigation for agricultural purposes;

(vi) the availability of water for livestock.

Thus the provision of water for our rural population should be regarded as a social service whose main objective is the improvement of their standard of living, health, and general productivity and is a prerequisite to economic and social development.

One of the factors which must always be considered in any programme of providing water to rural areas is the cost involved. Mr. Chairman, as most of the participants at this Conference know, Tanzania has decided that as many people as possible should live and work in Ujamaa Villages. Apart from this policy being an instrument of economic, social, and political development of the people, it also aims at minimising the cost of providing safe and adequate water to our rural areas in Tanzania. For, it is obvious that it is much cheaper to supply water to people living in a compact village than to the same number of people living in homesteads scattered over a large rural area. I am very glad to report, Mr. Chairman, that the rural population of Tanzania, in general, are actively and practically supporting this TANU's and Government call urging them to live in Ujamaa Villages and which is already paying dividends.

The Government of the United Republic of Tanzania has recently decided that within the next 20 years all Tanzanians living in rural areas should be provided with safe and adequate water supplies which should also be within reasonable reach of everyone all the year round. As at present only about 1.2 million out of 12 million Tanzanians living in rural areas are provided with adequate and wholesome water, the magnitude of the task remaining to be done is staggering. However, the Government of Tanzania is determined to accomplish this task within the next 20-year period. To this end, Mr. Chairman, participants at this Conference will be interested to know that a new Ministry of Water Development and Power has been established in the Government of Tanzania and is being organised on a functional basis so that it could effectively implement this ambitious rural water supply development programme. To prepare the ground for the design and execution of the thousands of rural water projects that will be constructed during the next twenty years, the Ministry will, in the next 3 to 5 years, complete the preparation of a Water Master Plan for the whole of mainland Tanzania. This will be done largely with the technical assistance of a number of friendly countries.

Mr. Chairman, I notice from the programme of the Conference that among the themes for discussion at the Conference are such topics as "water policy", "design standards and criteria", "equipment innovation", "construction and operation of water supplies" and the public health aspect of rural water supplies. With the exception of the first, most of these sound innocuous and appear of interest only to professional engineers and hydrologists. But, in my experience, the implementation of the recommendations of professionals and academics on such topics will always depend on political decisions. For instance, in Tanzania the decision that all water supplied from a public domestic point or kiosk, whether in town or in rural areas, shall be free of charge was a political decision. The purchase or importation of equipment for rural water supplies, including its innovation, must also ultimately be the result of a political decision as will also be the provision of the necessary finance by governments for the manpower which will be needed for the construction, operation, and maintenance of a comprehensive rural water supply programme. Finally, Mr. Chairman, even the public health criteria of rural water supply must ultimately be influenced by political decisions based, of course, largely on the advice and recommendations of a country's public health authorities. A case in point in Tanzania is the disturbing fact that the water from a large number of our rural boreholes has an undesireably high content of fluoride. The question which immediately faces us is whether we should discard all water boreholes with a high fluoride content inspite of the fact that the average cost of a water borehole is around shs. 60,000/= to shs. 100,000/= Tanzania shillings! Obviously a compromise will have to be struck. Conferance participants will be interested to know that we in Tanzania have recently established an inter-Ministerial Committee known as Water Supply Health Standard Committee which will be recommending on the establishment of a local water safety standards. It is more than likely that when this Committee has completed its task, Tanzania may be forced by circumstances to accept a higher ceiling of water fluoride content than that currently accepted by the World Health Organisation (1.5 parts of fluoride per million parts of water).

Mr. Chairman, I have laboured the importance of political decisions in rural water supplies because, much too often, engineers, economists, academics, and professionals in general fail to communicate or explain their ideas or advice to policy makers. Alternatively, policy makers sometimes base their decisions on insufficiently understood information from engineers and professionals in general. Both defects are undesirable in the East Africa of to-day. I am very glad to note that at this Conferrence Keynote Papers will be submitted from various experts in the field of water. In addition, I am glad that my Ministry has enabled our Regional Water Engineers and hydrologists to come and participate at this important Conference. Both these groups of persons should inject realism and a practical approach into your discussions. It is from them also that you should expect statements regarding the effectiveness or otherwise of policy makers in each Country as regards the implementation of our respective rural water supply programmes. For example, one question which will have to be discussed at this Conference is whether the procurement of equipment (P.V.C. pipes and pumps) for our rural water supplies is as efficient and fast as Regional Water Engineers would like it to be! A related question will be whether we policy makers are tackling this serious problem sufficiently energetically.

At this juncture, Mr. Chairman, allow me a brief digression so that I can, on behalf of the Government of Tanzania, express our deep gratitude to the Government and people of Sweden, for the very generous soft loans they have made available to us, through the Swedish International Development Agency (SIDA), for our rural water supply programme during the last seven years. This generous Swedish credit up to date amounts to 88 million Swedish Kroners, shs. 123,000,000/= and symbolises, in practical terms, Swedish resolve to assist Tanzania in as many aspects of her development as possible for which Tanzania is very grateful.

Finally, my Ministry would also like to extand special gratitude to the Bureau of Resource Assessment and Land Use Planning (BRALUP) of the University of Dar es Salaam which, in addition to co-sponsoring this Conference, has made a major contribution to the implementation of our rural water supply programme through studies the results of which will greatly improve the effectiveness of the distribution system from Bulenya Hills and Mwamapuli Dams in North East Nzega and from other rural water sources. As these projects will cost many millions of Tanzania Shillings when completed, BRALUP's contribution is an example of the many ways in which the Nation's University can, in a practical way, assist the Government to determine how it could most effectively utilise its scarece resources.

Mr. Chairman, as a layman in the area of rural water supply development, I can do no better than simply introduce the subject to the various experts, engineers and economists who are participating in this Conference. As I now feel I have accomplished my task, on behalf of the Government of Tanzania, I have much pleasure in declaring open this "Conference on Rural Water Supply in East Africa". Mr. Chairman, ladies and gentlemen, I wish your Conference every success and it is my sincere hope that the results of your deliberations will serve to advance East Africa further along the long and difficult path of development.

I. PLANNING AND POLICY

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FLEXIBILITY, COORDINATION AND CHOICE IN WATER RESOURCE PLANNING: THE UTILITY OF RECENT PLANNING INNOVATIONS FOR WATER DEVELOPMENT IN TANZANIA

by

Robert W. Kates
Clark University, Worcester, Mass., U.S.A.

Two years has brought marked change in the commitment, organization and knowledge of Tanzanian water resource planners. The returning scholar finds: a major national commitment for the provision of improved water supply to every Tanzanian, a good consultant review of the potential for a massive rural water supply programme, a ministerial reorganization providing for greater administrative unity in the development of this critical resource, an applied research programme yielding data and understanding unique for developing countries, and the launching of a series of water master plan studies which are to provide the perspective for regional water development over a twenty year period.

Upon these master plans rest the critical needs for improved hydrological and geophysical data, for the orderly programming of the massive national objective for rural water supply, for the identification of new opportunities for water based development, and for bringing the entire programme within the investment capacity of Tanzania. Indeed viewed in the context of the overall planning effort in Tanzania, the water master plans may be the most ambitious planning effort, to-date. Only one other comparable exercise, that of high level manpower planning, had a long-term goal; other planning efforts being limited to the five year development plans. And planning for improved water supply for all Tanzanians twenty years hence, appears to be a more complex and difficult exercise, than the impressive and successful effort at long-term manpower planning. Thus, because of their key role in extending the planning horizon to longer-term perspectives, themaster plans should in their design benefit from the widest experience of comprehensive water resource planning.

Some recent innovations in comprehensive water resource planning, particularly in North America, seem to be relevant. Not that the experience is simply transferrable, for the differences in levels of resource development, available data, manpower and investment capability, and criteria of social choice are well known. And the opportunities for socialist planning and choice in Tanzania make unnecessary some of the peculiar games water resource planners play when they try to plan social investment by the rules and standard of the private enterprise capitalist system. But what does appear relevant are some of the experience and innovations related to three apparently universal problems of longer-term comprehensive regional planning exercises; problems of flexibility, coordination, and choice. This paper identifies these problems from the viewpoint of one knowledgeable about water and planning in Tanzania but lacking the intimate knowledge of those with day-to-day responsibility in this field. The paper then suggests some adaptations of new techniques that could be realistically applied in the Tanzanian context to help meet these problems.

Problems of Longer-Term Comprehensive Water Resource Planning

To plan is to anticipate and to guide change. Independent Tanzania is ten years old, the master plan is for a period twice that life. Reflect on the tremendeous changes of the past ten years and try to project those twice that distance into the future. How can that unusual vision be incorporated into the master plans? And at the same time how can the flexibility to provide for unforseen changes be made part of the plan?

To plan is to coordinate, but now will the master plans, each a regional study carried out by teams of differing national origin and make-up, be coordinated? How will they relate to the ongoing economic and social effort and the growing need and capability for regional and district planning and development?

And finally "to plan is to choose", but consultant reports should not pre-empt the choices to be made by Tanzanians as to how, where and when their critical water resource developments should take place. And over twenty years, choices made now, should not pre-empt choices required in the future under differing conditions and needs. How can the master plans present in understandable, non-technical form information for such critical choices?

The problems, although posed in the Tanzanian context, are universal and a variety of techniques and innovations, many still under development, have been evolved to deal with them. To guide and anticipate change, the use of data banks, perspective planning, computer modeling and simulation, and the neo-science of futurology, have been advanced. To provide for coordination, water planners increasingly use standard techniques, assumptions, and projections. These are frequently prepared by specialist agencies with advanced knowledge of economic and demographic trends or by such specialists who are part of interdisciplinary or interministerial teams. To provide for choice, programme budgeting, cost-effectiveness and multiple-objective-cost-benefit techniques have been developed. At the same time simpler, more readily understood modes of public presentation and discussion have been sought.

On reflection, this armory of techniques and innovations appears to be a mixture of tools and toys, science and fad, complexity prompted by necessity and complexity designed to conceal the critical choices of post-industrial societies. What, if any, of these techniques might be useful in the Tanzanian context and how should they be applied?

The Development of a Set of National Perspectives

Over twenty years very significant changes will or could take place in Tanzania affecting the planning of water development and the provision of improved rural water supply. Changes over twenty years in income and population distribution, available investment, social and political needs and organization, technological change and industrial development, as well as changes in the standards of what are considered improved water supplies; will seriously affect plans designed over the next two to four years.

To chart such changes it has been found useful to develop a set of perspectives, broad statements of direction and possibility, as contrasted to more specific projections of future trends. In the present context they are needed as a framework within which to fit the regional master plans. And such perspectives need not be fuzzy extensions of present direction. Rather, for a planned society, they should include visions of what ought to occur, what is needed, and what is socially desirable.

Consider some examples of perspective changes and the questions these pose: Among the initial master plans, will be studies of Dodoma and Shinyanga Regions, areas of highly contrasting patterns of population and water availability. Yet by the end of the plan period, Dodoma district is likely to have a population density equivalent to that found today in Shinyanga district, and Shinyanga, a population density equivalent to such densely-populated areas as Arusha or Lushoto district. Should the approaches to water supply adopted in these regions be expected to markedly change by the end of the plan period?

Present allocations of regional development funds are on the basis of parity for all regions; the allocation of water development funds is proportional to the regional human and cattle population; more recently Devplan has suggested for discussion the desirability of adopting a compensatory formula - more aid for the lesser-developed regions. What assumption as to regional investment capability should govern the programming of project?

The number of Ujamaa Villages has about doubled each year since the end of 1968. The impact of such villages on water development is considerable as they lead to great concentration of population and they are given preference in the development of water supplies. But such a growth rate as a yearly doubling obviously cannot be maintained. What perspective as to the rate of growth, distribution and character of the Ujamaa village Programme should govern the master plans?

The next twenty years will contain major advances in technology related to water development, can any of these be expected to alter the present practices for providing rural water supply? For example, would a low-cost plastic material with the durability characteristics of butyl rubber shift the cost-curve away from pumps and gravity schemes in favour of the now, relatively high-cost, rain catchments and charcos schemes? Or would low-cost power associated with major hydro-electric schemes make feasible rural electrification in selected areas and make available low-cost, low-maintenance electric pumps, tube-wells and sprinkler systems?

Water planners assume a rising level of water demand over the plan period, an assumption well in accord with most experience. But not only will total water demand change over twenty years but the standards of quality and delvery will change as well. Bu the end of the planning period, will supplies without chlorination and filtration be as acceptable as they are today? And will a distance of 400 metres to a water point be adequate as a measure of improvement? Will a movement develop in more favoured economic and climatic areas for household self-supply by roof cisterns, hand pumps and wells, or house connection from piped supplies?

Not all perspectives deal with external factors of population or technology that affect plans for water development, there are important "backward" linkages as well. For example:

> A twenty year plan opens up fresh possibilities for a specialized internal market for industrial goods. Bought as they are now in small quantities on an annual or project basis, they are with few exceptions (plastic pipe, concrete products) the products of foreign manufacture. But if one considers the entire plan period, a base market on which to build local industry can be assured, Providing water for 20,000,000 people might require 50,000,000 feet of plastic pipe, 100,000 taps, 50,000 hand pumps and 5,000 diesel pump sets. Indeed, even water supply techniques might change to accommodate industrial development possibilities, as for example, if butly rubber could be produced cheaply in a petro-chemical complex. Water development commands between six and twelve percent of development spending, how can crucial supporting linkages to other sectors of the economy be identified and strngthened?

National perspectives of long-term trends and desired direction, such as the foregoing, can be developed by a study group or seminar representing the various ministries, their planning units, the University and other locally available experts. These national perspectives, in turn, can serve as a basis for the preparation of region-by-region projections to guide the master plans.

Consistency Between Regions: Projections, Areas and Design Standards

Some common problems of coordination are found in systematic water planning. The areal unit favoured by water planners, frequently river basins, do not coincide with either the administrative regions or the economic regions employed in development planning. Seldom is the water plan well-coordinated with the overall planning effort, and the comparability between regions or river basins is difficult to insure especially when the planning teams vary in background and skills. Various stratagems have been developed to minimize these problems. Increasingly, the river basin, an area of water supply, have given way to areas of water demand, these service areas conforming more readily to administrative and economic considerations. Liaison with the overall development planners to prepare the specific projection of expected and desired growth and development that serve as the basis for deriving water demand. And comparability between plans has been enhanced when the terms-of-reference suggest a standard set of sub-regional units, when major economic and demographic projections are centrally provided, and when a common set of design standards and assumptions are adopted. Building-in consistency this way seems more effective than the use of coordinating or liaison committees which in practice seldom seem to function well.

In the Tanzanian context, consistency between regional plans, coordination with development planning, and with the regional and district administration can be enhanced in similar ways. A set of sub-regional areal units are now available for over half the country.

These agro-economic zones, being prepared by BRALUP for general planning use, conform to district, regional and census enumeration area boundary lines, are relatively homogeneous with respect to agriculture, ecology and economy, and include a basic set of prepared data. An example of these data for the zone of Eastern Kahama, is given in Appendix A along with a map of the zones for Sukumaland. If these zones were adopted for water planning a master plan for Shinyanga region would contain fifteen sub-regional units.

A standard set of regional projections can be prepared for each region in a consistent manner by a specialist group such as the Regional Planning Division of Devplan. This group, with Regional Economic Secretaries and District Planning Assistant in most regions, could construct the set of regional projections that should serve as a basis for deriving water demand. Ten and twenty year projections might include:

Regional population and its distribution

Regional Income

Available investment trends

Major economic activity

Urban growth and emphasis

Requirements for social, educational and health services.

These projections will probably be required for regional planning purposes in any event and can be prepared region-by-region on a rolling basis as arrangements for master plan studies are made. Preparing these projections externally would free the master plan team to concentrate on its major field of expertise - water development. It would also use the existing knowledge of social and economic conditions currently available and provide automatic liaison with Devplan and the regional planners.

New standards for design and assumptions of water demand are, from current reports, apparently being developed. The responsibility for providing comparable assumptions and standards for each master plan would seem to rest best with the Ministry, perhaps with the forthcoming planning unit. In all, a healthy division of labour can envisaged with the Regional Planning Division of Devplan providing specific regional projections of major demographic and economic variables, BRALUP providing a set of viable sub-regional planning units, and the Ministry offering guidelines as to water demand assumptions and design standards. These, if followed by the master plan teams, would encourage a considerable standard of comparability for a minimum effort of central control.

<u>Information for Choice</u>

That "to plan is to choose" has been widely recognized, that the planners should not necessarily be the choosers is also well-known, but that the planned - for the people themselves might help to make choices, has only received belated recognition. Nonetheless, under a wide spectrum of social systems, planners are seeking to find ways of public participation in the planning process, some seeking meaningful ways, while others unfortunately seek to erect only the facade of participation.

One critical problem is how to provide information on projects in such form that the choosers, whether they are planners, designers, representatives of the people, or the people themselves, can make judgements. The problem has been compounded by the fact that experts and professionals of all types frequently make judgements by experience, skill, intuition or even prejudice, without specifying to themselves or others the basis for the judgement. In most cases this may be adequate, for example, one goes to a doctor precisely to obtain his judgement. But in the case of water development, the critical choices may well be non-technical, such as a decision to favour Ujamaa villages in providing water supply. Thus it is now increasingly realized that projects serve many purposes and have many possible scales. Emphasizing one purpose or scale may mean foregoing others. Ways, hopefully understandable, should be devised to make such comparisons possible. The need to formally set out such information is not obviated by the master plans, for most of those who prepare or approve the master plans today will not participate in the many revisions and updating of the plans that the future will require.

In one current effort seeking to specify the varying objectives of water development and trade-offs between these objectives, the effects of each project on national economic growth, regional economic growth, and environmental quality are estimated. In another proposed system, a fourth broad factor would be added, the well-being of people. In such exercises, a specific project, for example a hydro-electric dam, is seen to have varying impacts from each point of view and even though these impacts are not fully quantifiable or even known, they do provide a sounder basis for choice than that of ignorance.

These criteria, of course, are not sensibly applicable in the Tanzanian context. Criteria of choice in Tanzania should be related to the actual choices being made. Apart from the important choices of engineering design, most projects of a specific scale and phasing have three critical aspects: the project has some service potential - to provide health and convenience for people; some development potential - to increase the productivity of the population; and a differing cost structure - money, time, supervision, and other scarce resources. To balance these qualities of service, development, and cost is desirable - more service for less cost, service with development where possible, etc. But the possibilities are not always intuitively obvious. For example, the service potential of a given project can vary with the degree of population density, but this need not be taken as given but can be changed as through the Ujamaa Village Programme. Or the development potential can vary greatly depending whether ancillary investment, planning, and coordination takes place as has been shown in studies of North-East Nzega. The cost-effectiveness of a project differs not only in total and unit cost, but in requirement for foreign exchange, mechanical equipment, technical supervision or the potential to employ self-help.

Can these many possibilities be evaluated in a sensible and comparable way? Tables 1 and 2 set out such on analysis for a project which has received study roughly comparable to that of the master plan. The format can be used in the design process to analyse different alternatives, scales and phasing of the same project or to display the qualities of preferred or recommended projects. Simple indicators are used to measure <u>service potential</u>: population served by distance zones, potential consumption, reliability, water quality, and the number of facilities served. Indicators of development potential include: Ujamaa villages, cultivable land made accessible, irrigated land, livestock watered, fishponds, and rural industry. Cost-effectiveness indicators include: money, time, and the various constrants of scarce resources.

The example given in Tables 1a, b, c, 2a, b, c, the Mpango Water Supply Project, illustrates one use of these indicators. The project is in two phases and Table 1a, b, c, presents data on Phase I to be compared with Table 2a, b, c, which gives similar information for the two phases combined. One possible comparison, therefore, is between building the project only to the scale of Phase I as against building the entire project (Phase 1 plus 2).

From the Tables we learn that the smaller project is considerably cheaper. Its total cost is but a third of the combined project, and the capital cost per capita or per liter is two-thirds that of the larger project. Furthermore, the operating costs of the smaller scale project are much smaller; while the demands on scarce resources are only slightly more modest.

In service potential, the larger project will serve from two to three times as many people with similar quality and reliability. More facilities will be served by the larger project. And in development potential the larger project will have considerable scope as it apparently provides water to those areas most in the need for new facilities and with greater potential for development.

What should be the choice between these projects? There is, of course, no simple answer as it depends on the available resources, other alternatives, regional and national priorities at the time the choice needs to be made. But the decision will not be made in total ignorance of the consequences if these indicators are readily available.

TABLE 1a.

PROJECT TITLE: MPANGO WATER SUPPLY PHASE 1

DESCRIPTION: Water Intake on perennial stream: gravity main 30 km. 35 km. distribution line, domestic outlets in valleys

REGIONAL/DISTRICT DEVELOPMENT PRIORITY: very high priority

A. COST/ EFFECTIVENESS

1. CAPITAL COST

TOTAL COST:	AFTER CONSTRUCTION	2,200,000	SHS.
	5 YEARS	-	SHS.
	10 YEARS	-	SHS.
	20 YEARS	-	SHS.

		PER CAPITA	PER M^3	PER L/*DAY
AVERAGE:	AFTER CONSTRUCTION	52 Shs.	Shs.	1.7 Shs.
	10 YEARS	-	-	-
	20 YEARS	-	-	-

2. OPERATION & MAINTENANCE: ANNUAL 14,000 SHS.

3. CAPITAL COST CONTENT:

% FOREIGN EXCHANGE	25%
MECHANICAL EQUIPMENT CONSTRUCTION	68%
TECHNICAL SUPERVISION CONSTRUCTION	10%
SELF-HELP LABOUR POTENTIAL	10%

4. ESTIMATED TIME FOR COMPLETION: 1½ YEARS

*LITER

TABLE 1c.

PROJECT TITLE: MPANGO WATER SUPPLY PHASE 1

C. DEVELOPMENT POTENTIAL

TYPE	WITHOUT ADDITIONAL INVESTMENT NUMBER	WITH ADDITIONAL INVESTMENT, PLANNING, OR COORDINATION NUMBER	TYPE OF INVESTMENT	ESTIMATED COST OF ADD'L INVESTMENT (SHS)
1. UJAMAA VILLAGES				
NUMBER	5	0	-	0 Shs.
POPULATION	4000	0		
2. RELEASED LABOUR HOURS/ADULT/DAY	0.7			
3. CULTIVABLE LAND AVAILABLE IN TOTAL-SERVICE AREA	(ha.) 12,080			
CULTIVABLE, BUT NOW UNCULTIVATED (ha.)	10,900			Shs.
SUBSISTENCE CARRYING CAPACITY UNCULTIVATED	38,000	0	-	0 Shs
4. IRRIGABLE LAND POTENTIAL (ha.)	0	0	-	0 Shs
5. PRODUCE MARKET CO-OP BUYING POINTS	0	0	-	0 Shs
LOCAL MARKETS	0	0	-	0 Shs
6. LIVESTOCK ANIMAL UNITS WATERED	0	0	-	0 Shs.
DIPS	0	0	-	0 Shs.
MARKETS	0	0	-	0 Shs
7. FISH PONDS SURFACE AREA (HA)	0	0	-	0 Shs
8. RURAL INDUSTRY EMPLOYEES	0	0	-	0 Shs

TABLE 2a.

PROJECT TITLE: MPANGO WATER SUPPLY PHASE 1 AND 2

DESCRIPTION: Water intake on perennial stream, gravity main 30 km., pump and rising main 35 km., earth dam reservoir 75 km. distribution line, domestic taps and cattle troughs

REGIONAL/DISTRICT DEVELOPMENT PRIORITY very high priority

A. COST/EFFECTIVENESS

1. CAPITAL COST:

TOTAL COST:	AFTER CONSTRUCTION	7,000,000	SHS.
	5 YEARS	-	SHS.
	10 YEARS	-	SHS.
	20 YEARS	-	SHS.

		PER CAPITA	PER M^3	PER LITER/DAY
AVERAGE:	AFTER CONSTRUCTION	78 Shs.	Shs.	2.6 Shs.
	10 YEARS	-		-
	20 YEARS	-		-

2. OPERATION AND MAINTENANCE: ANNUAL 90,000 SHS.

3. CAPITAL COST CONTENT:

% FOREIGN EXCHANGE	27%
MECHANICAL EQUIPMENT CONSTRUCTION	12%
TECHNICAL SUPERVISION CONSTRUCTION	8%
SELF-HELP LABOUR POTENTIAL	10%

4. ESTIMATED TIME FOR COMPLETION: 2½ YEARS

Table 2b

PROJECT TITLE: MPANGO WATER SUPPLY PHASE 1 AND 2

B. SERVICE POTENTIAL: SERVICE AREA 500 KM^2

	BEFORE - CONSTRUCTION WET SEASON	DRY SEASON	AFTER CONSTRUCTION	AFTER 10 YEARS	AFTER 20 YEARS
1. ESTIMATED POPULATION IN SERVICE AREA	31,700	31,700	34,300	59,000	89,00[illegible]
SERVICE POPULATION BY DISTANCE: 400 METRES	5%	6%	15%	15%	15%
800 METRES	20	4	20	20	20
1600 METRES	25	9	25	25	25
1600 METRES	50	87	40	40	40
2. POTENTIAL CONSUMPTION AVAILABLE l/DAY/CAPITA:	40 l	20 l	40 l	35 l	30 l
ACTUAL OR ANTICIPATED					
% 10 l/day	10%	18%	10%	5%	0%
% 10-20 l/day	45%	42%	50%	50%	55%
% 20 l/day	45%	40%	40%	45%	45%
3. RELIABILITY					
% OF YEAR SUPPLY ASSURED MAJOR TRADITIONAL SOURCE	99%	94%	x	x	x
NEW IMPROVED SOURCE	x	x	95%	99%	97%
4. QUALITY					
% OF SERVICE POPULATION WITH:					
TRADITIONAL SOURCE	80%	88%	8%	8%	8%
TRADITIONAL SOURCE-HIGH RISK	6%	3%	2%	2%	2%
IMPROVED SOURCE	14%	9%	10%	10%	10%
IMPROVED SOURCE-HIGH RISK	-	-	-	-	-
TREATED SOURCE	-	-	80%	80%	80%

5. FACILITIES (NUMBER)

SCHOOLS	6	7	8	8
DISPENSARIES	4	6	8	8
GOV'T CENTRES	0	0	0	0
OTHER SERVICE CENTRES	6	8	8	8

Table 2c.

OJECT TITLE: MPANGO WATER SUPPLY PHASE 1 AND 2

DEVELOPMENT POTENTIAL

TYPE	WITHOUT ADDITIONAL INVESTMENT NUMBER	WITH ADDITIONAL INVESTMENT, PLANNING OR COORDINATION NUMBER	TYPE OF INVESTMENT	ESTIMATED COST OF ADDL INVESTMENT (Shs.)
UJAMAA VILLAGES NUMBER	16	0	–	0
POPULATION	11,000	0		
. RELEASED LABOUR HOURS/ADULT/DAY	0.7			
. CULTIVABLE LAND, AVAILABLE TOTAL - SERVICE AREA (ha.)	42,500	___	___	___
CULTIVABLE BUT NOW UNCULTIVATED	39,800			
SUBSISTENCE CARRYING CAPACITY UNCULTIVATED	142,000			
. IRRIGEABLE LAND POTENTIAL (ha.)	0	0	–	0
5. PRODUCE MARKET				
CO-OP BUYING POINTS	0	2	small godowns	50,000
LOCAL MARKETS	2	0	–	0
6. LIVESTOCK ANIMALS UNITS WATERED	0	0	–	0
DIPS	0	4	cattle dips	60,000
MARKETS	0	0	–	0
7. FISH PONDS SURFACE AREA (HA.)	0	0	–	0
8 RURAL INDUSTRY EMPLOYEES	0	20	saw mill	125,000

AFTER 0 YEARS	AFT 20 YEA
9,000	89,00
15%	15%
20	20
25	25
40	40
35 1	30 1
5%	0%
50%	55%
45%	45%
x	x
9%	97%
3%	8%
2%	2%
0%	10%
–	–
0%	80%

The indicators based in the analysis might be expected to improve as our understanding of the dynamics of rural water development increases. For the present, we do not know whether released labour is in practice productively-used or to what degree is disease reduced by increased water use. Thus we can only state the possibilities and speculate on the effects. But current research now underway promises to strengthen our knowledge of these effects.

Mastering the Master Plan

A master plan is a document, planning is a continuing process. Increasingly, the concern of planners is shifting from the production of documents to the provision of planning services. In the context of Tanzanian resources, consultant assistance in preparing the plans seem necessary. But long after the master plan teams depart, the planning unit of the Ministry will be called upon to revise, update, and reschedule the programmed effort. Will the volumes of plans, many of them attractively printed and illustrated, lend themselves to this treatment? If the usual experience with such reports holds in the future, it is indeed unlikely. Even as good and competent a report as "Tanzania Rural Water Supply Development" does not lend itself easily to reprogramming its suggested twenty year programme for rural water supply. It should seem reasonable to demand of each master plan the quality of easy revision and review. The use of consistent projections, unit areas, and design standards will encourage these qualities but the format of presentation needs to be scrutinized as well with the view that the plans strngthen and reinforce the future planning capability of the ministry's own unit.

Conclusion

An essential skill in short supply in developing countries is the ability to wisely use, guide, and direct consultants. Unfortunatly, this skill is not included in most formal education, rather it is acquired by experience, some of it painful. It is furthered by a comparative and current knowledge of the applicable techniques of analysis. And it is maintained by the constant strengthening of the nation's own internal planning and technical services.

The deeply - held desire of Tanzanians to provide improved water for all deserves the very best of consultant work. And the high costs of such work, comparable to building major dams or construcing irrigation works, argue for exercising the same care in the design of consultant effort as in the desgn of a major engineering structure. A small effort now by the existing planning and technical services can insure that the water master plans are flexible to meet the changes of the future, are consistent with development policy, and are helpful in making needed and sometimes difficult choices.

A P P E N D I X

KAHAMA DISTRICT (131) Zone 131.1: Eastern Kahama

A. LOCATION:

The zone includes all of Kahama Division, Ngongwa Sub-Division of Msalala Division and the nrth-eastern part of Dakama Division.

B. GENERAL FEATURES

This is a flat to undulating zone with large areas of mbuga, especially in the east. It is an area of fairly long Nyamwezi settlement and the desity of population (which is medium[1]) is much higher than in any other part of the district. Most people live in the west and central part of the zone, while the mbuga areas are used mainly for grazing. Paddy, which is becoming increasingly important, is the main cash crop, followed by cotton. Other important crops include maize, cassava, groundnuts and other legumes. As in all parts of the district, ridging is the normal form of tilling but, in this area, many farmers use ox-ploughs. There are more livestock than in the western zones but less than in Zone 2. Unlike most of Sukumaland, livestock owners use manure for cultivation.

C. PHYSICAL RESOURCES

The area is flat to undulating with a few granite outcrops and, especially in the eastern part, large areas of mbuga, On the slopes the soils are well drained, dark red loams and sandy clay loams while in the valleys and the flatter areas poorly drained, dark brown or very dark grey to black sandy clays and clays predominate. The average annual rainfall is probably 950-1000 mms.

D. CROP PRODUCTION

1. Land availability and tenure: Most land suitable for cultivation is already in use but land shortage is not a problem as in much of Sukumaland. Land rights are held on an individual basis and the normal means of obtaining land is by inheritance; land is occasionally sold but not normally rented or loaned.

2. Farm size: The average area cultivated per household is medium[1], although there are some very large farms. On the smaller farms most of the land claimed is cultivated every year but those who own a large area may leave much of it fallow. In most farms the plots are scattered.

3. Crops: Paddy the main cash crop, is grown by most farmers and is becoming increasingly important. It is grown in the valleys and other low-lying areas. Cotton is also a major cash crop but it is less important than in zones 2 and 3. Maize and cassava are the main food crops while other crops include groundnuts, chick peas and other legumes, millet, sorghum and sweet potatoes.

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[1] See Introduction for scale of population density used throughout this report.

[1] See introduction for scale of farm size used thoughout this report.

4. Planting: Most crops except paddy and cotton are interplanted or planted in succession. The times of planting and harvesting the major crops are as follows:-

	planting	harvesting
paddy	Dec. - Mar.	May - Aug.
cotton	Nov. - Dec.	June - Aug.
maize	Nov. - Jan.	Apr. - June
groundnuts	Nov. - Dec.	March
millet/sorghum	Nov. - Dec.	June - July

5. Tillage: Ridges are normally used for all crops except paddy and chick-peas.

6. Seed: Improved seed is used for cotton (supplied free by the Lint and Seed Marketing Board and distributed through the Cooperatives) and occasionally for maize.

7. Soil erosion and conservation: There is some soil erosion but it is not serious as in many part of Sukumaland. Conseration measures (other than ridging) are seldom practised, although sisal hedges are occassionally planted.

8. Soil ferility: Since this area has been cultivated for a long period of time measures to restore soil fertility are required. Those farmers with livestock use manure, particularly for maize and cotton, and a number of people use artificial fertilizers. Other measures include intercropping (practised throughout Sukumaland) ridging and, where enough land is available, the use of fallow.

9. Water control: Apart from the construction of bunds in paddy fields to conserve water, there is usually no form of water control.

10. Mechanization: Most cultivation is probably done by hand but a considerable number offarmers use ox-ploughs.

11. Crop protection: The uprooting and burning of cotton plants after harvesting as a precaution against disease is compulsory and most of those people who use artifical fertilizers also use insecticides. The other main means of protection is individual or group scaring and hunting of birds and animals.

12. Labour: Hired labour is not widely used but co-operative labour between neighbours is very common. It is used for many agricultural operations and other activities and payment is in the form of food, beer or reciprocal labour.

13. Marketing: All cotton and much of the marketed rice, maize and goundnuts are sold through the Co-operatives. Other produce is sold on local markets (including black marketing).

E. ANIMAL HUSBANDRY

1. Cattle: The proportion of farmers owning cattle is medium/low.[1] The average herd is fairly small (probably under 20 head) but there are some large ones of several hundred head. Cattle are an important indicator of wealth and are used for dowry, milk, majure and work but are seldom sold unless cash is urgently required. They are Zebus and there are no improved stock.

2. Small stock: The number of households owning goats and sheep is somewhat less than those with cattle. They are used mainly for meat and for religious purposes.

3. Donkeys: A few farmers keep donkeys for transport purposes.

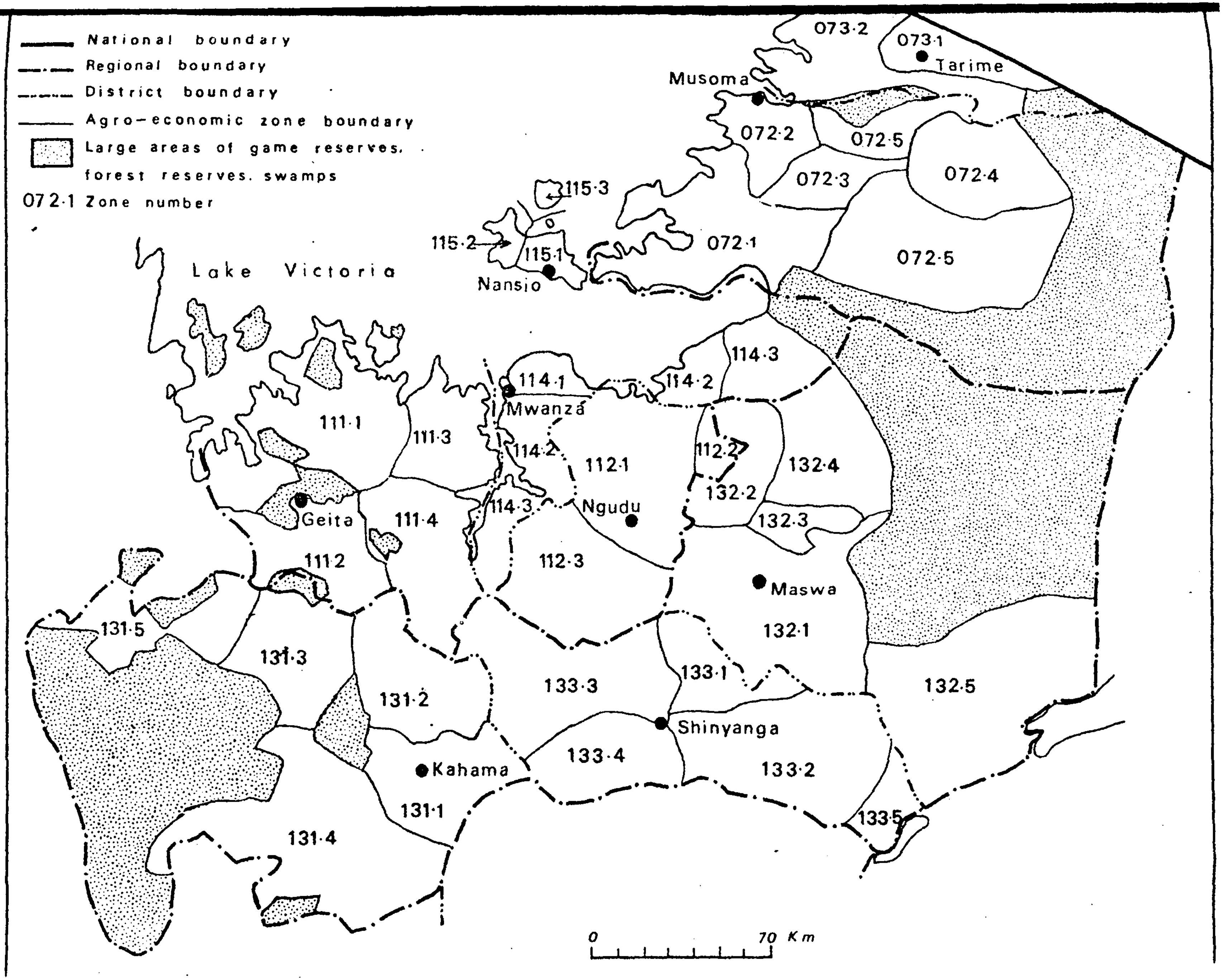
4. Poultry: Almost everyone has a number of poultry, used for meat and eggs.

5. Husbandrry: When there are no crops in the fields livestock are grazed anywhere, irrespective of ownership of the fields. At other times they are grazed on permanent pasture (land unsuitable for cultivation) or fallowland. The low lying, poorly drained areas (particularly in the eastern part of the zone) are used mainly in the dry season and there is considerable seasonal migration, especially of larger herds. Permanent pasture is owned communally and animals are often herded communally among neighbours, tended by youths and men. Herders are not hired but the tending of cattle owned by others in return for milk, manure or the use of ozen is common.

F. POPULATION AND SETTLEMENT

1. People: The main in the zone are the Nyamwezi, but there are also a number of Sukuma, Tusi and Sumbwa.

2. Settlement: Most settlement is in the form of clusters of homesteads (household units) scattered through the zone, although larger nucleated settlements form a long road or around features such as shops and Co-operative buying posts. A homestead consists of one or more buildings, often surrounded by a fence or hedge. The whole area is divided into "villages" but a "village" is a unit for administrative and identification purposes rather than a nucleated settlement.


National boundary
Regional boundary
District boundary
Agro-economic zone boundary
Large areas of game reserves, forest reserves, swamps
072.1 Zone number
Lake Victoria
Musoma
Tarime
Nansio
Mwanza
Ngudu
Geita
Maswa
Shinyanga
Kahama
073.1
073.2
072.1
072.2
072.3
072.4
072.5
115.1
115.2
115.3
114.1
114.2
114.3
111.1
111.2
111.3
111.4
112.1
112.2
112.3
132.1
132.2
132.3
132.4
132.5
131.1
131.2
131.3
131.4
131.5
133.1
133.2
133.3
133.4
133.5
0
70 Km

PLANNING FOR RURAL WATER DEVELOPMENT IN TANZANIA

by

L. Berry and
D. Conyers

BRALUP, University of Dar es Salaam

INTRODUCTION

Rural water supply has been a priority of the Tanzanian development programme since Independence and in some areas even before that, but it is only in the last two or three years that comprehensive steps have been taken to reappraise the whole problem of providing an adequate supply to rural areas and to establish a detailed plan for meeting national objectives in this field.

We now have a policy decision which aims in the next two decades to achieve this very considerable goal. To tackle this task we have to define our priorities in rural water supply and plan to meet them in the most economical way. The engineering task in bringing water to millions of rural dwellers is immense and the planning task is no less daunting.. However some clear guidelines are being laid down and from the beginning it has been agreed that the first focus of planning should be at the regional level with work beginning almost immediately on the preparation of plans in some priority regions. Such plans are essential if the great investments to be made in the provision of water during this period are to yield maximum returns and if they are to be fully integrated into the country's development. However, to aid their success it will be important to have a carefully designed general format within which all the plans would be drawn up, particularly since they are to be prepared by a variety of different teams, most of whom are from overseas and so are relatively unfamiliar with Tanzanian conditions.

In this paper we put forward as a basis for discussion some suggestions for the format of a standard master plan. We consider the factors on which we think the plan could be based, the types of data required and their sources, the formation of the plan and its integration into other development programmes for the region and, finally, we consider briefly the coordination of the plans for all regions at the national level.

The basis for a master plan

The aim of national water development policy is to supply the whole of the country with adequate water by 1990. However, "to plan means to choose" and, in the context of water development, this means choosing which areas or projects should receive priority and choosing between alternative ways of supplying them. The purpose of a water master plan is to aid these decisions.

The first stage in the preparation of the plan is to identify the factors which will determine the choices. These may be divided into four main groups:

(i) the quality of existing supplies;

(ii) the development potential and programmes for development;

(iii) hydrological conditions and potential;

(iv) manpower and financial resources.

The first two may be considered "demand" factors and the second two "supply" factors.

On the demand side, the quality of existing water supplies in an area determines the basic need for improved conditions. Thus, on these grounds priority would be given to areas where the traditional water resources are most inadequate and no improved sources have yet been provided. However, one must also take into account the development potential of an area and programmes for its development, partly because one must obtain the maximum economic as well as social benefits from investment in water supplies and partly because adequate water supplies essential for the success of any development project. For example, given an equal need, a densely populated, highly productive area might be given priority over one with a sparse population and low productivity. The most difficult priority decisions are when the choice is between a project with a lower need but a higher return and one with a real social need but no major economic return. However, in practice the issues are rarely so clearly defined.

The priorities in terms of the demand for water have, however, to be reconciled against the factors affecting its supply. The possibility of meeting any demand and the most feasible way of doing it are determined by, on the one hand, hydrological conditions and, on the other hand, the availability of manpower and financial resources.

These are the four factors which must be taken into account if the master plan is to meet the greatest needs for water development in the region and to be implementable with the resources available. The next stage, therefore, is to collect the relevant information about these factors.

Data collection[1]

(i) Existing water supplies

It is necessary to understand existing patterns of water use in the region as a basis for evaluating future needs. For this purpose various categories of water use can be distinguished:

(a) rural
- (i) domestic
- (ii) livestock
- (iii) irrigation
- (iv) other (incl. mining, rural industry, etc)

(b) urban
- (i) domestic
- (ii) industry, commerce
- (iii) other

[1] A summary of the data required and its sources is given in Appendix I.

For each category one requires information on the sources of water, the area and approximate population served, the capacity and reliability, the quality of the water and the perons or authorities responsible for maintenance (if any). The data will thus include both traditional sources and any form of improved supply. In many cases, particularly rural domestic use and livestock watering, it will also be necessary to distinguish between dry and wet season sources.

The information on improved supplies can be obtained from local records of the Ministry of Water and Power, District Councils and other bodies (for example, missions) which may be responsible for their construction or maintenance. Data on traditional sources is less readily available. However, a general picture of conditions in different parts of the region could be obtained from discussions with local officials at the regional, district and divisional levels. This could be supplemented by simple sample surveys of water use (similar to those used in the Bureau of Resource Assessment and Land Use Planning studies in Geiro and Handeni)[1] in selected, representative areas or in areas where more detailed information is required.

(ii) Development potential and programmes

The relationship between investment in water and other forms of development is twofold. Firstly, the provision of adequate water supplies is essential for the success of any development scheme, whether it be an Ujamaa village, a state farm, an extension programme, an industrial project or an urban housing scheme. Secondly, it is important that significant retunns are obtained from the large investments made in water development. There will be many cases where the returns from particular small schemes cannot be quantified easily and the social and health benefits will be the major returns to the nation. But in major investments, projects which involve their own infrastructure and studies, returns are to be expected and worked for. It is likely that in most cases substantial and visible economic returns from investment in water supply will only occur when such investment is accompanied by complementary inputs into other infrastructure, extension programmes and so on. It is, therefore, essential that the water plan be related to the development potential of the region and the plans and programmes which exist for other sectors. Moreover, equally important is the need for planning in other sectors to take into account the water development programme. In other words, the plan cannot be made in isolation but must be an integral part of an overall development plan for the region. This is consistent with the increasing emphasis now being placed on regional planning.

In preparing the water plan it will thus be necessary to collect a variety of information related to the general development potential and prospects of the region during the plan period. The first need will be to formulate some broad perspectives for overall development, which would form the framework not only for the water plan but for all forms of planning in and for the region and, in particular, for the Third Five Year Plan. This would involve the identification of:

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[1]See BRALUP, Research Reports Nos. 15 and 22.

(i) the potential for development;

(ii) the main constraints;

(iii) the major policy goals or objectives, including the activities on which attention would be focussed (e.g. ranching, dairying, a particular crop or industry, etc.); and

(iv) the types of strategy to be adopted to achieve these goals.

A large part (or possibly all) of this work could be done not by the water team but by local personnel, especially the Regional Economic Secretary and other members of the Regional Development Committee, the Regional Planning Division of Devplan and perhaps BRALUP.

Within this framework it will then be necessary to obtain more specific material relating to individual sectors, including population, agriculture, urban and industrial development and infrastructure other than water.

As water supply projects have a long design period, probably 20 years in most cases, the current and design population is a most important factor. A vital component of the plan data base will consist of information on the present population and its distribution and estimates of its growth rates and future distribution. Settlement patterns - both existing ones and the hoped - for future pattern - will also be important design information.

Agricultural data may be divided into two types. First there is information on the existing agricultural systems and the general development potential of each part of the region. This will indicate the most productive agricultural areas - either at present or in the future - which should receive high priority for water development because they will yield the greatest returns to investment. Second, data is required on proposals for specific agricultural or related rural development projects during the plan period, so that the water programme can be designed to support them. Examples of such projects include major extension programmes (such as the tea schemes or dairy extension projects), irrigation schemes, state farms, ranching associations and, in particular, Ujamaa villages. In each case it will be necessary to know the timing, location and water requirements of the proposed projects.

For the planning of urban water supplies one needs to know the present and estimated future demand for domestic, industrial, commercial or other purposes. One will therefore require information on present population, expected growth rates, existing and planned industrial and commercial development and any other major activities. These will be related to any plans which exist for the overall development of the urban centre, especially in the case of the nine "growth" towns. Connected to this is the need for information on rural industries and any other major users of water outside the main towns, such as mines. Finally one requires data on infrastructure other than water, including communications, marketing facilities, power, education, health and other social services.

If the maximum benefit is to be obtained from all investment, including that in water, it is essential that the planning of all forms of infrastructure be coordinated and related to other development programmes.

Information on development potential and programmes can be obtained from a variety of sources (see Appendix I). Data on present population size and distribution is available from the 1967 Population Census and some simple methods are available for making projections of future growth, as used, for example, by BRALUP in Handeni.[1]

Some information on settlement patterns can be provided by local officials while local agricultural officers have considerable knowledge of the existing agricultural conditions and potential of different parts of the region. Much of this data has already been collected by BRALUP for about half the country and plans are in progress to cover remaining areas in the near future. In consultation with local Kilimo staff, districts have been divided into "agro-economic zones" and for each zone a brief description of the existing agricultural system and settlement pattern is given.[2] As well as supplying some of the data required for the master plan the zones could also provide a basis for defining planning areas within the region and a framework for the collection of other data.

Most of the information on existing urban and industrial development and on the location of infrastructure can be obtained from the relevant ministries or from the Regional Economic Secretary, although it may be necessary to carry out a few special surveys, particularly in connection with urban facilities. Much of this material will be required for planning the nine "growth" towns and part of it has already been gathered by BRALUP.

Details of development proposals in all sectors can be obtained through discussion with the ministries or other bodies responsible for their planning and implementation. The discussions should be a two-way process so that the other sectoral programmes are related to water development as well as the reverse. It is here that coordination between the various bodies is most important and the Regional Development Committee could act as a forum for the presentation and discussion of all planning proposals.

Much of the information considered above is relevant not only to water development but also to the planning of other sectors and to regional planning in general. Considerable time and effort could therefore be saved if at least part of the data collection for all forms of planning in the region was organised centrally. This could be done by the Regional Economic Secretary, assisted by the District Planning Assistants and coordinated by the Regional Development Committee. The emphasis throughout should be on low cost methods of collection, making maximum use of secondary sources of material - such as local officials - and only undertaking new surveys when absolutely necessary.

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[1] See BRALUP, Research Report No. 22.

[2] See BRALUP, Research Reports Nos. 13, 16 and 23.

The information needs to be collected for the whole of the plan period but obviously only very rough estimates will be available for the latter part. The period could be divided into four five-year phases, for which detailed information will be available only for the first. For the remaining phases the aim will be to obtain a broad outline of the direction which development will take and to identify the main factors which will affect the planning of water development in the future, so that additions and adjustments can easily be made as more data becomes available.

(iii) Hydrological conditions and potential

The possibility of providing any area with adequate water and the most feasible way of doing it are determined, to a large extent, by the hydrological conditions of the area. Knowledge of the existing resources and their development potential is, therefore, required. As it is likely that a large part of the skills of any planning team will be centred on the hydrological and engineering conditions it is necessary only to summarise a few points here. A recent BRALUP publication[1] outlines in Chapter I some of the prevailing conditions in meteorological and hydrological data collection and the bibliography provides adequate supporting material.

While it is easy to get general rainfall data from the longer established precipitation stations[2] problems often arise in the interpolation of these results into other areas with shorter term and less efficiently collected data. In brief the rainfall data is less comprehensive than it appears at first sight.

Tanzania has an admirable gauging network on many of its major streams and for some of these there is a substantial period of data. Information on the characteristics of small basins is naturally more scarce and this can be a problem as many rural water supply projects (especially those which could be undertaken largely on a self-help basis) involve small basin hydrology. It might be worthwhile in some areas and as part of the planning process to obtain data on representative small basins which then might serve as models for the region.

The greatest deficiency in hydrological data is at the moment the lack of any overall information on the potential of sub-surface water for the rural water development programme. Steps have been taken towards a better data base but at the regional level special studies are likely to be needed.

While we have suggested some investigations which need to accompany the plan proposals it is important in our view to make maximum use of the data already available. The first stage in the survey of hydrological conditions will thus be a study of the existing information, including published, unpublished and oral records and reports. Much of this can be obtained from the publications and files of the East African Meteorological Department and the Ministry of Water and Power, from surveys carried out by consultant firms and various other groups or individuals and through discussions with local officials. The next stage will be by making comparisons with similar areas in other parts of the country for which data is available.

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[1] Water Development in Tanzania: a critical review of research, Research Paper No. 12, 1971.

[2] See BRALUP, Research Notes No. 5a.

Some additional surveys will inevitably be required. However, since they will consume a great deal of time and resources, they should not be considered until the first two stages have been completed, thus revealing the major gaps in formation needs. However, they should be integrated into an overall national programme for the improvement of hydrological records.

(iv) Manpower and financial resources

The other factor affecting the feasibility of alternative methods of meeting water requirements is the availability of the necessary manpower (especially technical) and financial resources for the planning, construction and maintenance of the schemes. One therefore requires information on the expected costs in term of manpower and finance of all proposed projects and the availability of these resources. In the early stages of evaluation detailed costing of the projects will not be necessary. In most cases it should be adequate to classify them into three levels - these which could be carried out by self-help through local agencies, those handled by the regional water development department or other section of government at the regional level, and those which would require national or international assistance. These can then be compared with the availability of resources at each level. However, more detailed costing will be required when choosing between alternative projects of similar cost.

Plan formulation

It might be useful to discuss what kind of water development plan we need and what processes of plan formulation will best fit the particular Tanzanian circumstances.

It seems important to us that in each region the broad strategy of the plan should be formulated in the context of the overall development perspectives for the region. Within such a broad strategy it will be necessary to outline more specific objectives and projects tentatively for the five-year plan periods of the programme and more specifically for the first five years. It would seem to be useful if all projects were categorised into self-help, regional and national levels of implementation with appropriate combinations of these where necessary. At least in the first phase of the programme one would need specific data on costs, benefit implications and timing of each major project or important set of small projects.

The first step in the formulation of such a programme will be to rank areas or projects in order of priority in terms of their demand for improved water supplies. This will involve comparing the areas which have priority because of the poor quality of existing resources with those where improvements will be of greatest benefit to other forms of development, and producing a satisfactory compromise between the two.

The next step will be the identification of alternative ways of supplying each of the priority areas or projects on the basis of the hydrological conditions and potential. Preliminary costings should be made for each feasible alternative and the projects then divided into the three possible levels of implementation (self-help, regional and national). These may be compared with the availability of manpower and financial resources at each level.

Finally, a revised priority ranking of projects can be drawn up, taking into account both the demand for water and the feasility and costs of supplying it and allowing for alternative projects or combinations of projects, especially in the later phases. The projects would be subdivided according to the level of implementation and then grouped into five year phases to produce the final development programme.

In many cases the choice and ranking of projects will be fairly straightforward but in others it will not be so obvious and some form of cost-benefit analysis will be required. In such cases simple analytical techniques, along the lines discussed in other papers at the conference, could be used.

Presentation and integration of the plans

We envisage that in most cases there will be close coordination between the planning teams and the various ministries at all planning stages, so that as wide a group as possible are involved in the planning process. In particular the Regional Development Committees will have been involved in many stages. However, it will be important to present the draft plans both to the Regional Development Committees and to the national Ministry of Water and Power for comment and amendment so that the plans are formally approved by both the future implementing bodies.

At the national level a major task will be to establish the right kinds of priorities and allocations between the regions. There will obviously be a high demand for finance and manpower resulting from the flurry of planning and much resolution of priorities between regions will be necessary. The regional allocation of funds should be based on the same criteria used to determine the choice of projects within a region; using the data presented in the plans, the needs and development potential of each region should be compared with the feasibility and costs of the proposed schemes.

At the regional level the Regional Development Committees will consider the feasibility of the plans in terms of regional resources and overall regional development proposals. They will also be responsible for ensuring that any action required by other ministries to support the water programme is taken. The need for this was illustrated in the case of north-east Nzega,[1] where it has become obvious that considerable investment in other infrastructure, agricultural extension programmes and so on will be required to support the investment in water supplies if maximum benefits are to obtained. It would be advisable if, wherever a major water project - like that in Nzega - is proposed, a mechanism were established to ensure that such integrated development takes place.

Manpower requirements

It appears that most of the regional master plans will be prepared largely by outside teams. However, if the final plans are to be feasible in terms of national and regional resources and if they are to form an integral part of overall development plans, as outlined above, it is essential that, through the Regional Development Committee, they maintain very close contact with local officials, especially the Regional Water Engineer and the Regional Economic Secretary.

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[1] See BRALUP, Research Report No. 6/10.

In terms of the composition of these planning teams it seems to us that they should be as broad-based as possible. This does not refer to the need for travelling many miles in a landrover but to the need for a careful assessment of the economic and social aspects as well as the more obvious engineering and hydrological aspects of the operation. Local conditions will determine some of the orientation of skills; for example, in some areas a ground-water hydrologist is essential and in others possibly of little use. In fact the final composition of a team might only be determined after perhaps a three month period of technical reconnaissance. In our view the range of skills needed could be met by a team including the following specialisations: hydrology, engineering economics, geography or land use studies and regional planning. Any other skills - for example, those of a demographer - could be coopted for short periods as and when necessary, probably from within the country.

Conclusion

We have attempted here to put forward some ideas on the role, content and methodology of water master plans and, at the same time, to provide a guide to the sources of some of the data likely to be required in preparing the plans. We hope that this will form a focus - if a focus is in fact needed - for a discussion of the new problems of planning for rural water supply which have arisen as a result of the firm and ambitious programme which has been launched. It may be that viewpoints raised in our paper and the reactions to it from the various delegates to the conference may be helpful to the Tanzania Government in its definition of the planning process in this field.

Appendix : Sources of Data

1. Maps and air Photographs

   1. Base maps: Topographical maps at scales of 1:50,000 and 1:250,000 for a considerable part of the country and district base maps at varying scales for each district are available from the Surveys and Mapping Division, Ministry of Lands and Urban Development.

   2. Geological maps at a scale of 1:125,000 are available part of the country from the Mineral Resources Division, Ministry of Commerce and Industries, Dodoma.

   3. Air photographs are available for all areas but at varying scales and dates; details may be obtained from the Surveys and Mapping Division.

   4. Population Census 1967 district Enumeration Area maps, from Census Office, Bureau of Statistics.

2. Published data

   (a) BRALUP publications

Agro-economic zones of north-eastern Tanzania, Research Report No. 13, 1970

Agro-economic zones of Sukumaland, Research Report No. 16, 1970

Agro-economic zones of Southern Highlands, Research Report No 23, 1971

Extension of the Kisitwi-Rubeho pipeline. a planning Study, Research Report No. 15, 1970

Handeni water supply - preliminary report on design criteria, Research Report No. 22, 1971

Heiinen, J., The river basins in Tanzania: a bibliography, Research Notes No. 5e, 1970

Jackson, I.J., Rainfall stations in Tanzania, Research Notes No. 5a, 1968.

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North-east Nzega planning project: Final report, Research Report No. 6/10, 1970

Water development in Tanzania: a critical review of research, Research Paper No. 12, 1971 (especially Ch. I and bibliographies)

(b) Other publications

Bureau of Statistics, 1967 Population Census. Vol. 1 Statistics for Enumeration Areas 1969; Vol. 2

Bureau of Statistics, Recorded Population Changes 1948-67, Tanzania

Bureau of Statistics, Directory of Industries, 1967

East African Meteorological Department, Various publications.

Ministry of Water and Power, Hydrological Year Book

3. Unpublished data

1. Ministry of Water and Power (Ubungo and regional offices): records of existing improved supplies; hydrological data.

2. Regional, district and divisional officials (especially Regional Economic Secretaries), District Councils, etc: miscellaneous data on existing conditions, activities and infrastructure and proposals for future development.

3. Infrastructure: Data on the location of a wide variety of infrastructure - including administrative and political facilities, road and telecommunications, commerce, social services and economic facilities - has been collected by A. de Souza, University of Dar es Salaam, and will be published by BRALUP in the near future.

4. Urban data: Data on land use, population and human characteristics has been collected for 15 towns by A.de Souza, University of Dar es Salaam, and will be available in the near future.

TOWARDS A RATIONALE FOR WATER SUPPLY POLICY IN DEVELOPING COUNTRIES

by

Ian Burton

University of Toronto

The economic development literature gives only veiled hints regarding the desirable levels of expenditure on community water supply at different periods in the economic growth of nations, and some of the hints are flatly contradictory. Writers such as W. Arthur Lewis[1] and W.W. Rostow[2] have asserted the need for high levels of social overhead investment at an early stage of development. Others, notably Albert O. Hirschaman, have argued the case for "development by shortage" as a safer way to avoid overinvestment. It seems clear that economic development theory provides little guidance for those who would make rational resource allocation decisions in the community water supply field. The way is left open for some to assert the primary importance of water supply in economic development and for others to downgrade its significance. In neither case do the proponents have very convincing arguments.

A Policy Rationale

It is not the purpose of this paper to try to resolve a complex and intractable issue, but rather to present a possible rationale for water supply policy and to suggest some of its merits.

The first proposition is that all people have certain minimal water requirements for survival, health and livelihood ~~and that it~~ is the responsibility of the whole society, usually at the national level, to insure that these needs are met. A government charged with the task of bringing its population more firmly and securely into the modern world might therefore well accept as high priority item the provision of a safe minimal supply of water to all its citizens. In many countries this implies a significant allocation of resources to community water supply at an early stage in the development process.

The criteria for investment at this stage are primarily in the engineering design and health fields. The question is how a water supply system can best be designed at low cost to provide such a quantity and quality of water to the consumer that a substantial improvement in health can be realized. One danger here, at least in the East African area, is pointed out by David Bradley elsewhere in this collection of papers. If the improved community water supply is adequate either in quality or quantity to achieve the expected health benefits then the expenditures will be largely in vain. Granted the extremely limited availability of capital there is strong pressure to design systems at low cost.

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1 W.A. Lewis, Theory of Economic Growth. London: Unwin, 1955

2 W.W. Rostow, The stages of Economic Growth. Cambridge: Cambridge University Press, 1960

3 A.O. Hirschman, The Strategy of Economic Development. New Haven and London: Yale University Press, 1066

Nevertheless, many low cost systems can add up to substantial sums of money and if no significant improvement in health occurs the money will have been wasted.

There is still very inadequate understanding of the relationship of water supply to health. In general it seems that in large cities where the danger of typhoid, cholera and other epidemic diseases is present the key factor is water quality. In some rural areas where population density is less and the number served by a single system is much smaller the diseases prevalent are more often associated with quantity of water use. At the present time the Government of Tanzania has embarked upon a substantial rural water supply programme largely upon the basis of the first proposition described above. It is vitally important for the success of the programme to gain better understandings of the relationship of engineering design to health and some further research and possibly experimental work in this direction seems highly desirable.

Proposition two is that as the level of income rises and as the requirements of proposition one are met, then the basis for investment in community water supply must switch from engineering and health criteria to more strict financial criteria. At this stage additions to the water supply system would be based directly on a community's ability and willingness to pay. Thus the water supply operation would come to function on the basis of raising its own capital and paying off the debts by raising revenue from those served.

Acceptance of propositions one and two should produce over time a growth of per capita water supply investment as shown in Figure 1. At Phase 1 a rather sharp rise in investment is needed to meet basic requirements. This is the Phase now represented in Tanzania by the rural water supply programme. Phase 1 may last for a considerable period of years and ends only when basic requirements have been met. By this time the substantial majority of the potential health benefits will have been realized. The outstanding questions during Phase 1 center around the design of water supply systems in relation to health benefits.

Further expansion and improvements in the quality and quantity of supply are required as inputs to productive activities and for convenience. At this point the criteria become financial. Can a community afford an improved water supply? Will the revenue raised from productive activities cover the costs? or will the consumers be willing to pay? As standards of living improve the demand for better quality water in greater quantities may be expected to grow and per capita investment will slowly rise. he key questions during Phase 2 center around efficienty water utility management. During Phase 2 investment in water supply is likely to rise very slowly, however, as more pressing needs are dealth with. As the economy approaches a more affluent standard the rise may eventually accelerate as shown in Stage 3.

Consequences of Deviation?

It is a matter for research to fix the values and levels illustrated diagramatically in Figure 1. As shown in Figure 2 there is a wide variety of standards at present applied and no clear pattern emerges. In some countries much higher levels of consumption are found at similar levels of economic development than at others. Without knowing where the proposed curve in Figure 1 actually lies it seems that it is not being generally followed.

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Fig 1 PER CAPITA WATER CONSUMPTION AND PER CAPITA GROSS NATIONAL PRODUCT

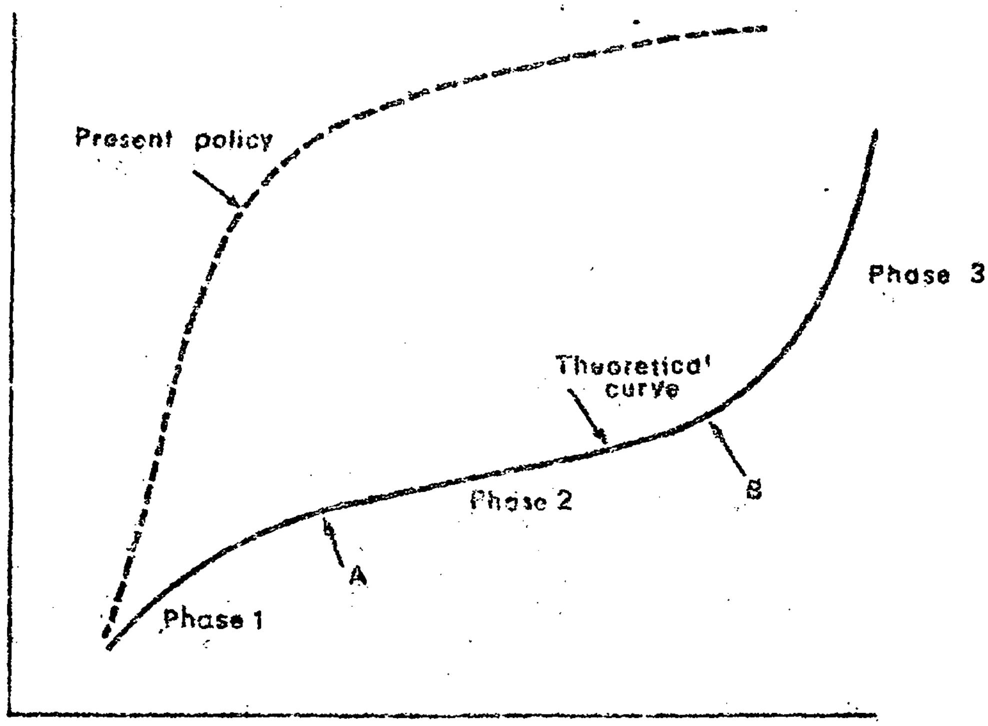
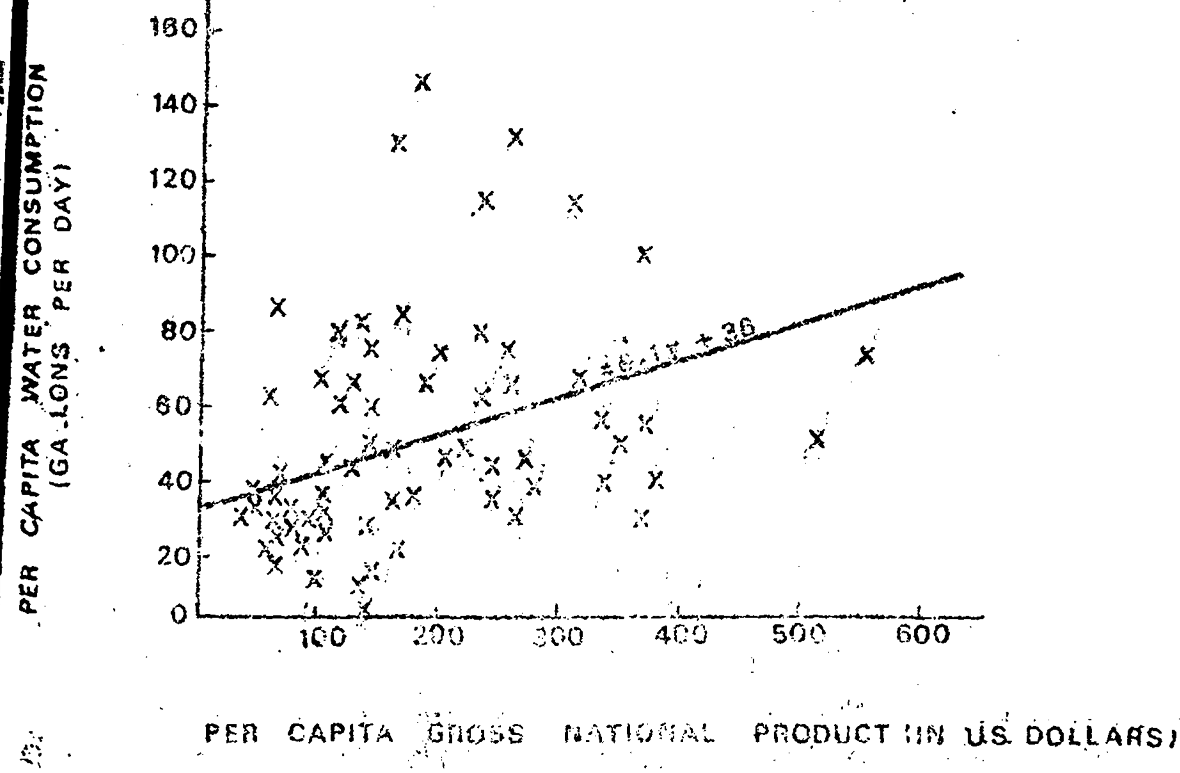


Fig. 2 CORRELATION OF WATER COSUMPTION, AND GNP



What are the consequences of deviation? In the case of Phase 1 some countries have not yet started the substantial investment in community water supply that is needed for basic requirements. A consequence is that health standards remain relatively low and that national development is handicapped. It may also be that death rates remain relatively high and that the population pressures being generated are not as great as would otherwise be the case.

Another possible deviation is that the trend established in Phase 1 will continue on up resulting in higher levels of investment at Phase 2 than would otherwise be the case. This implies an overinvestment in water supply to the detriment of other needs.

Rural and Urban Differences

The curve in Figure 1 does not reflect rural and urban differences. It is perhaps usually the case that cities are further along the curve than small towns or rural communities. The greater wealth accumulated in cities may mean that there is a greater tendency to continue Phase 1 trends into Phase 2. Certainly the plans proposed for urban water supply systems in some large cities in the developing countries suggest that a tendency to overbuild is not unknown.

The allocation of considerable sums to urban water supply may be a sound rationale. Cities are the growing points of the economy, where new industries are being established and where the better educated concentrations of population demand higher quality services. In the design of urban water supply systems, therefore, it seems particularly important that the financial constraints of Phase 2 be applied and be reflected in the designs. Not to do so may deprive much of a nation's population in the rural areas of basic water needs.

IMPACT STUDIES OF RURAL WATER SUPPLY

By
J.D. Heijnen,
LIDEP, Soni
and
Diana Conyers
BRALUP, University of Dar es Salaam.

EXISTING STUDIES

Impact studies are designed to examine the effect of new and improved domestic water supplies in the rural area. Ideally, therefore, they should be conducted over a number of years. A "base line" study ought to establish the relevant facts before the construction of the improved supply, while further investigations, after the construction, should measure the impact. Preferably these changes should be traced over at least several years.

Applying these criteria, it should be admitted that very few-if any - true impact studies have been done in Tanzania. During the past few years, however, some attempts have been made in this direction, although the results are available only in a preliminary form. The main studies are as follows:

(i) The most comprehensive study has been undertaken by D. Warner of the Economic Research Bureau. He conducted a survey in 26 villages in 10 different districts. In 10 of these villages an improved supply was installed during the study, so that observation could be made before and after improvement. The fieldwork is now completed and preliminary reports have been issued.

(ii) Another study of this kind is being conducted in Ismani (Iringa District) by J.D. Heijnen of BRALUP, in cooperation with Mr. and Mrs. D. Feldman (ERB) and the Max Planck Nutrition Unit. The baseline study, which attempts to measure water use before the construction of the pipeline, is complete. A first evaluation of the changes in water consumption has been done, and a follow-up study is now in progress.

(iii) BRALUP has undertaken a comprehensive survey in North-East Nzega District, combining an evaluation of the existing Bulenya Hills pipeline and a planning study of the area to be served by pipelines from the new Mwamapuli Dam. This does not constitute a true "before-after" study and only some of the effects of the Bulenya Hills pipeline were measured. However, some conclusions can be drawn and the data could be used as a base-line study, to be followed up after the construction of the new pipelines.

(iv) A short questionnaire has been given by J.D. Heijnen to 100 respondents in Mlola, Lushoto District, where an improved water supply has just been completed.

In addition, some information can be gained from other studies although these were not designed primarily as impact studies. The most comprehensive of these is that by G.F. White, Bradley and A.U. White. They studied water use in twelve sites in East Africa, including two in Tanzania, together with an analysis of health statistics and the existing literature. Another example is the planning study carried out by BRALUP for the extension of the Kisitwi - Rubeho pipeline in the Gairo Area of Kilosa District. This included a survey of water use - both around the pipeline and in the area of the proposed extension.

Other sources of information are reports on the progress of certain rural development projects, which included improved water supply. One example of this is the project of the Max Planck Nutrition Research Unit in Mayo village (Lushoto District). From a research point of view, however, the problem is that, in these cases, water is only one of a whole package of development inputs into the area.

PROBLEMS OF EVALUATION

The main problem in evaluating the effects of improved water supply is that they are so manifold, and often present great problems to the researcher. This is particularly true since proper impact studies need a number of years, during which the situation in the area may change due to other inputs ... etc..

Furthermore, impacts need not necessarily be "positive"; for example, it can easily be imagined that an influx of cattle as a result of improved water supplies in North-East Nzega could have a serious effect on the rate of soil erosion. Thus in each case, depending on the type of improvement and the area, one needs to set out with a number of presumed effects and these hypotheses must then be tested.

THE BENEFITS OF IMPROVED WATER SUPPLIES

In Tanzania the view is taken that rural water supply is basically a social service although with some economic benefits. Thus it becomes important to register what the social benefits are. This does not mean, however, that the economic side can be neglected. Indeed, unless the economic ramifications are substantial, the question could be asked whether, at the present stage of its development, Tanzania can afford to invest heavily in (largely) non-productive projects. Most of the present projects are financed with Swedish aid. Even though the terms are very liberal, sooner or later the loans and interest will have to be paid back. Thus the present policy objective, to supply the whole of rural Tanzania with improved water supplies during the next twenty years, will place a great financial burden on the next generation.

An additional problem in evaluating the effects is that few of these are purely social or economic. Thus improved health leads to a feeling of greater well-being (social) as well as to greater capacity to produce (economic).

We shall now proceed to examine the most important hypotheses related to the social and economic benefits of improved rural supplies. The benefits which we consider are those which are most important in terms of national goals and aspirations and they therefore form the basis for justifying the rural water supply programme.

Hypothesis 1: <u>The distance travelled to obatin water decreases</u>

It is generally assumed that improved supplies reduce the distances which people have to travel to fetch water. In part, the problem appears to be one of comparison. The improved supply will provide water all the year round (so that the distance travelled remains the same). Under the traditional regime, however, in many areas there is a significant difference between the distance travelled in the wet and in the drey season. From the economic point of view often the distance travelled in the wet season (which is the farming season) would be the most important measure. From the social angle, a decrease in the dry season, especially as walking distances of one hour and more are frequently involved, is also an important benefit. Another consideration is that, in some cases, the distance travelled may actually increase because more trips are made. To some extent evidence is contradictory. Warner's preliminary figures, using averages for the whole year, indicate a significant decrease. The first Ismani results show (in so far as the people used the supply) a decrease in the dry season, but an increase in the wet season.

Obviously, the situation would change by improving the distribution system. But bringing the water to where the people are now might clash with another government policy objective, namely villagisation. Where the people are already living in villages, however, substantial benefits can often be gained. Unfortunately, dispersed settlement is the rule, rather than the exception, in Tanzania. The cost of a proper distribution system would, moreover, often be extremely high.

Lastly we would want to mention our strong impression that many schemes are constructed in settlements where people are already better off than others in the same area, who are not served at all by the new supply. The data collected in Ismani and Mlola appear to support this thesis. The explanation might be, that relatively dense settlement patterns will only occur in those areas where water is obtainable at a reasonable distance.

Hypothesis 2: <u>The qualiyt of water used improves:</u>

At first sight, this appears almost a truism, yet the findings of research done so far indicate that unfortunately it is not. As for the notion of "quality", we must distinguish between (i) chemical content (amount of Tolxe solids, etc.) and (ii) the degree of pollution. Not only does the chemical content of the water influence the taste, but it might also have an important effect on health (for example, if certain elements are present in excessive amounts). Naturally, the "improvement" as far as the chemical content is concerned, is easily measurable and new water supplies are normally sampled to see whether the water is acceptable in this respect. The W.H.O. standards are not applied in Tanzania as it is felt that these rates are too rigid. As yet, no definite standards have been set in Tanzania itself.

Bacteriological pollution, mainly of animal origin, gives rise to some further comments. In cases where surface water is used, this water is generally heavily polluted. In order not to make the supplies too expensive, a filtration plant is often omitted (as in Ismani and Bulenya Hills). In Ismani, where Kreysler counted coliforms, the purity of the supply at the taps was reasonably good, at any rate presumably much better than that of traditional surface water resources. However, the water taken from the overflows (which was also used by the people) was very heavily polluted. Moreover, after the water from the taps was carried home (in debes) the coliform counts indicated a significant increase. Furthermore, untreated water may spread other diseases e.g. Bilharzia (c.f. hypothesis 8).

Observations are as yet too few in number to make any difinite statement. Yet it is clear that research cannot overlook this hypothesis.

Hypothesis 3: Time and energy expended decreases

The time and energy expended on obtaining water is at least partly a function of the distance travelled, yet other factors may be important, such as the nature of the journey, the conditions of obtaining water, and other activities, such as queueing and talking.

White et al undertook a complex analysis of energy expended by estimating distances, speed of travel and time taken and converted into energy requirements, in terms of calories and costs.

A much simpler method was adopted by Warner and Heijnen and in Nzega, when merely the time spent was recorded. As might be expected there is a fairly close correlation with the distance. However, in both Nzega dnd Ismani an important new factor was the time spent in queueing for water. Furthermore, in Mlola it was found that people living less than five minutes from the tap, in a number of cases spent more time collecting water than before owing to increased consumption.

Hypothesis 4: The quanity of water used increases

White et al did a detailed study of the various factors affecting the quantities used. Thus the size of the household, wealth, cost (purchasing), season, distance and energy spent, type of source etc., may affect the quantity as might also the quality in certain extreme conditions.

The results obtained in the various impact studies vary considerably. Warner's study shows an increase in the quantities used. But in Ismani (after one dry season) the increase per head per day was statistically not significant, and in Mlola the increase was significant only for those living within 5 minutes of the tap. Finally, in Gairo people using the taps claim to use less water than those using only traditional sources.

The question of quantities used is an important one. Apart from the health aspect (hypothesis 8), the expected rate of consumption is obviously directly relevant for the design of the supply. In Ismani, for instance, it was found that the average quantity taken home amounted to just over 10 litres per day and similar quantities were recorded for people using the taps in both Gairo and Nzega. Yet, the design in Ismani is based on 22.5 litres, i.e. more than twice that amount, and the standard estimate used by the Ministry of Water and Power is 30 litres per head.

Again, more work needs to be done in order to establish proper criteria in this respect. Presumably, however, a fairly large sample would be required. Before and after measurements have for practical reasons to be done with a relatively short period. Furthermore, the consumption per head tends to vary tremendously between individual families (in Ismani between 1 and 54 litres per person per day), so that large standard deviations must be expected, which will make it difficult to come up with statistically meaningful changes.

Hypothesis 5: Improved supplies are more reliable

When the improved supply draws its water from underground water (boreholes), the availability becomes less dependent on ariations in climate. The same probably holds true for the larger surface reservoirs and perennial streams. The problem, however, is the distribution system. Both in Nzega and in Ismani the new supply is often interrupted because of pipe breakage and maintenance (cleaning of pipes and tanks). Also at times the pressure is insufficient to fill the storage tanks. In the case of boreholes the major problem is connected with maintenance. The pumps are frequently out of order and apparently it is often a long time before they are repaired due to the shortage of technically qualifified personnel and, especially in the past when the District Councils were responsible for maintenance of the supplies, lack of finance.

Hypothesis 6: All people who do not live too far from the improved supply will make use of it

In Ismani this undoubtedly holds true, although the full distribution network is not yet complete in this area. The "critical" distance appears to be somewhere between $1\frac{1}{2}$ and 2 hours walking. But here the improvement in the water (taste, smell, turbidity, etc.)is very noticeable and appreciated by everyone. Data obtained in Nzega prove, however, that this hypothesis is not an axiom. Some people at least travellong distances to traditional sources, when taps have been installed much nearer. Similar results are reported by Ellman in Hanang[1]. Warner does not mention this phenomenon in his sample villages.

White et al suggest that the reasons for using a particular source are complex, but based on rational criteria such as smell and taste; while many other factors, such as social relationships and expected rate of pollution also play an important part. If people are convinced that the new supply is better, they will use it. This is supported by evidence from Nzega, where the frequency with which the pipeline breaks down is probably the main reason why it is not always used.

Clearly, the evidence obtained so far is insufficient and in this field also much remains to be done.

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1 Personal communications.

Hypothesis 7: The additional time made available through improved water supply may be put to productive use.

There is a great problem here, namely how to examine the hypothesis in practice. It is easy enough to compare the time used to obtain water "before" and "after". But to investigate how the time saved (if any) is used, is quite a different matter. At a minimum it would require two separate time expenditure studies.

Warner attempted to evaluate this impact, by taking down statements of the respondents. The question is, however, how much reliance can be placed on this. The results for (i) domestic work and (ii) shamba work could easily be biased in view of the prevalent positive attitudes of respondents in interview situations.

Obviously, there is a big gap in our knowledge here. Another matter is whether White et al have taken the right approach by simply assuming that the extra time is used productively. It is somewhat simplistic to contend that the time spent on certain activities is and on certain others is not productive. For example, how does one classify more time spent on cooking and cleaning the house? Furthermore, assuming that there are health benefits, it would be reasonable to expect that less time would be lost by visiting dispensaries, through illness. These "secondary effects" also have to be taken into account, making the problems of measurement even more complex.

We would here venture the thesis that any time saved, especially by women, has social and economic benefits at the present stage of Tanzania's development, since at least the energy saved will make it easier to maintain the often precarious balance between health and disease, threatening undernourishment, etc.

Hypothesis 8: Improved supply means better health

In so far as the quality of the improved supply is significantly better, it could easily be imagined that this would be the case. As we noted earlier, however, particularly if the water is left untreated the numbers of coliforms may still be very high by the time the water is actually consumed at home. Furthermore, it should be noted that many more consumers will now use the same source. If the surface water supply is not treated, the dangers of sudden epidemics (e.g. typhoid) are thus very much greater. Watering points may become contaminated with hookworm etc., while diseases like bilharzia can be "distributed" with the water.

If the amount of water used increases, especially the quantity used for washing clothes and bathing, the incidence of other diseases, such as lice born diseases, may decrease. Other possible benefits, such as the time saved, may lead to improved nutrition and health.

The problem is then, how to measure the changing health conditions. Obviously two surveys - one "before" and one "after" - will be required. Furthermore, again the sample will have to be rather large - because of the likely observational errors - so the costs will be high.

Even then, however, laboratory conditions cannot even be approached. Thus one cannot very well examine a thousand people without also treating the diseases found (bilharzia, hookworm, malaria etc.). These diseases would not disappear anyway, no matter how significant the improvement. Therefore, at least one other sample - outside the sphere of influence of the pipeline but otherwise similar - will have to be included.

The only attempt in Tanzania so far has been in Ismani where Kreysler of the Max Planck Research Unit conducted a baseline survey, comprising both villages supplied by the new pipeline and areas further away from it. This survey will hopefully be repeated in 1971.

Dispensary records have been used both in Ismani and Nzega, but their value is limited because of the fairly broad categories of diseases used and the possible diagnostic errors. Lastly it should be mentioned that several studies of factors affecting specific diseases (e.g. bilharzia in Mwanza) may contribute evidence indirectly.

The limited evidence available so far nevertheless allows one to draw some tentative conclusions:

(i) It is not sufficient to supply "improved" water unless health education on aspects such as treatment of water, is also provided. The people in the rural area tend to think that if the new supply is clean, it is safe to drink etc. without boiling.

(ii) Presumably, in order to reap the maximum benefit in this sector it would be worthwhile to consider treating the populations for existing water related diseases.

(iii) The contention that any "improved" supply has a positive impact - even if the water is not treated - does not seem to be true. While the incidence of certain diseases may decrease, other health hazards like epidemics, hookworm and perhaps bilharzia may outweigh this benefit.

Hypothesis 9: <u>By providing more and better water for livestock an improved water supply increases the returns from animal husbandry.</u>

Since lack of water is one of the main obstacles to livestock production in most parts of the country there is a tendency to assume that the provision of better water for livestock is desirable, because it will improve the condition of existing animals and allow larger numbers to be kept. This is reflected in the fact that one of the criteria used by the Ministry of Water and Power to justify a project is the number of livestock which it will serve, two livestock units being equivalent to one human.

However, when the question is examined in more detail, it becomes apparent that this hypothesis is not always true. In the first place, although more frequent watering improves the quality of animals, improvements in other aspects of husbandry, especially disease control, are equally if not more important. Secondly in many areas which already suffer from overstocking an increase in livestock numbers is not desirable since it will only result in a shortage of grazing (and, therefore, deterioration in the quality of animals) and erosion. Erosion is particularly likely where animals concentrate around the new water points. Thirdly, even if improved water produces more and better livestock, this will have little economic value unless it is also accompanied by higher sales of animals or animal products.

There is very little evidence available to either confirm or refute these hypothesis. No direct studies have been made and, in any case, the effects are likely to vary greatly from one area to another, depending on the existing livestock situation. The main source of information is observation in north-east Nzega. This area is already overgrazed and an increase in livestock is definitely undesirable. The effect of introducing water on livestock numbers seems to depend on the part of the area concerned. In areas where cultivation is possible, the increase in cultivation is forcing livestock out but in grazing areas there is likely to be an increase in livestock numbers. In both cases, the pressure on grazing will increase and there is already evidence of greater erosion, particularly around water points. Very little information is available on the effect of water on the quality of animals or livestock sales in the area.

<u>Hypothesis 10</u>: <u>The economic benefits of water supply projects may be increased by using excess water for small scale irrigation</u>.

Where an improved water supply is constructed primarily for domestic or other (such as flood control) purposes there is often excess water available and it may be argued that this can be used for irrigation, thereby increasing agricultural productivity and perhaps also improving nutrition.

The main impact studies do not consider this aspect. However, BRALUP made a study of three such villages in Dodoma and Singida Regions to examine the way in which water was used for irrigation. It was found that in none of the villages was the full potential for irrigation developed. The main reason for this was that the inhabitants, who are unfamiliar with irrgated agriculture, received inadequate assistance in the form of organisation, supervision and extension. Connected with this was the fact that irrigation is a form of intensification of agriculture and at present there is no population pressure in these areas to act as an incentive to intensification. Other important reasons include inadequate marketing and other infrastructure, poor soils and the lack of drainage facilities.

One may, therefore, conclude that, when considering the use of excess water for irrigation, allowance should be made for the variety of other inputs which will be required in order to obtain benefits in the form of increased productivity.

Hypothesis 11: The economic bemefits of surface water resources may be increased by using them for fishing.

This hypothesis is very similar to that relating to the use of water for irrigation, being based on the assumption that subsidiary benefits from surface water projects may be gained by using them for fishing. No systematic studies have been made but some evidence is available from the BRALUP survey of irrigation villages and from experience in other reservoirs. Three conclusions may be drawn from this. Firstly, some spontaneous fishing is likely to develop in most reservoirs but, in areas where fishing is not a traditional occupation, the fishermen will usually be immigrants while the local inhabitants will show little interest in either catching or buying fish, unless there is a major campaign of education and extension. Secondly, infrastructure in the form of transport and marketing facilities is required. Thirdly, if a reservoir is to be used for fishing the vegatation should be cleared before the land is flooded to avoid both pollution of water and damage to nets.

Hypothesis 12: An improved water supply provides a stimulus for the development of secondary economic activities.

One of the supposed benefits of a new water supply is that it encourages the growth of economic activities other than agriculture and fishing, especially water-using industries and commerce, and the acquisition of new skills. The only impact study to include this hypothesis in its initial terms of reference is that by Warner, for which results are not yet available. However, some evidence can be gained from observations made by BRALUP in north-east Nzega and by the Max Planck Unit in Mayo village, Lushoto.

In Nzega the introduction of water has been accompanied by a marked increase in both water-using industries (notably brick-making) and commercial activity. As the whole area is already experiencing rapid economic development it is impossible to say how much of this is directly attributable to water, but it appears that at least part of it is since those villages which have water points are growing more rapidly than others. In Mayo village the provision of water, combined with a campaign to build better houses, encouraged an increase in brick-making, while the pipe installation provided training in the fitting and maintenance of water pipes.

Hypothesis 13: A new water supply will encourage the clustering of settlement around the water point.

This is a hypothesis which is particularly important in Tanzania at present because of the effort being made to bring people together into villages. A major policy issue with regard to the provision of water is whether waterpoints should be located where people live at present or where one would like them to live. This issue cannot be resolved unless one is able to predict the effect of water points on settlement pattern and the information required to do this is not yet available.

In order to test the hypothesis properly repeated observations for a considerable length of time are required and no such study has been made. Some evidence can be gained from observation of settlement patterns in north-east Nzega and from studies by White et al of factors affecting the location of existing settlements. These results tend to refute the hypothesis In Nzega rapid growth of settlement seems to have occurred around water-points located in existing villages, and more moderate growth around those located not in a village but on a road, the combination of road and water providing a nucleus. However, those points located elsewhere have not yet attracted any noticeable settlement. These observations were supported by farmer interviews in Nzega and by the conclusions made by White et al, both of which suggest that water is not the main factor determining the location of settlement.

However, the evidence is at present very meagre and further impact studies of this important aspect are urgently required.

Hypothesis 14: The input of improved water acts as an incentive to overall rural development.

One of the hypotheses often used to justify the installation of an improved water supply is that it will encourage other aspects of rural development, such as better living conditions, new agricultural practices, education, Ujamaa and so on.

Evidence on this topiccan be obtained from various sources. In the BRALUP study of irrigation villages and of settlements along the Bulenya Hills pipeline in Nzega a number of criteria were used to measure the degree of "Community of the villages. Warner is using these and other criteria in his studies but the results are not yet available. Other information is available from the observation ofvarious projects in which water has been installed, including the pipelines in north-east Nzega and Ismani, the Shinyanga lift pump in Sukumaland and various Ujamaa villages which have been supplied with water. The other major study in this field is that in Mayo village, Lushoto District, where the circumstances were rather different. Here water was only one of a number of inputs, including improvements in health, nutrition and education, which were introducted as a "package deal", and the villagers were involved in the planning and implementation of the project from the start.

The results of these studies suggest that water alone is not enough to stimulate rural development. Various resaons have been suggested for this. For example, Duffy attributes the failure of the Shinyanga pump to encourage development, to the lack of community feeling among the Sukuma, while Cunningham maintains that the key to successful Ujamaa is the quality of local leadership. However, the most valuable results are those from Mayo village, where the combination of water and other inputs has resulted in a definite increase in the level of overall development. It appears, therefore, that water must be provided as part of a "package deal" and that the - local people should participate fully in the project from its inception.

CONCLUSIONS

In discussing each of the above hypothese it has only been possible to draw very tentative conclusions with regard to the impact of new or improved water supplies, because of the lack of information. Consequently, large sums of money are at present being invested in rural water supplies on the basis of inadequate information on impact benefits. We have seen that genuine impact studies are difficult and costly to plan and implement, but in view of the size and long term nature of the rural water development programme, the rate of return on such studies will be high.

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PROBLEMS OF BENEFIT COST ANALYSIS IN PLANNING OF RURAL WATER SUPPLY

by
George Irvin
Institute of Development Studies
Sussex, England.

I Introduction

The following paper is concerned with some of the problems confronting the economist and the professional planner in planning investment in rural water provision for domestic use. Not the least of these is that not a great deal has been written on the economics of rural water supply,[1] although there is, of course, a voluminous literature on water resource development for irrigation and flood control, power generations, etc. The paper is, therefore, more a collection of analytical and practical guidelines, than an attempt to define a rigorous theoretical framework or review empirical evidence. In particular, some of the more esoteric aspects of benefit-cost analysis, notably problems of shadow price derivation, the estimation of social time preference, etc., are not dealt with. Rather, the discussion is confined to problems in the identification, and to a lesser degree, the measurement of net welfare in a context where the scope for alternative design choices facing the planner is complex, and the planner must weigh up a number of objectives of policy simultaneously. It has also been attempted to set the discussion in the context of a planning framework, in which cost benefit analysis is seen as only one contributory element in improving the effectiveness of the overall planning process.

The section which follows (section II) looks at some of the problems of evaluating benefits and costs of rural water supply. Section III considers rural water supply in the context of a policy of income redistribution as well as that of the growth of rural incomes. Section IV deals with investment choice within a planning framework, and section V summarises our main conclusions.

II (1) Cost and Benefits of Rural Water Supply

Given the distinction drawn between the provision of rural water supply for domestic use, and its provision for agriculture, it is apparent that part of the difficulty in drawing up a precise analytical framework for empirical investigation in the former case arises from the fact that the distinction itself is unsatisfactory. It is hardly ever the case that village water supply schemes make no contribution whatever to local agriculture. Typically, some part of the benefits associated with readily accessible supplies of clean water - notably better health and increased leisure - have an impact on productive potential, and in some cases a part of the total supply will be used for watering stock, or even small scale irrigation of subsistence plots. Indeed, some of the

[1] For a recent survey of literature pertaining to the East African context, see "Water Development, Tanzania - A critical review of research" BRALUP, Research Paper No. 12, The University of Dar es Salaam, 1970.

empirical work carried out suggests that a substantial portion of the benefits derived from such schemes arises from the use of water as a direct agricultural input. Nevertheless, let us maintain the distinctions, even only as one of degree, and consider a number of headings under which benefits and costs might be placed.

II (2) Benefits of Rural Domestic Water Supply

The first heading under which benefits of water supply schemes are usually considered is that of health. Where existing water supplies are polluted, or simply unreliable, provision of extra water will have important implications with respect to the number of man days lost through illness, the incidence of disease - or what may be more important, the relative incidence of different types of disease - and more generally on infant mortality rates, life expectancy, and ultimately the size and structure of village populations. Where we come to measuring such benefits, it is clear that starting from the question "what is the value of a life saved?" is unlikely to be helpful. Immediate benefits - those arising from the often dramatic short-term improvement in village health may be measured in a number of ways. Firstly, in the form of increased output, though, of course, there are often multiple factors at work here. More water may mean more man days available - and this will be particularly important where drought or contamination of existing water supplies coincides with peak labour requirements for subsistence agriculture - but it will also mean an increased capacity to make use of other inputs complimentary to labour. Even in the short term, therefore, the increase in output arising from a change in the health and size of the work force may be only partly attributable to increased water supplies. Moreover, there are the usual dynamic effects - e.g. a first round of increased food output and consumption per capita will have further impact on labour availability in the second round, and so on. Useful measurements of what we might call "health induced" benefits will therefore turn virtually on the ability of the investigator to relate changes in the village production possibility boundary to changes in the availability of time-dated inputs, and to identify the sorts of input complimentarities which may be at work, both in a static and dynamic sense.

An important component of total health related benefits may equally accrue as a saving in resources. Firstly, to the extent that lack of adequate water can be related to a serious shortfall in local production, investment in rural water may be a partial substitute for Government famine relief programmes. Better rural health will also ease the pressure on skilled medical resources, which in the short term may be extremely important given the differential gestation lags in the production of more wells as opposed to more doctors. While this sort of saving is extremely difficult to measure on an individual project basis, it can hardly be ignored when speaking of a national programme. We are, of course, not arguing that these resources can or should be thought of as fully substitutable. More doctors and health workers will remain a priority item on the agenda of most national plans for a good many years. But for those who argue that rural water schemes are particularly costly in terms of foreign exchange, it is well to remember that doctors, and the drugs they administer, are almost pure foreign exchange costs.

The second heading under which we may consider the returns to rural domestic water provision is that of labour saving and leisure. It is often argued that the labour freed from the inefficient and cumbersome task of water-carrying would, with the provision of an immediately accessible water source, be released for more productive activity. Again, this is one of those hypotheses which is intuitively satisfying while apparently immune to empirical validation. The short answer is that one can say little without reference to particular cases, and that the variety of experience encountered makes any generalisation difficult.

Water-carrying is in many African countries a sex-specific task - the range of alternative productive activities for which labour released from water-carrying can be put is itself therefore likely to be delineated by social custom. While the labour released from water-carrying may amount to as much as several labour hours per day which multiplied over the year and by the number of village families may be substantial, the key question is usually one of timing. If, say, the shortage of harvest labour is serious and all members of the village participate, then the returns to marginal labour released from water-carrying may at this time of year be very significant. This is typically the case in an agricultural setting where peak labour demands are set by highly time specific operations - e.g. where the harvest must be got in and new ground prepared before the first rain falls. More labour may mean not only bigger harvest; it may mean the possibility of later planting and higher yields, and a change in the cropping pattern and cropping calender will in turn have implications for the marginal returns to labour released at other times of the year. The point may sound unnecessarily esoteric for the general purposes of our argument - nevertheless, it is precisely such dynamic effects which are crucial to evaluation and which tend to be ignored.

Even in those situations where the use of labour for water-carrying may have insignificant opportunity cost, some gain in total welfare will result from the provision of rural water supplies even if time-saving is translated wholly into extra leisure. Quantifying the benefits arising from extra leisure time is, of course, difficult, though certainly not impossible. A rough guide to benefit estimation in such a case isoften best obtained where the family or village group is confronted with a choice of marginal investments - the Government will provide either more x (where x is a new well) or more v but not both! Assume that v is a project whose net benefits are more readily measurable than those of x. If x is chosen, net returns from x can be assumed to have a lower bound set by the net returns on v. If some new choice option, z, is now presented, and proves to be preferred to x or v, an upper bond for x can be established. And so on until net returns from x can be assessed to lie within a reasonable interval. Although the use of such a roundabout procedure for measuring intangible benefits by questions of the form "how much would you pay for x if you could buy it?" is usually highly misleading where provision of the service in question is thought to be a natural responsibility of Government. Nor can benefits accruing in the form of leisure be ignored simply because they are difficult to measure; while it may not be possible to devise a standard procedure for quantification of leisure benefits, some guide is provided by reference to other fields of economic analysis where time-savings is a critical factor - viz., transport economics.

In addition to the types of benefits we have discussed so far, the provision of rural water, even if primarily intended for household consumption, will usually have some use as a direct input into traditional farming. Typical examples are the use of a village well or standpipe for the watering of domestic animals, and where the installation permits, for providing a direct supply of irrigation water to nearby fields or garden plots. Even with the provision of quite modest installation, daily flow capacity is likely to be in excess of daily drinking requirements.[1] Moreover, with few exceptions, the technology of water provision is such that fixed investment cannot be treated as coninuously divisible, and marginal costs of water will fall in the range between each new lump of required capital. In short, it will often be economical to provide capacity in excess of domestic requirements, even where the marginal return to water in non-drinking use is falling.

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[1] This is usually the case for gravity schemes.

Where existing water supplies are not only distant but unreliable i.e. subject to periodic "drying up", the impact upon the livestock economy of assured water supply may be quite striking. Providing other complementary resources are available, not only are yields per head likely to increase, but the size and composition of the herd may change, Existing grazing practices, previously limited by the need to lead cattle to a distant source, can now benefit from a more rational rotation of existing pasture and potential access to new pasture.[1] Water reliability may mean a gradual change in herd composition and the introduction of less hardy but higher-yielding breeds. So, too, the provision of an immediately accessible source may have repercussions on the communal organisation of stock rearing, it now being possible to water - and therefore to keep - stock individually. Such changes are unlikely to be observed in the short-term, given the complex nature of economic and social constraints governing the livestock economy.

Use of water for small-scale irrigation is an equally critical consideration in the planning of water supply. Even in rainfed areas where total seasonal rainfall is relatively high, the key problem is often the timing of crop moisture requirements and the confidence which can be placed on rainfall at certain specific times of the year. The provision of small-scale supplementary irrigation facilities - e.g. designed to meet temporary moisture deficits, not the total seasonal moisture requirements of the crop - can be of decisive importance, particularly where local population pressure is starting to be felt in relation to land, and where food yields per acre are at a premium. The critical effects on yields of moisture deficits at particular times in the growing season for certain types of high-yielding staples is well known - particularly in passing from coarse food grains (sorghum, millet) to those of higher nutritive value (wheat, maize, rice). Moreover, water reliability is critical to be effective use of complementary inputs such as fertiliser which high yielding varieties require. In such cases, the return to assured water at the margin will be extremely high. Moreover, if water, even in small quantities, can be assured at key times of year, not only yields, but the entire cropping pattern may be affected. Staggered planting of subsistence crops a phenomenon which for years has dified the reasoned arguments of extension workers that highest yields are obtained by planting as close to a particular date as possible, is a typical response to the vagaries of intra-year rainfall patterns. So, too, the mixing of low-yield drought resistent varieties with higher-yielding varieties, even where cultivation takes place on a very small scale. With the advent of reliable water supplies, the rationale for these traditional forms of crop insurance is weakened, and a series of practices which make more efficient use of land ranging from the selection of optional varieties, and the use of complementary inputs, to major changes in the cropping pattern become possible.

As with the case of the livestock economy, changes in the crop economy typically take some time to work themselves out. Indeed, the whole notion of adjustment paths between equilibrium positions is misleading in an agricultural environment where small changes can set off a cumulative series of reactions which in turn alter the environment in very dramatic ways. What is important to recognise in any analysis

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[1] An interesting example is cited in the case of the Ambaseli Basin in Kenya. This region has an excellent tourist potential for game viewing, but is also used for seasonal stock watering by the Masai. By investing in an assured water source for stock outside the region, thus breaking the migratory pattern, the tourist potential of the region could be more fully developed. See I. Carruthers, "Issues in Selection and Design of Rural Water Projects", Discussion Paper 88, IDS University College, Nairobi, December 1969.

of this kind is that reaping the large potential benefits from a change apparently so innocuous as the provision of single village well or watering point will turn critically on the planners' ability to identify the complex nature of the constraints system governing present production, and to include water as one element in a package of complementary resources. To take a simple example, while the return on an extra unit of water taken above may be x, and the return on an extra unit of fertiliser taken above may be 2x, the return on both together may be 5x. Recognising such complementarities will be critical if full value is to be had for the resources invested. So, too, the planner must sense the agricultural environment as a carefully balanced set of inter-relationships in which small changes can have large cumulative repercussions. This is why the business of predicting responses in anything but the very short-term is so difficult, and in agriculture the very short-term can be a notoriously misleading guide to policy.

II (3) Costs of Rural Water Supply

While estimating costs of rural water supply is less difficult than estimating benefits, the decisions which determine the cost structure require careful appraisal. The complex nature of policy alternatives facing the planner such as rate of build-up, scale of provision, input mix, and import content makes for a situation in which whether or not the project is socially beneficial depends as much on how it is done as on how farmers respond to it. While very elaborate models can be worked out to determine such matters as optimal scale and timing of investment and optimal technology on a regional or even village-by-village level, this sort of perfectionist approach has a significant cost in terms of skilled manpower, and even more important, in terms of delay. Not only is it important that the planner should carefully consider the alternatives open to him, it is equally important that he should fairly quickly be able to reduce the choice set to manageable proportions, even at the risk of making mistakes.

A first choice in the provision of rural water is usually an engineering type decision concerning how best to capture available water resources. Where the water table is not too deep, a well or borehole may be perfectly adequate, estimated peak flow requirements determining the number of holes sunk and depth required size of pump at each. Even within this limited area of consideration, there may be significant alternatives. Several hand or draught powered wells may be preferable to a single diesel or electric pump set where the water table is close to the surface, and hence digging costs per m^3 low. In other cases, however, where the location of the water table makes individual village boreholes relatively expensive, it may be preferable to dig a centrally-located high capacity well and pipe water to several villages from a single point. Again, there may be situations where domestic water can best be provided as an adjunct of a multi-purpose river basin scheme by building suitable conduits. To some extent, these options will be determined by purely technical considerations. But where several options are technically feasible, choice of system will usually then mainly depend on envisaged scale of operation; e.g. if a high capacity system is envisaged, it may be more sensible to provide a central pumping station than a large number of individual boreholes regardless of the average depth of the water table. In some countries, where water is very scarce in relation to land, high cost centralised systems are justified purely on the grounds of long-term water table management, but this is unlikely to apply in the East African case.[1]

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[1] In Israel, for instance, very elaborate investment in underground pipes, water metering equipment, and personnel to supervise and enforce a complex system of water quotas is thought to be necessary because of the critically limiting nature of water as a natural resource.

Another area of choice facing the planner is the level of sophistication of provision to be adopted. Is there a case for piped water to individual dwellings? Or is not, for adopting standards of mains design which will make such provision possible at a future date without having to dig up the whole system? Or should a policy of minimum basic provision be pursued - i.e. the universal adoption of rudimentary communal watering points, in order to spread benefits over as large number of villages as possible.

In addition to delimiting the area of choice with respect to what we might call the engineering-hydrological aspects of rural water supply, the planner will also want to have a clear idea of the implications of using alternative imput mixes in the construction of a particular project. A familiar argument for this type of scheme is that, given the general shortage of capital and foreign exchange which is thought to characterise the situation of most developing countries, wherever possible, local labour should be substituted to the limit for these resources. Of course, it is true that where a pool of unemployed labour exists, or where the timing of construction can be organised to coincide with labour slacks, every opportunity must be taken to employ the low cost resource. But it must not be assumed that highly labour-intensive methods are always best. It may be the case that, for instance, the indiscriminate adoption of a labour-intensive construction programme will lead to sub-optimal design of delivery systems which in the long term will prove more expensive. Shallow draught powered wells, earthen conduits, small barrages, etc., are not always preferable to more sophisticated systems, particularly where water is in short supply and efficiency of water use is at a premium. It is generally the case that the higher the delivery capacity per capita envisaged, the higher the real labour costs per m^3 water at the margin - not only in construction, but in maintenance over the years. Moreover, large labour projects take time, and tend to tie up skilled engineering and supervision resources - these costs, too, must be considered. Since the economic life of a rudimentary construction may be assumed shorter than that of a more sophisticated design, the former alternative may simply be a way of deferring capital and foreign exchange costs which will eventually have to be incurred. This should not be taken as an argument against using self-help schemes as a basis for rural water provision - the point is rather that what is at issue is not some simple process of substitution of labour for capital at one point in time, but a rather more difficult question of estimating the relative present values of alternative time profiles of resource costs.

II (4) The Costs and Returns of Integrated Rural Domestic Water Supply and Irrigation

So far, the argument has proceeded on the assumption that the irrigation component of a rural water supply scheme can be taken as small or negligible. There is some evidence to suggest, however, that really significant returns from water supply only begin where a portion of the flow is used as a direct input into agriculture. We have already argued that water reliability - and therefore supplementary irrigation - may be a critical question even in apparently rain-abundant regions. Where returns to supplementary irrigation are large, it obviously pays - indeed it may be crucial to the scheme's economic viability - to design systems of high enough capacity to meet such needs. Under these conditions, design becomes very much more critical. The seasonally peaked nature of irrigation requirements often means a substantial investment in capacity which at many times of year will be under-utilised, or else provision of elaborate storage facilities. Where an irrigation component is explicitly included in the scheme, it is no longer possible simply to estimate total water consumption and provide low cost well to meet it. Rather, one must judge the potential for supplementary irrigation at those times of year when a shortfall in water will be most critical, and the likelihood that farmers will in fact make use of this potential if it is provided. Should enough capacity be provided to allow all farmers to irrigate simultaneously? Can some system of water rationing be enforced? Can simple water storage systems be designed at an acceptable cost? How far will an irrigation component set off changes in the local economy which alter the time profile of local water use, and how far is it necessary to plan for this in designing highly flexible systems? All of these are questions which have obvious bearing on how the configuration of technical and economic is perceived at the start. Such questions can, of course, be ignored if the terms of reference of the study are confined strictly to small-scale water provision, but to do so may result in an overall programme which, though relatively inexpensive in aggregate, will fall short of realising the very much greater returns which could be had for a slightly greater cost.

III Distribution of Costs and Benefits of Rural Water Supply

One of the important returns to investment in rural water supply arises from the apparently redistributional nature of such investment. Since the basic investment is small-scale, a given lump of resources can be spread to the benefit of many people, with consequent gains in the credibility of Government's claims to be helping the worse-off members of the community. Whether or not the programme really is redistributive is another matter. As with most agricultural investment, the operative question about redistribution is more likely to be "How are investment resources divided amongst different classes of farmers?" than simply that of whether or not transfer of resources takes place from town to country. Rural water supply schemes, disregarding the irrigation component they may have, tend to do well by such a criterion if simply because rich and poor farmers alike have equal access to the benefits conferred; irrigation schemes, on the other hand, tend to benefit better-off farmers only because it is these who can afford the complementary resources which make irrigation fully profitable. Given the argument above for making fullest use of resources by linking rural water supply investment to meeting some irrigation needs, there is an apparent dilemma here. For a given total of resources available nationally, an irrigation-linked approach not only means greater investment per capita (and therefore a smaller total population directly affected), but differential ability amongst those affected to make full use of irrigation potential.

This argument need not be telling, however, if sufficient care is taken in the first instance to place high per capita investment in low per capita areas. Of course, irrigation investment is high per capita not only because of the need for more water, more sophisticated delivery systems, etc., but also because it requires other elements to be included in the "package" if the whole thing is really to get off the ground. For poor farmers particularly, it often means high cost back-up services in the form of good extension workers and administrators as well as access to complementary agricultural inputs. Moreover, even if the planner is successful in channelling the right resources to those who most need them, secondary effects are sometimes such as to mitigate the primary redistributive gains. Where local conditions facilitate the development of monopoly conditions in distributions, the private marketing of cash crops by poor farmers enriches middlemen; even where co-operatives exist, the gains are not always equitably distributed. Unless care is taken to assure the contrary, it is almost always the case that a part of the total benefits of the

IV Rural Water Supply within a Planning Framework

So far, we have been concerned with placing rural water supply investment within a general analytical framework; e.g. raising some of the questions associated with the identification and measurement of costs and benefits. Successful planning is, however, much more than just a matter of predication and measurement. Not only must the planner be able to ask the right questions, he must be in a position to relate information flows to the sequence of decisions through time which make up the planning and evaluation process.

In an investment programme which both commands high priority, and is likely to involve heavy resource commitments over a longnumber of years - such as is the case in Tanzania - the planner cannot afford to await complete information upon every aspect of the subject before committing resources to investment. Rather, the planning process itself must be geared to identification of the most urgent needs in the initial phases, using selection criteria information. As the programme gathers momentum, however, it will be possible to identify alternatives more clearly, drawing upon previous experience and more comprehensive data to improve decision-making. To some extent, too, it will be an aim of policy-makers to ensure that as the investment programme develops, its efficiency in terms of skilled manpower use improves - that is to say, that decision-making criteria can be simplified and standardised to an extent which will shift the burden of choice in all but the very broad areas of policy towards the local level, thus freeing higher level manpower for other planmig tasks, or put another way, that the programme will become increasingly routinised. These two characteristics of what we might call a "mature" investment programme are not always strictly compatible. Particular care is needed in making sure that selection and design criteria are not overly standardised in the interst of efficiency, and that some review procedure is adopted which makes it possible to periodically re-assess the overall aims of the programme in the light of its achievements and failures.

What sorts of issues does this raise in the context of the Tanzanian programme? The aims of the rural water supply programme are laid out in the Second Five Year Plan; these are, broadly, to supply communal watering points to the vast majority of the rural population over the next twenty years, a programme which will lay claim to something in the order of ten per cent or more of annual Ministerial development expenditure,[1] and involve a very significant cost in terms of skilled manpower. To further this aim, the Government has recently launched a series of regional master plans for water resource development, and steps have been taken to co-ordinate the various administrative and technical services involved by bringing them togehter in a new Ministry. The impressive nature of this long-term commitment to water resource development as a social as well as an economic priority is backed by an already considerable collection of data on regional hydrology, population concentration, resource endownents and economic

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[1] The Second Five Year Plan allocates Shs. 406m. to this sector, or according to Denis Warner, about 12% of Ministerial Development expenditure. At present, about 90% of the rural population is estimated to have inadequate water provision. See D. Warner, "The Economics of Rural Water Supply in Tanzania", ERB paper 70.19, The University of Dar es Salaam.

potential arising from the work of Government departments, consultants, and bodies such as BRALUP.[1] On the face of it, therefore, Tanzania seems well placed for launching a successful programme.

Some reflection is needed, however, on how success of the programme is seen at present, andhow this might change over the future. At the moment, the goal of universal water provision as a social objective is seen as overriding; limitations on resources dicate that in order for the programme to be feasible, investment will have to be spread thinly over the rural population as a whole, This means, practically speaking, that per capita water consumption targets must be set at a fairly low level, and that engineers will be asked to design schemes which are low cost in terms of the use of presently limiting resources, often with some penalty in terms of economic life and maintenance requirements. The political decision to provide rural water - at least at communal watering points - free of charge, while consistent with a policy which rightly stresses the welfare of the neediest members of the community, does effectively eliminate the possibility of income redistribution through the financial structure of the scheme itself, and reinforces the tendency towards the adoption of design criteria which simply minimize present costs per capita. The burden of redistribution is thus thrown on selection criteria - i.e. on evolving a set of rules which will ensure that investment is initially channelled to the neediest, as identified by existing data on per capita income, population concentration, nature of existing water provision, incidence of pollution-related disease, etc. But, given that priority is also accorded to the co-ordinated development of rural water supply within the context of the Ujamaa village programme, it is not clear that even the redistributional aim of the programme can be followed with full consistency.

If it is the case, broadly speaking, that the terms in which success of the programme are presently defined bias design criteria towards minimum standardised water provision using a technology which, while cheap in the short term may be inefficient in the long term, and if it is also true to say that the natural momentum in the programme towards routinisation of decision-making is likely to imbue initially policies with a certain sanctity, it remains fair to ask whether there is any reasonable alternative. In principle, such an alternative would be the design of water delivery systems which maximised net social benefits in each individual case rather than minimizing costs subject to providing minimum standard benefits across the board. This might imply, for instance, the provision of high capacity systems and of individual house connections in certain cases where it could be shown that really significant marginal returns to water were only possible far above the "standard drinking requirement" threshold. Distributional problems could then be sorted out by levying differential tariffs between beneficiaries. There are two objections to this, however, one theoretical and one practical. Firstly, since we are considering the social returns to a whole investment programme over a very long period, it is not necessarily the case that present value of the net benefit stream of a high-cost, discriminating provision programme over, say, forty years - supposing this to be the time period necessary to effect such a programme to cover the whole of the rural population - would be greater than that of the standardised "cost-minimisation" approach. And the practical objection is simply that, given all the difficulties of measuring potential net benefits associated with each bit of investment in the programme - i.e., equating costs with social benefit at the margin in each case - such on approach is useless to the planner.

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1 Bureau of Resource and Land Use Planning, The University of Dar es Salaam.

While the strength of these objections is sufficient to dismiss the argument for totally recasting the terms in which the present rural water supply programme is seen, certain points are nevertheless worth retaining. Firstly, present design criteria cannot be derived solely from some notion of a universally valid target per capita water norm. For one thing, it is not known with any degree of precision how consumption standards adopted as the basis for present design will change with rising incomes and a changing agricultural environment in the next twenty years. And even if these norms can be set on a per capita basis, population movements - themselves possibly arising from the attraction of permanent water supplies - will complicate the business of forecasting total water demands for each individual site. Secondly, it is not clear to what extent a standardised minimum provision approach contributes towards the realisation of any of the alleged benefits of rural water provision over and above that of simply having a village standpipe. For example, it has recently been suggested that real gains in rural health and hygiene may only come with individual house connections. The same is true for benefits accruing in the form of time-saving, not to mention benefits associated with such part of water supplies as might be used as a direct agricultural input.

In short, even if a fully optimising policy is not practicable, much more needs to be known about the impact of small-scale rural water provision before the selection and design criteria now in use can be formalised or generalised with any degree of confidence. "Success" of the programme needs to be defined not merely in terms of the general aim of providing adequate supplies of clean water to all or most of the rural population over the next twenty years - success indicators in the field of rural health, time-saving, and impact on agricultural potential will have to be worked out in detail, and an important role allocated in the programme to a research and monitoring function which has a feedback to the design and implementation function.

Generally speaking, then, while a certain portion of the necessary information for successful design and implementation of Tanzania's rural water supply programme already exists, and while additional research into such things as hydrology, population, health, etc., can be initiated on a fairly standardised basis for regions not already covered, research has not so far been geared to tell the planner very much about the impact of rural domestic water supplies or to link such information to criteria of project design and a strategy of project location. This state of affairs reflects, in part, the inherently difficult nature of devising adequate measurements of the phenomena being investigated. More important, it reflects a problem in research strategy. Assessing the impact of rural water supply investment, both in terms of the categories of potential benefits enumerated above and in terms of the problems of complementarity and dynamic repercussions outlined in the early part of this paper is likely to be, in the early stages at least, more of an exercise in gathering new insights and formulating tentative hypotheses than a rigorous quantitative exercise. To attempt to design a comprehensive survey without sufficient attention to the complex nature of the interaction between water supply and the local economy is likely to result in a situation where the observed variability of results is such that, even within an apparently homogeneous population, no conclusions can be drawn.[1]

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[1] See Warner, D. "A Preliminary Assessment of the Impact of Rural Water Supply upon Households and Villages", ERB paper No. 70.12, The University, Dar es Salaam. Also, "Water Development - Tanzania; a critical review of research", Research Paper No. 12, BRALUP, The University, Dar es Salaam.

A practical and not too costly way of providing such a starting point for research would be the establishment of a small research team including, say, an economist, a sociologist, a rural health specialist, and a statistician. Such a team would initially select a small number of villages and carry out a series of in depth studies over a period of, say, six months. The team might initially be linked to an academic establishment, though at a later stage should have direct access to policy-makers in charge of the investment programme. The terms of reference of such a research team would be to draw up a blueprint for establishing a permanent monitoring system within the context of the investment programme, as well as providing guidelines for further academic research which might be carried out. The report on the former would include provisions with respect to the size and location of a monitoring presence, the methodology and scope of data collection, and the interpretation of results and their relevance to specific questions of design and implementation of the programme.

These suggestions are, of course, tentative, and serve, at best, a partial function in providing for the formalisation of an information feedback system within an investment programme as large as that presently being carried out in rural domestic water supply in Tanzania. Certain general points, however, need stressing. Design and location criteria cannot, by their very nature, be fully evolved before an investment programme of this sort is set into motion, but must be allowed to mature with the development of the programme. Identification of actual and potential benefits of rural water supply, even where a programme cannot be based on a comprehensive principle of maximising net social returns, is still a key element in the development of adequate criteria of investment design. While the present emphasis on the formulation of regional master plans for long-term water resource use is laudable, and will provide a general framework in which regional resource structure and economic potential can be related to priorities in the development of water resources with respect to domestic water provision, irrigation, power generation, etc., it is unrealistic to expect that detailed criteria can be laid down in such plans. Such research as has already been carried out on the economic and social impact of rural domestic water supplies, while raising a number of interesting issues, has failed to relate conclusions to location and design policy, in part because firm conclusions have been hard to come by, and in part because no clear mechanism exists for integrating research - particularly where carried out by academic institutions - and policy-makers. If this state of affairs is to be remedied, a research and monitoring function will have to be built into the investment programme itself. The suggestions presented above represent one way of making a start in this direction at minimum cost in manpower.

V Conclusions

The economics of rural water supply is a field in which serious work is only just beginning, though its implications for raising the level of welfare in the countryside are obviously very great. While special problems exist in the identification and instruction of benefits, these are not so insufferable as to make the exercise one of pure guesswork. Indeed, what is known suggests that very substantial returns are possible, particularly in the field of health, and in the direct and indirect contribution of assured and convenient water supplies to agriculture. The full estimation of such benefits, particularly where such schemes have a supplementary irrigation component, requires a sensitive awareness to problems of dynamic response and complimentarity. Typically, the real source of benefit is not just extra time or improved health, but the set of cumulative changes which these make possible.

On the cost side, the area of choice in the provision of domestic water, as with the provision of irrigation water, is typically very complex. In the case of investment projects where substitutability exists between inputs at a given moment in time as well as between inputs now and in the future, no simple guidelines exist. While technical constraints may severely limit the area of choice in particular cases, the temptation to evolve simple rules such as "labour intensive capital saving technology in all cases" can sometimes result in choices which in the long term are inefficient with respect to the use of all limiting resources.

It is probably the case that the highest returns per unit of investment resources is to be had from projects sufficiently sophisticated and located in such a way as to have a supplementary irrigation component. Nevertheless, if distribution of welfare as well as its maximisation is a consideration, an irrigation-linked strategy will not always be optimal. Redistributive effects are an important aspect of rural water supply schemes, and the planner must ensure that considerable care is taken in planning the financial side of the scheme if it is to benefit those most in need.

In the case of Tanzania, where the provision of domestic water supplies to the rural population is seen as an over-riding social objective, emphasis has been placed on spreading resources thinly over as large an area as possible. The scheme is not designed to be financially self-supporting, though recipients are expected to make some contribution towards resource costs, mainly in the form of labour donations. Generally speaking, the risk involved in such a strategy is that, given the emphasis on minimising costs per capita, provision will be set at a level incompatible with the realisation of many of the potential benefits associated with water provision. Before design and location criteria can be formalised to effectively discriminate between areas having vastly different needs, resources, and economic potential, more research will be needed into the impact of domestic water provision, and this research specifically geared to improving decision-making in the programme.

Finally, the planning of rural water supplies, because it touches on the responsibilities and functions of a number of different departments of Government, raises a number of important issues with respect to the co-ordination of sequence of decisions where there are multiple decision-making centres. Benefit cost analysis of rural water supply, while it can contribute to effective decision-making, is no substitute for a planning process in which alternatives are identified fairly early on, and the sequence of decisions leading to a final programme is sufficiently well appreciated at the outset to allow planning to proceed quickly and reasonably efficiently in relation to the resources available.

THE USE OF MATHEMATICAL MODELS IN WATER SUPPLY PLANNING

by

Gerhard Tschannerl
BRALUP, University of Dar es Salaam

Water development planning in Tanzania is now at a crucial stage. Up to now projects have largely been conceived and designed in the regional offices, where the selection of projects for implementation also took place. The number of proposed projects was small enough so that the regional water engineer, together with the regional administration, could formulate a programme. Projects were also fairly small in size and scattered throughout the region, so that the possible alternatives of water supply strategy were limited by local conditions and engineering considerations.

Whether this planning procedure is in fact the best one to use under the circumstances which prevailed up to now does does not matter much at this stage. No doubt, some lessons could be learned for future water planning and for development planning in other sectors of the economy. But we must realize that identifying past water development objectives and measuring the degree to which these objectives have been fulfilled - our means for judging past performance - are extremely difficult tasks in the light of the intricate decision making process which involves several ministries and TANU on the district, regional and national level.

Two observations should, nevertheless, be made about past performance. One is that the decentralized nature of the decision making process allowed the incorporation of some objectives which would otherwise have been difficult to implement, such as local economic and social development priorities and the extent of self-help. The other point is that this decentralization might have retarded (a) the evaluation of how effective the programme has been in realizing anticipated benefits (such as the movement of isolated homesteads to a village because a public water supply has been provided there[1])

1. For an excellent discussion of presumed explicit and implicit benefits, see the article by Heijnen and Conyers in this volume.

and (b) the exploration of different strategies (such as assessing the savings in cost that would occur due to economies of scale if the many small projects were consolidated into a few bigger ones [1]),

The reason why past planning procedures must be critically examined is that the recently established accelerated pace of water development in Tanzania has completely altered the planning picture. New initiative is being taken in the formulation and selection of projects, which stems mainly from a strongly expanded investment budget and from the decision to prepare regional water master plans for the entire country. Suddenly much more effort and money will be spent on planning: many more projects will have to be investigated; the consequences of alternative assumptions, for example of population growth, must be looked at; alternatives such as groundwater versus surface water supply, must systematically be explored; and the starting time of construction of the different projects within the 20 year period must be decided.

These new demands on planning call for the rapid examination and sorting of alternative project designs. The aim of this paper is to show that the suitable formulation and use of mathematical models can greatly assist in this gigantic task. After some discussion of the different levels of decision making needed for the preparation of a master plan, a simple model is presented which optimizes the design of each project according to certain criteria and then ranks the projects for the purpose of deciding which ones should be built with the available budget, and at what time.

Cost-Benefit Analysis

In the broadest sense, cost-benefit analysis is nothing but the weighing of the costs of an action against the anticipated gains from it. By this definition, everybody uses cost-benefit analysis, even in private life, because the desire for efficiency of some sort is basic to human endeavor.

The criticism of cost-benefit analysis as a planning tool applies to its use under a much narrower definition, which usually makes, among others, the following two assumptions about costs and benefits. The first is that the costs and benefits can be measured in clearly defineable units [2], such as the reduction in the number of deaths due to a given improvement in water quality, or the hours of productive labour gained. The second assumption goes a step further and requires that the units in which the costs and benefits are measured must be the same [3], so that the difference between benefits and costs can be computed.

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1. Studies based on cost estimates of implemented projects have shown a considerable decrease in project cost per unit of capacity as the project size increases.

2. There is usually more a problem with measuring the benefits. Non-measurable benefits are called intangeable benefits.

3. Called commensurability.

Since the biggest cost component [1] is in monetory units (shillings) the common measure that is usually sought is in those units.

The strict adherance to these two requirements - and most analysts aim at fulfilling them - often leads to erroneous and absurd results, because all the benefits and costs which cannot be directly attributed to the project in question and measured in monetary units are simply neglected. Most analysts have suceeded in convincing themselves that the non-monetary benefits are unimportant. To cite one case, in a Ph.D. thesis from a well-known University, the impact of a rural sanitation programme on health was measured mostly in terms of the reduction in the wage loss from sickness and death, thereby leaving out persons not engaged in wage work - all the women in that case.

Another consequence of the strict adherence to the two assumptions is the insistence on measuring in monetary terms the benefits from goods and services provided. This might be appropriate for a number of water uses, such as irrigation and power, but for domestic water supply the definition of benefits as "the consumer's willingness to pay" (Maass, 1966, p. 21) has no practical value.

The blame for this narrow application of cost-benefit analysis is not entirely with economists; the most blatent misuse has been made by people in other professions who applied a standard procedure without adequate appreciation of its limitations and without knowing ways of relaxing the assumptions. There is continued debate in the economics literature about the appropriate forms of cost-benefit analysis to be used in various areas of public decision making.[2]

Levels of Decision Making

Returning now to water planning in Tanzania, the central problem to be treated in this paper is how to rapidly sort through a large number of alternative projects proposals with the aim of arriving at a selection of project to be implemented in a specified time period. The question should also be taken a step further to the systematic exploration of alternative strategies and assumptions about the design inputs.

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1. The main cost component consists usually of construction cost, and operation, maintenance, and replacement cost. Other costs, not readily expressed in monetary terms, could be, for example, the displacement of people or the deterioration of other water sources through the installation of an additional well.

2. See especially the following references listed at the end of this paper: Freeman and Haveman, 1970; Major, 1969 Haveman, 1967;

Before discussing some techniques of analysis which would be useful for water supply planning in Tanzania, it might be well to identify the following levels of decision making:

1. Engineering decisions: groundwater versus surface water utilization; the cheapest way of meeting a given set of objectives; etc.

2. Design input decisions: medium, high and low population projections; economic development potential; rainfall probabilities; etc.

3. Policy decisions (which deal with the setting of objectives): total expenditure level; degree of preference for Ujamaa villages; desired quantity, quality and distance to water; area concentration or dispersion of projects; etc.

This classification, which in reality is never so clearly divided, suggests that there has to be a division of labour in decision making. It is necessary to clearly define responsibilities for each level and to establish guidelines about the desired interaction between them. The necessity to do this should be obvious, but it happens almost as a rule that those who are responsible for engineering decisions also, in fact, make decisions about the other levels, be it by default or for expediency. Unless those responsible for the first level can present the necessary choices to the other levels in an appropriate form and accompanied by all relevant information, the decisions will not always be made by those who should make them. Convenient ways of presenting these alternatives are outlined below.

Two forms of choice

The desired selection of projects for implementation is achieved by ranking all proposed projects (for one region and one time period) in their order of desirablity. The size of the available budget will then determine for that ordered project list the cut-off point which divides the projects to be implemented from the ones not to be built. This ranking of proposed projects can be achieved in basically two alternative ways, (1) by making a list of all the inputs and outputs for each project and then comparing lists for different projects visually with one another with the aim of ordering the projects by some cirterion of desirability,[1] and (2) by expressing the relationship between inputs and outputs entirely in the form of a mathematical model and then ranking projects according to the degree to which each project fulfills the stated set of criteria in the model. The advantage of the former procedure is that the lists are comprehensive and flexible; its drawback is the impossibility to keep track of all the factors in/comparison between projects. The advantages of the latter procedures lies in the speed of computation, which can be done on the computer; its disadvantages have already been mentioned.

For the planning situation discussed here, a combination of the two approaches seems the most appropriate. Those important relationships which can be explicitly stated should form a mathematical model. The remaining benefits (and costs) which cannot be incorporated in the model under one unit of measurement are simply listed for each project alongside the results from the mathematical model.

The ranking of projects is then carried out in two steps. A preliminary ranking is first achieved by the mathematical model alone, which is subsequently refined on the basis of the additional factors on the list.

The Method

In the preparation of a regional water master plan, it is not appropriate to analyze, at the start, projects that are so small that they comprise only a few villages. It will be helpful to delienate zones, which form fairly homogeniqus units of water supply and demand characteristics. One such zone could be,for example, a large flat drainage basin with fairly evenly scattered homesteads, limited groundwater availability and no perennial streams. Another zone could be a series of high-land plateaus on which villages are located. The preparation of the master plan would then involve dividing the region into a number of such zones, based on initial field studies of the water supply and demand conditions. A separate zone should also be established for any area where there are major choices about strategy to be made, be it the source of water (e.g. pumping from the ground versus a pipeline from a nearbly mountain range), or the overall development potential of the area (future in or out migration, prospects for irrigation).

1. A single Zone

Each zone could first of all be considered separately to see which alternative means of providing water, thereafter called water supply strategy,[1] is the most advantageous for each zone. Taking a certain population forecast and density distribution for a zone, the minimum cost alternative for providing the water should be found.[2] Additional considerations, such as the reliability of the water during the dry season and its quality, should be recorded, and sometimes such information might be used to discard the minimum cost solution in favour of one with more attractive other features.

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1. The term project used in the beginning of this paper is synonymous with water supply strategy.

The mathematical model which can be used for the simplest possible case of cost minimization for one zone is shown in Appendix A. The example consists of a cost curve, one for each water supply strategy, as a function of the number of people supplied, and of a constraint about the minimum number of people to be served. In addition to finding the least-cost strategy, the solution also finds the marginal value of water supplied to the last person, which is implied by fixing the minimum number of people to be provided with water. The marginal value of water is equivalent to the previously mentioned unit benefit (per person).[1] This fact is of considerable importance, because it is a way out of the narrow definition of cost-benefit analysis which was critisized in the beginning of this paper. Instead of assigning a benefit, in shillings per person supplied, the number of people to be served is fixed, which, as a property of the mathematical model, implies a unit benefit.[2]

An obvious implication of this relationship is that the planning procedure currently used in Tanzania does not neglect to consider the benefits from rural water supply, as is often charged. It does not directly assign a value to the benefits, but by setting appropriate constraints a benefit is in fact implied. This gets around the futile endevour to assess benefits from rural water supply through measuring the various benefit components, such as better health, time reallocated to production, and the boost to economic development of the area.

The numerical example presented here postulates a zone with at least 12,000 people to be served. For simplicity only one strategy (.i.e. one possible way of providing water) is assumed, with a cost curve as given in Appendix A (cost curve for zone 1 in Fig. 1). The solution is to supply the 12,000 people at a cost of 815,000 shs. The implied unit benefit (per person) is 94.4 shs., and the average cost is 67.9shs. If there were several alternative water supply strategies for this zone to choose from, the one with the lowest total cost should be selected, unless for other reasons a different alternative is preferable.

2. Budget Constraint and Phasing of Construction

In this manner, the minimum cost solution and the implied unit benefit are computed for each zone. Adding up the cost for all zones gives the total budget requirement for the region over the entire plan period. If this exceeds the budget that has been allocated to the region, it follows that the water supply for some of the zones cannot be built in the plan period. Those zones which are preferable must be singled out for implementation. Because the previous calculations already found the least-cost design for each zone, and there is no further cost saving can be obtained, a reduction in cost could only be achieved by lowering the water supply standards (water quality, quantity, per person per day, distance of fetching, etc.).

1. This is demonstrated in Appendix A for the example considered. Henderson & Quandt, 19 show that this relationship is true in general.

It is, of course, possible to approach to the problem of planning under a budget constraint differently. One could require that every needy person in the region must benefit from the water investment, and that as a consequence the water supply standard must be modified so that the total expenditure remains within the allocated budget. This is again a decision which must be made by policy makers and not by engineers or economists. The latter must supply the information so that a choice can be made at the policy level. Policy makers must be told that for a certain standard of water supply the required budget is so much, but if another standard is applied, the requirement is that much.

No matter which approach to planning under a budget constraint for the entire plan period is chosen, a preference ranking for zones must still be established. Not all the zones can have their schemes built at one time. Some will be built earlier, some later. The ranking of projects according to their relative desirability can help in making the selection of zones to be supplied first.

The relative desirablity of each zone's scheme is also a useful indicator of the overall development emphasis that should be given to that zone; if the prospect for the development of a zone is poor, people should not be encouraged to settle there in the future. The water master plans would thereby establish zonal priorities for overall development and settlement of people from the water standpoint, which would be of great help to regional planning because of the fact that water is serious problem for most regions.

To decide the phasing of construction of the schemes for the zones in a region, the total planning period must be divided into sub-periods, and the most advantageous group of zones selected for the first period, the next best group for the second, and so on. More precisely, once the length of the sub-periods is chosen, a budget constraint is assigned to each period. The selection of zones for implementation in the first period is then carried out from among all the projects as if the first period were the only one in existence. Then the selected projects are set aside and the choice from among the remaining projects made for the senond period if it were the only one, and so on.[1]

3. Selection of Zones in one Time Period

Having broken down the problem of deciding which zones should be taken up in which sub-period into one of choosing the most desirable ones for implementation in a specific time period, all the zones not implemented in other periods are ranked in descending order of desirablity and the cut-off point for implementation established, so that the budget allocation for that period is exhausted.

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1. There are cases where this method does not give an optimal ranking. See Marglin, 1963, pp. 28-29, 51-52, for a precise statement of the conditions when it does. Domestic water supply projects normallly meet these conditions.

A number of different ways to rank projects have been employed in the past, not all of which give the correct ranking. In fact, only one of them always gives the correct ranking in the precense of a budget constraint, while some others do so under some limiting conditions. It will be demonstrated with a numerical example how other ranking criteria produce different rankings , which are incorrect.

The recommended ranking procedure consists of computing an index, which is the difference between the total implied benefits and the toal cost multiplied by a coefficient (see Appendix B).

Index = Benefit - (Coefficient) x (cost)

This coefficient represents the shadow price of capital (the cost of one shilling, so to speak) and is an undetermined value; it is greater than one. As the magnitude of the coefficient increases, the index decreases, until a point is reached where the index becomes negative. Furthermore the ranking of zones according to the magnitude of their indices might change with different values for the coefficient. The desired ranking is obtained by adjusting the value of the coe ficient until the cost for zones with positive indices adds up to the budget allocated to that period. This procedure , which is explained in some detail in Appendix B, assures that those projects are built which best meet the given objectives.

An an illustration, four projects are given, each being the best for its zone. Three of them cost 815,000 shs. each, and the fourth 1,630,000 shs. It is given that only 1,630,000 shs. can be spent in that ime period, so that a choice of zones for implementation must be made. The costs and benefits, in shillings, are as follows:

Project	Total Benefit	Total Cost	Average Cost
1	1,133,000	815,000	67.9
2	1,101,000	815,000	54.3
3	749,000	815,000	102.0
4	2,040,000	1,630,000	81.5

For different values of the coefficient, denoted by s, the following ranking of e zones by the size of the index is obtained:

s = 1

Zone	Index	Total cost
4	410,000	1,630,000
1	318,000	815,000
2	268,000	815,000
3	-66,000	815,000

	Zone	Index	Total Cost
s = 1.25	1	113,000	815,000
	2	80,000	815,000
	4	0	1,630,000
	3	-71,000	815,000

When s = 1, that is when the index is simply the difference between benefits and total costs, the indices of three zones are positive, indicating that schemes for these zones should be built. This exceeds the budget constraint, and so s is gradually increased to make the index of some zones negative or zero. When s = 1.25, only the indices for zones 1 and 2 are positive, and their combined cost of 1,630,000 is equal to the size of the budget. It should be noted that the ranking has changed with the increase in s.

It is interesting to compare the results obtained from different ranking procedures, out of which only the one using the s - coefficient on the cost term is correct. Zones are ranked in descending order of desirability.

(i) Ranking index shown above(using s coefficient)

Zone 1)
Zone 2) To be built
Zone 3
Zone 4

(ii) Difference between benefits and costs (i.e. s = 1)

Zone 4) To be built
Zone 1
Zone 2
Zone 3

(iii) Average cost

Zone 2)
Zone 1) To be built
Zone 4
Zone 3

The fact that procedures (i) & (iii) lead to the same overall conclusion, that is to build in zones 1 and 2, is a coincidence, because one can show that if the budget constraint were 815,000 shs instead of 1,630,000 shs, by increasing s to s = 1.35 the solution would be to build in zone 1. This is different from the answer obtained by procedure (iii), which say to build in zone 2.

It follows that the importance presently attached to the average cost is an inadequate measure of the relative desirability of projects.

So far the ranking has been carried out only on the basis of the results from the mathematical model. But as has been proposed in the beginning of the paper, additional factors relating to each project should also be taken into consideration for the final ranking. These could be, for example, the economic development potential of the area, the foreign exchange component of construction, and the condition of the present water supply. Bringing in these factors might change the ranking obtained with the help of the mathematical model, but the refining of the priorities will be greatly facilitated if a preliminary ranking has already been done.

Conclusion

The planning picture can now be further expanded - and this is only possible if project evaluation and selection are systematically and rapidly handled - by setting different projections, estimates, and objectives, and exploring what the outcome, in terms of project size, location, staging of construction, etc. would be. One could for example, determine what difference it would make to the staging of projects over a 20-year period in a certain region if for example water stimulated rapid economic development in some sector of agricultural production, and what it would be like if it did not. A similar exercise could be done for projections of people living in Ujamaa villages as opposed to homesteads scattered over a large area. By holding some inputs fixed and changing others, the link between assumptions and their associated results can be fairly simply displayed, so that the necessary decisions can be carried out at the appropriate level.

The advantages of obtaining a preliminary project ranking with the aid of mathematical models are not fully apparent in the simple example which has been discussed. As more factors are added for each project and as the number of projects increases, an intuitive judgement becomes more and more difficult. Too many projects, too many factors, and too many time periods have to be kept in mind. The situation is somewhat like that of a card player's who is a player at every table of a tournament hall where different card games take place, and who goes from table to table making a move at every table when his turn comes. He has to remember and history of each game and its present state. This is where mathematical modelling and the use of the computer become valuable tools in decision making.

APPENDIX A

MODEL OF A SINGLE PROJECT

The objective is to minimize the total cost, $C(x)$, of the project, subject to the constraint that a minimum number of people P, must be provided with water. The variable, x (which is a dummy variable since always for this model $x = P$), is the actual number of people to be supplied.

Model 1 : Minimize $C(x)$

Subject to $x \geqslant P$

The solution to this problem is obvious, the population to be served is $x = P$ and the cost becomes $C(x) = C(P)$. We can, however, gain an additional piece of information if we keep x as a variable and solve the problem by some standard optimization technique. For our case, the method of Lagrangena multipliers is appropriate. The Lagrangean function is $L = C(x) + k\ (x - P)$ where k is the undetermined Lagrangean multiplier associated with the constraint.

The solution is found by maximizing L with respect to x,

$$\frac{dL}{dx} = C'(x) + k = 0$$

Where $C'(x)$ is the first derivative of $C(x)$ with respect to x. It follows that $k = - C'(x)$.

The Langrangean multiplier k represents the shadow price of P, i.e. the benefits foregone by <u>not</u> supplying the (P+1) <u>st</u> person. In our case the shadow price equals the negative marginal cost evaluated at the solution point (i.e. $x = P$).

The reason why k should be determined is that a slightly different problem formulation leads to exactly the same result. This alternative formulation is:

Model 2: Maximize $N = (-k)\ x - C(x)$

The interpretation given to $(-k)$ here is the benefit derived from supplying one person with water. The solution is:

$$\frac{dN}{dx} = -k - C'(x) = 0$$

and it follows that $k = -C'(x)$.[1]

[1] For a proof that the two alternative models always give the same result see Henderson & Quandt, 1958.

e can therefore use either model to arrive at the same sult. For model 1 the minimum number of people, P, has be fixed, and for model 2 the unit benefit (-k). The cision which formulation to use depends on the ability assign actual values to these parameters. Present anning in Tanzania is done largely along the first rmulation (i.e. cost minimization subject to a minimum mber of people served).

xample:

The project cost, $C(x)$ is composed of the capital st, C_o, (fixed cost) and operation/maintenance/ eplacement (OMR, running costs). The present value the annual OMR costs is denoted by C_{OMR}

$$C(x) = C_o + C_{OMR}$$

Where $C_o = a + bx^r$

and $C_{OMR} = hx$

so that

$$C(x) = a + bx^r + hx$$

This form of the fixed cost function was found fit past project cost data in Tanzania.[1]

Setting $a = 200{,}000$, $b = 0.0036$, $r = 2$, $h = 8$, and

$P = 12{,}000$, the total cost in shillings is:

$$C(x) = 200{,}000 + 0.0036\ (12{,}000)^2 + 8\ (12{,}000)$$

$$= 719{,}000 + 96{,}000 = 815{,}000 \text{ shs.}$$

and $C'(x) = rbx^{r-1} + h = 0.0072\ (12{,}000) + 8 = 94.4$ shs.

It follows that the average cost is $C(x) = 815{,}000/12{,}000 = 67.9$ shs.

. Tschannerl and Mlaki - "The Cost of Rural Water Supply", BRALUP Report, in preparation. A solution for models 1 and 2 can be found only if $r > 1$, that is when the marginal cost curve increases (see Henderson & Quandt 1958).

The historical data showed invariably functions with $r < 1$. Using the the past trend, however, these curves were extrapolated to the point where $r > 1$, thereby increasing the scale of projects. These considerations suggest that water supply projects in Tanzania should be built on a bigger scale than up to now in order to realize some economies of scale.

APPENDIX B

PROJECT RANKING IN ONE TIME PERIOD

Four zones:

Four (mutually exclusive) zones are to be ranked according to how well the proposed water supply project for each would fulfill the criterion of cost minimization subject to supplying a fixed minimum number of people. The first zone is the one discussed in Appendix A. The other zones have the same cost function as the first, but they have different values for the cost parameters. The following is a summary of the notation which was introduced in Appendix A.

a = constant in the capital cost function

b = slope in the capital cost function

r = exponent in the capital cost function

h = present value of OMR cost per person

P = minimum number of people to be served ($x = P$)

C_o = capital cost

C_{OMR} = recurrent cost

$C(x) = C_o + C_{OMR}$ total cost

$MC = C'(x)$ marginal cost evaluated at x

$AC = C(x)/x$ average cost

B = total benefits (present value)

$NB = B-C$ net benefits

R_i = ranking index for i^{th} zone

s = shadow price on capital

The value for the parameters ($a,b,r,h,$ and P) for the four zones are given in table 1 together with the results from the computation.

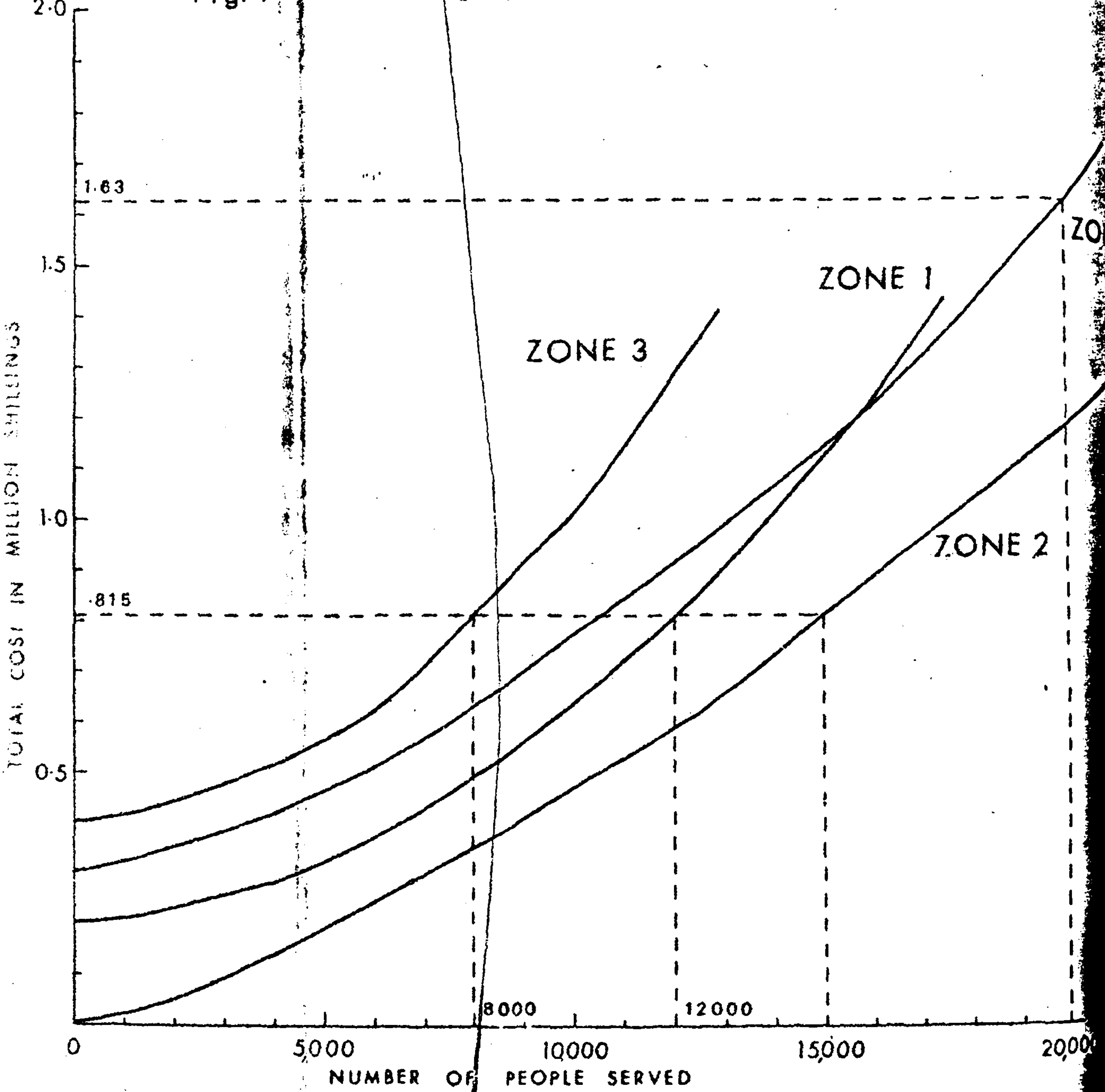
TABLE 1. COSTS AND IMPLIED BENEFITS FROM THE FOUR ZONES

Zone	COST parameters				No. of people	cost, in shillings (notation on previous page)						
	a	b	r	h	P	C_c	C_{OMR}	C(X)	MC	AC	B	NB
1	200,000	.0036	2	8	12,000	719,000	96,000	815,000	94.4	67.9	1,133,000	318,000
2	0	.313	1.5	16	15,000	575,000	240,000	815,000	73.4	54.3	1,101,000	286,000
3	400,000	.00523	2	10	8,000	735,000	80,000	815,000	93.6	102.1	740,000	-67,000
4	300.000	.154	1.6	8	20,000	1,470,000	160,000	1,630,000	102.0	81.5	2,040,000	410,000

NOTE: 1. All the cost figures are computed with the equation given in Appendix A.

2. The cost curves for the 4 zones (all having the same function but different parameters) are shown in Figure 1.

Fig. 1 COST CURVES FOR FOUR ZONES



RANKING

The ranking index is defined as:

$$R = (-k)x - s \quad C(x)$$

where s denotes the shadow price of capital due to a budget constraint being present (a scarcity of the shillings, so to speak). When the budget constraint is binding, s is greater than 1. As explained in the main text, the index R is calculated for each zone by setting a value for s, and the desired ranking is obtained when the value of s chosen is such that for the first project (from among all the zones) which cannot be built because the budget would then be exceeded, the R is equal to zero.

Setting the budget constraint at Shs. 1,630,000 and defining R_i as the ranking index for the i^{th} zone, the following ranking occurs, in descending order of desirability:

s = 1	R_4	=	2,040,000	-	1,630,000	=	410,000
	R_1	=	1,133,000	-	815,000	=	318,000
	R_2	=	1,101,000	-	815,000	=	286,000
	R_3	=	749,000	-	815,000	=	-66,000

Zone 4 is the most desirable, 3 the least. The first three zones should be implemented, which violates the budget constraint. One, or two, zones (depending on which ones they are) must be driven out. To achieve this, s is gradually increased until one zone (other than zone 3) has an R of zero. This is reached when s = 1.25 .

s = 1.25:	R_1	=	1,133,000	-	1,020,000	=	113,000
	R_2	=	1,101,000	-	1,020,000	=	80,000
	R_4	=	2,040,000	-	2,040,000	=	0
	R_3	=	749,000	-	1,020,000	=	- 71,000

Remaining are zones 1 and 2, and their joint budget requirement exactly exhausts the available budget. The solution is therefore to implement the schemes for these two zones. The remaining two zones might still be taken up in a later time period, with the selection being done by a separate ranking. It should be noted that zone 4 has dropped from first place to third place with the increase in s. This happened because the budget constraint makes money scarce, thereby penealizing projects with a high cost component. The cost for zone 4 is much greater than for the other zones, and an increase in s makes it less desirable relative to the other zones.

Suppose a solution had not been reached at s = 1.25, what happens when s is increased further? The R of the next project becomes zero at s = 1.36 and the following ranking obtains:

s ≐ 1.36:	R_1	=	1,133,000	-	1,101,000	=	32,000
	R_2	=	1,101,000	-	1,101,000	=	0
	R_4	=	2,040,000	-	2,202,000	=	-162,000
	R_3	=	749,000	-	1,101,000	=	-352,000

The ranking is unchanged from s = 1.25, but only zone 1 is to be implemented, which does not fully utilize the available budget.

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INVESTIGATIONS, SURVEYS AND DESIGN OF RURAL WATER SUPPLIES

By Andre Harlaut

SWECO - VBB, Stockholm, Sweden

1. General

Due to difficulties with communications and lack of accumulated information the investigations, surveys and design for rural water supplies are often difficult to carry out within the limited economical range available. It is therefore necessary to develop procedures in order to avoid unnecessary communications and delays.

The three principal bodies involved in a given project are generally a Regional Office, a Head Office and Specialist Sections such as Engineer Geologist, laboratories, etc. It is advisable to establish a procedure which allows a division of work and responsibility between the three bodies and facilitates comprehensive overall planning.

The schematic procedure should be based on the following main principles:-

1. All work involving knowledge of local conditions should in the first place be the responsibility of the Regional Office.

2. All work involving special knowledge or equipment should be carried out by Specialists sections.

3. All design work involving calculations, economic studies, details design and standard design should be the responsibility of the Head Office.

4. The project work should preferably be divided into three main phases. The first phase should include all activities in connection with the selection of the projects and the overall planning. The second phase, resulting in a Project Report should include all investigations and studies necessary for the implementation decision. The third phase should include all surveys and design for the preparation of all documents and drawings necessary for the construction.

The various steps of the procedure are schematically listed below:-

OVERALL PLANNING

Water Master Plan
Three years Planing

PROJECT PREPARATION

Preliminary survey

Programme of investigation
of water source

Investigation of water source

Project report

Pre-investment studies

Implementation decision and actions

DESIGN

Programme of surveys

Surveys and survey Reports

Construction documents

In order to achieve the preparation and design of the projects with the minimum of expenses, the third phase should be commenced only after the implementation decision has been finally taken. It may however be advisable in many cases to adapt the time schedule to the specific conditions for each project and the project planning should find the most favourable time schedule for each project. The procedure adopted finally for each project should always be discussed with reference to the cost involved so that the cost of preparation and design or the project is kept on a reasonable level.

2. Overall Planning

2.1 Water Master Plan

As a guide for the selection of projects it is in the long run necessary to have in each region a Regional Water Master Plan summarizing the overall water situation in the Region. The Master Plan should show information on the main factors to be taken into consideration such as population, livestock, existing water supplies and sources, hydrology, hydro-geology, possible water resources, etc. The task of establishing such a Master Plan should probably be given to a central body or to consultants, but the continuous revision and up-dating of the Plan once established should be the responsibility of the Regional Office. In many cases a preliminary Master Plan could be compiled in the Region on the basis of available information and used until the Water Master Plan for the whole country is established.

2.2 Three Years Planning

Since the preparation and design of a project requires the common effort of several bodies -- Regional Office, Specialists, Head Office, etc. -- It is necessary, in order to avoid delays and improvisation to plan carefully the programme of work for the whole organization for at least three years in advance. The programme should be revised continuously and should be the responsibility of a planning section.

3. Project Preparation

3.1 Preliminary Survey

The aim of the preliminary survey should be to collect the information necessary to access the main features of each project

As a rule the results of a survey should be recorded on standard survey sheets accompanied by a topographical sketch of the project. The following information should be collected:-

1. Existing water demand
   Number and location of:-
   Population
   Institutions (schools, hospitals, dispensaries, etc.)
   Livestock.
   Other water consumers.

2. Existing water sources
   Type, number and location, quality of water.
   Present estimated water consumption.

3. Anticipated development and water demand.
   Existing plans.
   Expected development.
   Estimated future water demand.

4. Topographical sketch giving the main features of the area such as roads, paths, valleys, main level differences, etc.

5. Possible water sources
   Type, number, location and elevation

6. Possible layout of the schemes.
   Location and elevation of reservoirs with alternatives, if any.
   Location of mains with alternatives, if any.
   Location of domestic points and home connections.
   Possible extensions with alternatives, if any.

7. Special problems and other information of interest concerning the project.

3.2 Programme of Investigation for Water Sources

In many cases the preliminary survey may not give sufficient information as to the availability of water. It should in most cases be necessary to establish a programme for the required investigations by specialists of all the likely water sources to be executed. The programme should include the information needed by the specialists such as topographical sketches, expected water demand, existing and possible sources, etc.

3.3 Project Planning

The work of the specialists should be coordinated by planning section which should establish a time schedule for the project. Close cooperation between involved bodies will have to take place and a standard routine should be developed to avoid unnecessary delays. It should be the duty of the planning section to achieve and maintain efficient routines for the necessary co-ordination.

The results of a level survey could simply be a plan and a number of levelling sheets with the corresponding calculations. It should be the task of the Design Section at the Head Office to develop such standard routines.

It is also essential that all information of importance to the project, e.g. nature of soil, obstacles, etc., is continuously noted during the survey and adequately reported.

4.2 Construction Documents

The construction documents should include the following items:-

1. Construction drawings
2. Specifications
3. Bills of Quantities
4. Cost calculations

If and when it is decided that a contractor shall construct the project then the documents 1-3 completed with the Conditions of Contract should form the Tender Documents and later on the Contract Documents.

Note:- The present paper is based on experience from surveys and studies of rural water supplies carried out by SWECO-VBB, Consulting Engineers and Architects, Stockholm, Sweden, in Tanzania and other countries.

II. HEALTH

SIGNIFICANCE OF FLUORINE IN TANZANIA DRINKING WATER

by

S.L. Bugaisa,
Mineral Resources Division, Dodoma.

It is generally accepted that the health of community depends in large measure on the ample supply of a whole-some water supply. Diseases of very varied character and nature can be, and are transmitted to man by water. The casual agents conveyed by the water may be chemical poisons, pathogenic micro-organisms, and higher forms of life, like worms. However, certain diseases have also been ascribed to either deficiency or over abundance of certain chemical substances in the water supply; for instance, it is sometimes claimed in the medical field that absence of certain substance in water, such as chlorine and calcium is detrimental to health. At the same time the presence of certain substances in water such as arsenic, lead, and fluorine, leads to ill-health.

Mottled enamel, a developmental defect of the teeth, was first noted in 1901 among emigrants from Pizzuole, Italy, and has since been observed to occur endemically throughout the world. From the time of the first recorded investigations, suspicion was cast on the water supply, some abnormal constituent of which was believed to be the casual agent. But the exact nature of the latter was discovered only in 1931 when Chruchill reported the presence of fluorine in the water supply of various endemic areas in the United States. Later in the year some investigators produced the condition in experimental animals fed on diets containing (a) sodium fluoride, and (b) the residue of the drinking waters from the affected areas. Ample evidence has since been forth-coming to confirm the responsibility of fluorine in drinking water for this teetch condition in man and other mammals.

For example in North Africa the presence of fluorine in soils has been shown the cause bone diseases, in addition to dental deffects in horses and cattle. Sometimes acute poisoning has been reported in aluminium factories where flueride is present in the dust. However such severe effects are exceptional; most cases of chronic fluorisis are limited to the teeth and are due to the continued ingestion during the early childhood of small amounts of fluorine in the drinking water.

The teeth disease, known as mottled enamel - chronic endemic dental fluorisis - is almost entirely confined to the permanent teeth and occurs solely during the calcification. Hence it is chidren up to the age of ten years who are susceptible, and the defect does not become manifest until after the permanent teeth have erupted, ie. from the age of six years onwards.

The infected teetch lose their customary lustre and become chalky white, later they develop disfiguring patches of yellow brown, or black staining and may ultimately become pitted and absolutely black. The defect once established is permanent and incurable. However, one curious result is that teeth only mildly affected are more than normally resistant to decay, but those showing the grosser lesions are unduly brittle and soon deteriorate.

The danger of fluorine, particularly to teeth of children, was discovered about 1931 in one area in the United Kingdom with water of 1.5 ppm fluorine; the teeth of 100% of all children examined were affected and damages were most serious in 20% cases of these.

Fluorine even as low as 1.5 ppm attacks the enamel of teeth of children and in large amounts even the teeth of animals. In even larger quantities it leads to density in the bone structure of both man and beast. Usually the toxic action of fluorine is accumulative, but watering points with high fluorine content which are used occasionally, say a few months in a year, are less dangerous than supplies used permanently. Broadly speaking, the severity and incidence of the disease are proportional to the fluorine content of water. Fluorine content in water as little as 1 ppm, can cause the condition, but inadequate diet is said also to play a contributory part, Waters containing less than 0.8 ppm of fluorine appear to be harmless, in fact minimal amounts are thought to be beneficial in preventing dental caries. For example up to 1 part per million of fluorine is added to public water supplies in a growing number of cities for its beneficial effect on the teeth of growing children.

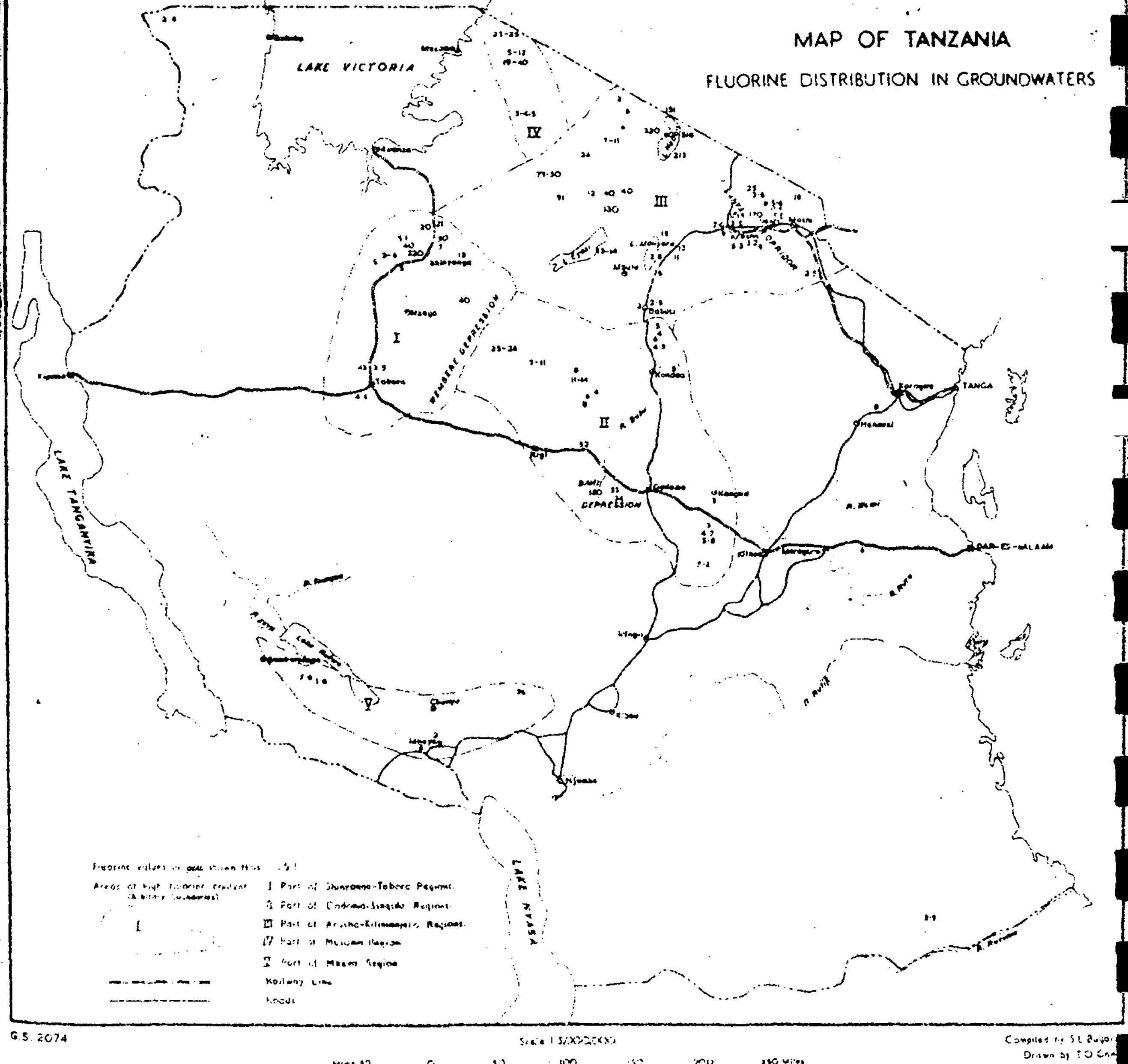
In mainland Tanzania the problem of fluorine content in almost all ground water supplies is quite an acute one. So far large tracts of land have been delineated in which the fluorine content in ground-waters is abnormally high, and the toxic action of fluorine on human beings and beasts in these areas is quite endemic. his is certainly one of the main problems of potability of ground-waters trhoughout the country. The results of some water analyses are given in Table 1.

The main areas in which fluorine occurs in excessive quantities are indicated on the accompanying map. These include:-

(i) Shinyanga/Tabora Region, ranging between 10 to 120 ppm F.
- (i) Isanga basin - N.W. of Shinyanga.
- (ii) Seke - North of Shinyanga - here waters from boreholes driven in kimberlite rocks show fluorine content of 21 to 250 ppm F.
- (iii) Wembere depression - with waters showing fairly high fluorine content, ranging from 7 ppm to 40 ppm F.

(ii) Dodoma/Singida Region:
- (i) Bahi depression - with up to 180 ppm F. It is reported that ground-waters in Bahi depression are contaminated beyond the area of the lake deposits. Thus ground water struck in boreholes located in basement rocks and granites in the vicinity of Bahi show fluorine content of up to 34 ppm.
- (ii) Kongwa - with up to 90 ppm F.
- (iii) Kondoa - water struck in boreholes contained between 4 a and 7 ppm F. and in one borehole in Chubi mbuga contained about 80 ppm F.

(iii) Arusha Kilimanjaro Region
- (i) Sanya Corridor - up to 170 ppm F. Further north water contains between 4 and 8 ppm F.
- (ii) Ngorongoro Crater and Lemagrut volcanic Cone



MAP OF TANZANIA
FLUORINE DISTRIBUTION IN GROUNDWATERS
LAKE VICTORIA
LAKE TANGANYIKA
LAKE NYASA
WEMBERE DEPRESSION
BAHI DEPRESSION
TABORA
TANGA
DAR-ES-SALAAM
Kigoma
Mwanza
Kondoa
Dodoma
Morogoro
Iringa
Njombe
Mbeya
Railway Line
Roads
G.S. 2074

(iii) Serengeti area up to 150 ppm F.
(iv) Ol Balbal depression - over 86 ppm F.
(v) Mbulu District - Up to 99 ppm F.
(vi) Lake Natron Basin - up to 330 ppm F.
(vii) Rivers from N.E. Meru area also known to contain large concentrations of fluorine.

(iv) Musoma Region:

(Several thermal springs in Musoma District also carry fairly large amounts of fluorine up to 25 ppm F.)

(v) Mbeya Region:

Rukwa depression - fluorine concentrations up to 75 ppm have been encountered at Ivumba. And in other areas within Mbeya Region, concentrations up to 96 ppm have been recorded.

Generally, fluorine is a rare constituent of groundwaters and the high fluorine concentrations in groundwaters as outline above are attributed to some geological and hydrological processes and conditions.

1) Volcanic Activities:

(a) Volcanic rocks including kimberlites, carbonatites, pyroclastic ashes and salt deposits. The most obvious example of volcanic rocks, pyroclastic and ashes contributing to high fluorine concentrations in groundwaters in general is the east and S.E. Meru area including the Sanya Corridor. Borehole water in South sanya corridor was found to contain up to 96 ppm F., while further north water contained only 8 ppm F. An area west of Ngorongoro Crater and Lemagrut Volcanic Cone had fluorine content in spring waters between 40 and 140 ppm. Probably it originated from ash beds deposited in Serengeti Plains. A borehole sunk north of the National Park boundary in basement rocks has shown fluorine content of only 6 to 10 ppm F. Another area where it is suspected that springs and volcanic ashes have contributed to the high fluorine content is N.E. Kondoa area. Again waters derived from kimberlites, as in Shinyanga area show fluorine content of the order of 110 to 250 ppm.

(b) Thermal springs situated in or near deep fracture and fault zones and connected with juvenile sources; this is exampli-fied by thermal springs in Musoma District which carry fairly large amounts of fluorine; and some springs in Mbulu area which drain into Lake Balangida show concentrations of up to 99 ppm F. Extremely high fluorine contents of 330 ppm have also been recorded in thermal springs in Lake Natron.

2) Concentrations through evaporation in undrained areas of saline groundwater and mixed juvenile waters. This is examplified by the exceedingly high fluorine concentrations in waters of Wembere, Bahi, Ol Balbal depressions, Rukwa, Manyara and Arusha Chini - Pangani basins and Serengeti lake beds.

3) The presence of minerals such as fluorine and apatite in rocks or lake deposits. For instance high fluorine content in Isanga basin - Shinyanga area - is attributed to the mineral fluoride which is known to occur in younger granites in Lake Region.

In addition to these examples, certain rock formations are characterised by relatively high fluorine concentrations. Consequently groundwaters originating from these rock formations are highly contaminated with fluorine; for example the younger granitic rocks, with fluorine concentrations ranging from 11 to 36 ppm. and the Nyanzian formation have been shown to contain relatively high fluorine values of more than 4 ppm.

CONCLUSION

The toxic action of fluorine from the waters of the contaminated areas may not at first be apparent as the ill-effects are not dramatic in the early stages. However, it should be borne in mind that toxic action of fluorine in the long run is far-reaching and has ill-effects on human beings and other mammals. In areas like Arusha, Kilimanjaro Masailand , Mbulu, Kondoa, and Kongwa, a greater percentage of the communities loose their teeth or develop deffective bone structures in their early youth and a great number of domestic animals (cattle, sheep, goats, etc.) are lost each year through bone breakage and wear of teeth. All these are believed to be largely due to fluorine toxic action.

Nutrition authorities reckon that water supplies with fluorine concentrations greater than 2 ppm are unsuitable for human consumption, particularly where such water supplies are used by children from the age of 6 years onwards.

A research Chemist in the Veterinary Department in Tanzania came to the conclusion in the course of a fluorine survey that fluorine concentrations of 18 ppm was the maximum amount compatible with good husbandry of cattle and that the abonormal increase of bone breakages and wear of teeth was great above this amount.

Thus it is the duty of our water supply authorities, the nutrition department, institutions like school and nurseries, and veterianary departments concerned with animal husbandry, to take necessary steps to safeguard our youth and domestic animals against fluorine toxic action. As remarked earlier, once fluorisis has developed it is incurable. Hence it is only through preventive measures that we can safeguard our communities. This can be achived by either providing good fluorine free water supplies and discouraging the use of fluorine contaminated waters; or in areas where it is practically impossible to get fluorine free water to carry out possible chemical purification processes to reduce fluorine concentrations in these water supplies to the permissible limits.

Some investigations of the possibility of removing fluride from water have been made and various methods have been proposed. Of these, treatment by"Trica lcium phosphate" appears to be the most promissiong.

TABLE 1 SOME WATER ANALYSES

LOCATION	pp.m. Fluorine
Shinyanga	3.0
Bahi Swamp	26,6
Bahi Depression	123.0
W.D.D. Yard, Arusha	3.5
Wembere,Singida	26.5
Wembere	27.0-34.0
Mbutu, W. Wembere, Nzega	34.0
North Chubi	80.0
Ikasi, Dodoma	25.0
Oldonya Narok	11.0
Igombe, Tabora	2.9

Tumbi Valley, Tabora	4.6
Igombe Valley, Tabora	4.6
Uvinza, Nyanza Salt Mine	10.0
Ikasi, Dodoma	33.0
Ikasi Dodoma	22.0
Singida Township	12.0
Singida	7,5
(Tikiti Spring Water	6.0
(Moro 1 Spring Water	75.0
(Moru II Spring water	50.0
(Marangweni Spring Water	91.0
(Kidamudango Spring water	35.0
(NE.E. Eyasi Spring Water	71.0
(Endarihuno Spring Water	13.0
(Endamifaz Spring Water	14.0
S.W. of Msughaa and E. of Ikungi	10.0
Maji Moto Hot Spring	20.0
Manyoni Hot Spring	10.0 - 42.0
Bukene	3.0
Lake Kindai, Singida	6.0 - 7.0
Lemuta(D.S. 12)	24.0
Lake Singida	10.0
Kisangiro Moshi	2.0
Kisangiro Moshi	360.0
Kikabogo, Morogoro	148.0
Seronera	112.0
Kitengure, Bukoba	8.0
Manyara, Singida	3.0
Mjimwema, Coast	2.5
Seronera, Serengeti	12.5
Magongo, Mwanza	5.6
Lake Magadi, Serengeti	12.5
Munanka Warm Spring	11.0
Nyamosk Hot Spring	23.0
Easter Shore of Lake Eyasi Warm Spring	68.0
Crater Lake of Embagii	130.0
L. Magadi, Moru, Area, Srengeti	280.0
Meriannet Oldoway	40.0
Ereneet, Oldoway	24.0
Majo Moto Hot Spring	23.0
Bahi depression	92.0
Bahi depression	30.0
Bahi depression	7.0
Bahi depression	7.7
Igombe Valley , Tabora	4.6
Sanya Juu	8.0
Sanya Juu Mission, Maswa	5.0
Kiambai, Dodoma	10.0
Kititumu, Iramba	6.0
Kinamba	9.0

*Taken from files of the Mineral Resources Division, Dodoma.

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INFECTIVE DISEASES AND DOMESTIC WATER SUPPLIES

by David J. Bradley

Sir William Dunn School of Pathology,
University of Oxford.

I have been asked to take a critical look with you at the relations between domestic water supplies and health. By far the greater part of these concern infective disease; for this reason and also because the chemical problem of excess fluoride is being covered admirably at this conference already, I shall restrict myself to infections.

Traditional water supply thinking, deriving from experience in municipal systems for temperate countries, has been dominated by the common source epidemic, and rightly so, but in the varied tropical situations there are many other hazards. I therefore hope firstly to broaden our view of the ways in which improved domestic supplies can affect health.

Secondly, it seems necessary that I should distinguish clearly between what is known with assurance about the effects of changing supplies upon diseases and what is uncertain or speculative. You may be rather horrified how little is certain, especially at the quantitative level. Of course we cannot wait to do anything until all the relevant data is to hand - otherwise nothing would ever get done. But equally we should clearly distinguish between those actions that are solidly based and the points at which we are compelled to guess.

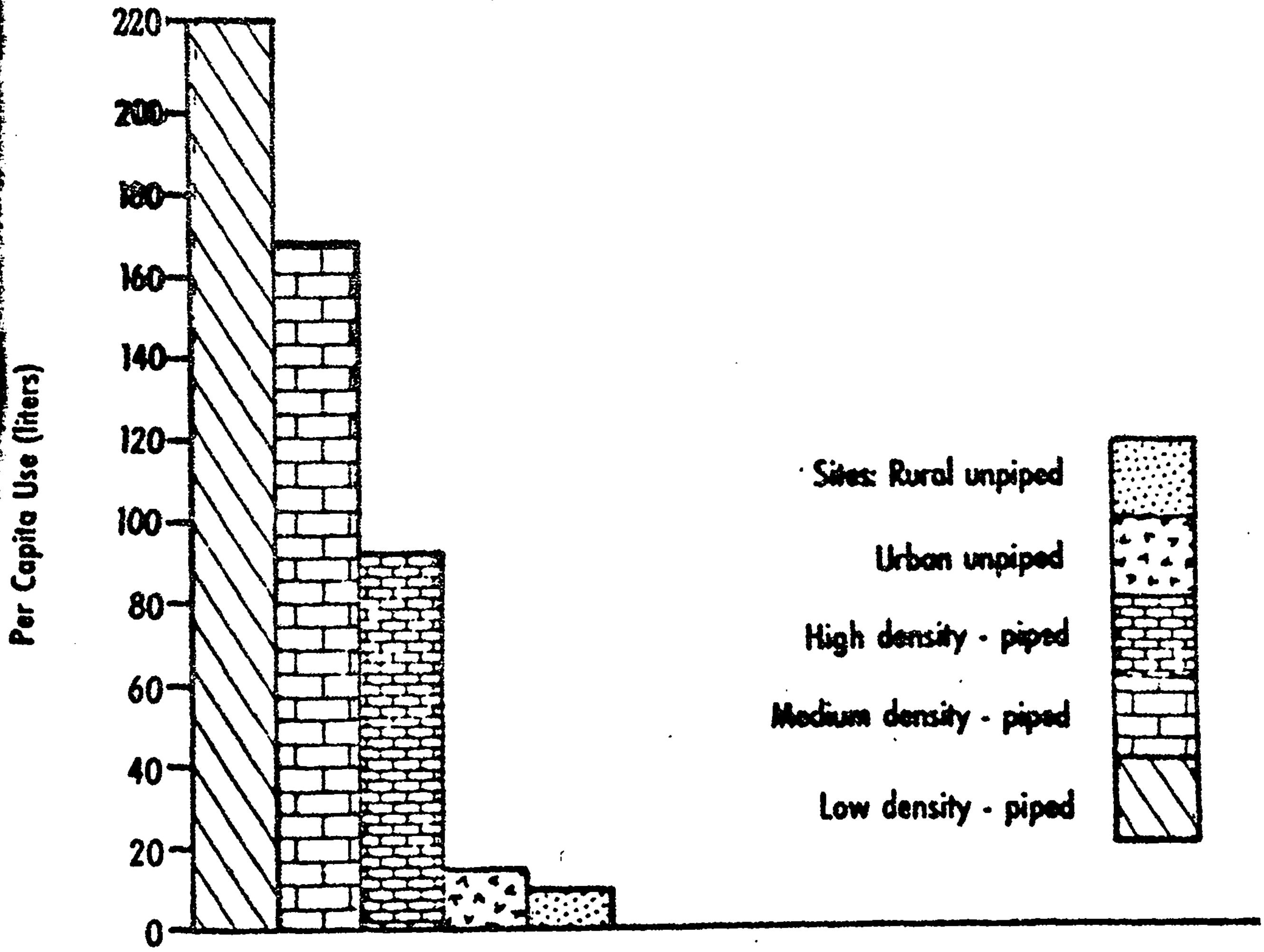
Thirdly, I would like to make some attempt to separate the effects of increasing quality and quantity of water. Whatever the idealists may assert there are frequently situations where it may be possible only to alter one of these and I would like to consider the health aspects of such alterations.

There is certainly plenty of room for changes. Fig. 1 gives some of the daily use levels for different East African communities as determined in the rather widespread study by Prof. White and myself (White et al 1971).

We may for convenience in discussion, classify the infections related to water as follows (Table 1).

Category 1A, the classical water-borne diseases are the obsession of every temperate water-works. If a disease - typhoid and cholera are examples - is to belong to this category the minimal infective dose must be very low, that is, only a very few microbes must be needed to infect the recipient. There aren't very many infections like this. For a common source epidemic the water supply must be polluted at some central point and the infective water carried to the consumers. If the water supply is chlorinated the residual chlorine will have killed the microbes before anyone is infected. So three unlikely events for a town system have to occur simultaneously: (1) pollution of the common source (2) the polluter needs to be a disease carrier (3) the chlorination system must be in abeyance. The other mechanism by which this may occur is when pressure in the mains falls greatly. There is a considerable leak from many distribution systems and if similarly leaky sewers or

1. Per capita mean water use for different habitats and facilities in East Africa.



sewage disposal pits are nearby there may be diffusion of infective organism into the water supply. The size of the resulting epidemic is chiefly proportional to the number of users of the supply. The likelihood of infective pollution is also related to the number of people around who might pollute the supply, so that the risk of this sort of epidemic affecting a user of a system is proportional to the size of the system, other things being equal. So much for large urban supplies, and the moral is clearly to maintain the pressure in the system and never stop chlorinating.

There is a second group of potentially water-borne disease. These have in the part been called faecal-oral infections, they have higher infecting doses of microbes and generally are transmitted via faecal contamination of hands. In most circumstances water is not sufficiently polluted for their transmission. However, in rural semi-arid areas one may get an exceedingly high level of pollution and I suspect that then these faecal-oral infections become water-borne. The infective dose being high, only few of the already few users of such source get the infection so that it is almost impossible to study the situation by classical epidemiological methods. The nearest example on a macroscale was infective hepatitis (infectious jaundice) in Delhi. Usually the sewage from Delhi goes into a river, well below the town water intake. Once after a massive flood the river flow was briefly reversed, much swage got into the water supply and before anything could be done many thousand people were infected with hepatitis. The importance of this is that in general the evidence is clear that hepatitis is not water-borne. I suspect that here our methodology acts as blinkers, and that there is a great deal to be gained by getting as many sources as possible away from the ultrapolluted condition, and of course, persuading people to boil their water.

The above infections are reduced by improving water quality. What about quantity? Here we should be quite clear that increasing the availability of water alone without improving quality at all will reduce greatly the incidence of several unpleasant infections. We have called them the water-washed diseases. They are infections of skin or of the intestine, and table 2 shows which they are, along with the names of the other water-washed infections. Qualitative evidence for their reduction as water is made available is good, the degree of reduction is uncertain. The diarrhoeal diseases need a more critical inspection. These have tended to be put down to poor quality water but careful studies, admittedly using the rather specialised Shigella dysentery as an indicator, show clearly that availability of water is important in determining their incidence (Table 3). Diarrhoeal disorders are a major cause of illness and death in young children in East Africa and although not all causes of them are water-related it seems reasonable to extrapolate to saying that some are. Cutaneous water-washed infections are extremely common (Table 4) and are mainly at the nuisance level though some can be incapacitating. An attempt is made in Fig. 2 to show the effects of changing the quality and quantity of supply upon the health of a community.

The water-based infections are locally of great importance. Guinea-worm, though rare in East Africa, is one infection that can definitely be eradicated by simple water supply improvements. Bilharziasis can be reduced but only greatly so by a rather carefully balanced programme of water improvements or under particular circumstances.

Fig. 2. The effects on health of improving the quality and availability of water for domestic use.

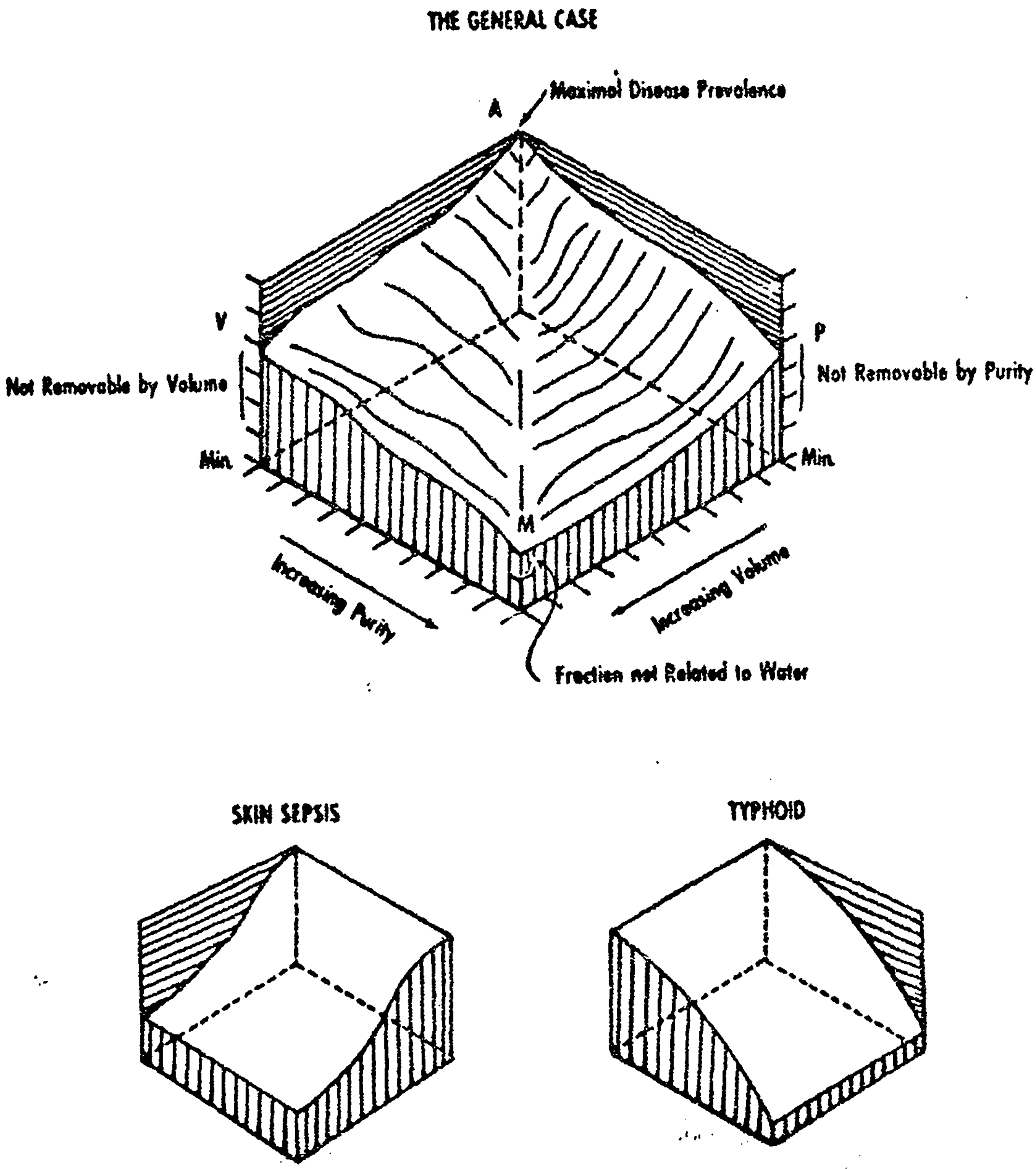


Fig. 3. Categories of water improvements.

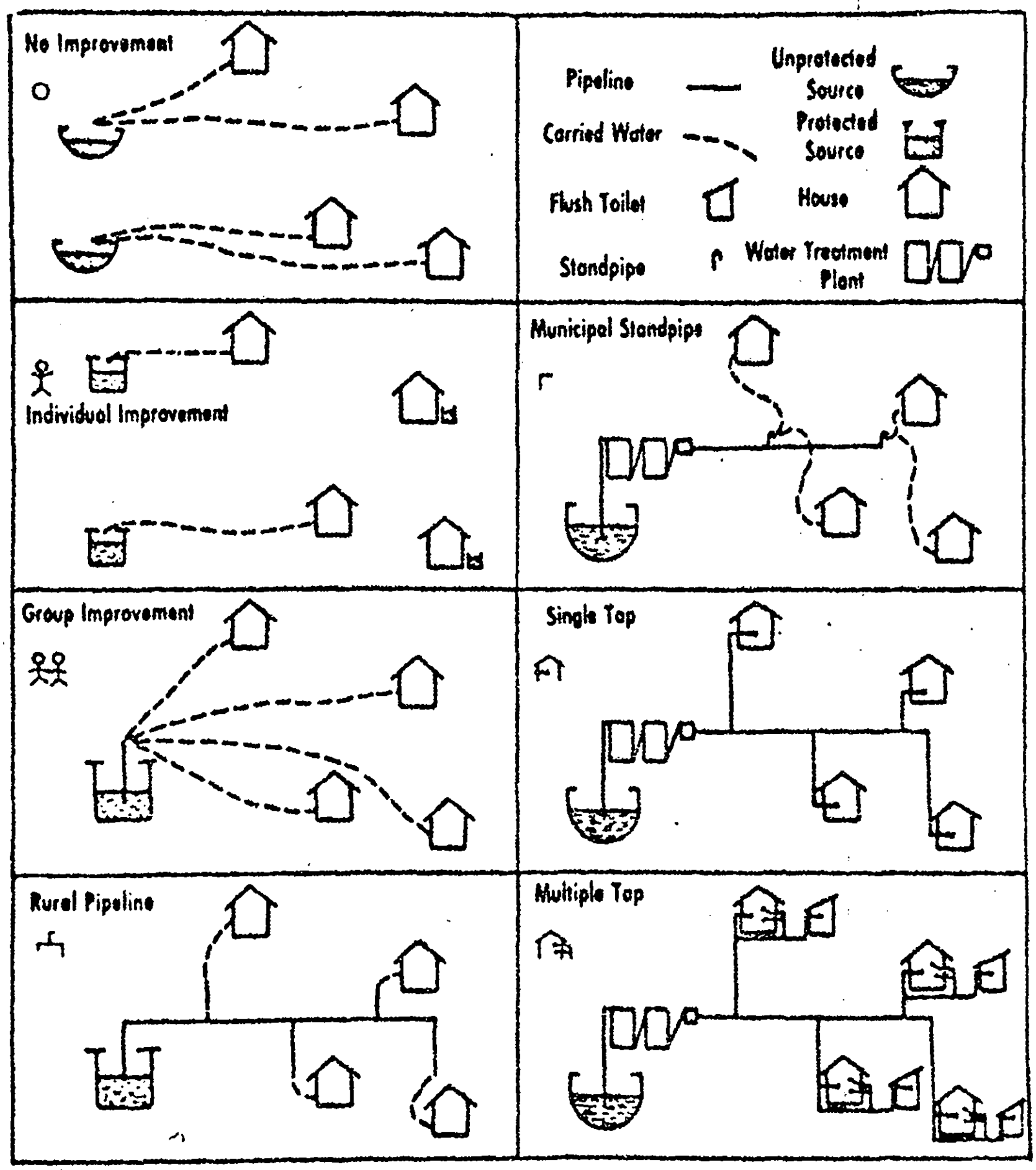


Fig. 4. Supply and health costs for the different levels of water improvement shown on Fig. 4 in different East African habitats.

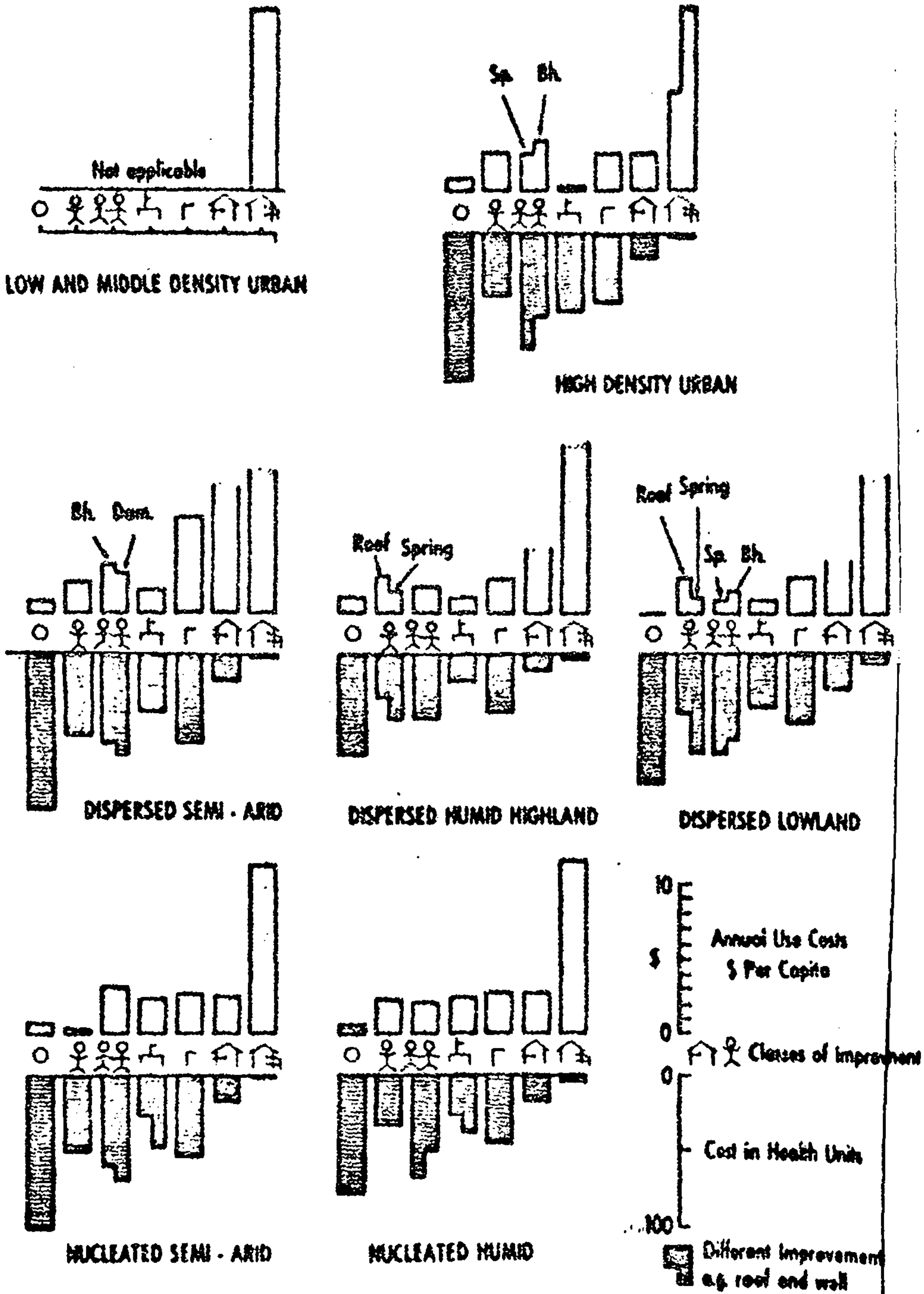


Table 2

Water supplies and Infectious Diseases

	Disease	Common	Severe	Chronic	Water Effect	% Reduction
IA	Cholera	(3)	4		PPP	90
IA	Typhoid	2	4		PPP	80
IA	Leptospirosis	1	3		PP	80
IB	Bacillary Dysentery	3	4		VVPP	50
IB	Amoebic Dysentery	2	3	3	VVPP	50
IB	Tularaemia		3		P	40?
IB	Paratyphoid	1	3		VP	40
IB	Infective Hepatitis	3	3	2	P	10?
IB	Enteroviruses	3			VP	10?
IIA	Gastroenteritis	4	4		VVPP	50
IIB	Skin Sepsis	4	2	2	VV	50
IIB	Chronic Skin Ulcer	4	2	3	VV	40
IIB	Trachoma	4	3	3	VVV	60
IIB	Conjunctivitis	4	2	2	VV	70
IIB	Scabies	3	2	2	VV	80
IIB	Yaws	2	3	2	V	70
IIB	Tinea	2	2		V	50
IIB	Leprosy	3	2	3	VV	50?
IIB	Louse-Borne Typhus	1	4		V	40
IIB	Louse-Borne Relapsing Fever	1	4		V	40
IIB	Ascariasis	3	3	2	VV	40
IIIA	Urinary Schistosomiasis	3	3	3	PP	80
IIIA	Rectal Schistosomiasis	3	3	3	P	40
IIIB	Guinea Worm	(3)	3	3	PP	100
IVA	Yellow Fever	1	4			10?
IVA	Onchocerciasis	3	3	3		20?
IVA	Malaria	4	3	2		10?
IVB	Gambian Sleeping Sickness	2	4	3		80

Table 3 A

Water-related Disease in the Rural U.S.A.

	Morbidity/1,000 0-4 yrs.	Mobidity/1,000 All Ages	%+ve Shigella	%+ve Ascaris
Water in toilet in	428	139	1.1	7
Water in toilet out	829	238	2.4	25
Water out privy out	1,140	360	5.9	42
Water out (Water on premises	953	307	5.8	41
Water out (Water off premises	1,320	413	6.0	43

Table 3 B

SHIGELLA in California (Migrants)

CABINS	% Children +ve	% families +ve
Inside water	1.2	
Outside water	5.9	
Faucet + shower/toilet in	1.6	2.5
Faucet only in	3.0	6.2
No inside water	5.8	11.0

Table 3 C

SHIGELLA in California

		%
A	Moderate Economic Status Water Inside	0.4
B	Low Economic Status Water Inside	2.1
C	Low Status. Water Out 15 families/Faucet	5.3
D	Low Status. Water Out 15 families/Faucet	9.2

p.08 Socio-Economic

p.01 Housing & Sanitation

p.0001 Water Access

Table 4.

Prevalence of water-related disease
in Ankole pre-school children

Scabies	49.6 per cent
Skin sepsis	42.3
Scabies and sepsis	26.1
Dermatophytosis	9.8
Total with one or more of above	70.1
Ascaris	47.6

Table 5

Mean per capita daily use
in litres

Connected	
Karuri	32
Moshi	130
Dodoma	73
Iganga	85
Kamuli	86
Tororo A	161
" B	100
Nairobi A	252
" B	177
" C	167
" D	30
Dar es Salaam A	254
" " B	158
" " C	161
" " D	154

Unpiped	
Kiambaa	11
Karuri	9
Mukaa	8
Masii	7
Manyata	10
Hoey's Bridge	6
Mutwot	8
Mathuri	11
Mkuu	8
Moshi	13
Dodoma	21
Kipanga	13
Alemi	18
Iganga R	13
" U	14
Kamuli	16
Mwisi	4
Kasangati	9
Mulago	13

Table 6

East African Habitats and Water

Characteristics	URBAN		RURAL		
	Lower Density	High Density	Semi-Arid	Highland Humid	Lowland Humid
People/Source	+++	+++	++	++	+
Sources/Total Water	+	+	+++	–	–
Sources/Unit Area	–	++	–	++	++
Financial Resources	+++	+	–	+	–
Distance to water	–	+	+++	++	+
Source Pollution	–	+++	++	+	++
Dangers of Disease	+	+++	+++	++	++
Needs					
Present Fulfilment	+++	–	––	–	–
Moderate Purity		+++	++	++	++
Great Purity		+++			
Volume		++	+++		
Increased Accessibility		++	+++	++	++
New sources			+++		
Suppression all. sources		++			
Special Measures			++	+	
Costs					
Moderate Improvements		+	+++	+	+
Maximal Improvements		++	+++	+	++
PRIORITIES		1	1	2	3

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III. HYDROLOGY AND METEOROLOGY

RAINFALL VARIABILITY IN ZAMBIA

By

S. Nieuwolt,
Department of Geography,
University of Zambia.

Zambia is situated between approximately 8 and 18 degrees southern latitude, and like most regions in a similar latitudinal position receives all its precipitation during summer. To explain this seasonal distribution the synoptic situation over the whole of southern Africa should be considered.

During the winter the circulation is dominated by a large and intensive high pressure cell, which has its centre at about 25 degrees south. Resulting winds over Zambia are the southesterly trade winds. These winds bring continental air masses, which have been stabilized by the predominantly subsiding air movements in the high pressure area. Consequently they bring no appreciable rainfall to Zambia. This situation prevails from about May to September.

In September the high pressure cell begins to weaken as the result of stronger insolation and higher temperatures over the continent. The high pressure cell moves eastwards over the Indian Ocean and the resulting winds over Zambia become more easterly. They bring air-masses from the Indian Ocean, which are rather humid in their lowest layers. Though they have lost most of their moisture over the mountain ranges of Mozambique and Malawi, they still cause convectional thunderstorms in Zambia, which indicate the end of the dry season. October and November are the hottest months in Zambia and the high afternoon surface temperatures favour the development of thunderstorms.

The main rainy season lasts from about December to March in the southern parts of Zambia, from November to April in the North. During this period the average position of the I.T.C.Z. is over Zambia. Actually three main air streams converge: from the north-east, from the southeast and from the west. Especially the last air mass, the Congo Air, is very humid and unstable, and it yields large amounts of rain when forced to rise, as is usually the case along the Congo Air Boundary, which can be considered as part of the I.T.C.Z. In most parts of Zambia, about 90 per cent of the total seasonal rainfall is associated with the convergence zones.

In April the synoptic situation closely resembles that of October, with easterly winds predominating. Thunderstorms again produce most of the rainfall, but they occur most frequently in the northern part of Zambia, still relatively near the I.T.C.Z.

Causes of Rainfall Variability

The above description of the seasonal changes in the synoptic situation over southern Africa is based on broad generalizations and average conditions. Actual situations vary considerably from this basic outline.

For Zambia's rainfall, the movements of the I.T.C.Z. and its C.A.B. - branch are of greatest importance. Both its general southward movement, during October and November, and its return journey towards equatorial latitudes in March and April are often and irregularly interrupted and sometimes even temporarily reversed. And from December to March, when the average position of the convergence zone is over Zambia, it actually oscillates between extreme positions to the south and to the north of the country. Sometimes, however, the whole convergence area remains in the same position for weeks.

The convergence zone also shows strong variations in intensity. Sometimes it cannot be located on weather maps because there is almost no convergence. Often the zone disappears, to reappear again in an entirely different new position.

These irregularities in the movements and the intensity of the I.T.C.Z. are the main cause of rainfall variability in Zambia.

But also of great importance is the very localized rainfall pattern associated with thunderstorms. These produce large amounts of rain over relatively small areas and differences between adjacent stations can be very large, even if they are only a few miles apart. This second cause of variability is most important during the beginning and end of the rainy season, when practically all rainfall comes from small-scale systems. During these periods one storm can produce more rainfall than the monthly median amount. But it is also effective during the main rainy season, because most of the rainfall in the convergence areas is the result of local thunderstorms.

Short-term variability

This term describes the differences in rainfall during one single month. It can be shown only by daily rainfall figures.

Even during the presence of the convergence area over a place large variations in daily rainfall totals are possible. Highest daily figures are not necessarily related directly to the I.T.C.Z. In Lusaka during 1969/70, the highest rainfall occurred when the convergence area was well south of Lusaka. This emphasizes the main difference in conditions to the north and to the south of the I.T.C.Z.: on the northern side equatorial air masses prevail, which are humid, warm and unstable, and thunderstorms develop frequently. But to the south of the convergence relatively dry and stable air masses predominate, which do not produce many thunderstorms.

This difference is clearly illustrated by the frequency of occurrence of dry spells at Mbala, in the North of Zambia, and in Lusaka. In Lusaka almost every major displacement of the I.T.C.Z. to the north is followed by a dry spell. But in Mbala, which during most of the period from November to March is to the north of the convergence zone, interruptions of the rainy season are rare.

A third method to illustrate short-term rainfall variability is to indicate the frequency of occurrence of raindays with specified amounts of rainfall. This was done for 5 day periods (pentades) and for twenty years at Kasama. The diagram shows a clear attenuation of rainfall during January, when the I.T.C.Z. is far to the south normally. However, this does not constitute an interruption of the main rainy season.

Long-term rainfall variability

Most articles on rainfall variability study the variations from year to year, because it is felt that short dry spells are lften compensated by wet periods. However, annual (or, in Zambia preferably, seasonal) totals fail to show the full extent of the rainfall variability in its consequences for agricultural production. The example of a station in the Southern Province of Zambia during the 1969/70 seasonal variations show the seasonal total was about normal, but the very dry November and the exceptionally wet December both caused a great deal of damage to crops and the production was very low. The result was widespread famine in the Southern Province during 1970.

It is therefore prefereable to use monthly figures. These were collected for 134 stations in Zambia and were expressed in a Variability Index, which is the quartile deviation in percent of the median rainfall. The normal period of observations was 30 years, but this was not available at all stations.

The method of quartiles and medians was used, because most of the compilation of data and subsequent calculations were carried out by mathematically untrained students, without the help of calculating machines. This method is not very susceptible to errors in calculation and it also copes well with skewness of the frequency distribution of rainfall records.

The maps of the Variability Index show that the rainfall variability is generally larger in the southern parts of Zambia than in the north. This is true during all months and it can be explained by the less frequent interruption of the rains in the north and west of Zambia, caused by the prevalence of equatorial air masses.

The Variability Index also shows a very significant correlation with elevation. This correlation was calculated after the effects of latitude and longitude had been excluded. The residuals of the V.I. on longitude and latitude showed a negative correlation with height which is significant at the 0.1% level during most months of the rainy season.

ON THE DISTRIBUTION OF RAIN SHOWERS IN THE TANGA REGION OF TANZANIA

by
H. T. Mörth
E.A. Meteorological Department.

INTRODUCTION

Daily rainfall records are taken at numerous rainfall stations throughout East Africa. From it are routinely derived and published monthly and annual totals, number of raindays, averages and extremes. For selected drainage areas the areal average rainfall is given.

These data all refer to point values of rainfall, or to areal averaging of point values. They give no information on the size or distribution of rain showers. For a direct measurement of these it would be necessary to maintain very dense raingauge networks, with a gauge distance in the order of one kilometre.

In the following, an attempt is made to derive, empirically, the number, size, and character of rain showers from a conventional rainfall network, with a gauge spacing around 25 km.

DATA

Daily rainfall as published by the E.A.M.D. for the year 1959 has been used. The area is the geographical 1-degree square bounded by latitudes 5^{o} and 6^{o} South and longitudes 38^{o} and 39^{o} East. The following 16 stations have been used:

95.38.03	Amani	5^{o} 06'S	38^{o} 38'E	2989 ft
95.38.04	Ambangulu E.	5^{o} 05'S	38^{o} 26'E	4000 f
95.38.06	Pangani	5^{o} 26'S	38^{o} 59'E	30
95.38.07	Handeni	5^{o} 26'S	38^{o} 02'E	2222 ft
95.38.08	Korogwe	5^{o} 10'S	38^{o} 28'E	959 ft
95.38.09	Sakura E.	5^{o} 37'S	38^{o} 53'E	130 f
95.38.11	Ngomeni	5^{o} 09'S	38^{o} 54'E	600
95.38.13	Karimi E.	5^{o} 14'S	38^{o} 35'E	940
95.38.15	Magunga E.	5^{o} 00'S	38^{o} 38'E	2000
95.38.17	Mandera Sisal E.	5^{o} 10'S	38^{o} 20'E	1400 f
95.38.18	Ngombezi Sisal E.	5^{o} 10'S	38^{o} 25'E	1100
95.38.19	Makinyumbi E.	5^{o} 19'S	38^{o} 37'E	850
95.38.20	Kwamdulu Sisal E.	5^{o} 12'S	38^{o} 29'E	1000
95.38.21	Pongwe E.	5^{o} 07'S	38^{o} 59'E	330
95.38.22	Mwera E.	5^{o} 31'S	38^{o} 57'E	200
95.38.25	Kiwanda School	5^{o} 14'S	38^{o} 47'E	750

The area is, apart from the coast, hilly and includes the southern end of the Usambara Mountains.

Reports from the weather stations at Tanga and Mombo indicate that much of the rain falls from cumulus-type cloud, in the form of showers.

ANALYSIS

The daily rainfall during 1959 was extracted for these stations (16 stations x 365 days = 5840 station x days).

The days were grouped into 17 classes depending on how many of the 16 stations reported rain on a particular day, e.g. class 6 would contain all those days when 6 out of 16 stations reported rain.

The area average of observed rainfall (Ao) was computed for each day by adding all rainfalls reported by the stations and dividing the sum by 16.

The maximum reported 24-hour rainfall (Mx) was noted.

The figures were then scrutinised for consistency. Only one report, that of Handeni for 23rd December, was rejected when the station reported a fall of 2.15 inches while all other stations received no rain.

The numbers of occurrence for the 17 classes as well as percentages and cumulative percentages are given in Fig. 1.

It was felt that a division into 11 classes (0, 1, ...10) would be more desirable. A class is then termed "Area Index", in accordance with previous work on rainfall in East Africa (1), (2).

A simple transformation to 11 classes was made and the result for the number of occurrences is presented in Fig. 2.

The means of Mx and Ao were then computed for all values in each of the 17 classes.

The results are plotted in Figs. 3 and 4, and curves were fitted.

DISCUSSION

Figs. 1 and 2 show that, during 1959, on more than 80% of the days, the Tanga Region received rain that wetted less than half of the ground. On more than 20% of the days there was either no rain, or so little, that less than 10% of the area was affected.

Fig. 3 indicates a linear increase with area index of the maximum 24-hour rainfall intercepted by one of the 16 gauges. The plot for 16/16 area index 10, is off the chart. Obviously, this class includes all rain situations from the one where the showers just cover the total area to any degree of overlapping. Therefore the plot does not belong to the statistical population formed by the lower classes.

Fig. 4 shows a non-linear increase of observed area mean rainfall with area index. Taking account of the linear increase of Mx with area index, this means that not only the intensity but also the area size of the showers must grow with area index.

DESIGN SHOWERS

Taking note of the above, and guided by some preliminary results (3) of the Tropical Urban Rainfall Experiment in Dar es Salaam, the following assumptions were made:

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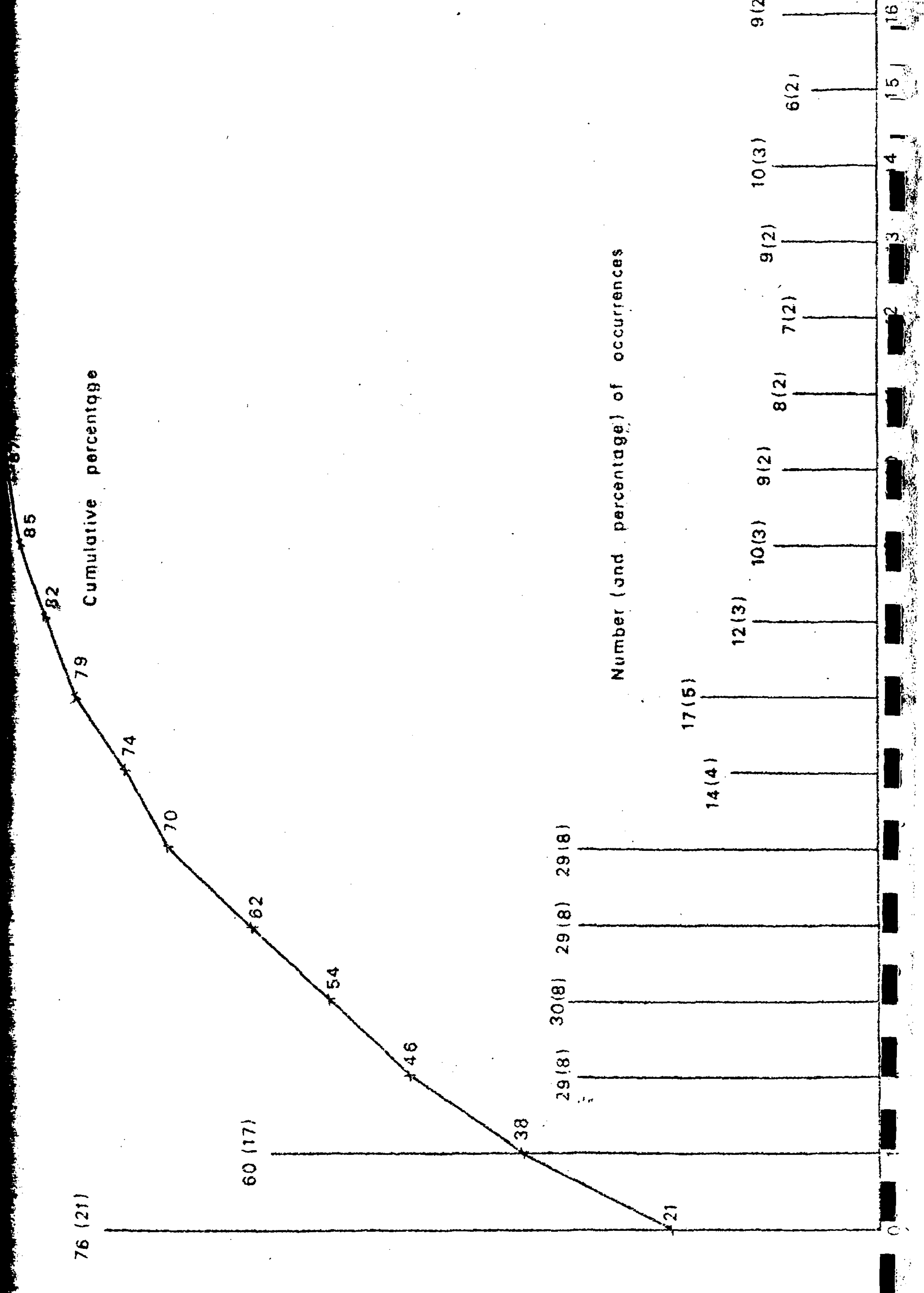
FREQUENCIES OF OCCURRENCES FOR 17 CLASSES IN 1959



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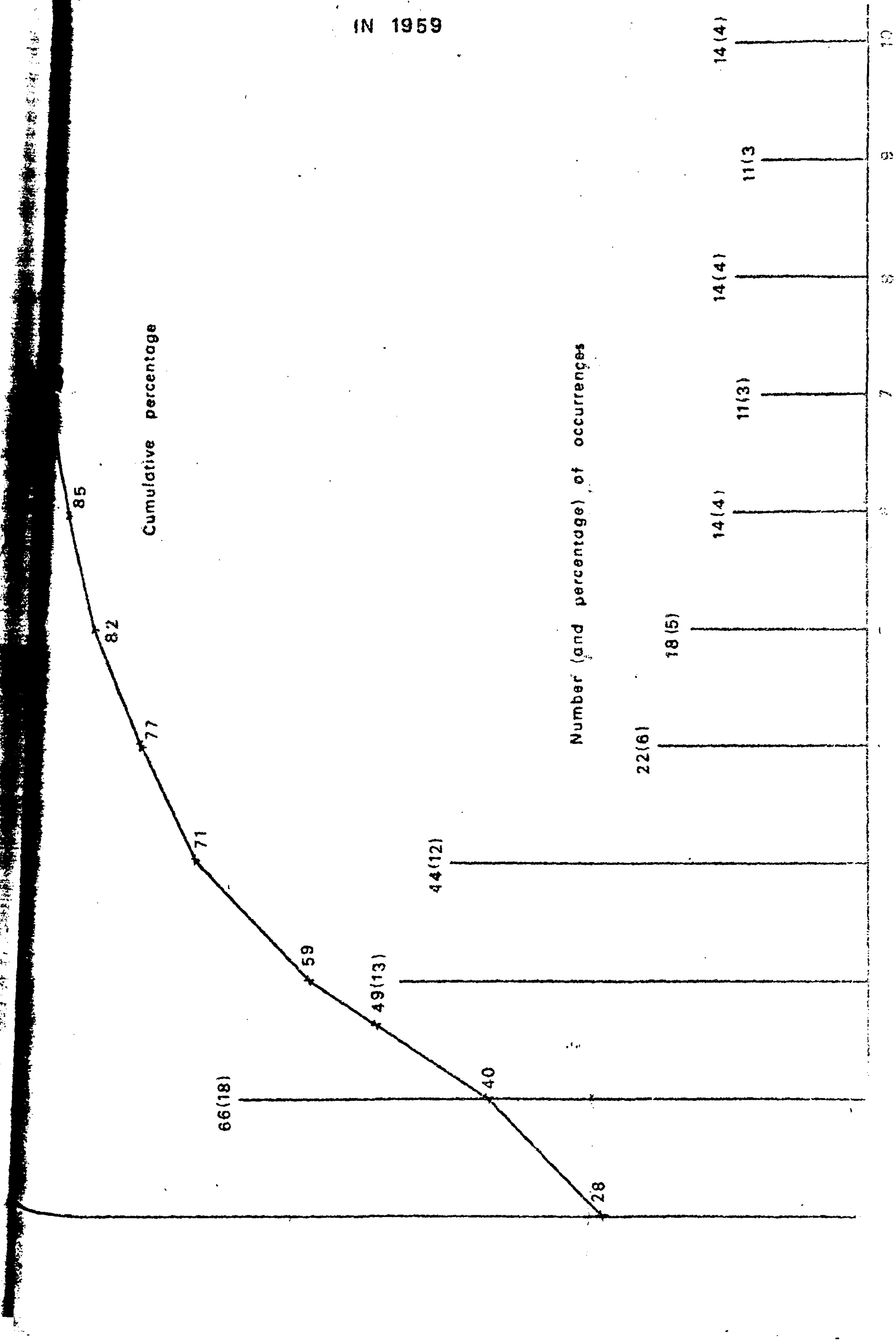
DERIVED FREQUENCIES FOR 11 CLASSES IN 1959



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MEANS OF MAXIMUM REPORTED RAINFALL
FROM 16 STATIONS

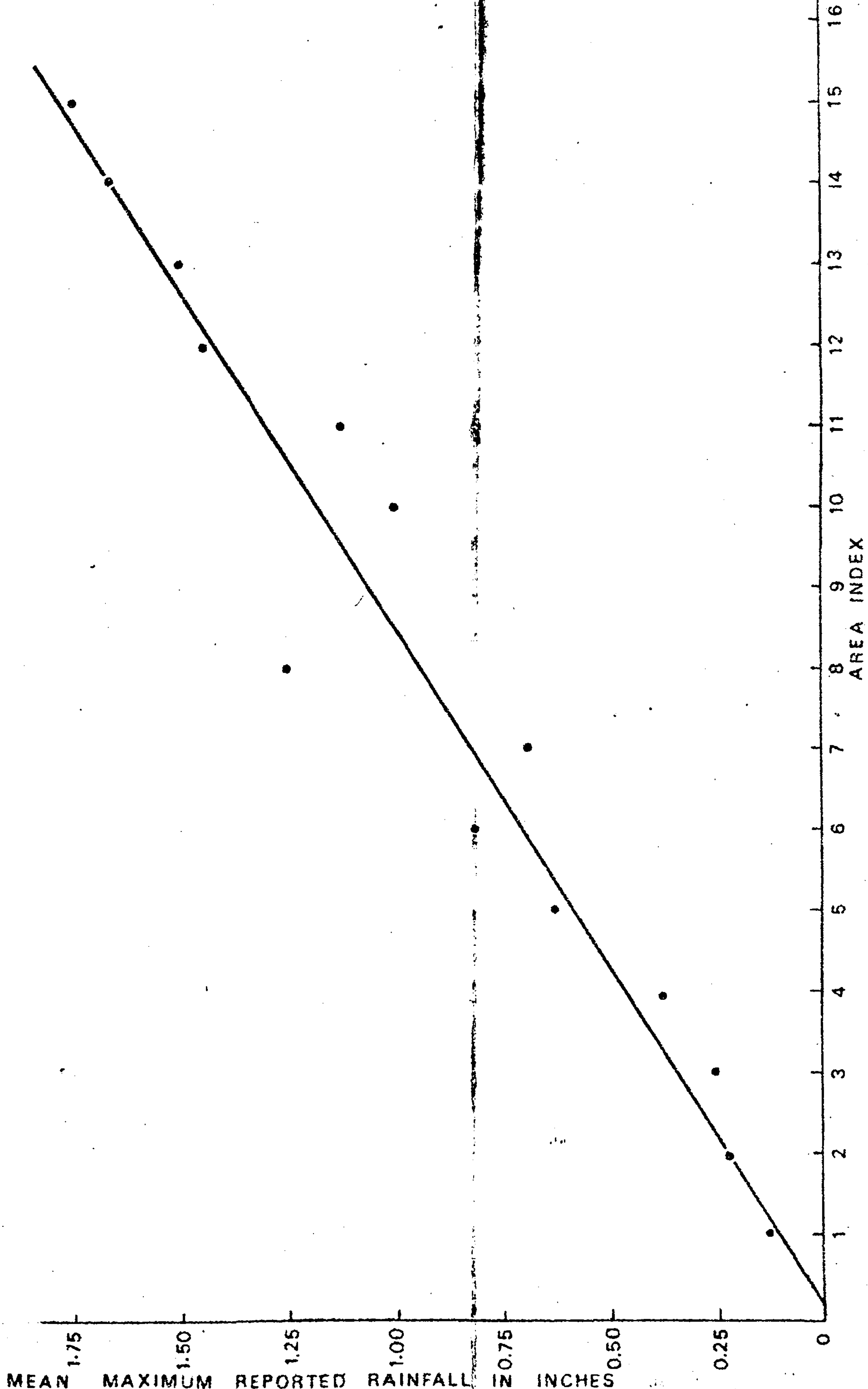
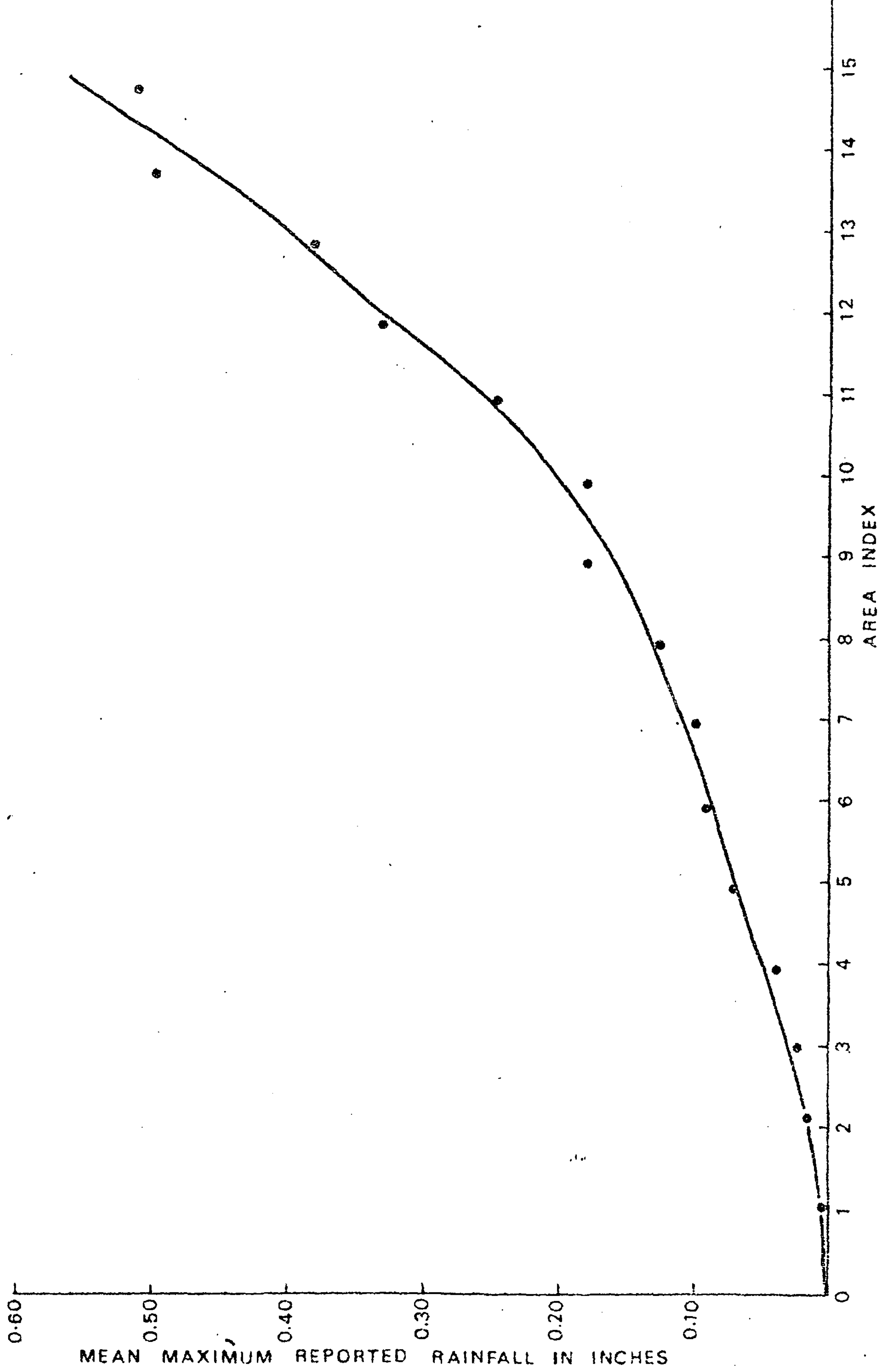


Fig. 4 MEANS OF AREA AVERAGE RAINFALL (AO) FROM 16 STATIONS



A rain shower

a) does not move,
b) is circular in shape,
c) has its maximum precipitation in the centre,
d) has a linear decrease of precipitation from the centre to the circumference,
e) has a radius in km five times its central (maximum) rainfall in inches e.g. for Mx = 0.6 inches the shower radius is 3 km.

The precipitation amounts can therefore be represented by a symmetrical cone and the mean precipitation over the shower circle is 1/3 of the maximum precipitation.

Making the assumptions that in one 24-hour period

f) not more than one shower affects a raingauge,
g) the showers are all of the same size,
h) the showers are regularly spaced,

one can now, using the observed mean shower maximum Mx for classes 1 to 9, compute for such design shower.

i) the size of the shower,
ii) the mean rainfall in the shower area,
iii) the mean rainfall (Ac) in a 1° -square,
iv) the number of storms (N) in a 1° -square,
v) the mean shortest distance (S) between showers,
vi) the mean longest distance (L) between showers.

The results are presented in the following table:

Area Index	1	2	3	4	5	6	7	8	9	10
Wet Area (km^2)	1210	2420	3630	4840	6050	7260	8470	9680	10890	1210
Mx (inches)	0.19	0.38	0.57	0.76	0.95	1.14	1.33	1.52	1.71	1.90
$\frac{1}{3}$ Mx (inches)	0.06	0.13	0.19	0.25	0.32	0.38	0.44	0.51	0.57	0.6
Radius (km)	0.95	1.9	2.85	3.8	4.75	5.7	6.7	7.6	8.5	9.5
Ac (inches)	0.006	0.03	0.06	0.10	0.16	0.23	0.31	0.41	0.51	0.6
N	400	200	146	105	86	71	65	53	48	43
S (km)	3.7	4.0	3.5	2.2	2.5	1.7	0.4	-0.1	-1.3	-2.3
L (km)	6.0	7.2	7.3	7.5	7.4	7.2	6.2	6.1	5.2	4.6

The theoretically derived area averages (Ac) are in Fig. 5 compared with the area average means (Ao) that have been computed from the observed data. The divergence of the curves above area index 7 should be expected as regularly spaced design showers covering 80% or more of the square will actually overlap (see shortest distance S in the table above). This will result in a higher observed area average rainfall. The values of area index 10 have, for reasons given earlier, been omitted.

CONCLUSIONS

The high correlation between the curves in Fig. 5 encourages confidence in the basic assumptions on the structure of design showers and their distribution. One must, however, bear in mind that these relations pertain to mean values, and that departures from the model are likely to be large on individual days.

The above results provide a type of information that is normally not available for large areas. They are relevant to rainfall network design, interpretation of point rainfall data, space diversification of crops, and the hydrology of small catchments.

Future work should extend this study in time, say over a period of five years, and test the validity of the results for other areas.

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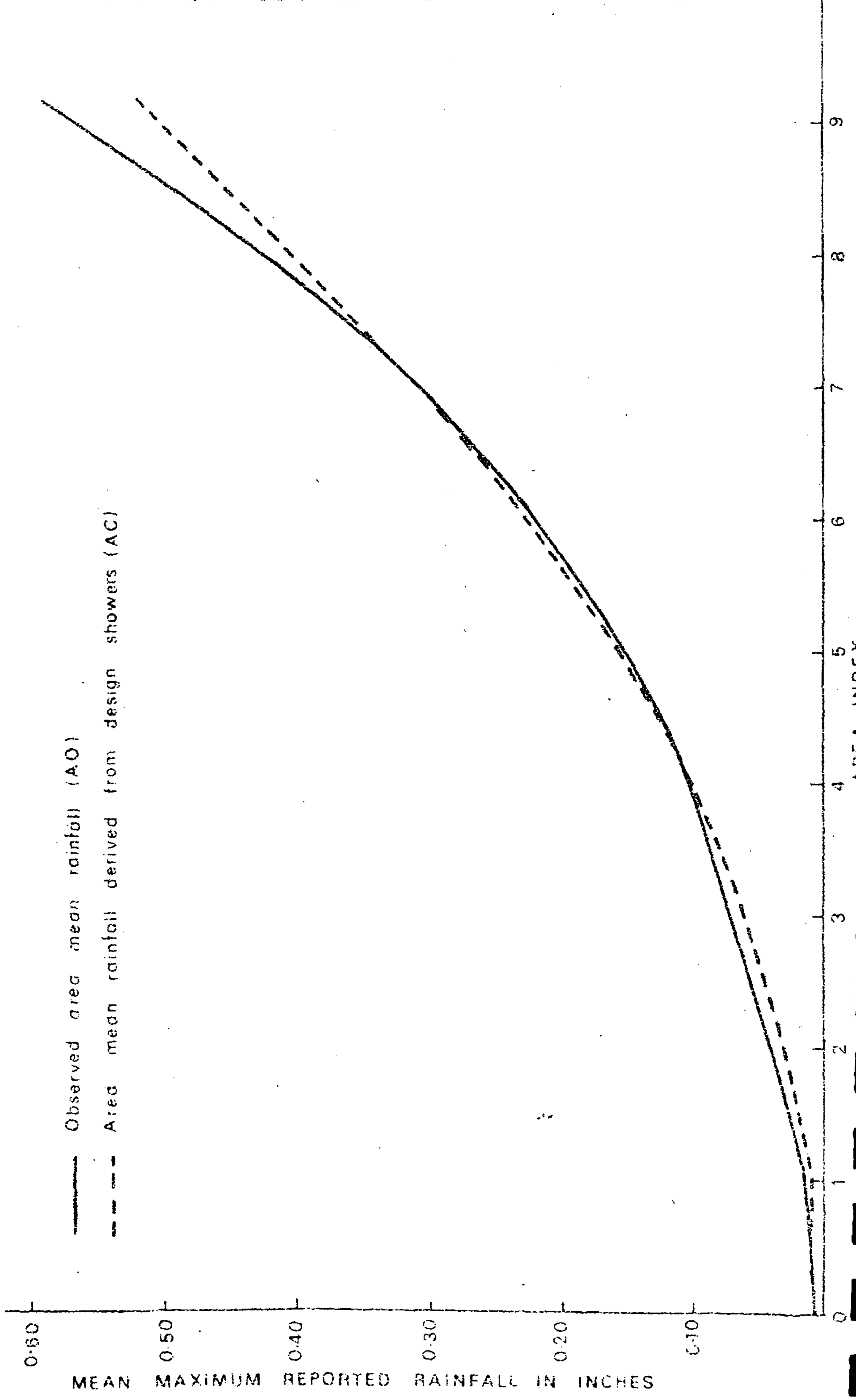
5 COMPARISON OF OBSERVED AREA MEAN RAINFALL WITH VALUES DERIVED FROM DESIGN SHOWERS



ASSESSMENT OF WATER RESOURCES UNDER CONDITIONS OF SCARCITY DATA

by

J. Bear
A. Issar
Y. Litwin

Balasha-Jalon Consultants & Engineers Ltd.,
Haifa, Israel.

INTRODUCTION

An evaluation of the available water resources is the first step in planning the development and management of water supply systems, whether on a small, local scale, or on a large, regional or national one. Estimates of these resources are needed both at the general planning phase, as well as for the design of specific elements of the system. Obviously, because we are dealing with a natural phenomenon - water as part of the hydrological cycle - we can aim at best, at estimates of long-term averages, expected values or probability distributions of the sought quantities. The development of procedures for predicting surface and ground water resources has been the goal of engineers for many years and several such procedures are described in the literature.

Different types of estimates are required for the two planning phases mentioned above. In the first the general planning phase, estimates are needed mainly of the long-term average annual ground water surface water yields. These are often expressed for each available source of water in the form of a safe yield, defined as the amount of water than can be withdrawn annually without producing undesired results, and limits of withdrawal which constitute constraints on the withdrawal based on present and future needs of downstream areas. For the design of specific hydraulic structures which constitute elements of the water supply systems, the data requred include such items as peak rates of flow, annual and monthly flows of specified frequency, etc.

There is no need to elaborate on the fact that the only source of information from which any estimates of the above planning and design parameters can be derived is actual observations of various elements of the hydrological cycles: precipitation, ground water elevations, spring discharge, surface runoff, etc. Because of the variability of these observed parameters, resulting from the random nature of the precipitations, which may be considered as the input to the hydrological cycle, it is the length of record which determines the accuracy of any evaluation of water resources. Whenever a record of basic data (e.g. streamflow for surface water and elevation for ground water) is of a sufficient length and is available at the point of interest, the required assessment of water resources is relatively simple and can be obtained by a number of known empirical, mathematical or statistical methods. Unfortunately, in practice, especially as far as surface water is concerned, it is only seldom that data are available at the point of interest and for a sufficiently long period. This is especially true in developing countries, where the observation network is rarefied. In such cases, the assessment of water resources for point of interest must be based on a regional approach.

In the regional approach, the hydrological behaviour of a watershed or a ground water basin as a whole is taken into account. Obviously, the first step in such an approach is the definition of the region whose regime is to be investigated. In ground water, it is an aquifer or a group of aquifers. In surface water it is a single watershed or a group of watersheds, which behave in a similar manner from the hydrological point of view. Tests are available for checking this homogeneity in a hydrological regime.

The more simple regional analysis procedures include the extension of streamflow records by comparing them with those of rainfall. Rainfall records are usually available for a much longer period of time, thus enabling interpolation between stations for which observed data are available, and establishing relationships between flow and watershed parameters.

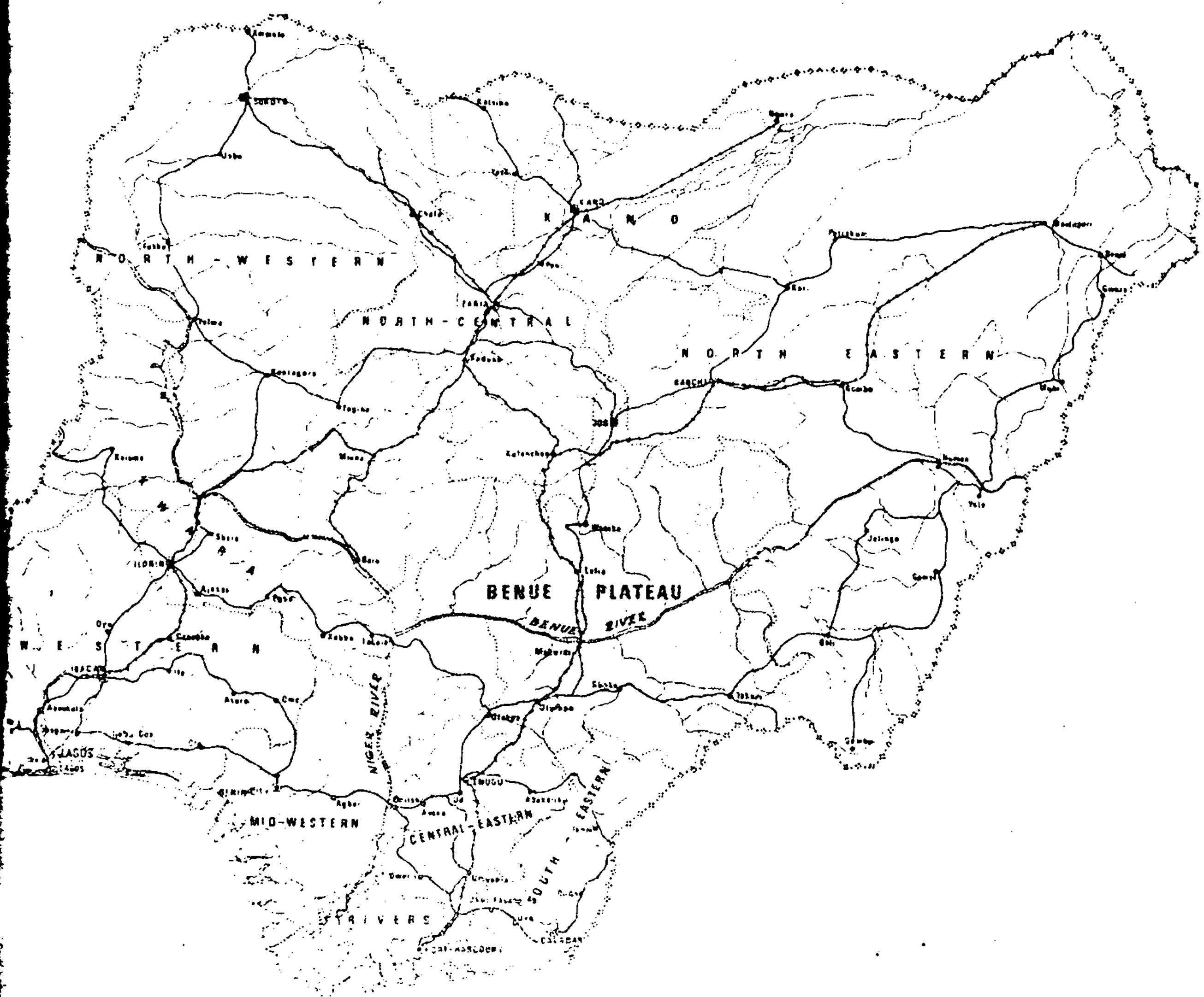
The problems and complexity of regional studies vary widely from one climatic region to the next. For example the problems encountered in humid areas differ considerably from those encountered in arid or semi-arid areas. The size of the considered region and its geographical and topographical conditions also greatly affect the selection of an appropriate regional study procedure. Moreover, because of the large variability in these and other conditions, it is practially impossible to develop a universally applicable procedure for evaluating water resources. There are, of course, certain basic principles which are common to all procedures, but beyond these principles, procedures are based on such local conditions as availability of data, homogeneity of region, etc.

The objective of the present paper is to review briefly several techniques commonly employed for the assessment of water resources and to outline a methodology developed in connection with two large-scale development projects carried out by Balasha-Jalon Consultants and Engineers Ltd. In both projects, an assessment of the water resources was required.

The two case histories to be discussed are the evaluation of the water resources of the Benue Plateau State (B.P.S.) of Nigeria as part of a Master Plan for Water Resources Development (Figure 1) and the evaluation of the water resources of the Jiroft Valley in Iran as part of the Jiroft Development Project (F. 2). In each of the two cases, both surface water and ground water have been considered.

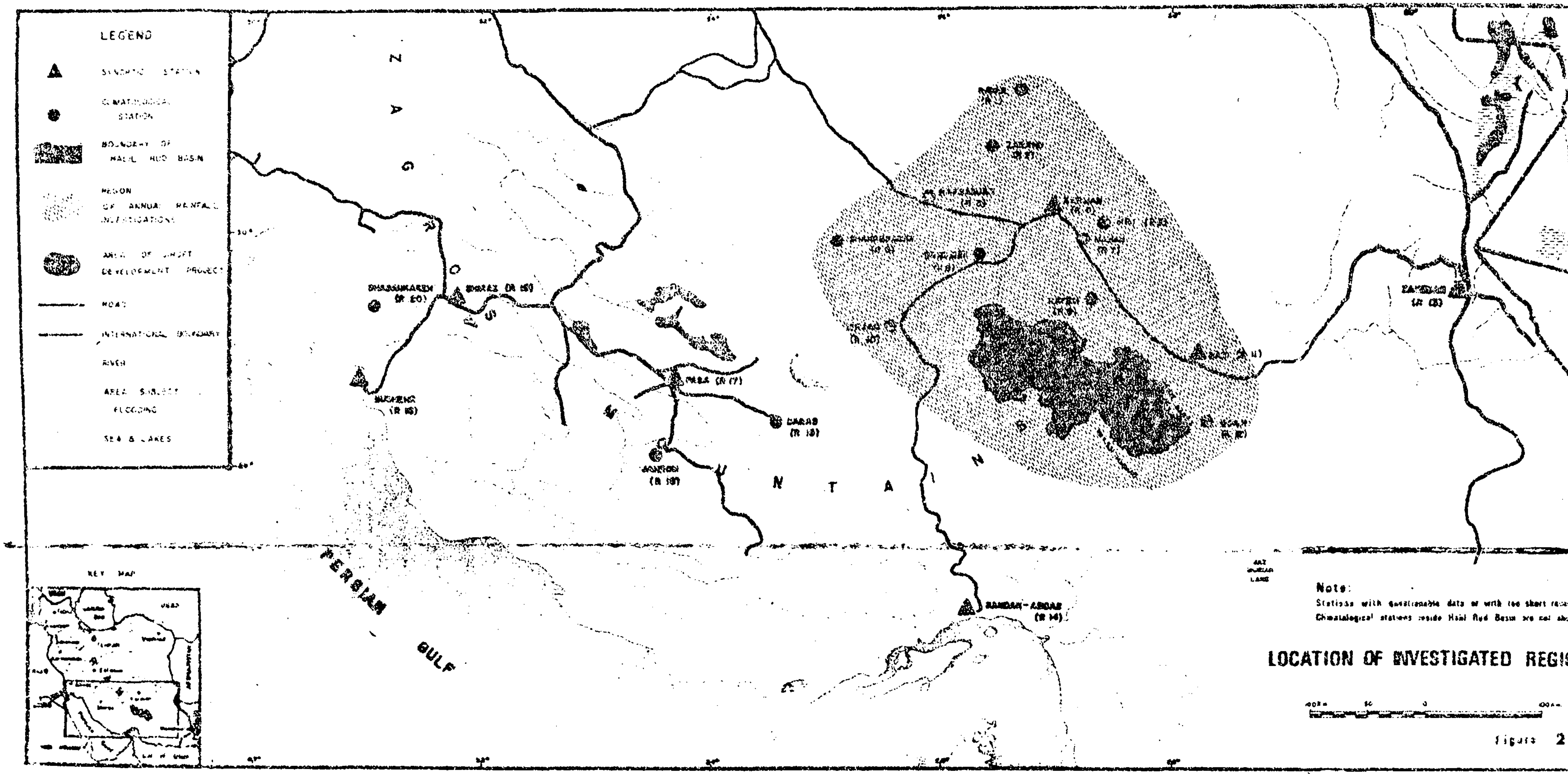
PROBLEMS ASSOCIATED WITH THE ASSESSMENT OF SURFACE WATER RESOURCES

The main feature of surface runoff is its variability which is composed of both deterministic elements (e.g. seasonal changes) and random ones which can be described by probabilistic methods.



LOCATION MAP

DERAL REPUBLIC OF NIGERIA BENUE PLATEAU STATE Figure .1



LOCATION OF INVESTIGATED REGI

Figure 2

In view of the stochastic nature of surface runoff, three major problems of assessment may be distinguished:- (a) determination of the frequency distribution of the various parameters characterizing the flow (e.g. annual flow, peak discharge), (b) analysis of flow fluctuations (e.g. seasonal fluctuations, occurance of wet or dry sequences and serial correlations), and (c) analysis of the continuous flow changes in time. Whenever a record of sufficient length (approximately equal to the design period) is available at a site of interest, the assessment of surface flow is based directly on an analysis of the available record. When the area of interest consists of a number of secondary watersheds, with records available only at a small number of gauging stations located in only part of these watersheds, correlations are established between the flow paramters (e.g. annual flow, or annual peak dischage) and watershed (measurable) factors such as area, shape, size, elevation, etc.

In practice, especially in developing countries, the density of gauging stations is low and the records are of a short duration. In many cases, although the total length of record seems to be of a sufficient duration, gaps and discontinuities exist in the record and in some cases the station underwent continuous changes and shifts so that the value of the record is questionable.

In order to overcome some of the difficulties mentioned above, methods have been developed for combining records of individual stations in a region. Several problems are encountered in applying the regional analysis method:

(a) Scarcity of data (streamflow, rainfall etc.) due to both small number of observation stations and infrequent observations.

(b) The large fluctuations in hydrological and climatological data. These increase with the size of the watershed and are especially high in mountainous areas in arid and semi-arid climates.

(c) Inhomogeneity in watershed parameters (e.g. topography, shape, slope, vegetation, etc.) as the considered region becomes larger.

A criterion for the success of a regional method is the possibility of assessing the accuracy of its results, using statistical methods. However, in many cases, it is difficult to carry out this assessment (e.g. in the form of confidence limits) because of the small number of actually observed data which are available.

Some of the methods employed by engineers for the assessment of surface water resources are rather simple, especially those based on a single parameter. Others, which are based on multi-parameter models of watershed behavior are complicated. Obviously, there is no use in utilizing sophisticated models for cases where only little data, and of poor quality (e.g. reliability) are available. The various methods may be classified either according to the type of required output (e.g. peak flows, monthly flows, annual flows, etc.), or acording to the type of input information which they required (e.g. runoff records, rainfall records, etc.).

METHODOLOGY OF EVALUATING SURFACE WATER RESOURCES UNDER CONDITIONS OF SCARCITY DATA

Most methods mentioned above are based on data on streamflow and rainfall available at the site of interest. In preparing the Master Plan for Water Resources Development in the Benue Plateau State it was required to evaluate the water resources of the State (area of 38,000 sq. miles) as a whole for the purpose of planning the development of rural and urban water supplies as well as irrigation projects (Fig. 1). The planners in this case needed data on available water resources not at a specific location, but rather for all watersheds in the State. The results of the investigations had to be presented accordingly. Because no specific project was considered, the results included various types of information, from mean annual flows through a frequency distribution of the flow in the thirty driest days of an average year. In the Jiroft Valley, on the other hand, the planners needed information on water resources in connection with a specific project covering a specific watershed (Fig. 2).

In both cases, the amount of measured data was insufficient and methods had to be devised for producing synthetic streamflow data from rainfall data which were available in larger quantities. Accordingly, the analyses in both cases consisted of two steps:

(a) Collection and processing of available data and supplementing records by synthetic data derived by specially developed generation models in order to arrive, as far as possible, at records of a uniform character. In the B.P.S. the record thus obtained covered a period of 20 years, whereas in the Jiroft Valley it covered a period of 50 years.

(b) Analysis of the surface runoff records obtained in the first step in order to arrive at the information requested by the planners in each case.

Figure 3 summarized the methodology of the investigations of surface hydrology of the Benue Plateau State. A similar sequence of investigations was developed for the Jiroft Valley project (Fig. 4). Four common basic phases can be distinguished in both cases:

A. Preliminary analysis of available rainfall and streamflow data.

B. Supplementing incomplete rainfall and streamflow records.

C. Producing of synthetic streamflow and rainfall data.

D. Deriving the required planning and design data by analyzing the available records, and presentation of the results.

Following is an elaboration of each of these phases.

A. As a first step, the investigated region was defined and tested for homogeneity (1),(2). Essentially, the homogeneity tests determine whether recorded observations in a group of stations differ from each other by amounts which cannot reasonably be attributed to chance. The analysis of data was then carried out for

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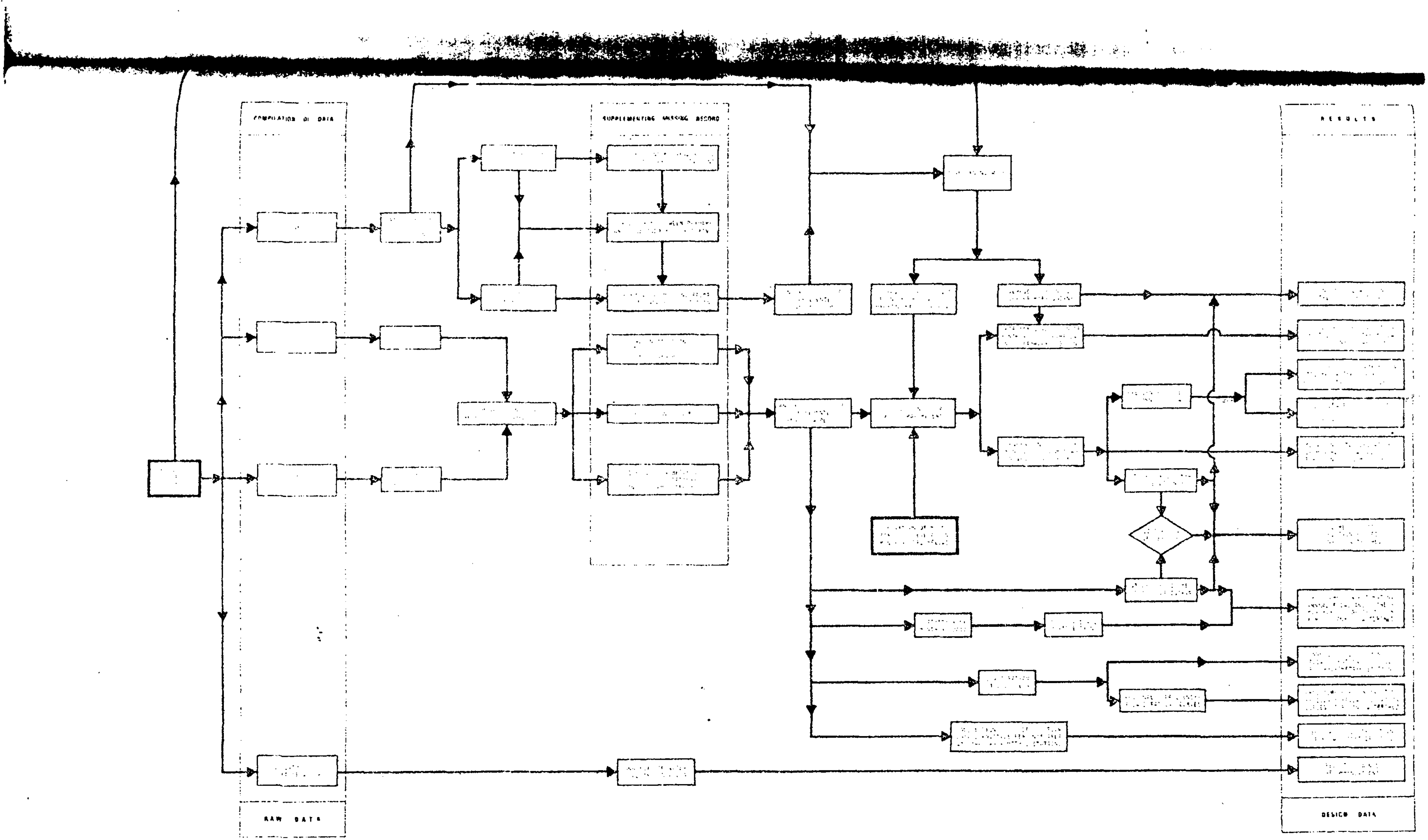
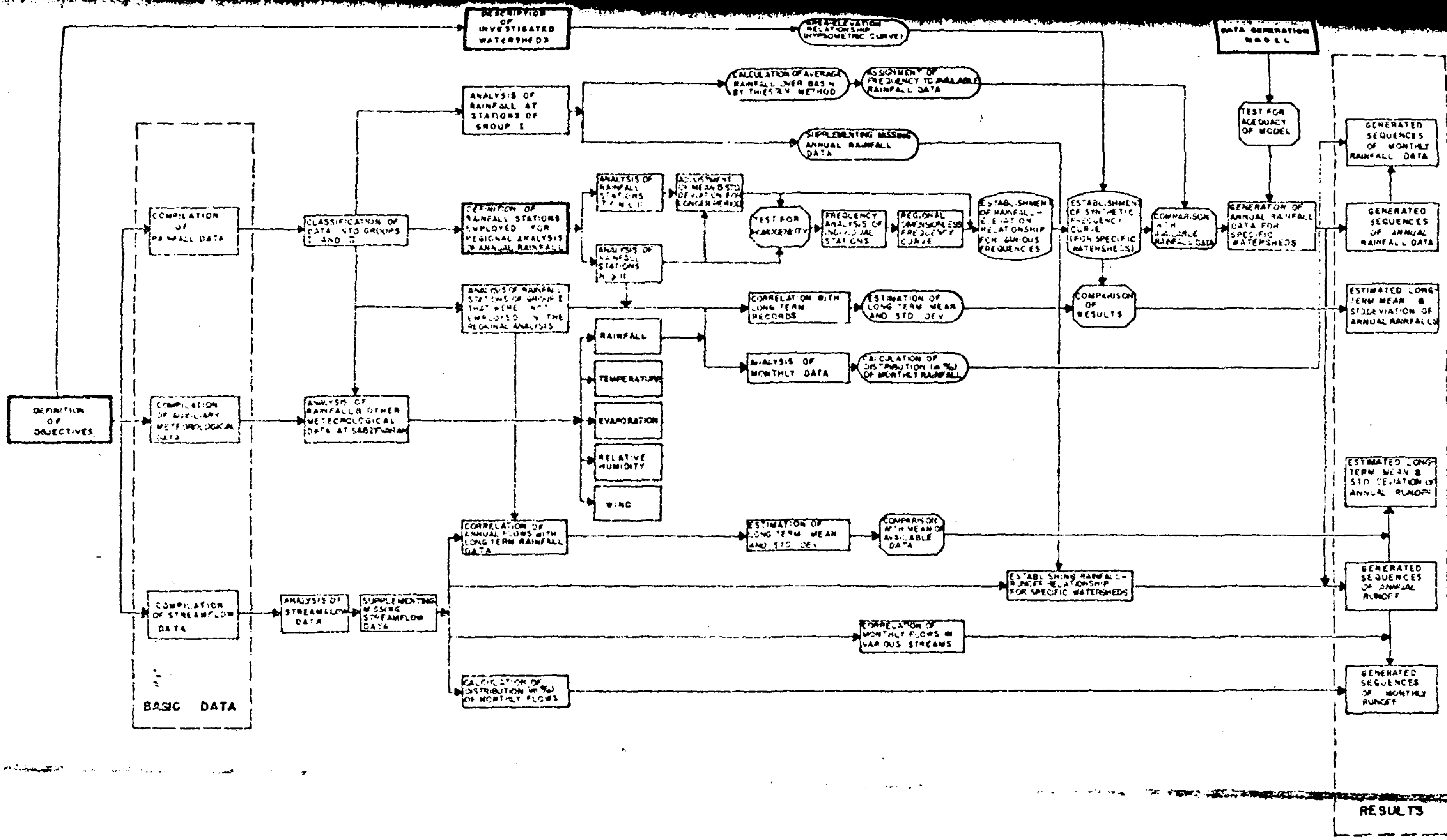


BENUE PLATEAU STATE SURFACE HYDROLOGY – METHODOLOGY OF INVESTIGATIONS

Figure 3



METHODOLOGY OF INVESTIGATIONS

Figure 4

homogeneous regions only. The watersheds comprising of the homogeneous investigated region, or regions, were also defined and their physical characteristics studied. Figure 5 shows the availability of rainfall data for the Halil Rud Basin in the Jiroft Valley.

B. Because of the general scarcity of data, an effort was made to complete the records in which data were missing for certain periods (from days to months), so that they could be incorporated in the analysis. Various methods are available for supplementing such data, depending on the intended use of the considered records, and the type of data contained in them. For the B.P.S., the objective was to obtain continuous records of monthly rainfalls at stations where a relatively small number of months was missing in each record.

When at least two rainfall measurements were available for the considered year the rainfall in any missing month was assumed to be a product of the long-term average for that month and a coefficient (C_R) calculated separately for the rainy season (in the case of B.P.S. six months from May to October) and for the dry season (during the remaining months of the year). In each season:

$$\text{for } 1 < k < 5 \qquad C_R = \frac{1}{k} \sum_{j=1}^{k} R_j/\bar{R}_j \qquad (1)$$

$$\text{for } k = 0 \qquad C_R = 1$$

Where: C_R = seasonal coefficient (there are two such coefficients for each year with R=1 or R=2 for the dry or the rainy season, respectively.

k = number of moths with available record in a season (k = 0,1,2,3,4,5)

R_j = rainfall during the jth month

$\bar{R}_j$ = mean rainfall in the jth month.

Because too large sampling errors were obtained by using C_R when only a small number of monthly rainfalls was available for a particular year, the coefficient C_R was replaced by an adjusted coefficient C'_R which takes into account the number of months within the season for which data were available:

$$C'_R = 1 + (C_R - 1) \,.k/5 \qquad (2)$$

By combining (1) and (2), the following expression was obtained:

$$C'_R = \frac{5-k}{5} + \frac{1}{5} \sum_{1}^{k} R_j/\bar{R}_j \qquad (3)$$

It should be noted that for $k = 0$, $C'_R = 1$ and

for $k = 5$, $C'_R = C_R$

The synthetic monthly rainfall (R^*_j) in any missing month was therefore calculated by:

$$R^*_j = C'_R \cdot \bar{R}_j \qquad (4)$$

Monthly rainfall data supplemented according to Eq. (4) proved to fit measured rainfall data rather well.

In the Jifoft Valley, the length of rainfall record differed from one station to the next. In this case, a procedure was developed, on the basis of 44 years of record, for adjusting means and standard deviations according to some common basic period. The adjustment of means was based on a simple proportion between means of corresponding years at stations which differ in length of measured record, but which belong to a hydrologically homogeneous region. The adjusted standard deviation was calculated from the adjusted mean using the coefficient of variation (C_v) which was assumed to be independent of the length of record. This procedure may be illustrated by the following example.

Let Station A have N years of rainfall record with a mean $\bar{R}_{AN}$ and a standard deviation σ_{AN}, both parameters calculated for the period of N years, and Station B has M years of record with a mean $\bar{R}_{BM}$ and a standard deviation σ_{BM}. Assuming that $M > N$, the adjustment for a longer period of the first two moments of rainfall data for Station A is done as follows:

(i) For the mean

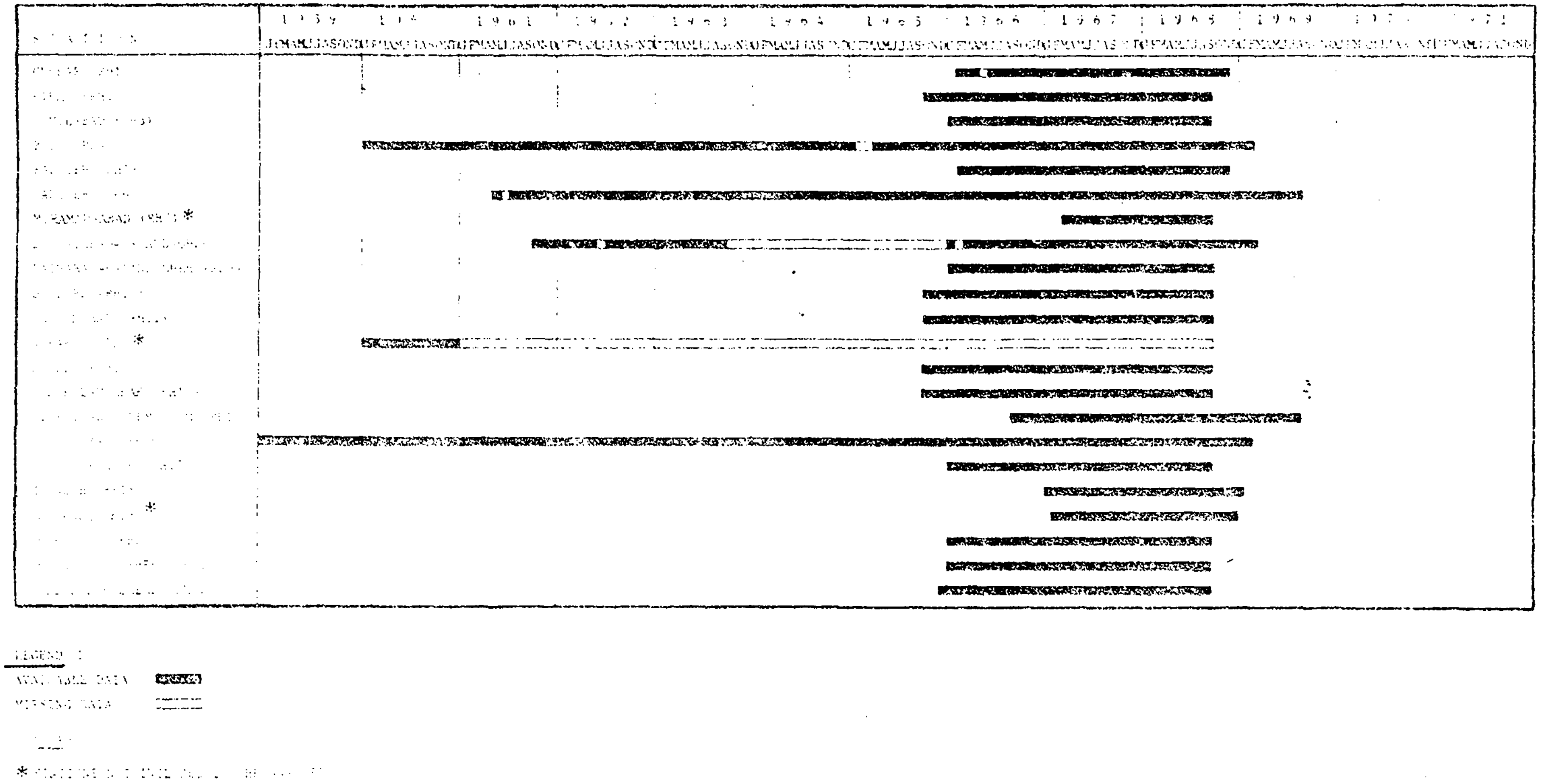
$$\frac{\bar{R}_{AM}}{\bar{R}_{BM}} = \frac{\bar{R}_{AN}}{\bar{R}_{BN}} \quad \text{or:} \quad \bar{R}_{AM} = \bar{R}_{AN} \frac{\bar{R}_{BM}}{\bar{R}_{BN}} \qquad (5)$$

(ii) For the standard deviation

$$C_v = \frac{\sigma_{AN}}{\bar{R}_{AN}} = \frac{AM}{\bar{R}_{AM}} ; \quad C_{vM} = C_{vN} = C_v \qquad (6)$$

Hence:

$$\sigma_{AM} = \frac{\bar{R}_{AM}}{\bar{R}_{AN}} \sigma_{AN} \qquad (7)$$



AVAILABLE RAINFALL DATA IN HALIL RUD BASIN ~~(Group I)~~

Figure 5

Several additional methods were developed for supplementing missing streamflow records:

(1) Reconstruction of hydrographs

This method was employed when observations of water stages in a stream were interupted for a few days only. In such cases the hydrograph was first drawn for all time intervals for which data on streamflow were available. Then the hydrographs were extended to cover also the periods for which no data were available. Finally estimates of the missing streamflow values were read directly from the curves.

(2) Streamflow recession at the end of the rainy season

Whenever the period for which data were missing lasted not more than several months, and occurred during the dry season or at the end of the rainy season, continuing into the dry season, the flow recession curve was employed for supplementing the incomplete record. From the preliminary analyses of hydrographs of streams for which streamflow data were available and the pattern of rainfall distribution during the year, it was concluded that for the dry period, lasting in the Benue Plateau State from November - December to March-April, the entire streamflow is a baseflow withdrawn from storage in the adjacent aquifers. During this period the hydrograph takes the form of a recession curve described by:

$$Q_t = Q_o \exp\ (-\alpha t) \qquad (8)$$

Where:

Q_o - Streamflow at the beginning of the recession period

Q_t - Streamflow at time t

α - recession coefficient ($\alpha > 0$) which depends on watershed characteristics.

t - time

From Eq. (8) it follow that:

$$Q_t = Q_o \ (Q_T/Q_o)^{t/T} \qquad (9)$$

where:

Q_o - daily streamflow just prior to $t = o$

Q_T - daily streamflow just following $t = T$

Eq. (9) may be employed for supplementing missing data for a period of T days.

(3) Correlation of streamflows

In many cases two or more hydrometric stations are located several miles apart on the same stream. Usually the daily flows in two such stations are highly correlated, with an appropriate time lag. Such a correlation, when found, justified the supplementing of incomplete records at one station by using the measurements taken at another station on the same stream. This approach can easily be extended to a larger number of stations. For arid and semi-arid regions, it was found convenient to carry out the correlation analysis with respect to a dimensionless discharge variable X_i defined by:

$$X_i = \bar{Q}_i/Q_j \qquad (10)$$

where Q_i is the daily flow, i is an index running through the entire period of record and $\bar{Q}$ is the monthly average flow for the specific month to which Q_j belongs $(1 < j < 12)$. The variable x_i is a measure of the relative streamflow at the station only when a flow record is available; otherwise x_i is undefined.

The various methods of supplementing missing records described above have been repeatedly justified in the literature and shown to yield results which are accurate for all practical purposes. By employing these methods complete rainfall and streamflow records were made available for the analysis of surface runoff. One should recall that the alternative to the approach of supplementing missing records, is the immediate initiation of a data collection programme for several years at a larger number of streams. This will postpone the evaluation of surface water resources needed for the preparation of the project until more data become available.

In all cases, the actual computations were carried out by means of digital computers.

C. In the Benue Plateau State, even with all available streamflow records completed as described above, the number of years for which streamflow data are available is still insufficient for a reliable evaluation of the State's water resources as required for planning purposes. On the other hand, as in most other cases, rainfall records are available for much longer periods of time and at a larger number of gauging stations. These records can be utilized for the reconstruction of the historical streamflows at the existing hydrometric stations for the entire period for which rainfall records are available. The reconstructed records can then be used for the estimation of the mean and standard deviation of the historical flows and for a frequency analysis of streamflows at each station.

The transformation of rainfall into streamflow data is carried out by means of a generation model capable of producing a synthetic record with frequency characteristics similar, in the statistical sense, to those of the historical flows.

The following scheme describes the concept of this transformation:

Input (Rainfall) Watershed Transformation system output (streamflow)

The input consists of a sequence of average rainfalls over the considered watershed. The output has the form of a sequence of generated streamflows for the same period and the same watershed.

The watershed transformation system may be described by various mathematical or statistical models. In each case, the choice of model depends not only on the physical relationship between input and output, but also on the type of input data and intended use of the generated output data.

In the case of the Benue Plateau State, a general multi-linear regression model was employed. This model is descrbied by the following equation:

$$Q_{i+1} = \bar{Q}_{j+1} + \alpha(Q_j - Q_j) + \beta(R_i - \bar{R}_j)A^{(r)} + \gamma(R_{i+1} - \bar{R}_{j+1})A^{(r)} + v_{i+1}\,\varepsilon_{i+1} \qquad (11)$$

where Q_i and Q_{i+1} are the monthly streamflows (in volume units) during the i-th and (i+1) moths, respectively, counted from the beginning of the generated sequence; Q_j and Q_{j+1} are the mean monthly streamflows during the j-th and (j+1) months respectively, withing a repetitive annual cycle of 12 months; R_i and R_{i+1} are the monthly rainfalls (in depth units) during the i-th and (i+1) months respectively, counted from the beginning of the generated sequence; R_j and R_{j+1} are the mean monthly rainfalls of the calendar month j and j+1 ($1 < j < 12$); is a multiple regression coefficient of Q_{i+1} on Q_1 when R_{j+1} are kept constant; β is a multiple regression coefficient of Q_{i+1} on R_1 when Q_i is kept constant; γ is a multiple regression coefficient of Q_{i+1} on R_{i+1} when Q_i and R_{j+1} are kept constant. v_{i+1} is a random number drawn from a normally distributed population; $A^{(r)}$ is the area of the r-th watershed; ε_{i+1} is an independent error term.

The model's details shown schematically in Figure 6. Comparison of measured and generated data for a 3 years period is shown in Fig. 7

The model as described above is based on the assumption that sufficient rainfall data is available. Quite often, rainfall records are also poor. Then it is necessary to generate them first and to use the generated rainfall data as input for producing sequences of synthetic streamflows. (Fig. 8).

From the streamflow records, both measured and synthetic, general estimates of streamflow parameters (flow duration curves, frequency of occurence of annual runoff, etc.) can be derived for planning purposes. Because data are generally available for a small number of watersheds, the regional approach was employed for each of the above streamflow parameters. For example, to obtain a regional frequency curve of annual runoff, frequency curves are first developed for each hydrometric station. Then these curves are transformed into a dimensionless for (=ratio of annual runoff to its long-term mean)

By comparing dimensionless frequency curves of stations belonging to the same region (defined by using a homogeneity test) a regional frequency curve is obtained. Figure 9 shows an example of such curve obtained for a certain region of the Benue Plateau State.

In order to estimate the annual flow in various streams, a vo volume-area relationship can be established for an investigated region which includes watersheds of various sizes. The assumed relationship has the form:

$$\bar{V} = CA^n \qquad (12)$$

where:

$\bar{V}$ - mean annual flow volume

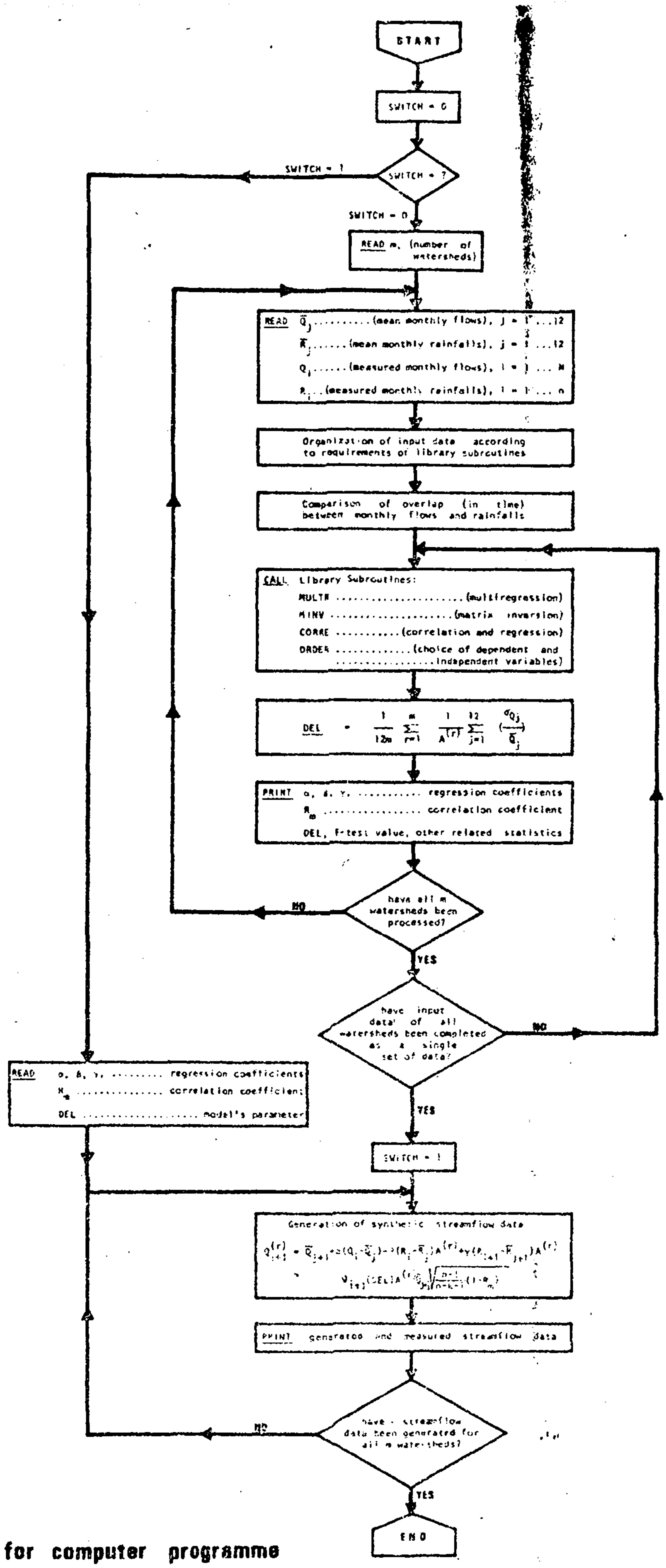
C, n coefficients

A - area of watershed

Figure 10 shows the volume-area relationship obtained for the Benue Plateau State)(excluding the hydrometric stations on the Benue River itself). The high computed correlation coefficient ($r = 0.97$) indicates a rather high reliability of this relationship. Whenever a frequency of occurrence of a given volume is required, it can be obtained by using the regional streamflow frequency curve and the volue-area relationship simultaneously.

In addition, flow duration curves and monthly distribution of flows were prepared for the planning of water resources in the State.

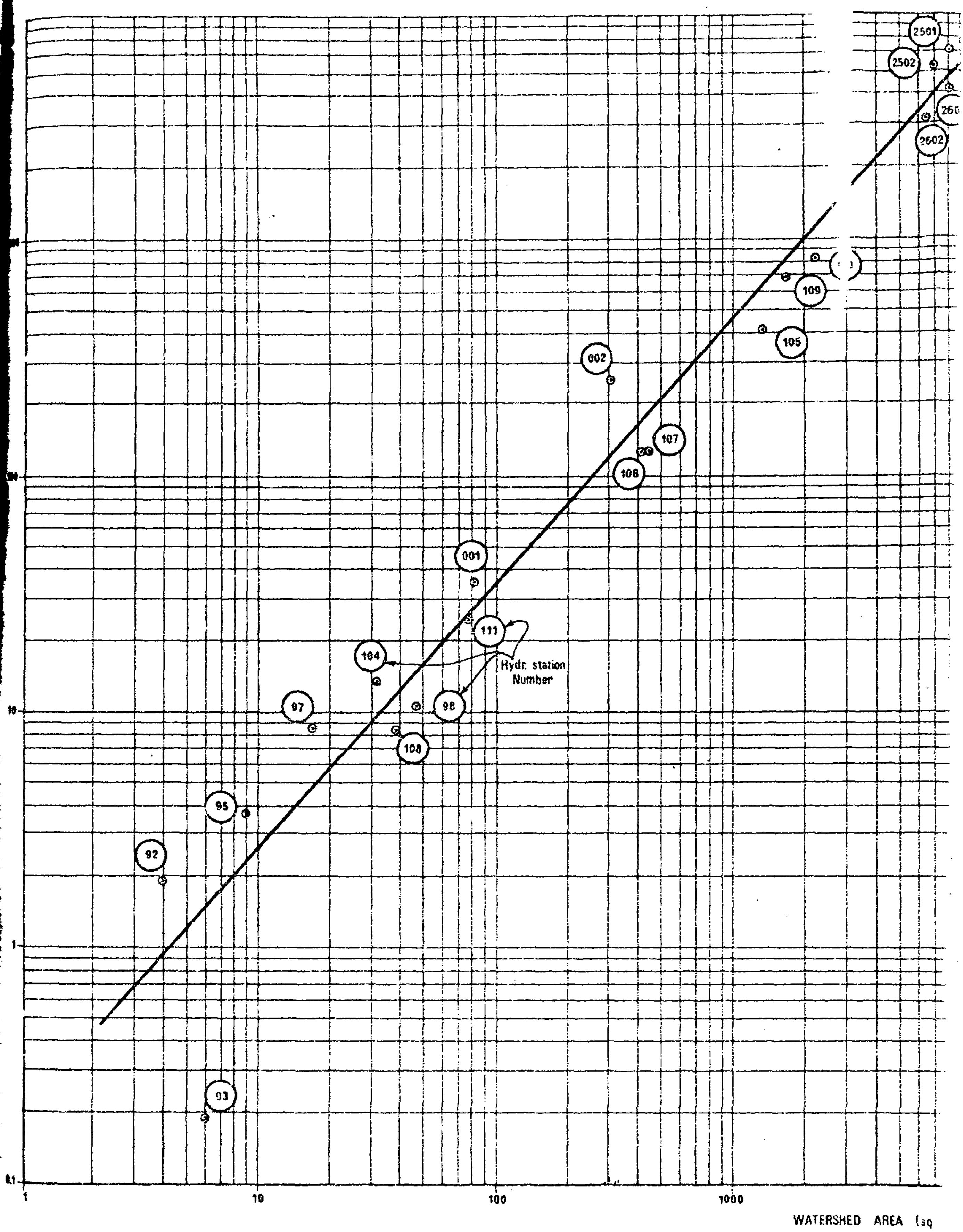
In the Jiroft Valley Project, also because of scarcity of measured data on surface runoff synthetic streamflows were obtained by using rainfall data collected in the surrounding area. These are available for much longer periods of record. The compiled data were tested for regional homogeneity. The rainfall stations which passed the test were included in the regional analysis of annual rainfalls. This analysis, is characterized by an effort to utilize the maximum amount of data available in the region of which the investigated Basin is a part. Data from stations included in this analysis were used for deriving annual rainfall-elevation relationships for various frequencies of annual rainfall. By combining the hypsometric distribution with the obtained rainfall-elevation relationships, areal averages of annual rainfalls for specific frequencies over any basin inside the investigated region were derived. Employing the method of regional analysis, these averages were used for establishing several frequency curves of annual rainfall for various watersheds within the studied basin.



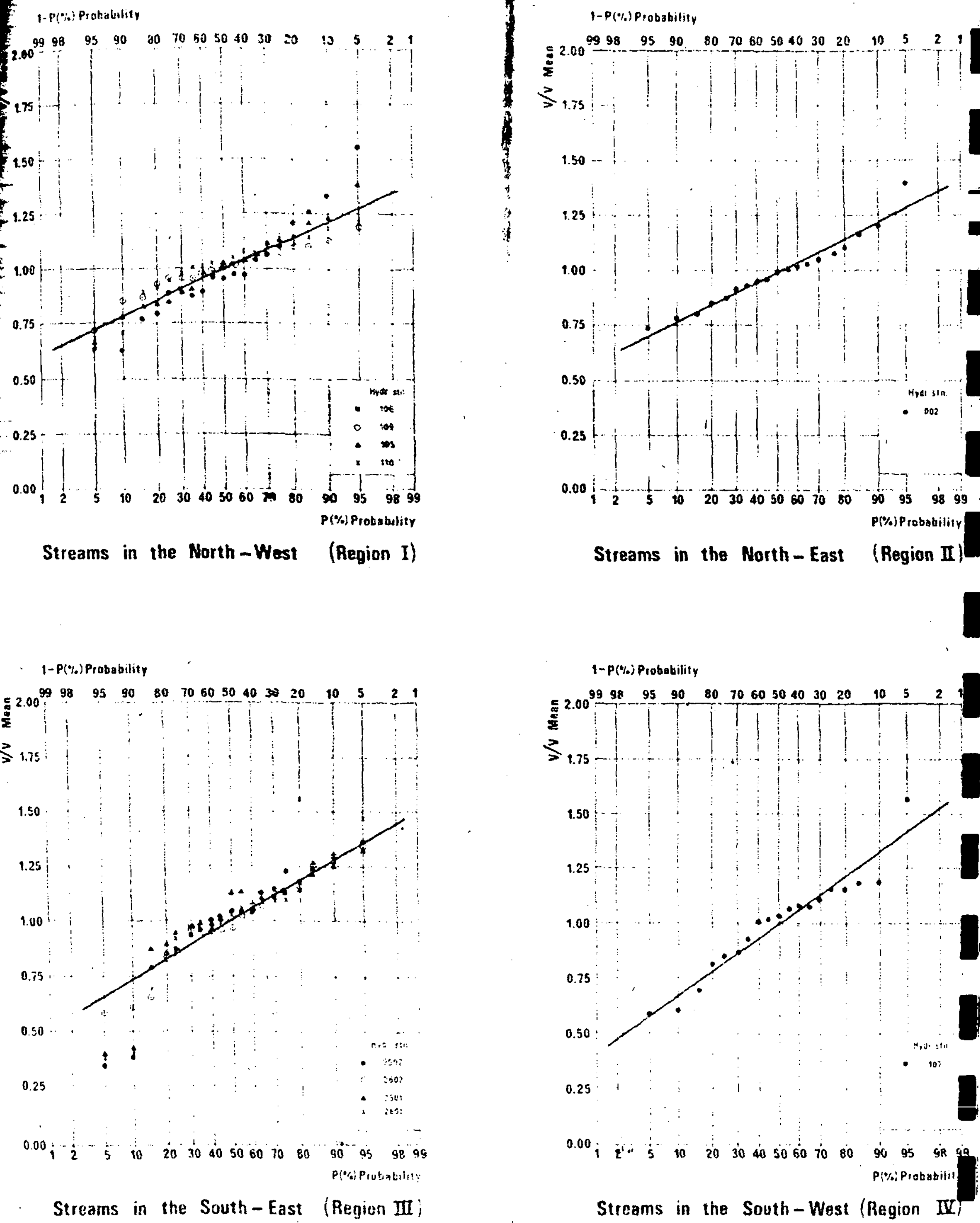
Flow chart for computer programme

GENERATION OF STREAMFLOW FROM RAINFALL DATA

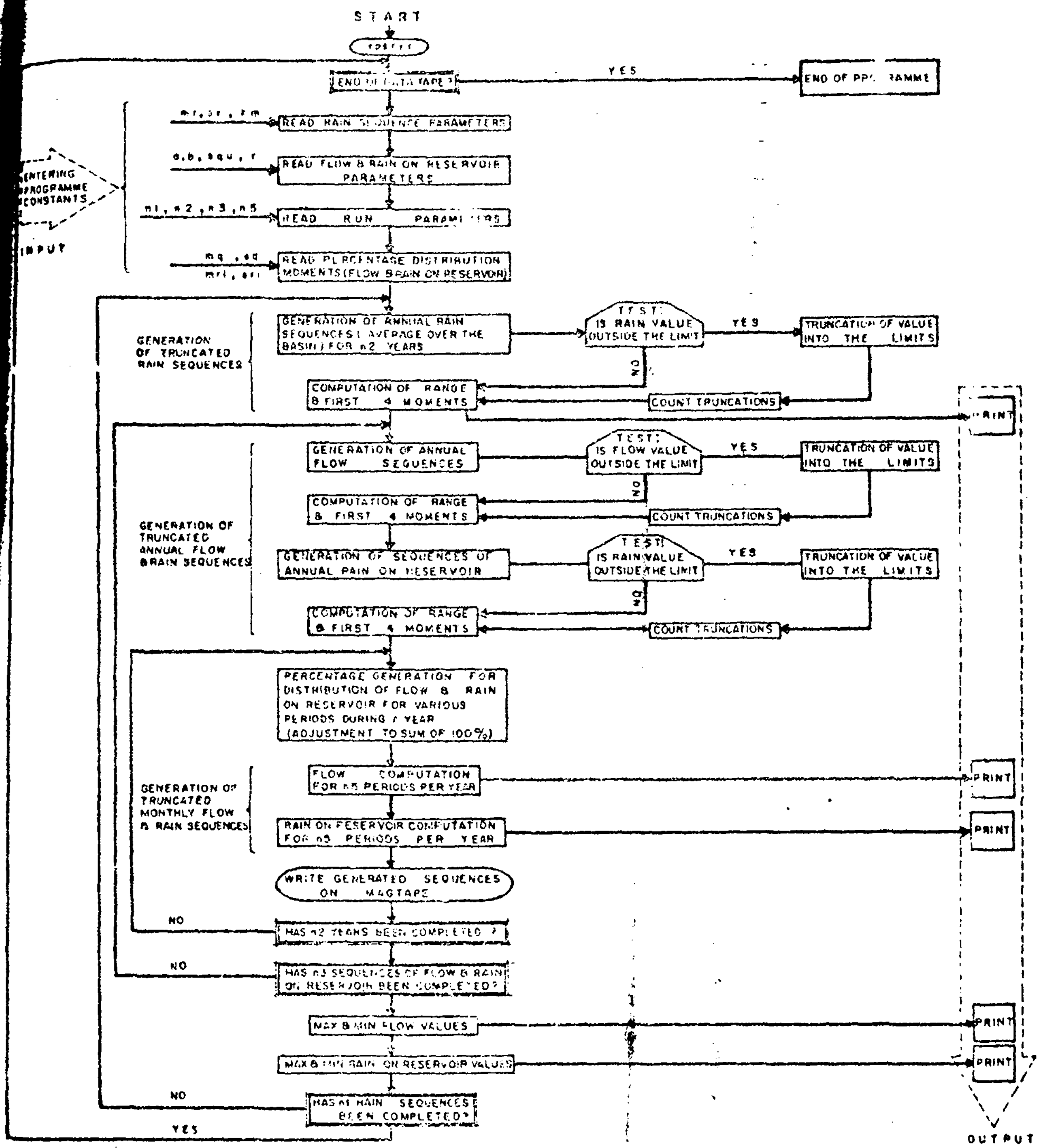
Figure 6



VOLUME – AREA RELATIONSHIP – Benue Plateau State **Figure**



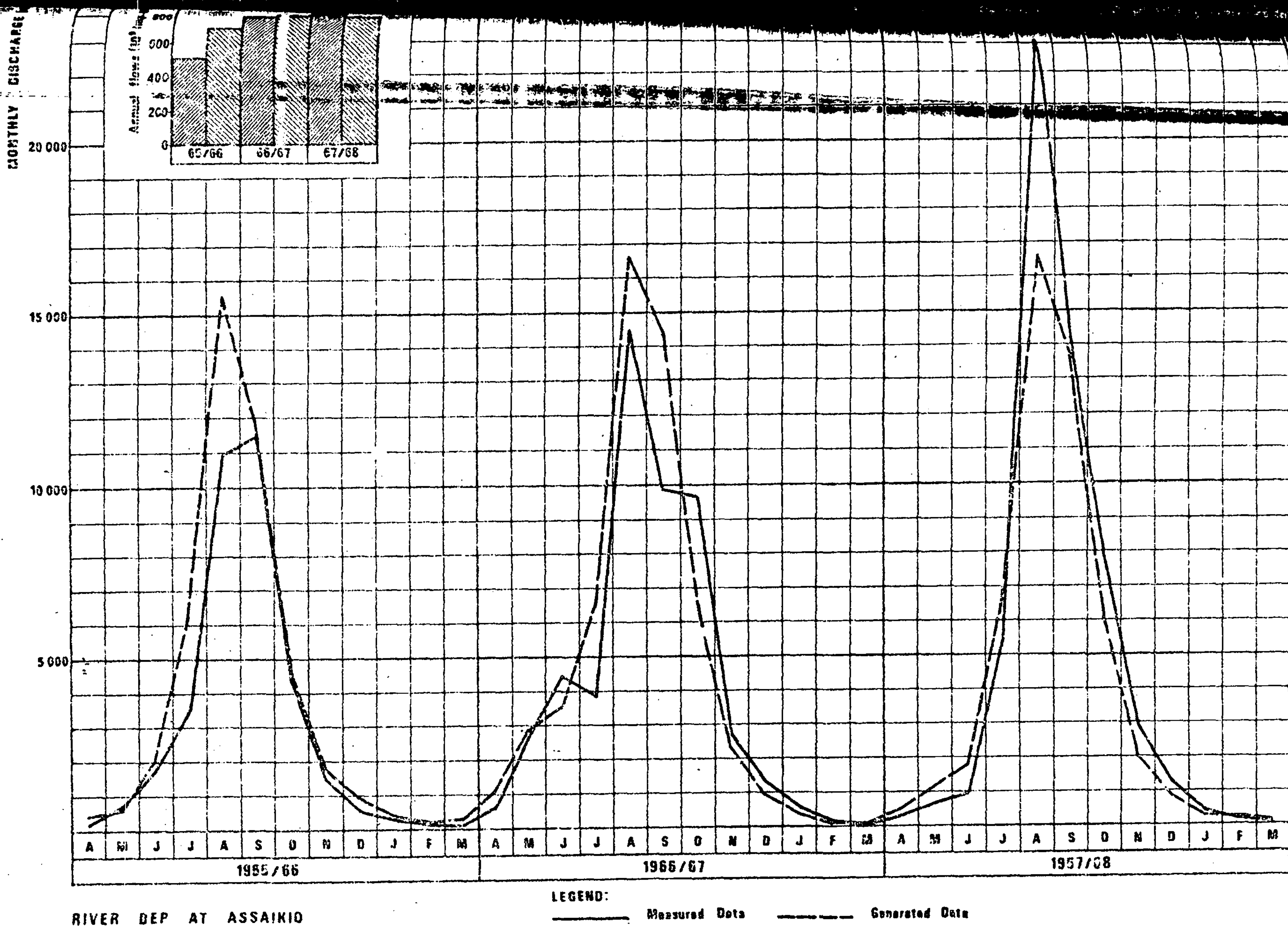
REGIONAL STREAMFLOW - FREQUENCY CURVES Figure 9



GENERATION OF RAINFALL & STREAMFLOW SEQUENCES

FLOW CHART FOR COMPUTER PROGRAMME

Figure 8



RIVER DEP AT ASSAIKIO

COMPARISON OF MEASURED AND GENERATED MONTHLY AND ANNUAL FLOWS

Figure 7

After verifying the results by comparing them with short term records measured inside the watersheds of interest, the basic input parameters, 50-years sequences of annual rainfall were generated for each of these two watersheds. These sequences then served as input for additional models by means of which sequences of equal length of synthetic annual and monthly streamflows were generated. Essentially these models were based on the relationship between the average annual rainfall over the entire watershed and streamflow, determined on the basis of a record of approximately 10 years. In a similar way synthetic sequences of monthly rainfalls and streamflows were also generated. These were later used for planning water resources projects in the Jiroft Valley.

As emphasized in the introduction, because of the large fluctuations in streamflows (especially in arid and semi-arid regions), the available water resources cannot be expressed as a single figure. The type of information needed as an assessment of surface water resources depends on the type of the project under consideration and its stage of planning and design. Several methods were described above for obtaining the various types of information under conditions of scarcity of data.

ASSESSMENT OF GROUNDWATER RESOURCES

Whenever available, ground water is a most attractive source of water which has a number of advantages over surface water. For example because of the usually large volume of water available in storage in the aquifer at any instant, this source is more reliable and less subject to fluctuations which depnd on climatic conditions.

It is also a source which is less susceptible to polution. Whenever both surface water and ground water are available, their conjunctive use is usually recommended. The decision in each case however, is based on local conditions.

Unfortunately, unlike surface water whose presence is easily determined and one has only to evaluate its quantities, the utilization of ground water requires first an exploration phase in which the presence of aquifers and ground water basins has to be determined. Once these sources of water have been located, the quantities available for exploitation have to be determined. Accordingly, scarcity of data in this case means scarcity of data for both stages.

When ample data are available, ie.e. when the aquifer if well defined, its hydrological properties (hydraulic conductivity, transmissivity and storativity) known, and records on water level elevations are available at a large number of observation wells and for a sufficient length of time to yield a reliable statistical averages, the available quantities of water can be estimated from the water balances prepared for an investigated aquifer. These water balances, based on Darcy's law take on the form:

$$\Delta t\left(\sum_{i=1}^{m} B_i T_i J_i + N + G + P\right) = \bar{S}\ A\ \Delta h \qquad (13)$$

where:

A - Area of investigated region

$\bar{S}$ - Average storativity of investigated region

Δh - average rise in water level over A during period of balance t.

N - natural replenishment over A

P - pumpage in A.

G - return flow in A

B_i - length of i-th segment of boundary of investigated region.

T_i - transmissivity along B_i

J_i - hydraulic gradient normal to B_i

Obviously this quantitative evaluation of available ground water resources cannot be carried out in the first stages of a regional development. Because of the large investments involved in the exploration phase, especially in drilled wells, an approach is recommended which combines exploration with the actual development of a region of interest. According to this approach the hydroeological investigations of a region in which little or no data are available consist of four stages:

Stage 1. Reconnaisance:

The purpose of this stage is to find out whether ground water basins or aquifers exist at all in the investigated region and whether the area may be regarded as generally rich or poor in ground water.

In order to answer these questions, the general hydroeological model of the region has to be established. This model is composed of the following components: climate, geology, morphology and surface water in the region.

The climate component can be established even on the basis of rather scarce meteorological data, or with supplementary observation from the vegetation and information gathered from inhabitants. When even this is not available, information can be obtained from comparison with other regions of the world with similar geographical conditions.

The geological component has to be based on a stratigraphical and structural analysis of the region. In the stratigraphical study the geological section is divided into hydrostratigraphical units, i.e. into aquifers, aquitards and aquicludes. The thickness, The activities during this stage are similar to those undertaken during the second stage, except that as more data become available, the obtained results become more accurate. A new feature in the analyses carried out during this stage is the time factor. Additional and improved water balances can be prepared and spring discharge fluctuations can be analyzed.

Stage 4. Accurate hydrological balance stage;

In this stage, more advanced methods of investigation, exploration and evaluation are applied in order to arrive at a higher degree of accuracy in the estimation of the ground water development potential. In this advanced stage possibilities of utilization of one time reserve as well as artificial recharge, conjunctive use techniques and detailed mangement programmes are also studied.

Data during this fourth stage is obtained from the actual operation of the project. The emphasis in this stage is on improved management procedures and on efforts to reach optimal utilization. During this stage, ample data is already available on the aquifers and a mathematical model of it is usually established for the purpose of determining its optimal yield.

In the Jiroft Valley Project, Stages 1 and 2 have been completed by now and a large number of wells are already in operation. These wells served first as exploration wells which supplied information on the quifer, and then were equipped as pumping wells. Pumping tests in these wells provided information on aquifer parameters. Water levels measure in these were used for drawing contour maps, which were in turn used for establishing a prelimiary water balance of the aquifer.

The project is now at its third stage of refining the information on available ground water. Plans are also being prepared for conjunctive use of surface and ground water resources based on the evaluation of surface water resources described in the previous section.

In general, actual development may start following the second stage. As the development continues, more observations of water levels (in time and space) become available and the assessment of water resources can be refined and up-dated continuously.

The various methods described above for supplementing missing data, preparation of synthetic sequences of natural replenishment, etc., can also be applied in the assessment of ground water resources.

The methods described above for the assessment of water resources under conditions of scarcity data, are by no means the only ones or the best ones. They were presented here as an example of how relatively simple methods can be employed in order to overcome the barrier of lack of data, both at the preliminary stages of planning the development of water resources and at the more advanced phases of detailed design of projects.

SHALLOW ARTIFICIAL RECHARGE OF GROUND WATER

By

Elfatih Ahmed Hasan

Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Albert

1. INTRODUCTION

Water trapped beneath the surface of the earth occurs in two zones which are separated by the water table. The water table exists only in water-bearing formations which contain openings of sufficient size to permit appreciable movement of water. The water table is generally considered to be the lower surface of the zone of aeration and the upper boundary of the zone of saturation, which extends down as far as there are interconnected openings. The zone of aeration is an unsaturated zone where voids are filled with water and air Ground water refers only to water within the zone of saturation or below the water table, where the soil is saturated.

Ground water stored within the zone of saturation is principally produced by rainfall on the surface of the earth that has gradually infiltrated down through porous soil strata or through cracks in rock formations and reached the zone of saturation. When and where the slow natural replenishment of ground water storage was in adequate, man has painstakingly tried and evolved many methods to artificially increase the quantity of water stored underground. The addition of water by man-evolved methods to ground water storage is called artificial recharge.

This paper discusses, with passing reference to East Africa, the different methods developed by man for shallow artificial underground storage or shallow artificial recharge of ground water.

2. Shallow Artificial Recharge.

The fundamental principle of shallow artificial recharge consists of first replacing the air within the zone of aeration by water. The zone of aeration is made up of a three-phase-system consisting of the solid matter (soil), water and air. The void spaces within the zone of aeration are filled with water and air.

Shallow artificial recharge is achieved only to the extent of filling the air spaces withint the zone of aeration by water that is, replacing the ground air by water. When the zone of aeration becomes saturated with water, additional surface water then seeps under the influence of gravity to the zone of saturation below the water table, where it is held in storage. Shallow artificial recharge is ideal at locations where the zone of aeration is permeable and readily transmits surface water to the zone of saturation where water is held in storage. If, at such locations, the water table is high (i.e. the zone of aeration is not deep) a better situation exists. The validity of shallow artificial recharge is determined by whether the infiltration rate through the zone of aeration is adequate and not depending on the geologic and soil formations of the location considered.

All shallow artificial recharge methods involve the spreading of water over the ground surface. The larger the wetted area over which water is allowed to spread and eventually seep through the zone of aeration into the zone of saturation, the better. The infiltration rate also increases with the length of time water is allowed to stand on the surface soil. Thus the time and area over which water is recharged influence the success or otherwise of shallow artificial recharge methods.

Shallow artificial recharge may be classified into five methods. It is outside the scope of this note to discuss the possible application to East Africa of every method in detail. This is because the topographic, geologic and soil conditions and other relevant factors and parameters vary from one country to the other in East Africa, and withing the same country from one location to the other. However, the particular experience in Sudan is referred to whenever it is relevant. Whether that particular experience can be effectively applied here in East Africa is left for the rural engineers to judge, each in his own jurisdiction and according to the conditions prevalent there.

2.1 <u>The Flooding Method</u>.

This method can be used in rural areas where the topography is flat or the land slopes are very gentle. It is particularly suitable in the basins and deltas of flashy streams that flow only for part of the year. The geologic and soil formations of such basins and deltas should, as a rule, be suitable to accommodate and permit the recharge of surface water in the zone of saturation. This method is mainly used to irrigate rural lands for the cultivation of quick-ripening crops that satisfy their water needs from water stored in the zone of saturation. It can also be used for rural water supplies. An advantage of this method is that recharged areas do not need to be elaborately prepared and the cost involved is minimal.

In this method, the recharged areas are first enclosed by low banks or small canals to effectively control the distribution of water throughout the flooding period. Regulators are also needed to regulate the release of water at suitable intervals over the upper reaches of the flooded areas. Practice in Sudan and elsewhere tells us that it is better to flood the recharged areas with a thin sheet of water and that this water should be made to flow at a minimum velocity so as not to disturb the soil.

In Sudan the flooding method is practiced to irrigate the deltas of the Gash river and the Baraka river in the Eastern Sudan and in the Abu Habl stream catchment in the Western Sudan. The practice followed in the river Gash catchment in Eastern Sudan will be discussed here as an example.

The Gash river is a flashy, erratic stream flowing from the Ethiopian highlands near Asmara.

The river is in flow for about three months, the bulk of the flood arriving between mid-July and early September. Flow is very Variable and flushes of 760 m^3 per second have been recorded. The average flood volume rarely exceeds half a milliard in any one year.

The Gash delta in Sudan covers roughly 300,000 hectared. The area effectively irrigated varies considerably according to the magnitude of the flood and may reach 30,000 hectares in a fairly good year, that is, 10 percent of the total available area.

Fig. 1 shows a plan of the Gash delta in Sudan below Kassala town. There are five head regulators which regulate the flow of the flood waters over the Gash delta. The opening in the head regulators, which are usually about five metres high, are controlled by means of stop logs which are inserted and withdrawn by hand - poerated steel hooks. The water from the river flows into main canals through these head regulators and from the canals/the plots by means of small water courses. The system of small water courses covers the whole delta. The crops grown in the Gash delta are millet and cotton which depend for their water supply on the water stored in the zone of saturation in the delta. /to

The flooding method in the Gash delta is also used for rural water supplies. A head regulator with a design capacity of 20 cumecs feeds a natural spills channel. The diverted water is used to replenish the natural underground sand reservoir at Gammam village. The well centre at Gammam village is not far from the Gash river, as shown on Fig. 1. Water is pumped from the Gammam well centre into overhead tanks for distribution by pipes to all parts of the delta. Water pumped from the well centre is of a far better quality than the contaminated silty water of the Gash river.

More important still is the fact that except during the rainy months of July, August and September when the Gash river is in flow, there is a severe shortage of water in the delta. Water artificially recharged into the Gammam aquifers during July, August and September, is the only source of water in the delta during the rest of the year. The system is designed to deliver 100,000 gallons of water per day, with scope for an additional 300,000 gallons per day.

The flooding method is used in the Gash delta both for irrigation and water supply purposes. The same method is successfully adopted in the Baraka river catchment and the Abu Habl stream catchment. The possibility of the adopting this method in East Africa, both for rural irrigation and rural water supplies, could be the subject of further studies.

2.2 The Basin Method

The basin method is used in rural areas where the recharged area lies alongside a surface stream. The geologic and soil formations of such recharge areas should be suitable for artificial recharge. The basin method is mainly used for rural irrigation Projects and rural water supply Projects. With this method is used, the land bordering the stream on (i) one, or both, banks is divided into basins by the contruction of longitudinal banks parallel to, and as near to the stream as they could safely be placed, and (ii) of cross banks joining longitudinal banks to from a network of inter-connected basins in series. The layout, size, and shape of these basins is dictated by the local topography in each particular case. Fig. 2 shows a typical system of recharge basins in series.

If needed a diversion structure is built across the main stream channel. Water is then admitted through on inflow canal into the upper basin. When the first basin is full, water overflows through an section into the second basin (at a lower elevation), and so on, until the entire system of basins is full. Water is then allowed to stand on the basins until percolation to the zone of saturation is complete. The remaining excess water can then be returned to the main stream channel through an outflow canal. The basins then is ready for cultivation. Water stored in the zone of saturation supports the plants throughout their growing phase.

The success of this method depends on the infiltration rate of the particular location considered. The method could be ruled out in silty and clay formations, where the infiltration rate is adversely low. Recharge rates of up to 9.6 feet per day had been observed in Santa Ana River, California.

Today the basin method stands out as the best method of artificial recharge on account of economy, ease of construction and supervision, and efficient use of space. Vast stretches of waste lands have been reclaimed by using this method in many countries of the world.

In Northern Sudan this method is extensively and successfully practiced in the Shendi and Dongola districts. The Shendi basins are a series of natural depressions near the banks of the Main Nile. Just before the peak of the annual Nile flood, water is admitted through a simple regulator into these basins, filling them to an average depth of two metres. It is held there for about 2 months and then returned to the river Nile after its level had fallen sufficiently. The following table gives the areas flooded in the Shendi basins in a fairly good year, in hectares.

Basin	Area flooded, in ha
Hugna	840
Hamid	3,800
Basabir	2,100
Salawa	3,000
Sayal	1,300
Guw	1,300
Taiy	3,000
Kelli	4,600
Kumeir	1,300

The total area flooded in a fairly good year is of the order of 20,000 hectares. The flooded area depends on the extent of the Nile flood and may vary from 4,00 hectares to 40,000 hectares depending on the floods. The crops grown are quick-maturing mainly, millet and chickpea because the basin method allows a single heavy watering during autumn with a single crop grown during the following winter.

The Dongola basins are similar to the Shendi basins, but the only ones of any importance are the Kerma basin and Letti basin. In a fairly good year they water 13,000 hectares and 3,000 hectares, respectively. In order to improve the watering of the Kerma basin and to augment the artificial recharge of groundwater a system of 16 inch tube-wells were drilled covering the Kerma basin. The results were immediately felt. The volume of water recharged underground in the zone of saturation increased appreciably to the extent that a second crop was grown after the first was harvested. Peasants in the Shendi and Dongola basins draw their water supplies from wells which are recharged by the annual flood waters of the Nile when admitted into these basins.

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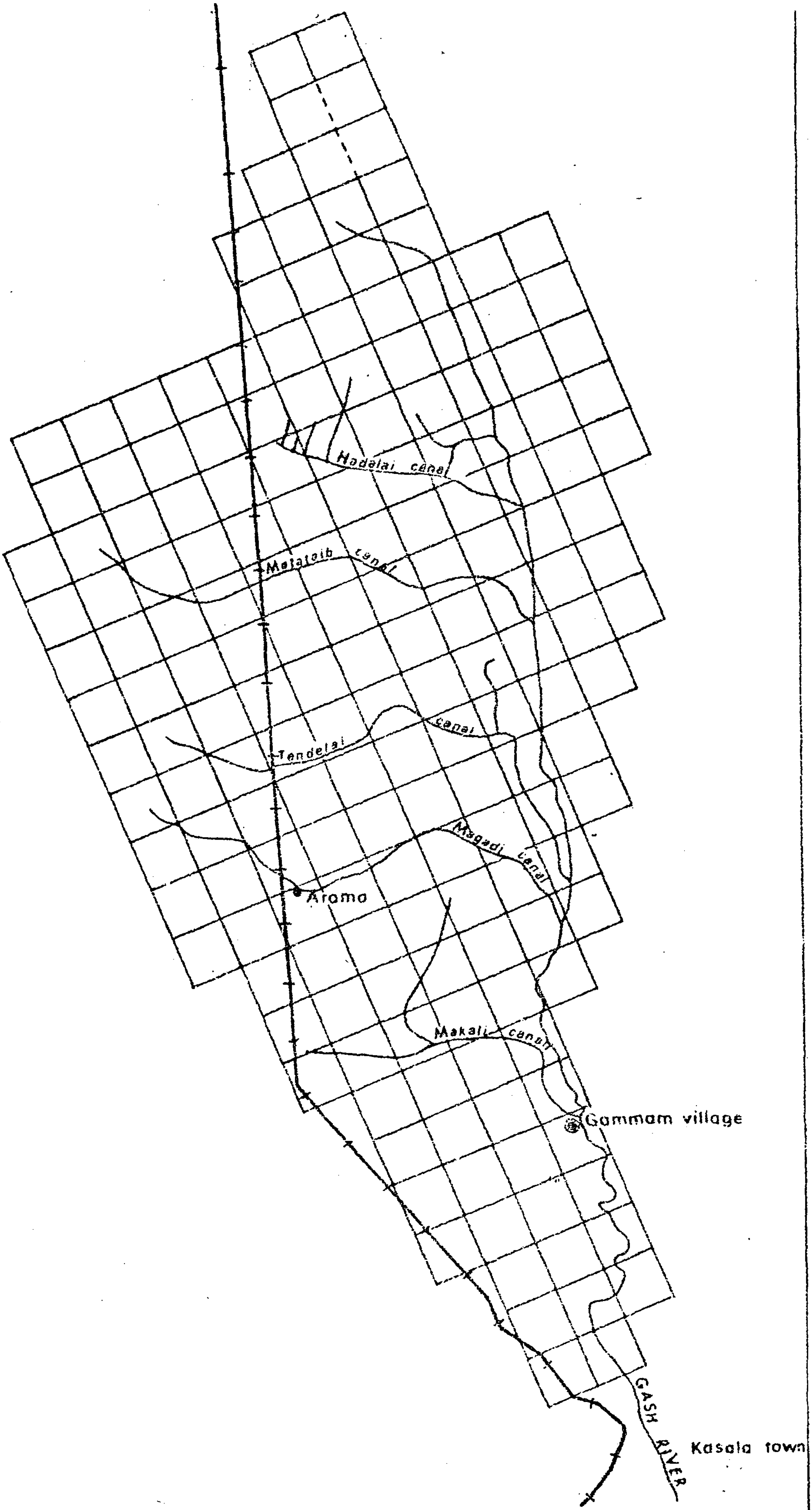
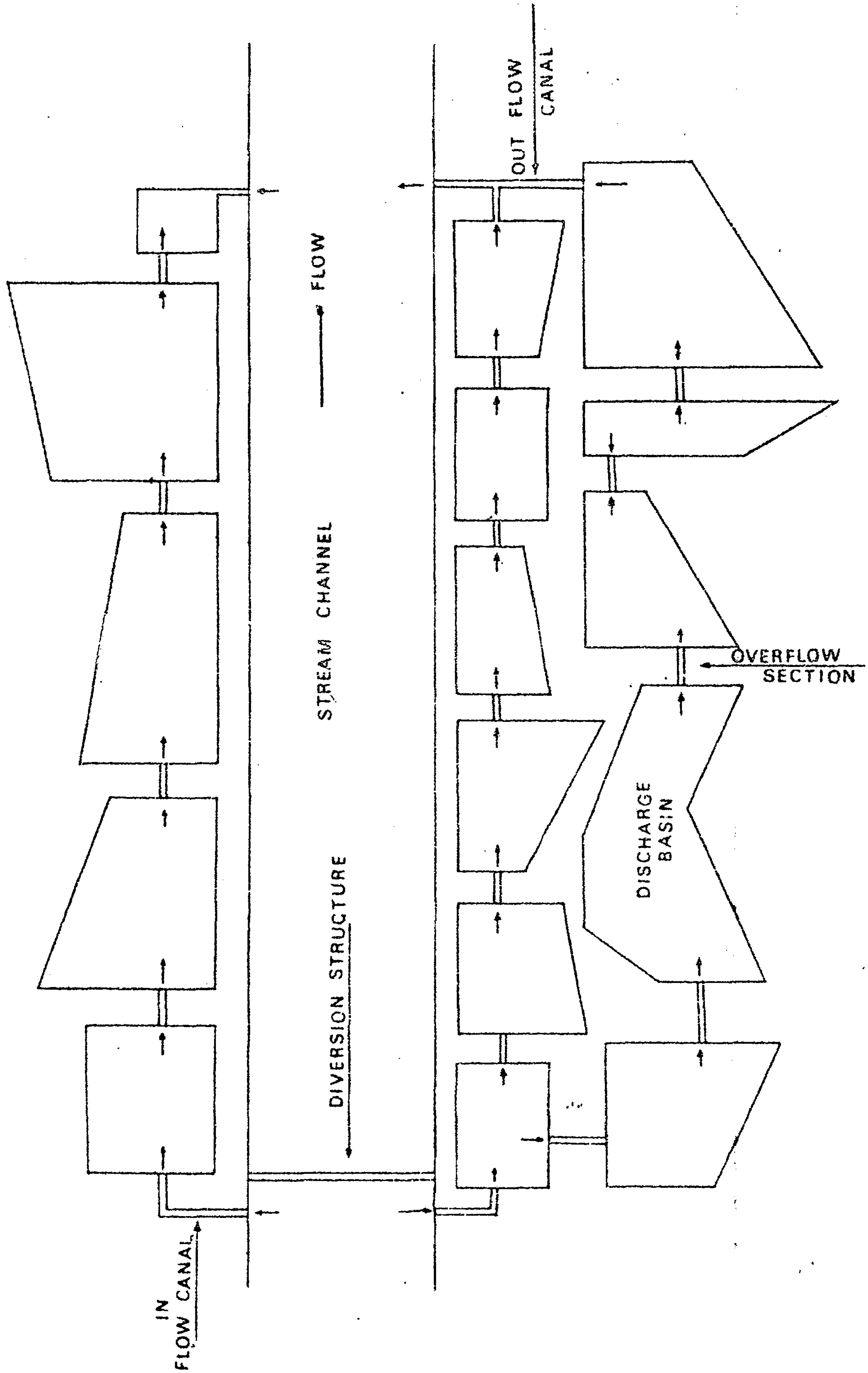


A SYSTEM OF RECHARGE BASINS IN SERIES AND BORDERING A STREAM CHANNEL



2.3 The Natural Channel Method

The essence of this method is to increase the time and area over which water is recharged from a natural stream by both retarding the natural flow of water, and by spreading it over the floodplain of the stream. In this method, longitudinal banks running along and some distance from either bank of the natural steam are constructed. Low check dams are then built across the stream and connecting the raised bandks on either side of the stream. These check dams are spaced at predesigned intervals. The natural flow of the stream is then dammed upstream from these check dams - in such a manner that recharge ponds are formed. Surface water from these recharge ponds then seeps down to the zone of saturation and replenishes the underground storage (see fig. 3).

Another version of this method is to construct a series of staggered temporary earth dykes traversing and spanning the larger portion of the stream section from which they begin. The flow of the natural stream then spreads across and is contained within the banks on either side of the stream. The serpentine path followed by the waters of the stream helps to retard the flow of surface water, giving it more time to seep underground over the extended recharge area (see fig. 4).

The natural channel method is extensively used in Sudan. A typical example is the river Rahad. The river Rahad is a seasonal stream, that flows in spates for three months every year. When the river bed is dry, the farmers build low check dams of rock and wire across its dry bed. When the river falls, recharge ponds are formed upstream from the check dams. Surface water from these recharge ponds seeps down to the zone of saturation and replenish the underground storage. A variety of quick-maturing crops, like millet and water melon, are then grown on the floodplain of the Rahad. Villagers depend for their existence on these crops on which they live for the whole year. Almost all the domestic water supply of the villagers along the river Rahad comes from wells dug in the floodplain of the river Rahad upstream from the check dams. The same wells are used to recharge the underground water storage when the Rahad is in flood. Useful pasture lands are provided on the Rahad floodplain upstream from the check dams, when the Rahad falls, Villagers have also found that such recharge ponds provide them with a good supply of fish. It can also be mentioned here that the Dinder National Park Lodge depends for its water supply on a system of wells dug in the river Dinder floodplain upstream a check dam.

The natural channel method is used here in East Africa mainly to reduce the flood hazards of erratic streams. There is however scope for its use in water supply and irrigation projects.

2.4 The Ditch Method.

This method is ideal for undulating land where the terrain is not flat. A ditch network bordering one or both banks of a natural stream is dug (see fig. 5). The peripheral ditches should be larger than the intermediate ditches. As a rule these ditches should be flat-bottomed, shallow and closely spaced to obtain maximum water-contact area. Water is then admitted into the system of ditches and kept there unitl percolation to the zone of saturation is complete. A collecting ditch at the downstream end of the area returns the remaining excess water to the main stream. Where the land slopes are steep, checks could be built and incorporated in the ditch system to facilitate a better water distribution.

Engineers have developed many different designs of ditch systems. Each design is dictated by the local topography and available recharge area. In America, the contour ditch type, the lateral ditch type, and the tree-shaped ditch type are most common. The ditch method might be used in East Africa to advantage because the terrain is generally irrigular.

2.5 The Pit Method.

Where rather impermeable subsurface strata (hardpan, clay or silt) within the zone of aeration cannot transmit water readily downward to the zone of saturation, the spreading techniques outlined above become invalid. When and where it is economically possible to remove such impermeable intervening strata by excavation, artificial recharge in pits may be attempted. Pits are dug to such depth that the impermeable geologic formations which restrict the downward flow of water to the zone of saturation are removed. The sides of the excavated pits should be nearly vertical, which avoids the deposition of silt on the sides so that side infiltration is not restricted.

Recharge through pits can only be used for water supply projects, and not for irrigation projects. This is a considerable drawback as far rural artificial recharge is concerned, because pits and shafts cost more to construct and recharge smaller volumes of water than do other methods mentioned earlier. Also in East Africa the use of the pit method to obtain potable, wholesome rural water supplies could be more expensive than the conventional chemical treatment of surface water. In developed countries where the rivers' water are polluted by industry, the use of the pit method could be economically acceptable, but most probably not in East Africa.

Recharge through pits could be economically acceptable in cases such as abondened gravel pits bordering newly built roads, or when the excavated soil from recharge pits could be utilized elsewhere. But often such cases occur only where there are no rural settlements to make use of them or where there are no surface streams to feed the recharged pits.

Aftrificial recharge through pits and shafts could be ruled out in East Africa due to, among other factors, the economic cost involved and the limitations in recharge volumes and consequent limitations in the field of application of this method.

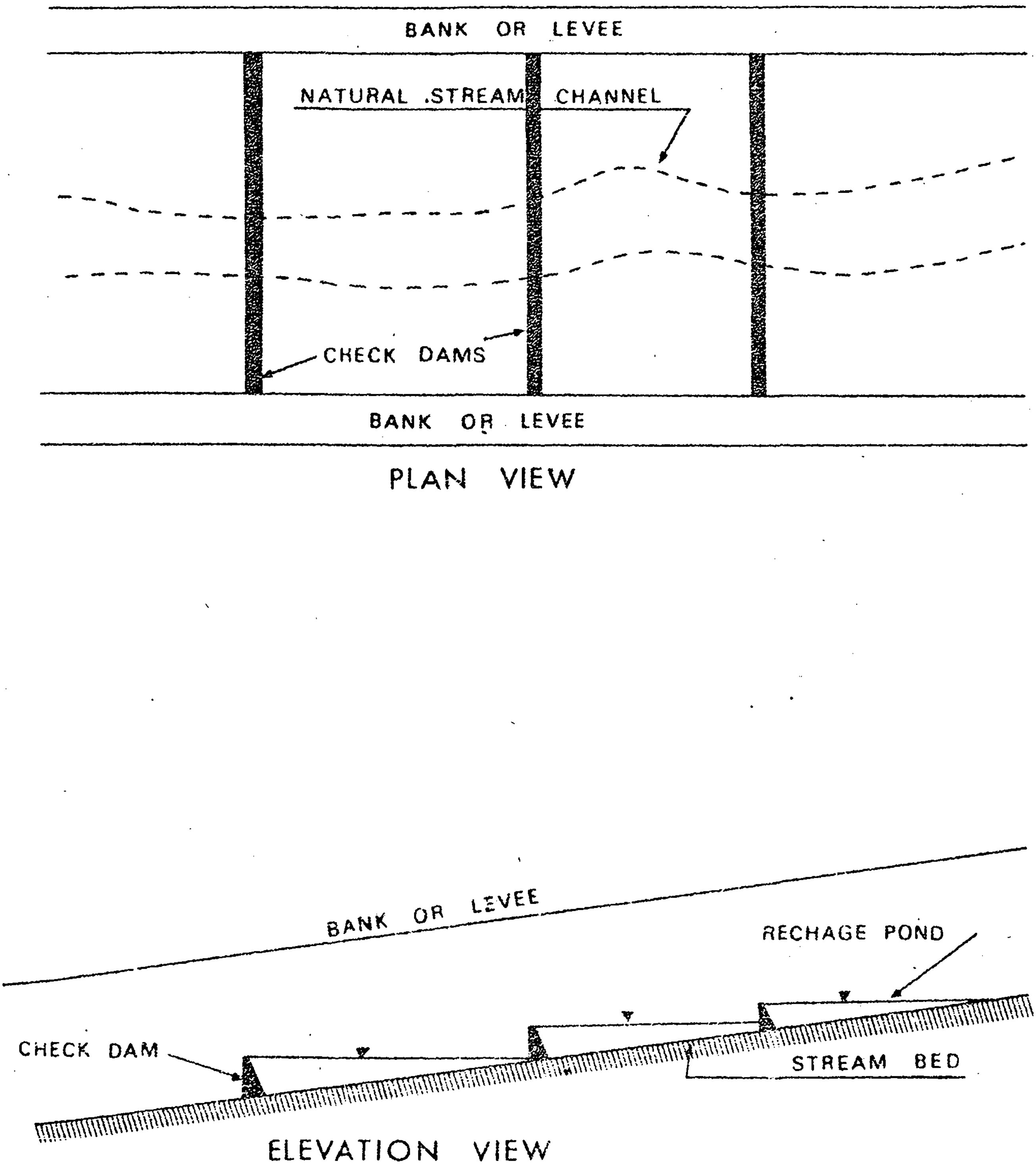
3 - CONCLUSIONS

The object of this paper is to introduce the different methods of shallow artificial recharge of groundwater. It is outside the scope of this not to discuss the possible successful application of any one method in East Africa. This is governed by the local topographic, geologic and soil conditions of the different regions and Localities in East Africa. Such conditions vary greatly from one country to the other in East Africa and within any one country in East Africa one region or location to the other. Also the successful application of any one method in East Africa depends on the volumes of available water to be recharged and the ultimate water use, whether for rural water supplies or rural irrigation projects or both. The land value, water quality and climate may sometimes play a decisive role and have to be considered. Even if any one method proves to be applicable here in East Africa, the economic cost incurred has to be reasonable and the cost-benefit ratio favourable.

Fig. 3

SYSTEM OF CHECK DAMS AND PONDS

(AFTER TODD)



SYSTEM ...

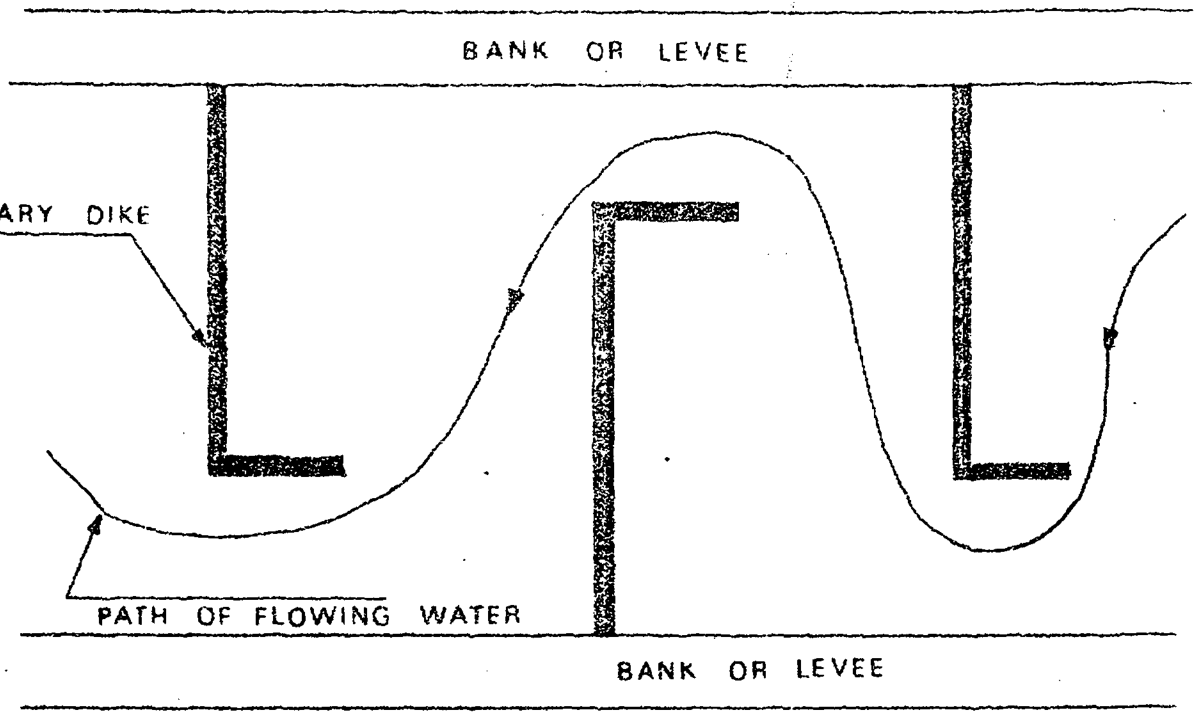
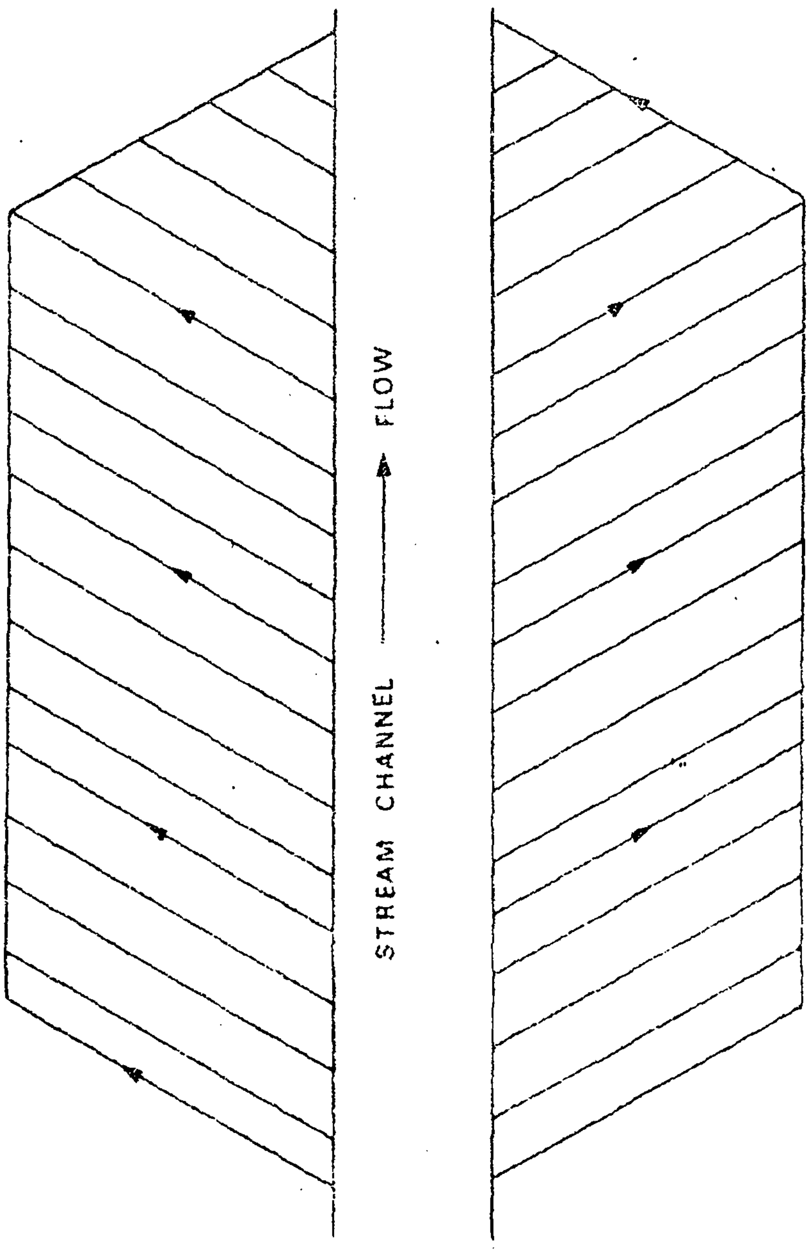


Fig. 5 DITCH NETWORK
(AFTER TODD)



The shallow artificial recharge methods cost least and can be used both for rural irrigation projects and rural water supply projects. These methods are therefore been treated in this note. The experience in Sudan is referred to whenever relevant. Of course, the successful application of these methods in Sudan does not mean that they can be successfully implemented in East Africa. This again depends partly on the topography, geology and soils of the particular location considered.

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RURAL WATER SUPPLIES IN SEMI-ARID CONDITIONS

PERMEABLE DAMS

by

R.L. RAIKES
Raikes and Partners, Consulting Engineers
and Hydrologists, Rome, Italy.

1. INTRODUCTION

I am assuming that this conference is essentially concerned with the practical aspects of Rural Water Supply. These aspects range from the location and listing of sources of water; the hydrological assessment of their long-term yields; the efficient long-term extraction of water from them; its distribution to the point or points where it will be consumed by people, animals or crops (under irrigation); purification of the water to the various standards that good public health practice dictates for various uses; and finally ensuring that used water, whether used by humans or animals or in irrigation does not contaminate water sources and, ideally, that it does not get wasted.

My concern is with location and extraction whether from surface of underground sources and, since the long-term use of underground sources can only be ensured if there is adequate natural or artificial recharge of the aquifer, I am also concerned with waste water as a potential source of recharge.

As regards this last I will only say that conditions can, or can foreseeably, be such that the full requirements of a particular scheme can only be met by a considerable degree of "recycling" of used water. The subject that I have chosen for this paper is that of intentionally leaking, or permeable dams. They are sometimes called detention dams as opposed to retention dams, the inference being that detention implies short-term storage: they are also called recharge dams. All the descriptions are valid. The concept has the advantage of intrinsic cheapness. It also has the advantage of flexibility in use: e.g. it can be used for direct flood irrigation or for recharge (of pumped aquifers) or both.

2. RELEVANCE TO TANZANIA

Much of Tanzania is semi-arid. These conditions are on the one hand aggravated by low latitude and on the other are somewhat mitigated by fairly high altitudes. The conditions are however, as far as climate is concerned, fairly characteristic of semi-arid tropics: high evapo-transpiration; high maximum temperatures; high diurnal range of temperature; pronounced seasonality of rainfall (often bi-modal); rainfall characterised by high intensities, high totals for single storms, short duration of individual storms and high seasonal and areal variability.

2.1. Under such conditions the run-off that results from rainfall is almost always more or less flashy in character and often with high peak discharges. I am only concerned in this paper with areas, such as for instance parts of the Serengeti, where torrent beds are dry except immediately after flood-producing rain. The hydrograph of a typical flood from even a small catchment of sub-catchment (of the order of say 500 sq. km. area) is seldom the product of rainfall over the whole of such catchment or sub-catchment; it is more likely to be the result of a single storm system (generally moving) of which only a part may cover the catchment in question or of which the whole may only cover a part of the catchment. The shape of the hydrograph under such conditions is extraordinarily constant as between one part of the world and another, particularly as regards the time base or duration. The run-off from larger catchments tends to take a more complex form since in effect the hydrographs of various individual storms are superimposed on each other with various lag times. The overall effect remains however much the same, with high combined discharges of relatively short duration or maybe a fairly quick succession of flood peaks at the outlet of the catchment. The outlet of the catchment for present purposes is the point under study at which it is proposed to conserve water for rural water use.

3. PERMEABLE DAMS

The basic intention behind a permeable dam or detention dam is to convert highly variable flood discharges into long-term flow of low variability (generally a combination of surface and sub-surface flow) with the smallest and cheapest structure practicable The conversion is achieved by:

(a) Allowing water impounded behind the dam to leak safely through it and under it (which requires that there should be permeable river-bed alluvium) and

(b) By using either a permanently open draft pipe or conduit, or one with a valve or penstock, to discharge water at predetermined rates depending on the head (i.e. maximum at full supply level, minimum at the take-off level) to direct flood-irrigation use or for recharge of an aquifer whose top surface is at a lower level.

Very often the aquifer is the same river bed alluvium, downstream of the dam, and if this is of not very great capacity complete absorption of outflow for recharge may require several kilometres.

4. CHOICE OF SIZE ETC.

Detention of all, or a predetermined proportion of, discharges at the outlet would require a very much larger capacity and larger dam structure than would be required for detention of all, or the same predetermined proportion of, discharges at each sub-catchment outlets. But assuming that the main outlet site and sub-catchment outlet sites have approximately similar shapes as regards longitudinal slope, side slopes, proportion of width of channel to height of dam (i.e. much narrower at sub-catchment sites) and form of upstream basin, the same capacity as is achieved by one dam of height H at the main outlet can be achieved by 8 dams of height $\frac{H}{2}$ at sub-catchment outlets.

For capacity & height^3 and $\frac{H^3}{(\frac{H}{2})^3} = 8.$

The ratio of 1:2 for heights is chosen for illustration only. Since the volume of material in any earth bank is, in practice and when account is taken of berms and of some additional top width and free board in the case of higher banks, approximately proportioned to H^3 it follows that the volume of material in multiple sub-catchment detention structures would be approximately the same as that in a large structure at the main outlet.

5. ADVANTAGES OF MULTIPLE SMALL DAMS

However there are certain very great advantages, some more obvious than others, in using multiple low dams. They may be grouped under the headings of hydrology, hydraulics and construction:-

5.1. Hydrology

Provided that reliable rainfall data are available, particularly as regards intensity/duration, daily depths, and their distribution in time and provided that some (probably short-term) related run-off data are either available or are made available during a preliminary phase of a water supply project, it is not difficult to determine the approximate thalweg length of a sub-catchment (for length is more important than area) for which the maximum probable flood event would be that due to a single storm. This is not necessarily a storm covering the whole of the sub-catchment since the durations critical for shorter thalweg lengths are associated with higher intensities of rainfall. The long-term flood regime of such a sub-catchment is generally easier to forecast with less dependence on subjective assumptions or on long-term flood records than that of the main catchment would be.

In studying rainfall and its related run-off the establishment of criteria we are searching to quantify such concepts as initial loss, surface detention storage, infiltration rate and so on which are often without much error treated as constants for a given catchment although not in fact so. Both initial loss and infiltration rate, however assessed, so diminish rainfall available for flood generation (rainfall excess) that an increase of rainfall intensity from i mm to (i + i) mm may double the peak discharge resulting.

The outflow regime and its effect on available storage in similar downstream structures is generally of little more significance hydrologically than low base flow even if overall cost effectiveness requires detention of only a part of available flows (after making allowance for designed outflows) with some occasional substantial spillway discharges. The routing of floods through storage for arriving at economical and effective combinations of storage and spillway capacity is much simplified in the case of carefully selected sub-catchments.

5.2. Hydraulics

There is firstly the question of flow through and under the dam determined normally by the flow-net methods originally developed in India for dams and barrages on permeable foundations. These methods although neat and effective are considerably dependent on assumptions made as to the degree of compactness of relatively coarse material in the dam itself. While the use of under-drainage or toe drainage can eliminate almost all risk that excessive seepage may cause flotation of particles of the dam material (piping) the risk nevertheless remains. In the case of a small dam the construction of a downstream berm to increase the flow path can be quickly and fairly cheaply done and is a permanent cure. The larger the dam the longer this operation would take and time might be important. A large penstock controlled outlet for use in emergency is advisable if the dam is just upstream of a settlement.

Secondly there is the question of the draft pipe which I perfer to visualise as permanently open without valve or penstock. The selection of the size of this is not very easy, the main problem being that of limiting the velocity of flow in the pipe. This requires careful consideration of head. As part of this question there is also that of siltation: it is recommended that the designer accept an amount of dead storage which represents the estimated amount of siltation in a given number of years. This may be at as much as half the height of the dam while representing only some 10% - 15% of its volume. It is recommended that the draft pipe be set horzontal at this level with a simple screened intake structure. It should be sited at a distance upstream from the dam, and at one side of the impounded basin, such that the velocity in the pipe is within the safe limit for the material used. This will still normally be a fairly considerable velocity and it is therefore recommended that the horizontal draft pipe be led to a small stilling pond downstream of the dam (and on the flank of the valley) from which the water can be conveyed to the river bed by an open channel in cascade.

5.3. Construction

On the one hand a large dam enables equipment to be used for a longer period in one place while possibly involving longer leads: on the other hand the multiple small dams mean shorter periods of use between moves but possibly shorter leads. Dams should preferably not all be constructed simultaneously unless completion before the flood season can be guaranteed since it is essential that upstream dams be completed first if the scheme is to operate as planned.

5.4. Materials

Selection of the material to place in the dam requires considerable judgement. Clay is out of the question since it is impermeable: a predominantly silty material is prone to "piping" and therefore requires more accurate flow-net calculations and very careful design of "inverted filters" at underdrains; neither of these factors justifies rejecting silt but they both require that the design be undertaken by experienced engineers. A sand/silt mix is generally easy to deal with but, even sand alone can be used if very fine. However sand has the disadvantage that the great permeability requires a longer flow path and therefore wider section and greater volume. At the same time sand unless very fine and rounded can be relatively difficult to load fast into scrapers while being easier than some materials, to compact. All these construction factors, and other not mentioned, have to be taken into account when designing.

6. OPERATION

The end product of a system of permeable dams is that floods generated above each unit are temporarily stored (and perhaps partially spilled) by that unit which, so long as there is water in the unit, will be discharging both through the draft pipe and underground. Phreatic levels in the river beds will rise and in certain circumstances sustained flow may result all through the rainy season. Phreatic water may be extracted by pumping, from wells or galleries, any large volumes of aquifer that may be identified by geophysical soundings: naturally the wells must be near where the water is required. Such pumped parts of the aquifer will act as drainage sumps for both surface and underground flow. In the case of sustained flow it may be most effective to lead this off at suitable points for irrigation or it may be allowed to flow unchecked to those drainage sumps. Extraction of groundwater can be done in several ways - shallow bore holes, pumped galleries, gravity-flow galeries etc. depending on the conditions. It is worth noting that these detention structures perform a valuable flood control task as well: indeed one could almost say that they are basic flood control and utilisation structures. Although I have referred specifically to torrents that are normally dry it is not difficult to modify the principle so as to apply it to small sustained seasonal streams. In these cases the main benefit is from increased surface flow for irrigation or other uses. Any recharge of groundwater in these circumstances can generally only be achieved by diverting regulated surface to potential groundwater reservoirs away from the river.

7. CONCLUSION

The foregoing describes a cheap type of earth dam that avoids the cost and difficulties of an impermeable core and deep cut-off. Any mobile earth-moving equipment can be used and skilled labour and rigid materials are required only for the spillway, draft pipe and, in certain circumstances, for the toe drain. Points to watch in design are:- the estimated transmissibility of the dam material and the measured transmissibility of the undisturbed material below it and their use in constructing a flow net; the risk of slips in the upstream face due to relatively rapid drawndown if a silty material is used. However the most important point of all is to get the hydrology right before design starts. This method of construction, properly designed and carried out, can control and utilise irregularly occurring floods by combined use of short-term surface storage and long-term ground storage.

IV. DESIGN AND IMPLEMENTATION

BASIC CONSIDERATIONS FOR THE DESIGN OF RURAL WATER SUPPLIES

By André Harlaut

SWECO-VBB, Stockholm, Sweden

1. General

The final objectives of any public water supply system are:-

to supply safe and wholesome water,

to supply water in adequate quantity,

to make water readily available.

From the purely public health point of view there is no doubt that the above objectives should be fulfilled also for rural water supplies. Unfortunately full satisfactory water supply systems are expensive and beyond the financial means of most rural water supply programmes. Alternative solutions must be compromises between economic realities and public health necessities.

However, the search for economical solutions which will serve a maximum of consumers within a given financial frame should not result in the implementation of inadequate systems which in the long run do not improve the public health conditions and may thus be even more uneconomical than more elaborate and expensive systems. The implementation of limited systems is justified only as a first step towards a more complete solution. The possibility of extending and improving the systems in the future should always be borne in mind.

A single water supply system which could apply to the whole country does not exist. The types of water resources available and the water requirements differ widely and, consequently, a great variety in conception and design of water supplies is required.

The rural population is very often scattered over large areas or is grouped in small communities. Concentration is being encouraged by the development of Community Villages but the process of concentration will most probably be slow and for many years to come a considerable part of the rural population will remain scattered.

For villages and communities where an increasing concentration and a future development can be foreseen, provision should be made, wherever possible, for the ultimate distribution of safe water to points easily accessible by the majority of the people. The distribution layout and the general design should facilitate future extensions and future individual house connections. The first step towards developing a more comprehensive water system could be a piped supply with limited distribution facilities but with the main structures designed so that future extensions could be easily carried out.

For areas with scattered populations it is not generally possible to provide the same distribution facilities as for communities. An improvement of the water situation can be obtained by creating safe and wholesome water sources or by improving existing water sources. Wells, boreholes or water points with ample protection against pollution and equipped with mechanical lifting devices should at many places be a satisfactory solution. In most cases it would not be feasible to provide distribution facilities.

2. Design Period

The period of operation for which a new water supply system should be designed is governed by a number of considerations, the most important of which are the anticipated growth of the population and water consumption, the durability of materials from which the component parts of the works are to be constructed and financial rates of interest and amortization.

Theoretically it should be necessary to have a reliable prognosis of the anticipated water consumption for a period longer than the most durable part of the works and, considering all the above mentioned factors, to search for each component part the most economical dimension.

However, since unexpected alterations in the prognosis made must always be anticipated, it is usually economical and reasonable to limit the design period for a water supply system to the period for which the prognosis can be considered as reasonably reliable. The general possibility to extend the works in the future should, however, always be borne in mind.

For urban conditions it is usually considered as economical and reasonable to limit the design period of a water supply system to 30 to 40 years. For mechanical equipment such as pumps and motors which have a high rate of depreciation and for those parts of the works that can easily be extended or doubled the design period may be 15 to 20 years or even less.

For rural water supplies there is no agreement between designers as to a suitable design period, but it is advisable to consider wherever possible an overall design period of at least 20 years. The system should be planned for the final stage at the end of the 20-years period and the possibility of development in stages and the necessity of replacing certain items of equipment at certain intervals should always be considered. The general possibility of extending and improving the system in the far future should always be borne in mind.

3. Number of Water Consumers to be Served

In order to arrive at an estimate of the number of water consumers to be expected throughout the whole design period it is common practice to consider the changes which have taken place in the past. In rural conditions, however, even the determination of the present population is in itself a difficult task, and attempts to forecast the future population generally encounter great difficulties. The designer must consequently exercise considerable judgement in predicting the future development.

4. Water Consumption per Capita

In rural water supplies the consumers are mainly the domestic consumers, the institutions such as schools and dispensaries and the livestock. In certain cases irrigation may be combined with domestic water supply but in this case special studies are required which are not considered in this paper. Generally there are very few reliable data regarding the present water consumption in rural areas. From the few research studies available the following observations can be made:-

- The average daily consumption of water provided from public tap seems to be less than 5 gallons (23 litres) per capita per day.

- The average daily consumption of water provided through house connections is considerably higher but does not seem to exceed 20 gallons (91 litres) per capita per day.

Generally it is considered that, including leakage and waste, an average of 10 gallons (45 litres) per capita per day is required for domestic purposes, i.e. drinking, cooking, ablution and laundry and that the provision of 25 gallons (about 110 litres) per capita per day is most desirable in hot countries.

Since the construction costs and the operation costs of water supplies are dependent on the amount of water provided it will be necessary to reach a compromise and adapt the final goal of the rural water development to the financial means available. However, since limiting the water consumption is always connected with technical and social disadvantages it is necessary to be prudent in this matter and always make provisions for an unexpectedly rapid growth of the water demand. As a first approximation to be confirmed by study of the real conditions it seems reasonable to assume that when water is available in sufficient amount the water consumption including leakage and waste grows as follows:-

	Average daily consumption per capita					
	1st year		10th year		20th year	
	litres	gallons	litres	gallons	litres	gallons
Domestic Consumption						
In densely populated areas with piped supplies and easily accessible public taps	30	5	45	10	70	15
Ditto with house connection	90	20	135	30	180	40
In sparsely populated areas without distribution facilities or with poor distribution facilities	15	3	18	4	23	5
Livestock Consumption (per livestock unit)	23	5	23	5	23	5

Taking into account local variations of conditions higher or lower values should be considered in certain areas. For the livestock hither values should apply if and where the future plans include the implementation of organized dairies.

5. Water Source

Before installing a water supply system, investigations of the available water sources are an important part of the design. It is necessary before deciding to invest considerable sums in systems such as extensive piped supplies, which in themselves attract a population concentration around the new facilities, to make sure that the water sources available will be sufficient not only in the near future, but also in the long run. The water source finally selected should in any case be capable of meeting the water demand expected after 20 years, and further reserves should exist for considerable extension if required after the considered 20 years period.

6. Pump Capacity

There is little information available as regards the durability of pumps and motors in rural conditions. It seems, however, reasonable to provide a pumping capacity sufficient to satisfy the expected water demand after 5 - 10 years and to make provisions for installation of larger pumps when required.

It is generally recommended to provide for a certain emergency capacity, However, for economical reasons provision of such emergency reserves should always be weighed against the possibilities of obtaining water from other sources during emergency periods. For most supplies the provision of two pump units together capable of delivering the daily demand with an effective pumping time of 12-16 hours per day should provide sufficient emergency reserve. The capacity of each pump unit should be chosen in each particular case with due consideration to the characteristic curves for pumps and water mains.

7. Storage Capacity

Generally the cost of storage tanks is an important part of the construction costs. Storage tanks are usually provided in pumped supply systems in order to maintain a necessary balancing effect as well as a certain emergency reserve. Considering the construction costs involved, it is advisable to investigate the necessary storage capacity for each particular case taking into account the advantages of a reserve in relation to the investment cost. For a pumped supply system equipped with two pumps as described above the need for reserve is less than for a pumped supply from one single borehole with one single pump. In many cases it may be economically and technically advantageous to construct a small tank in a first phase and to add a new tank in the future when the water consumption has increased. Such possibility of construction in phases should be considered in each particular case. For supplies by gravity from ponds or streams it may not be necessary in many cases to provide any storage capacity in the distribution system.

As a general indication it seems advisable to determine the storage capacity to be installed in a first phase on the basis of the water consumption expected after 5 - 10 years with due consideration given to the future possible extensions.

The volume required for balancing the daily variations in consumption can be calculated if the expected variations are known. For urban conditions this volume is usually 20-30 % of the daily consumption. However, if it is accepted for economical reasons that shortage of water may occur during short periods of the day, the said volume could be less.

The need for reserve will vary from project to project as mentioned above, but the storage capacity should always be sufficient to meet the water demand during the short interruptions of operation which may be required for daily or weekly routine maintenance. It does not seem economical to provide reserve for major repairs which, if they cannot be made within a few hours, will probably need several days of attendance. Emergency of this kind should be met by other means and principally by rationalization and increased efficiency of the maintenance routines.

Ground reservoirs are much cheaper than elevated tanks and should be preferred when possible. The storage capacity could be chosen somewhat larger for ground reservoirs than for elevated tanks.

It must be borne in mind when choosing the storage capacity that the operation of the water supply system is more complicated when the reservoir volume is small and if one wants to avoid waste and water shortage.

8. Pipework and Distribtuin Facilities

Depending on the layout of the particular scheme and on the relative location of the water source, storage tank and distribution points, the flow to be taken into consideration in dimensioning the pipes will vary between a value equal to the pump or intake flow and a value equal to the peak consumption.

It is thus important to design the general layout so that a minimum cost is obtained for the whole of the supply system. A development of the water mains and networks in phases should always be considered.

In most cases the pipework and distribution system are the most costly components of the water supplies. If and where a reduction of the initial construction cost is required, it seems advisable to consider in the first place a reduction of the distribution facilities providing that due consideration is given to possible future extensions. Such a reduction will involve a certain amount of inconvenience for the population served, and eill in itself result in a lower consumption of water. The risk of the consumers turning away from the supply towards easier but perhaps unsafer water sources should always be borne in mind.

As a general rule the dimensions of the pipes should be calculated for the flow expected after 10 - 20 years. When pumping is involved it is usual to determine an economical diameter for the pipes by taking into consideration the balance of the construction costs for the pipes against the operation costs for the pumping.

9. Dams and Charcos

Very often dams and charcos are not provided with distribution facilities other than hand pumps or intake wells in the immediate vicinity of the embankment. Considering the rather high costs involved, the implementation of dams and charcos without piped distribution systems should always be based on a serious investigation of the real possibilities for the population surrounding the site to obtain water from the supply.

10. Other Features

Considering the distribution of a population where a large part of the rural population is scattered and considering also the costs involved in the implementation of piped supplies, it is necessary to provide, in the water development programmes, for simple and cheap forms of water supply that could be installed in areas where the construction costs of well engineered piped supplies would be prohibitive. In this connection, it seems advisable to initiate special studies in order to examine and develop possible innovations. In the first place two objects seem worthy of special attention:-

1. The development of design and construction methods for low cost shallow wells with high hygienic standard and equipped with hand pumps preferably of local fabrication.

2. The development of standard types of small rainwater catchments with prefabricated or locally made tanks for areas where groundwater is not available. The possible use plastic material should be investigated.

11. Water Teatment

The question of the water quality and the necessity of treatment is not discussed in this paper but should always be subject to initial examination.

Note:- The present paper is based on experience from surveys and studies on rural water supplies carried out by SWECO - VBB, Consulting Engineers and Architects, Stockholm, Sweden in Tanzania and other countries.

INTERMEDIATE TECHNOLOGY AND RURAL WATER SUPPLIES

by

Gordon H. Bateman
Department of Applied Physical Science
University of Reading

INTRODUCTION

Water supply in the rural areas of developing countries is a subject that for too long has been seriously neglected, and it is heartening that interest in East Africa has now reached the stage where a major conference on the subject is being held.

In considering rural water supplies it is interesting to look at the way in which the whole subject of development in the developing countries has been approached in the past. Consider the country depicted in Fig. 1, which could be almost any developing country. It has the natural resources shown in the diagram. The traditional approach to development would be to send a team out to review and advise on how to develop the resources of the country to the most economic advantage, i.e. to reduce large-scale imports and expand large-scale exports - the factors which are basically involved in the economy of the country in relationto other countries. The team identifies the resources in Fig. 1. The river then provides a dam site, which leads to hydro-electric power and irrigation. The power means the mineral deposits can be readily exploited and industry developed (Fig. 2).

From the capital, and from the import/export balance sheet of the country, all looks well. But for the vast majority of the people of the country, who are living in the greater part of the country (Fig. 3) life is just the same. They subsist on rain-fed agriculture, they have no large rivers, no mineral deposits, no natural resources of note: hence the survey team mentioned above made no recommendations for the development of their part of the country. But they are people and they must be involved in development just as much as the others if the country in the longer term is to truly develop. If they are not involved in development, they will migrate to the industrialised areas and overload them - there are plenty of slums and shanty towns in the world to bear witness to this fact. The only logical way to reduce this migration is to develop the rural areas sufficiently so that all benefit, thus removing much of the incentive to go to the big cities.

How can these areas be developed? Briefly, the approach should be to start with what the people already have, with what they are doing and to build on it step by step. This is the approach developed by the Intermediate Technology Development Group and the reader is referred to their various publications for a more detailed study of it.

The Needs for Water

In the traditional approach to development outlined above, the attitude was, in the case of water, "Here is water, a large river, what can we do with it?" and the answer was "Build a dam, generate electricity and irrigate crops". In the rain-fed areas the approach should rather be, "here is a need for water, how are we to meet it?", i.e. start with a definite need..

What are the needs with regard to water? Consider a typical individual household in the area. What are the actual water needs at the home? Water is required for drinking, cooking, washing the pots, and for bathing and washing clothes. The latter two uses could be performed away from the home, though the preference is most definitely for them to be carried out at the house. The point of consumption is in the house itself and ideally the water should be supplied at the house. This is the first set of needs and it applies just as much in every house in the rural areas as it does in the big cities. What can be done to meet the need?

The second case is that of a farmstead: again there is a need for water at the house for domestic uses, but in addition there is a need for water for the animals, for irrigating a vegatable kitchen garden (not for field crops as it is a rain-fed agriculture). What can be done for this set of needs?

Thirdly, consider a complete village together with its lands around the village. In the village itself there are all the houses providing points of consumption for domestic water. There are all the little vegetable gardens, all the animals both near the house (especially chickens and goats) and out on the pasture land, and also water for the animals and men working on the arable land. How can all these needs be met with a supply of water right at the point of consumption, so that the traditional and very costly system of carrying water can be eliminated?

Possible Sources of Water

In seeking possible sources of water I think it is useful to consider the hydrological cycle, which I have depicted in Fig. 4. There are to my mind three major points at which water can be extracted from the natural cycle and put to man's uses:

(a) surface water
(b) ground water
(c) rainwater.

The use of surface water to precisely meet the needs listed above is costly - because those needs not only indicate a quantity of water, nor only a quality of water but also a location - the point of consumption to which our water supply scheme must deliver the water. The obtaining of surfaces water will perhaps include a dam or weir, as well as a distribution system of pipes and taps, and in places where gravity feed is not possible, pumps or hydraulic rams are necessary. It is technically possible to provide a piped water supply to almost anywhere - but the economic factors make it impossible.

Ground water may be a possibility, although there are plenty of places where groundwater is not present. If shallow water is available then there is a good chance that people are already using it - I recall the many hand-dug wells I saw in India. Deep groundwater is more difficult, of course, and its tapping is an expensive operation, including the inherent risks that not every borehole will be a success giving a good yield. There is the need for a pump, which on deep boreholes will almost certainly need to be power operated. Also, most boreholes give sufficient water to supply all the needs of a considerable area (which they must to make them financially worthwhile) - and that entails an expensive distribution systems as previously mentioned. Even with shallow wells it is quite likely that each well will have sufficient yield for a large number of households.

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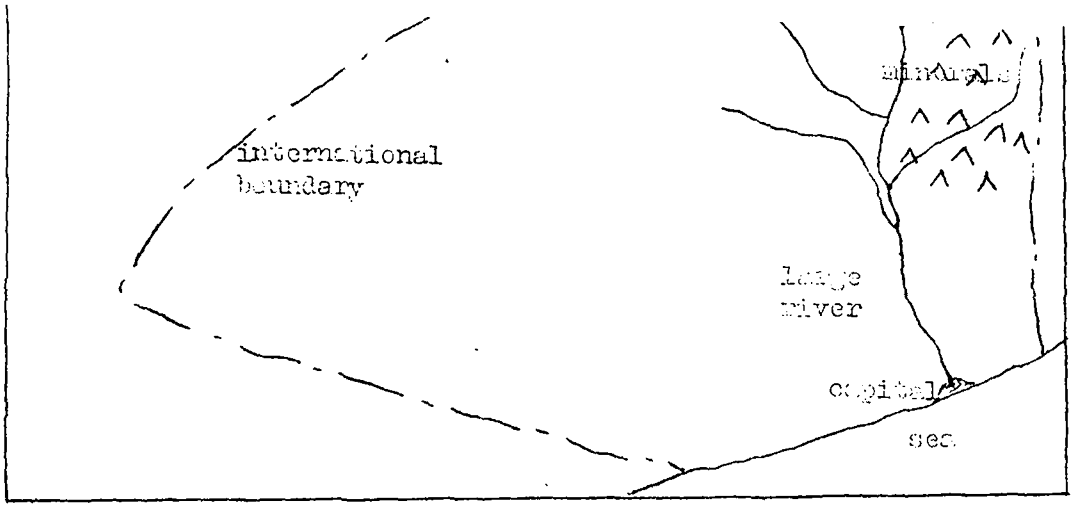

Fig. 1. A few Natural Resources

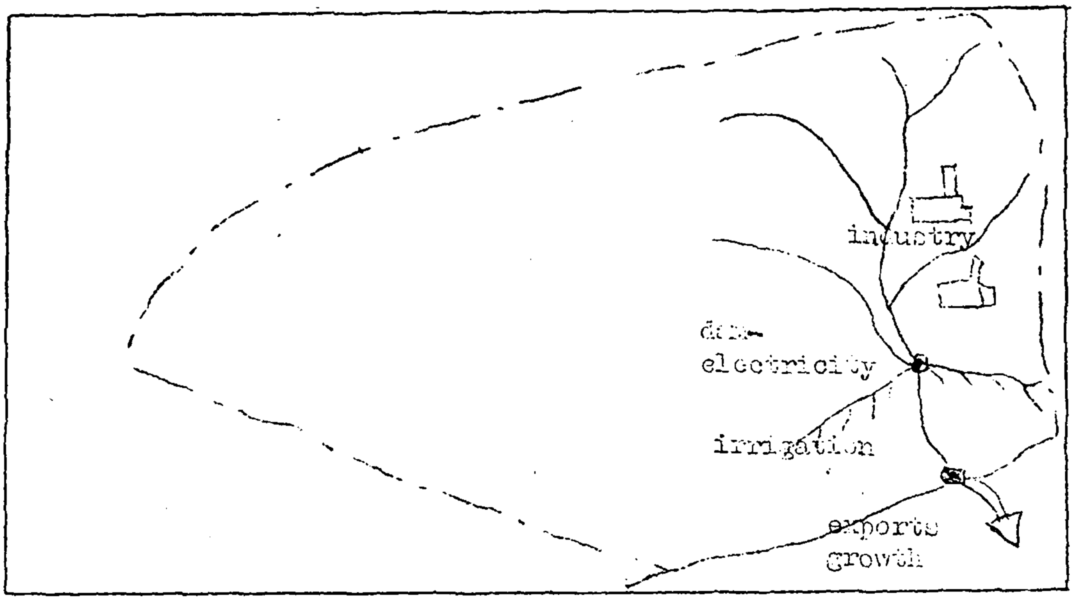

Fig. 2. Development of the Natural Resources

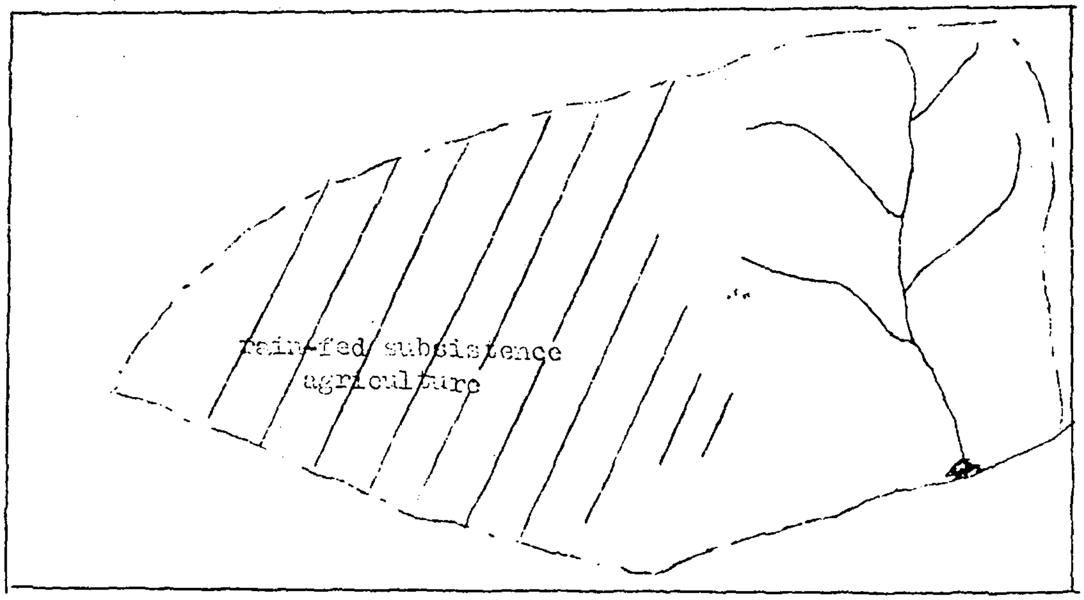

Fig. 3. The great Rain-fed Subsistence Agriculture Areas.

Thus both surface water and groundwater, except perhaps very shallow groundwater, generally have the disadvantages of requiring an expensive structure to obtain the water, and of having a lot of water in one place which then needs distributing to the points of consumption, i.e. the availability is poor.

However, the third source of water is rather different, obviously so in its availability. The area is based on rain-fed agriculture, so there is rainfall everywhere, i.e. at every point of consumption. All that is required therefore is a means of catching and storing the water. The fact that 1 inch of rain falling on 1 ft^2 gives about 0.5 gallons means that even with only a modest rainfall of 10 inches and a catchment area of 100 ft^2, the yield is about 500 gallons, assuming almost 100% run-off. Larger catchment areas will give greater yields. Rainwater has an advantage from a purity point of view as it is pure until it hits the ground (we are not concerned here with industrial areas and attendant air pollution), so if our catchment and storage system is constructed so as to keep the water clean there will be no need for expensive purification plant for the domestic water. (I shall return later to the matter of purification). Indeed rainwater catchment and storage is an ancient system of water supply, but it has taken on a completely new look with the advent of modern impervious membranes, plastics, resins, etc.

I was pleased to see that rainwater catchment tanks appeared in the Workshop on Rural Water Supplies held in Dar es Salaam in 1969, in a paper by Barker (1), where the use of butyl rubber membranes was described. While this is a perfectly good method of construction, it is very expensive and I will briefly outlined a method which is far cheaper and in some respects technically superior.

The Mud/Polythene/Sausage Method of Constructing Rainwater Catchment Tanks

This particular design was first developed in Kordofan Province of the Sudan by MG. Ionides, Project Manager of an F.A O. Land and Water Use Survey Project. It has since been used in Botswana, and more recently in Swaziland.

The design is fully explained in the report on the Introduction of Rainwater Catchment Tanks and Micro-Irrigation to Botswana (2). Briefly the method is to dig a hole to the approximate size required (e.g. a 10,000 gallons tank might be a rectangular hole 20ft x 16ft at the surface, sloping to 16ft x 12ft at the bottom, with a depth of 6.5ft). The system of lining is to put in the tank a series of layers of mud and polythene interspersed with "suasages". The "sausages" are layflat polythene tubing which is 4 or 4.5 inches wide, made of 150 gauge polythene. The tubing is cut into lengths of about 18 inches and filled either with dry sand (sand sausages) or a cement-sand mix (cement sausages). The cement sausages are filled with a dry mix of 15 parts of sand to one of cement (compared with 3 or 4 to 1 for ordinary cement work). Knots are tied at both ends and it essential that the sand is completely dry and the mix is well tamped down in the sausage for full compaction. In the case of the cement sausages, small holes are pierced along one side of the sausage, it is laid holes down in about half an inch of water just long enough to absorb capillary water, and then laid in position. In this way only just enough water to cure the cement is used and nearly 100% compaction is achieved. It is for this reason, together with the mix being enclosed in polythene and therefore in ideal curing conditions that such a weak cement-sand mix can be used.

The order of the various layers in the lining is shown in Fig. 5. It can be seen that the cement sausages provide a protective revetment. This lining was used in the tanks built in Botswana for irrigating vegetables, and the cost of materials on site in Botswana in 1967 was £12.50 sterling for a 10,000 gallon tank. There were no labour costs because the school children (even the eight year old ones) built it. The process is made up of a series of very repetative operations which can be quickly learnt. Clearly a 10,000 gallon tank is a very small one, in the Sudan tanks up to 0.5 million gallons were built: the larger tanks have a lower ratio of lining to volume stored, but there will be limits on size imposed by other factors, e.g. availability. For domestic uses, a sand filter system can be built as shown in Fig. 6. The "beehives" are also made from cement sausages reinforced with wire pins, i.e. they are reinformced concrete structures which require no external shuttering.

However, much further work needs to be done and other types of lining need to be evolved. At present I am working in Ghana, where polythene is over twice the price of polythene in Southern Africa - making the exercise not such an attractive one.

Table 1 gives the approximate quantities of materials required for a 10,000 gallon tank (drinking water type). These figures are based on the experience of my colleague Paul Moody.

Other Factors to Consider

To leave the details of these particular desings and return to my earlier argument on the use of rainwater compared with other sources of water, it should be realised that the cost per unit volume of water is greater for catchment tanks than for other sources, e.g. dams and boreholes. Upton found this when he made an economic appraisal of irrigation in Botswana (3). Such conclusions are typical of many facets of life - the small-scale item costs more per unit than the large-scale. However, there is the question of the availability to consider - whether or not the water is available exactly at the points of consumption it is to serve. In the case of rainwater catchment tanks it is nearly always technically possible to build a tank just where the water is required. Such a statement cannot be made of dams and boreholes. Further, catchment tanks lend themselves to self-help (indeed they would be most unattractive financially if they were built with paid labour) - and it is becoming increasingly recognised that the only way the developing countries will develop is by helping themselves, by using local materials as much as possible and by capitalising their labour.

I have already mentioned the matter of water purification in relation to rainwater. However, there is a more general point that should be made. There is a school of thought which takes the attitude that if any improvement in drinking water supplies is to be made, the system must provide pure water, up to World Health Organisation standards. There is some strength in this argument when applied to a water supply scheme which will serve several hundreds if not thousands of people - for if an infection like typhoid or cholera did enter the system then a large number of people would be affected. But when taken literally the unreasonableness of the arguement is demonstrated by the case of a village in Ghana. The village people have two sources of water - one is a very low yielding underground seep which contains guinea worm amongst many other infections. The other is a small dug-out which I would imagine from

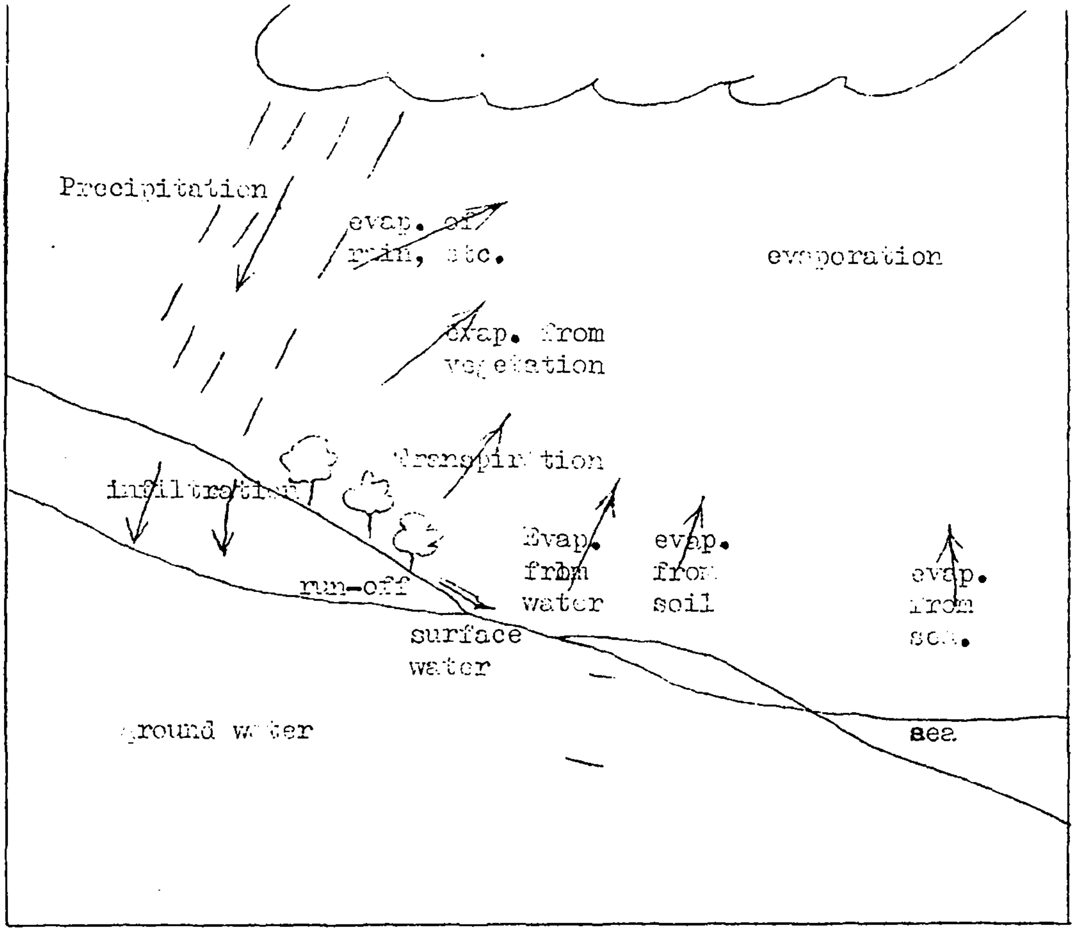

Fig. 4. The Hydrological Cycle

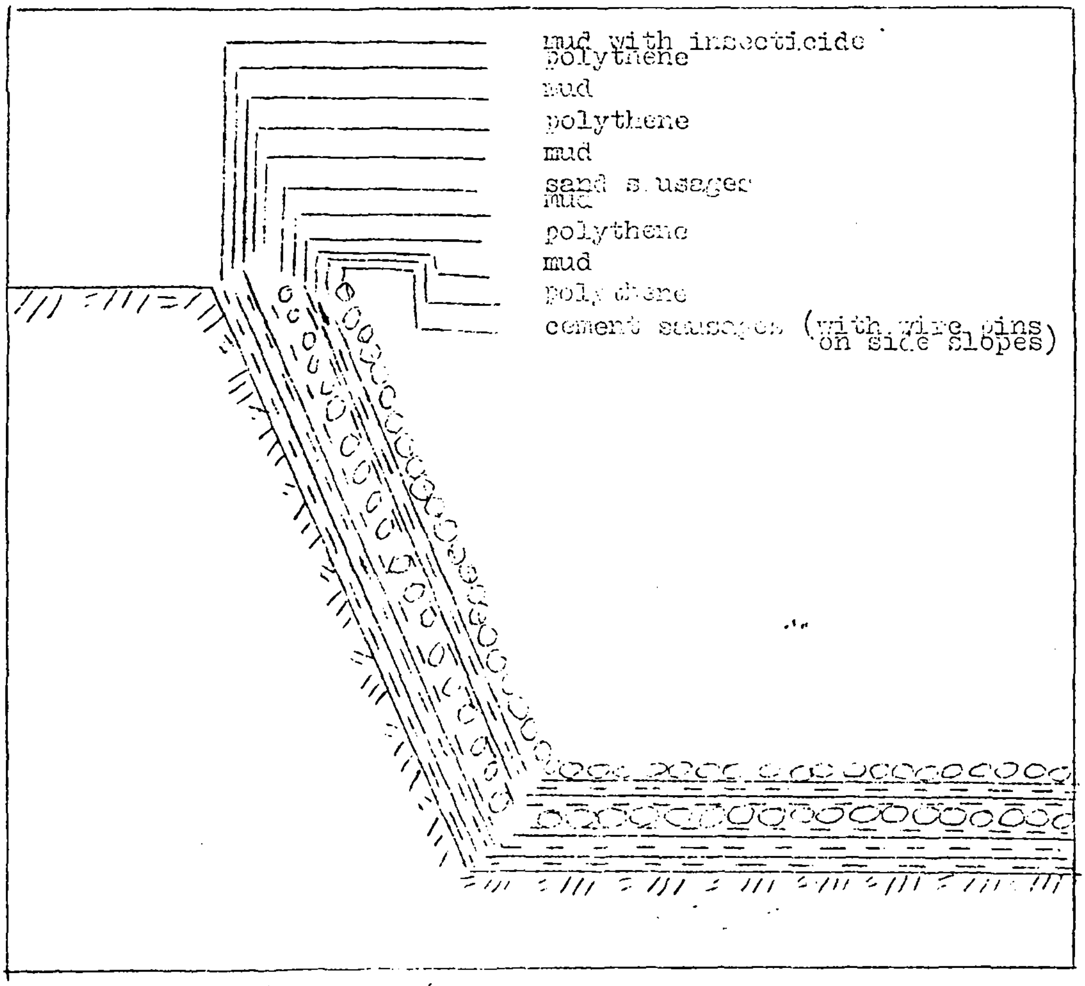

Fig. 5. The Mud/Polythene/Sausage lining

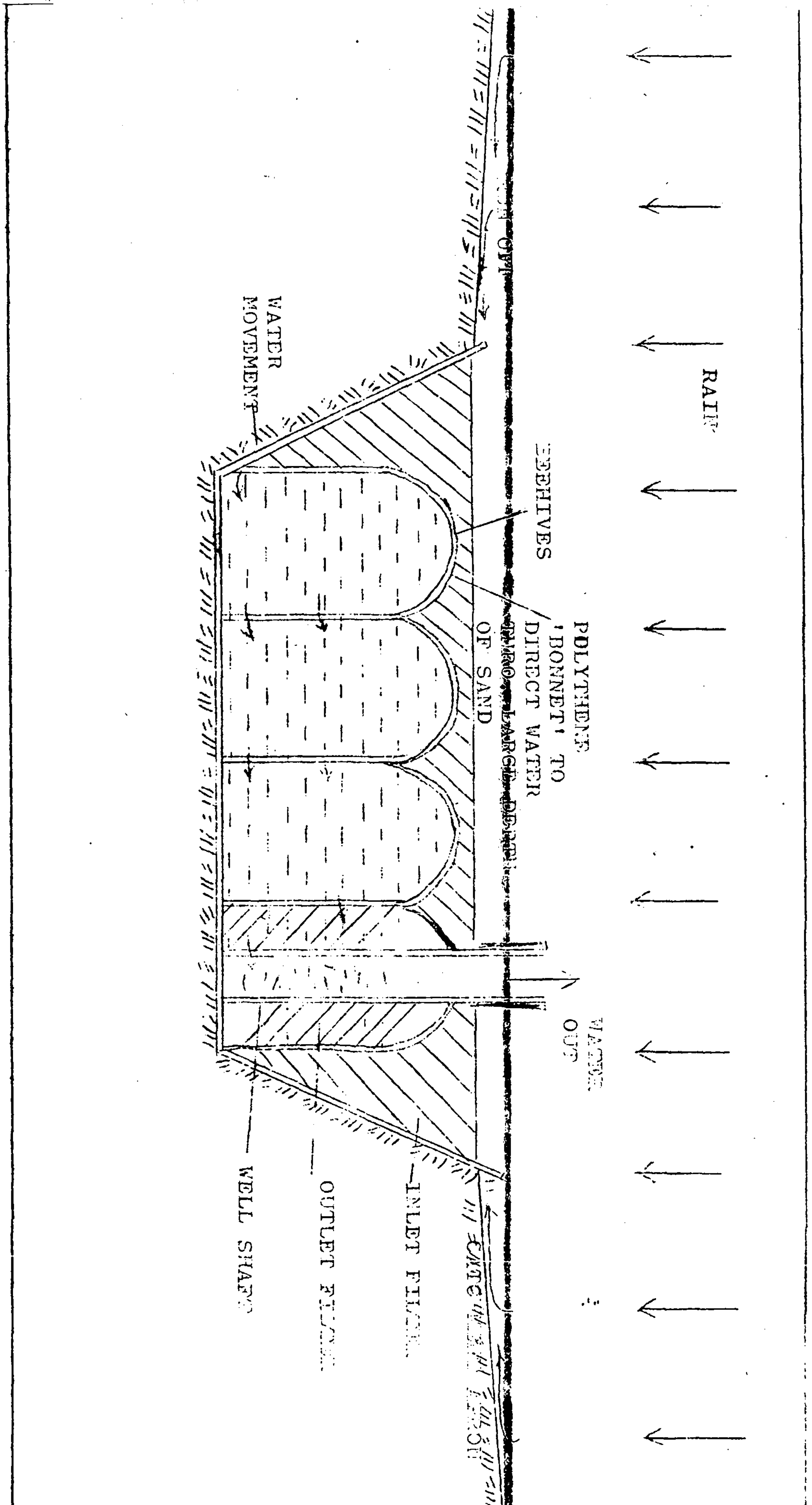

Fig. 6 . Cross-section of a drinking water-type tank.

the colour and from the numbers of small worms and larvae in it to be worse than the seep. On one occasion a water supply man visited the village, tested the water from the two sources, and declared the water unfit for human consuption. He then told the people not to drink it, and departed - making no further attempt to improve the situation. To him and to all of similar persuasion I would point out that the human body has unfortunately the ability to produce pangs of thirst, and that it is just a little unreasonable to expect people to live for years and not to drink from their sources of water (their only sources) because the water has been declared unfit for human consumption.

The water from the drinking water design of catchment tank I have described above is not pure, but at least it is reasonably clean and is a big step forward. We all hope that one day everyone will have pure water, but that day will not come overnight, and in order that the greatest number might benefit from some improvement intermediate steps are necessary.

However, I do not wish to leave the impression that I consider rainwater catchment and storage as the only possible way of providing water - it is not. But it is a most neglected subject, one that almost never figures in the standard engineering texts.

The Literature Available

This in fact is what is required - a text of ideas and methods on what Ionides calls the "Theory and Practice of Village Water Technologies". There are a number of references here and there on this level of technology, but they are rather few and far between. At Intermediate Technology Development Group I carried out a literature review on low-cost water technologies, which was published as a Bibliography (4) and a few ideas and sources of information came to light. Volunteers for International Technical Assistance, New York, have published a number of ideas, principally in the Village Technology Handbook (5). The Community Water Supply Research and Development Programme of W.H.O. have produced two background papers, "The Village Tank as a source of Drinking Water" (6) and "'Biological' or 'Slow Sand' Filters" (7). The first of these in particular contains a number of ideas on simple pieces of equipment which could be made fairly easily in the village - though I understand from W.H.O. that most of the ideas have not been actually tried out, so far as is known.

Various ideas have been put forward for simple pumps - perhaps the diaphragm pump is one that will come into vogue more and more with the availability of plastics and synthetic rubbers, making the diaphragm itself more reliable. Mention should be made of a special reprint of a series of articles by McJunkin and Vesilind (8) on the subject of practical hydraulics for the engineer. It is all basic material on the essentials of hydrostatics and hydrodynamics, bringing into a compact format the various equations for flows in pipes and open papers and ideas which to a varying extent contribute to knowledge of low-cost water technologies have been included in the Bibliography. The overall conclusion which I very definitely came to was that very little has been recorded on the techniques of village water supplies.

Future Work

In association with Intermediate Technology, further work on pumps is being done by a research worker at the University of Manchester Institute of Science and Technology. Desalination is a subject that is often raised as answering many problems, but while it has its place, it should not be allowed to grow out of perspective: there are only a limited number of places where saltwater is available. One aspect of it, solar distillation, is being looked at by a post-graduate student at Glasgow University. At the National College of Agricultural Engineering a postgraduate student is studying the problems of utilizing catchment tank water for irrigation in the most economic way possible - hopefully producing the poor man's answer to trickle irrigation.

My own work is to identify (quantitatively, qualitatively and specially) the water demands and needs of selected villages in S.E. Ghana, and also identify all the local resources - present water sources, soils, topography, village skills, traditional construction techniques, etc., that could have a bearing on the choice of design of water supply system, including the materials to be used. The intention is then to call on technical expertise in Britain to suggest how the use of imported goods (imported to the country and/or the villages) using the overall concept of rainwater catchment and storage. It seems likely that other designs, which would be alternatives to the one outlined above, could be developed. In particular the work is centred on providing good drinking water.

Much further work is needed, interest must be generated and ideas exchanged. Hence I was very pleased to learn of the growing interest in East Africa in rural water supplies, which has led to the present conference taking place.

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Table 1. Materials required for a 10,000 gallon Mud/Polythene/Sausage Catchment Tank Incorporating a Sand Filter

Dimensions:

top	-	20ft x 16 ft
floor	-	16ft x 12 ft
depth	-	7ft

Imported Materials

(i)	Polythene sheeting (150 gauge, clear) 3 rolls, 6 ft wide and 100 yds long	42 lbs.
(ii)	Polythene tubing ("Layflat" 4 or 4.5 in wide, 150 gauge, clear) 13 rolls of 500 yds.	70 lbs.
(iii)	Wire (8 gauge, plain galvanised) 4 rolls of 100 lbs each (approx. 485 yds each)	400 lbs.
(iv)	Cement 30 pockets (94 lbs/pocket)	2,820 lbs.
(v)	Insecticide (50% Dieldrin powder) 3 lbs.	3 lbs.
(vi)	String (meduim sized rolls)	5 rolls

Locally Available Materials

(i)	Mud (free of stones, grass, etc.)	Approx. 5 tons
(ii)	Sand (as clean as possible)	Approx. 24 tons

Labour

Total of approx. 250 man-days.

MAJI NA MAENDELEO VIJIJINI: THE EXPERIENCE WITH RURAL SELF-HELP WATER SCHEME IN LUSHOTO DISTRICT

by

R.R. Matango
Maendeleo - Lushoto

and

D. Mayerle
LIDEP - Water Development Section

GENERAL BACKGROUND

The importance of water for human needs is understood not only as an absolute necessity for life, but also because its quantity and quality make significant contributions to national development of any country. Tanzania has contrasting water-problems, ranging from arid and semi-arid areas without any water, to areas with plenty of water: some areas have either dirty water or scattered waterpoints where women have to walk long distances to fetch it; some have very little water, in which case the women have to queue for long hours at the wells for water. Tanzania's Rural Development Policy has purposely given a high priority to rural water supply - "for provision of better domestic water supplies (for health reasons), to reliease labour for other productive purposes and to allow a more efficient pattern of settlement".

Besides the natural contrasts of water problems, there exist great imbalances between demands of water in areas where it can be made available, and the administrative resources to meet them, between the meagre available funds for water and the non-existance of already trained personnel to implement them in the villages. In the following pages an attempt is made to show what has been done and is being yardsticks for economic growth, the experiences with water schemes in Lushoto may not apply to other districts of this country but it shows what people have managed to do with little funds, technicians and craftsmen and the problems encountered. One should in mind that an important aim of providing water in the rural areas is to serve where possible as a catalyst for Rural Development, besides being an economic investment and a social service.

Planning and Implementation

The Ministry of Regional Administration and Rural Development released Shs. 5495/00 for 10 shallow wells under Rural Self-Help schemes in Lushoto District, at the same time provided one technician and one lorry to form a Mobile Field Unit for Lushoto.

Funds were released and transfered to the Regional Office in Tanga. The area to start work was picked out of Lushoto District Second Five Year Development Plan. Lushoto Division (Ubiri) was one of the areas indicated for starting rural water supply in 1970/71 - if funds are available. Ubiri was therefore selected for being in the plan and nearer to the Administrative centre to people of Ubiri in the schemes was strongly felt, and it was realized that a self-help spirit among the people, we had to avoid full involvement in the running of the schemes. The TANU-branch Chairmen, Diwanis (councilors), and Village and Divisional Executive Officers from the wards in Lushoto Division (Ubiri) were invited to a meeting at the Ward's Headquarters.

At the meeting, the issue of water supply was discussed at length and the decision was made, first to elect a Divisional Rural Water Supply Committee, made up of 5 TANU-branch Chairmen (from 5 Wards), Ward Executive Officers (Village Executive Officers), 2 Ten Cell Leaders from each Ward, and 5 Diwanis (councillors). Secondly, 15 small committees made up of ten-cell leaders with TANU Chairmen and the Ward Executive Officers as ex-officios, to be elected by the people in each area where a scheme would be started. These small committees had to supervise the work, and in particular to ensure that every person in ten cell units reported for duty. If a person failed to do so, the committee would devise ways and means to prevent absentism and create deterrents. It was also their duty to impress upon their people that the solution of water problems was within their own means, while Maendeleo Division could provide the technical know-how.

The Divisional Committee had the power to allocate the materials to these water schemes and to withdraw or transfer the same materials for schemes in which people are not willing to participate, and to re-allocate the materials to other schems where people are prepared to work*.

Another duty for this committee is the allocation of materials to water projects, and to serve as people's representative in the whole operation.

There was a feelings to involve TANU at a higher level than the branch Chairmen. Two members of parliament were involved as catalysts; one in laying a foundation stone and doing the actual work for some days together with the people. A cinema-van came from Maendeleo Regional Office for a dual-purpose in reinforcing the campaign to complete the water schemes; firstly, by showing films on the spread of waterborne diseases and effects of drinking dirty water, and secondly, it showed films on self-help work done in West African countries, and the effect of such projects on rural life.

The Mobile Training Unit under the District (MTU) leader, is collaboration with a district Health Officer, followed in the footsteps of the film-van and conducted lessons on the need for clean water foe domestic supplies, waterborne diseases, their prevention and cure. While the work was in progress, Maendeleo Staff served the schemes in advisory capacity (Washauri), except for technical organisation and supervision with the people badly needed. In some schemes there was good response from the people, in others a very poor one. A number of reasons for these tendencies were observed, in areas where people turned out in great numbers to work, the balozis were capable to organise the people and there was little friction amongst them. In areas where there was a poor response, we observed that people felt it was the duty of Maendeleo Division to construct the water schemes for them and expected to be paid some wages they turned up for duty. Also there was little co-operation among the balozis.

Besides these setbacks, there were other factors which necessitated the progress in these schemes to be slow. When the work started, for instance, people were fasting (Ramadhani), and were at the same time expected to work on their shambas. There is a fixed timetable for self-help work in the Division (twice a week). Water schemes, therefore, increased the number of days these people have to work on self-help and so deprived them of part of their free time.

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*In fact, up to now, it has occurred only once, when the Committee withdrew sand, aggregated and cement from one scheme and re-allocated them to another for failing to comply with the requirements.

In addition, there are other seious problems which have brought some of the schemes to a complete halt. The technical advice available could not serve every scheme at the time it was needed.

There was only one technician whose movements were limited partly by lacking transport to reach the schemes or to deliver the materials, and sometimes was necessary to spend two to three days with one scheme before entrusting the work to the local craftsmen. Materials could not reach the schemes in time, because they had to be purchased in Tanga or Dar es Salaam, or because there were no transport facilities for the affected schemes. Lack of some tools like orga bits or bunka-drillers made the outcome of borehole-schemes uncertain. In some cases people thought there was water underground, but after digging ten feet they did not find water; such schemes are lagging behind now.

Despite all these difficulties there is progress. Three wells are now complete (see Appendix 1) and three more are nearing completion. More precautions are being taken to avoid problems to the villagers, particularly delays of materials and technical advice. Maendeleo Division has approached LIDEP (Lushoto Integrated Development Project, Soni) which also has some experience on rural water supply in Funta, Mayo and Mlola, with request to merge the two field units after which their services can be maximised to benefit more people than before. Already this new move has made it possible to complete Kwemlazi Water Scheme in a shorter period than was anticipated. LIDEP and Maendeleo have also agreed to share the costs in some of these schemes. It was mentioned above that the Ministry of Maendeleo had given Shs. 5495/00 for ten wells. Already this amount could not suffice even to construct ten wells (see costs in Appendix 1). To strengthen the merged field units, the Ministry has now employed 2 more technicians who have, however, to undergo an on-the-job training in this field before they can work alone in the villages.

Opportunities and Problems of Self-help in Rural Water Supply

It is not intended to raise an argument of whether or not there are potential opportunities yet to be exploited in our endeavour to develop the rural areas. Mwalimu Nyerere's authentic statement of "while some nations aim at the moon, we are aiming at the village"[2], made in 1961 has its relevance here. Which is the best rural development strategy to use if we have to aim at the village? Do we make plans in the central government and impose them upon the people of the rural sector for implementation, or can we plan and affect rural development from the bottom by giving some autonomy to local units, like Ward Development Committees (WDCs)? Or can it be done by compromising on using two principles of working from top to bottom, and vice versa together, which might mean abandoning all of them? Besides the choices of where plans are made, there are questions of improving quality and quantity and even technical designs to facilitate repairs and anticipate the likely future demands for more water through increased population, change of people's attitudes to water use and animals; and the elemination of water pollution.

For the experience gained in various self-help work in Lushoto and elsewhere in Tanzania, there are convincing reasons for the need to exploit more the field of self-help. There is firstly the need to understand the people's problems, more so to those unknown to the villagers. Secondly to educate the people so that they understand their positions as individuals in their society, nation or the world; making them aware of the rights they deserve and what they can do to change their environments to reach their desired goals. To this end we can bring our people's relations closer, as a group of common problems rather than that of blood relationship. It is true that every villager feels the need to have a water point at the door step but not every one knows how much pathogenic organisms in the water contains, nor does he really know into how much productive use could his idle labour or wasted time on fetching water be? We need not draw instances from outside Usambara which show that people's attitudes change according to their knowledge and feelings at given situations. Between the period 1885 and 1914 the Germans in the Usambaras found it difficult to get sufficient labour fource to work on their coffee plantations. They resorted to recruiting the labourers from Tabora, and made use of Hehe captives in constructing roads; later on they had to use force. Merensky, one of the German missionaries - (a) protested against the use of raw force to obtain labour (b) advocated the protection of the African from exploitation, and (c) advised the German administrators to get to know the language and the culture of the Sambaas.

Certainly in this way he felt there was need to know the problems, attitudes etc. of the people first before involving them in a programme. Today the Sambaas are among the well organised Tanzanians in doing self-help work if only they know how the project would benefit them.

The second instance is cited in an article by Dr. J. Kreysler, "UHURU NA MAJI"[3]. While collecting survey date for his Nutrition Research in Lushoto District, he found the Mayo village population highly infected with intestinal parasites. This was brought to the people's attention, and then guidance was given to make use of latrines and an improved piped water (supply) system for the village. People responded positively by doing the work themselves, collecting funds from amongst themselves to meet any necessary expenses. This does not only mean that the people volunteered to do the work because a group of leaders who were development conscious set the rolling but it is also because the people were educated, felt the need, and were given guidance and the necessary assistances.

The third instance comprises self-help projects in this district. The Maendeleo Annual Reports for 1969 and 1970 on self-help shows that in 1969 there were 59 different self-help projects. If we can examine the money saved on the completed projects in 1969 we get the figures of Shs. 312,065/75 while the figure for the 110 projects in 1970 is Shs. 724,256/70. This is a clear indication that self-help schemes could provide a viable rural development strategy if approached through the right channels.

It does not suffice to write only on miracles we expect to see in this field without exposing the problems facing self-help schemes. In fact at times those who advocate the promotion of self-help spirit are accused of being saboteurs of the schemes when they want to employ higher efficiency to complete the work in the shortest time possible. It has happended in several cases that when the labour force which was expected to come through self-help was not forth coming, a decision was made to employ paid labour to complete the work.

In our introductory remarks above the problem of lack of technicians is emphasised and the instances mentioned where we encountered problems with our rural self-help water schemes. There are many challenges which arise out of the analysis of self-help projects. Do we have any standards, judgement values or yardsticks in the field of self-help? Have we any evaluation units to determine whether our inputs for self-help and the outputs have relationship to the rural development strategies?

While we acknowledge the importance of planning, we need to survey our own resources for enhancing better plans on the village level. Without this, it is most likely that risks of starting ambitious self-help projects, which village resources can not meet will be great. We must also look into the better utilization of funds and skills and determine how to motivate the people and formulate training programmes.

The totality of all this would amount to formulating a policy for rural development. These are some of the very serious problems facing a developing country like Tanzania and a conference as this would recommend ways to improve the situation.

Maintenance and repair

Nearly all the self-help projects in Lushoto face, shortly after completion, problems of maintenance and repair. This problem is usually not considered in the initial planning. When this results in broken-down or half-working projects, the interest of the people rapedly fades. This could very often be prevented by simple planning: choosing the right design and materials and providing training and funds for repair.

Some of these problems can be illustrated by the experience at Funta. As a source for improved supply 2 wells were available; one at a destance of one kilometre from the village, but about 40 metres below the village, the other 3 kilometres away at a site 18 metres higher. The latter site had a smaller flow and a night storage tank would have been required with an additional costs of Shs. 3,000/00. The village favoured the first site, enthusiastic for having a piece of modern technology. But the experience in the Usambara and elsewhere showed that shortly after installation, pumps operate at half their expected efficienty and frequently break down. Also the petrol cost of Shs. 55/00 per month would in 5 years outbalance the higher cost of the tank.

Other design problems include taps: the stopcocks at Funta attract the children to open and close them. But the usual answer, spring taps, provide even greater attration and loss of water. More successful was the material chosen for the tank: locally available stones and galvanized bati roof, easily replaceable.

To provide for repair services when a project is being finished, a member of the village is trained to carry out minor repairs. The necessary tools are supplied Shs. 60/00. This man was not paid but having been selected by the inhabitants of the village, he therefore was freed of all other common duties. This solution is not regarded as optimal because some of these men leave the area or change villages.

In the middle of 1970, IIDEP started a training programme for Rural Mechanics at Soni. The six-month training course also covers skills required for maintenance and repair of water supplies. The trainees, supported by regular small workshops (outfit Shs. 650/00), are expected to remain in their villages.

Almost all of the trainees come from areas where the LIDEP-MAENDELEO Field Unit is in operation on water project; this solution which combines water repair with a basic trade can be regarded as more successful.

But the best solution would be if the Field Unit of Maendeleo could be a permanent operation over the years, and included a programme of maintenance and repair of self-help projects in their operations plan. Further, the villagers could be encouraged to provide a small contribution (for example per house and year Shs. 3/00, while the WD & ID rate per month is Shs. 6/00). The collection of this fees should be done by the responsible body of the village, (village Headman, TANU Chairman, VDC) for the expected upcoming repairs of the Water Supply (washers, taps, etc.) One characteristic which all self-help projects have in common (Food Mills, Water Supply) and should be encouraged is the creation of a personal and communal feeling of pride for their achievements, thus making each villager feel responsibility for taking care of the project, which is the best form of maintenance.

Costs of Self-Help Water Schemes

From the point-of view of district development the critical cost problem is how to provide the maximum improvement in water for people given a limited budget for materials with the available manpower and transport. The economist's point-of-view is somewhat different for he is concerned with "opportunity" costs, maintaining that even the labour from self-help is not really free, if the labour can be more productively used elsewhere.

For the 15 schemes in Lushoto Division and the other 4 schemes located elsewhere in the district, the estimated costs are shown in Table 1 along with quantity of water supplied, population served, and quality, where available. Excluding Funta, Mayo, Mlola, Mbula B and Majenga, where complete data are not available, it is anticipated that 4,840 people will be served with an improved water supply for a total cost of Shs. 63,730/00, including Shs. 26,490/00 for materials, Shs. 10,500/00 for technical supervision, self-help work Shs. 13,840/00 and transport estimated at Shs. 11,900/00. This gives a per capita cost of Shs. 13/10, reflecting both the ready availability of water in mountain areas and the considerable economics of small-scale-self-help project. Maintenance and repair are similarly low-cost involving some training costs, a set of tools worth Shs. 60/00 and self-help labour at each project site.

Change in Water Use

A programme of base line studies and evaluation, by Dr. J. Heijnen of the Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam who at present attached to LIDEP, accompanies the programme of Rural Water Development. The research is still underway but results of a short question given to 100 residents of Mlola are available. Of these 59 residents lived within 5 minutes distance from a tap, the others had to walk an average of 21 minutes to reach the new water source. All respondents used the tap water exclusively; no rainwater was employed.

The first results give rise to a few preliminary comments:

1. The system of distribution appears to be of paramount importance. Time savings only occurred in a significant way for those within a short distance from the tap.

Average time spent (in minutes) to collect water

	5 min or less	more than 5 minutes	Total
Before tap installation	85.03	108.95	94.84
After tap installation	25.06[a]	105.15	57.89
Number of people[b]	59	41	100

(a) Significantly different from "before tap" time (at the 0.1 level)

(b) These are man-equivalent units after Collinson who used to make comparisons between men, women and children.

2. In part this is caused by the fact that many people (58 in a total sample) collected more water. For example, those 15 minutes away from the tap often would spend more time actually carrying water.

3. A significant increase in consumption per head could only be demonstrated for these living in 5 minutes walk from the tap.

Consumption per head in litres

	5 min or less	more than 5 minutes	Total
Before tap	13.4	13.4	13.4
After tap	19.2[a]	15.7	17.8

(a) Significantly different from "before tap" (at the 0.1 level)

Although a single study in a specific environment is, of course, far from enough to justify any sweeping statements, there are some points to be learned, at least for future research on the subject. The increase in the consumption per head of the uncontaminated improved supply is presumably one of the main justifications for supplying the water at all. Secondly, there is the time saved and both elements have medical, social and economic aspects. If it is true that only a supply brought within 5 minutes from the house will bring the desired effects, that is a significant increase in consumption and time save, than the cost of a programme to supply the rural areas with improved supplies will go up tremendously. The present design criterion is to supply water within a distance of one mile.

It is suggested here that a carefully designed study be set up to measure the effect of even small distances on changes in consumption rates. Unfortunately the sample will have to be rather large in view of the large variance encountered in surveys of this nature.

The multiplier effect of self-help water schemes on Rural Development

It is an accepted fact that in Usambaras, and everywhere in Tanzania and the rest of Africa, women work hard and for long hours on the shambas. They go a long way to fetch water and they queue for long hours to get it. First, it is obvious that the amount of time wasted walking long distances and queuing at the water points can be usefully utilised for other productive activities if the women can get water right in the village. Secondly the labour which is wasted in carrying water across the fields can also be employed somewhere else for better profit. We have observed women queuing for hours at Kwemlazi and they even now continue queuing at Nkesse where it takes about 20 minutes to get 4.5 litres of water. The population which depends on this source of water is 625 of which about 200 are adult women. It is not amazing to learn that besides the time they waste, the water they draw is not clean. It is open for all possible contermination which in turn makes them not healthy, feeble and unable to work hard to produce more than the subsistence level. The improvement of rural water supply would provide more opportunities to improve social, economic and political conditions of the rural people.

If we take same improvements into large settlements like Ujamaa villages and other communities, we shall have set the pace to create multiplier effects in rural development, particularly if from the planning stage considerations for future expansions are taken into account and necessary data collected for future plans. Villagers, being trained to combat their own problems right from the planning stage to implementation, will it possible for their plans to be in line with national plans.

Table 1

Preliminary estimates of population served, quality and cost of Lushoto District Self-Help Schemes

No *	Name of Scheme	Type	Flow 1/min	Population	E. Coli	Cost of material	Cost of Self-Help labour	Cost of transport	Technical Supervision	Status
	Lushoto Div.									
1.	Mbula A	SC	24.0	285	Nil	1125	1040	Estim	Estim	PC
2.	Vulli	SC	7.5	217	Nil	880	380	total	total	PC
3.	Kwemlazi	SC	3.8	322	Nil	600	440	11.900	10.500	PC
4.	Mhelo S.	SC	10.8	465	Nil	875	360	(aver)	100%	IP
5.	Mhelo K.	SC	4.8	325	Nil	875	450	of one	time	EP
6.	Kwemdimu	SC	na	635	Nil	850	555	lorry	1 fundi	IP
7.	Nkesse	BH	na	625	na	895	350	load	1 tech.	SP
8.	Mhande	SC	na	395	na	745	630	per	60% time	IP
9.	Kabei	SC	na	176	na	745	600	day	1 tech.	IP
10.	Bondei	BH	na	325	na	820	275	40 mil	assnt.	SP
11.	Mabughai	BH	na	295	na	600	438	landr.	30% time	NS
12.	Mazumbai	BH	na	255	na	600	438	daly)	1 dev.	NS
13.	Maindei	BH	na	220	na	880	378		organ.)	SP
14.	Mbula	BH	na	na	na	na	na			SA
15.	Majengo	SC	na	na	na	na	na			SA
	Other Div.									
16.	Rangwi	PW	na	300	na	16000	7500			IP
17.	Funta	PW	11.8	750	Nil	9000	4200			PC
18.	Mayo	PW	na	600	Nil	30400	3159/80			PC
19.	Mlola	PW	na	650	na	6650	na	na		PC
	Total of 14 projects only			[illegible]840		26490	13840	11900	10599	

Grandtotal of costs: Shs. 63730/= or Shs. 13/10 per capita

Key to abbreviations:

SC = Spring catchment
BH = Borehole
PW = Pipe System
na = not available

PC = Project Completed
IP = In Progress
SP = Slow Progress
NS = Not Started
SA = Scheme Abandoned

*The location of schemes is shown in Map 1

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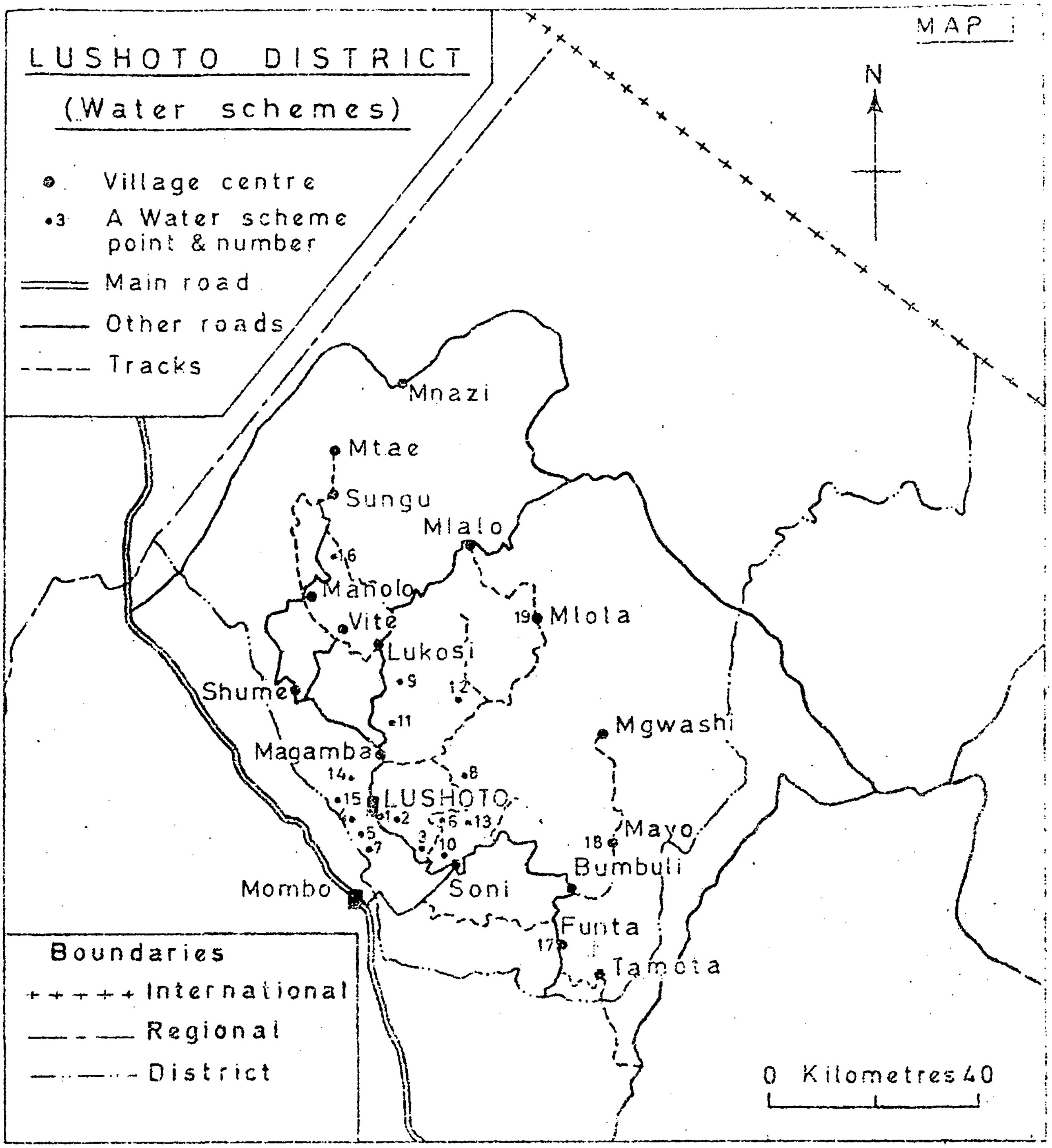


The numbers 1--19 refer to the water schemes in table 1.

SOME PROBLEMS OF WATER RESOURCES DEVELOPMENT

IN DEVELOPING COUNTRIES

By Eng. Z. Jalon & Eng. A. Mezer
of Balasha-Jalon, Consultants & Engineers Ltd.

A B S T R A C T

The object of this paper is to bring out problems encountered in planning, implementation and managment of water resources specific to developing countries. The objectives of water resources development and the methodology of planning are summarized and illustrated by projects recently completed by Balasha-Jalon Consultants and Engineers Ltd. in Africa and in Iran.

In developing countries the major objectives of water development are:

(a) Provision of adequate, close at hand, hygienically safe and dependable domestic water. This immediately and radically improves public health, serves as a basis for permanent settlements, both rural and urban and provide the necessary prerequisite for modern social and economic activities.

(b) Provision of irrigation water, especially in arid and semi-arid regions. This faciliates a rapid increase in agricultural production to provide adequate nourishment to the population as the first priority, and may also produce exportable cash crops to provide income for continued development. Irrigation will also greatly mitigate the effects of droughts. Irrigation, combined with other modern agricultural techniques, will also replace shifting agriculture by permanent settlements.

(c) Provision of water for industry, with due regard to quality requirements of specific industries.

(d) Flood protection and drainage of agricultural lands and urban area.

Priorities in the implementation of these objectives are assigned according to local conditions and development policies.

In developing countries, types of projects, degree of their technological sophistication and rates of implementation must conform to the technical ability of the population and the availability of skilled manpower for execution and management of the projects. Water development must be integrated in the framework of the national economic development.

Because of budgetary limitations and the gradual increase of demand, from the initial very low rates to the considerably higher ultimate rates, projects must be implemented in stages. Staging must be such that tangible benefits can be derived in reasonably short times and especially with relatively modest investments. In many cases this gives groundwater exploitation a decided advantage over surface water utilization (e.g. a well field with gradual, well by well expansion, as against a dam and impounding reservoir).

In developing countries, water planning is usually characterized by a lack of basic data, ranging from scarcity of maps, flow records, rainfall data, etc. to loosely defined development objectives. Demographic data on existing and future population, rates of demand, economic and social trends, etc. are very hazy in most cases. Therefore, techniques for producing synthetic data and correlations have to be evolved. Also, continuous collection of additonal data has to be incorporated in the design and the normal operation of the projects, especially in their initial stages. The initial, basic data can thus be reviewed and updated so that the design of subsequent stages is based on more reliable information. Designs have to be inherently flexible enought to permit radical adjustments within the lifetime of the projects, as new data becomes available.

The normal stages of planning are:

(a) Evaluation of present and future demands, by stages, for domestic, agricultural and industrial consumption. In forecasting future demands, special attention must be paid to the feedback effect of the development and the ensueing rise in standard of living.

In many cases, plans for economic growth and agricultural and industrial development, which establish future water demands, are totally lacking. It then becomes the task of the planning team to outline such development programmes in sufficient detail to permit it to estimate future water requirements.

(b) Evaluation of available water resources, of both ground and surface water. Quantity and quality and their areal and temporal distribution must be ascertained.

(c) Planning of water supply projects, basically accomplished by the superposition of present and future demands on the available water resources. Economic evaluations of the projects themselves, as well as their impact on the overall development scheme, serve as a basis for decision making in the planning process. However, in addition to economic considerations, intangibles, like social factors, national aims and local traditions must not be overlooked.

The planning approach should be regional, so that all pertinent factors are taken into account. The resulting optional solutions may take either of two forms. - intergrated regional schemes, or independent local schemes, covering the entire region. In developing countries, the latter form is often preferable, in view of the foregoing remarks on technical capability and the need for staging of construction. The design, however, must envisage the possibility of a future integration of local schemes, when local conditions are ripe in order to increase flexibility and dependability.

The construction, operation and management of modern water resources projects requires an administrative framework based on appropriate legislation. Guidelines for the necessary administrative and legal steps must be integration in the planning.

Three examples from the recent practice of Balasha-Jalon Consultants and Engineers Ltd., are presented to illustrate the application of the above concepts to actual engineering designs.

The first example is a domestic water supply system, installed on an area of about 1,600 sq. km., in the Nzega Region, in Central Tanzania. Although the soil in this area is relatively good, the area was sparsely populated and served only for seasonal grazing because of lack of drinking water in it. By the introduction of a domestic water supply system and the provision of stock watering facilities, the area is opened for full agricultural utilization and previously semi-nomadic population are expected to establish permanent settlements.

The second example is a Master Plan of Water Resources Development in the Benue Plateau State of Nigeria. In this Master Plan, a programme for the development of the water resources throughout the State, up to the year 2000 is presented. The programme provides the Government with a fundamental policy document on water development and can serve as a basis for the detailed design of the various schemes recommended in it.

The third example is the Jiroft Valley Development Project, in the semi-arid regions of south-eastern Iran. Here, detailed designs and plans for an area of 20,000 hectares of integrated development is provided, including agriculture, flood control, infrastructure and the required domestic and irrigation water supply project. Thereby, the present practice of soil robbing, shifting agriculture will be replaced by a modern, efficient agriculture.

THE USE OF WINDPOWER IN RURAL WATER SUPPLIES

by

F.J.H. van de Laak
Mdoleleji Water Development Scheme

1. INTRODUCTION

Rural Water Supplies have high priority in Tanzania, especially low-cost projects benefitting a large number of people. Villages, especially Ujamaa villages with their development potential, receive priority because of their population concentration.

In many areas where villages are still few and widely scattered and where water sources allow this, it will be often cheaper to construct small supplies for individual villages rather than a large supply where water is piped to many villages from a central source. Also, small village supplies may be a temporary or not so temporary, alternative to waiting many years until a large central supply becomes economically possible.

Water sources for one-village supplies may be concrete lined wells in the sands of river beds, lined wells dug into the water bearing strata of the sub-soil, or bored wells. Often such wells are located some distance from the village, and pumped supply piped to a storage tank in the village may be desirable. However, small piped water supplies in rural areas present some problems which grow larger as the number of such supplies increases.

Piped Water Supplies for Rural Villages

Engine powered supplies

Once it is decided that a village should be provided with a piped water supply, a power source must be chosen to pump the water to the village. Generally the employment of an engine is thought of as most obvious and reliable. The question is whether this is true.

Engine powered supplies have substantial recurrent costs aggravated in rural areas by the distance from the supply and repair facilities, and the conditions of the roads to the villages. Engines need fuel to run, and they need a daily attendant, either employed from public funds or recruited from an Ujamaa village itself. The reliability of the system and the frequency of breakdowns and costly repairs depend mainly on the skill of this attendant. Days may be lost in reporting breakdowns and for the repair team to reach the village. If breakdowns occur during the rainy season, the village may well be out of water for weeks because of impassable roads.

If a power-source could be found with lower running-cost and repair characteristics and without diminishing the reliability of the supply or requiring a substantially larger investment for its installation, such a power-source would be more in accordance with the low-cost requirements of the Second Five Year Plan and its alternative to engine powered supplies deserves careful attention.

It is my contention that in many instances a wind-powered supply compares favourably with engines for pumping water in rural areas.

Wind-powered Rural Water Supplies

Experience in the Shinyanga East Region with an 18 ft Climax windmill, and more recently with a locally manufactured 16 ft windmill, show that windpower can be a cheap and reliable power source which can easily complete with engines, provided that the choce of the mill is adequate for the work it has to do.

1. Windmills, one installed, require no fuel and not daily attention. They operate automatically and protect themselves from stom damage. Repairs are few. Maintanance is limited to at most a half-yearly oil change and check-up. Erection is relatively simple and cheap. A correctly installed mill, receiving its required maintanance, will often operate trouble-free for twenty years, and more. Mechanically, therefore, they are much better suited than engines to meet rural conditions. Hence, the main argument against windmills is not on its mechanical features but on the availability of wind.

2. Investment costs for a windmill installation appears to be the same or only little higher than an engine powered installation.

Wind-data

When designing a pumping plant an engineer who recommends an engine feels a security which tends to desappear when he wants to prescribe the use of a windmill.

The reason is that while engine performance can be accurately predicted from the manufacturer's specifications, in the case of windmills this information has to be supplemented with data about the reliability of the wind at the site of the plant. In Tanzania, windrecords suitable for windpowered plant design are scarce and usually inadequate; for most areas they are non-existent. The design of windmill plants then becomes only guess-work.

Considering the superior mechanical features of windmills as a power source in rural areas, it would pay to install the necessary with recorders at strategic central points, preferably at the district level. Reliable data on windregimes will then become available, and wind-mill performance predictions can be made with increasing accuracy in the course of years, making their reliability comparable with those of engines.

The recorders should be of the automatic type where windspeeds are continously recorded on a chart. When further windrecords are made at the site of the proposed plant, and at times shown in the central records to be crucial for windmill performance, comparison of these records with the central charts will show the relative windregime at the site, and an adequate windmill plant can be chosen.

To my knowledge, windrecords available at present are often on a 24 hour mileage basis. Such records are inadequate for inland conditions. Experience in the Shinyanga East Region has shown that at crucial times, usually at the change of theseasons, the 24 hour mileage record may show, for example 70 miles of wind. In reality, a windmill may pump on that day enough water for the daily requirements of the pump at all. The reason is that the mileage show may in fact be an hourly wind average of 2.9 miles/hr, at which speed no windmill will operate. The successful pumping may occur when the reading of 70 miles per 27 hour indicates a day of calm, except for two hours of hard wind exceeding 25 miles/hr. a normal occurance in the rainy season. During such a period, our climax mill which we have installed at Ndoleleji would pump in excess of 1500 gallons.

In the Shinyanga East Region, days of complete calm are few and occur only during the rainy season. Prolonged periods, exceeding three days consecutive calm, are very rare and are often followed by days of hard winds. Three years in Ndoleleji showed only four calm periods - crucial for the water supply - the longest of which was seven days. It should be noted that villagers, depending on a windmill operated system, soon find out its peculiarities and tend to be careful with water during calm days. The eason for the shortage can be noticed easily, as it is a natural phenomenon which farmers experience each day.

Contrary to what is generally assumed, a windmill plant need not operate on a 24 hour basis to be reliable, provided storage is available. Inland wind conditions are of a nature where winds occur over limited periods during the day. In Ndoleleji, night breezes often pump more water than the few hours of hard during the day.

For Rural Water Supplies, the dry season with its regular winds does not usually present a problem. The rainy season with its irregular winds, varying from light breezes to periods of calm followed by hard gusty winds, is a crucial time. Windmills should be designed to work with reasonable pumping capacities during light winds, at the same time being able to make use of short periods of hard winds. As pumping capacities rise to the square of the wind velocity, this dual demand presents no large problem. Windmills therefore, should in general be designed to match rainy season conditions, and excess water pumped in the dry season can be used for cattle drinking water, or irrigating a village garden, or it can be returned to the well via a float valve and pressure relief valve system. Float systems in the well, operating a return valve for the water, can take care of the problem of exceeding well outputs.

The demand for power in low winds calls for large sizes of mills matched to large pumps. For that reason many windmills which perform unsatisfactory in Tanzania are too small. These depend on long hours of operation in suitable winds. It is interesting to note that Australia, with its vast inland area, depends for many of its sheep farms on windpowered supplies and, to my knowledge, the Australian manufacturers are the only ones who manufacture mills in sizes larger than 18 ft diameter sails.

In the Shinyanga Region, windmills generally perform well if there size is determined on the basis of a 5.6 miles/hr. wind and the actual size of windmill and pump is one size larger than that recommended on the windmill chart.

Windmill Construction

The ordinary automatic governed-type windmill, suitable for rural areas, is the so-called multibladed windmotor. It is simple and robust and makes use of reciprocating pumps. The connection between the mill head and the pump is a wooden pumprod, moving between guides in the tower.

The rotating action of the sails is translated into a reciprocating action by means of two large gearwheels to which an accentric is connected. Usually the motion is geared down from three to four revolutions of the sails to one up and down stroke of the pump. Some Australian manufacturers (Comet, and Southers Cross) have direct acting mill heads, whereby the reciprocating action is obtained by means of a crankshaft. One revolution of the sails results in one up-and-down movement of the pumprod. The results is an extremely simple constiuction with few moving parts, especially the Comet mill. The manufacturers of Comet have added to this feature whereby the dead weight of pumprods and connections are balanced on the sailarms, taking some of their weight off the active stroke of the mill.

A disadvantage of the conventional type mill is that only about half of the windmill capacity is used for active work. The down stroke is a free stroke.

In the 16 ft locally manufactured windmill, at present installed in the water supply of Shagihilu village in Shinyanga East, the construction on this mill allowed for it to be used to full capacity. Because of lack of means to manufacture the normal moving parts, car parts were used. A landrover gear axle was placed horizontally on top of an Austin rearwheel which was fixed vertically on top of the tower. Another landrover axle was placed down. The differential pinions were made to face each other and were connected with a pipe. To the wheel end of the top axle a gearbox, activating a crank, was connected. The crank operates a seesaw via s short connecting rod, and to the seesaw the pumps are attached, each on one end of the pivot. The seesaw enabled the balancing of the mill with connecting rod and crank, and the balancing of the output, whereby on the up-stroke of the crank one pump operates, and on the downstroke the other pump, on the far end of the seesaw, operates.

The windmill starts in very low winds, and when necessary the output can be more than doubled by a simple shift of gears. It may be worthwhile to investigate the possibility of further developing this system for local manufacture, possibly diminishing the capital costs of windmill plants.

Recently, experiments and development of windpower have resulted in windpower plants making use of propellors. A Canadian experiment deserves mention in this respect where the Brace Airscrew windmill was developed incorporating a 32 ft three bladed Airscrew which operates a centrifugal pump. In its experimental stage it was used for irrigating a 10 acre plot and performed satisfactorily. In 18.5 miles/hr. winds the mill developed 10 HP, and in 30 miles/hr. winds 50 HP. It can be used for water supplies and, depending on wind power available, for irrigating fields and operating maize grinders.

Another propellor-type wind power pump is manufactured in Germany by Lubing, Barnstorf. These are cheap and range in price from Shs. 600/00 to Shs. 1000/00. They are used for small capacity cattle drinking water and garden irrigation. Their outputs are from 444 gallons to 1320 gallons per day at a head of 20 ft and in winds of 6.7 miles/hr. The firm also manufacturers larger plants on the same system suitable for small village supplies under certain circumstances, costing up to Shs. 6000/00.

Conclusions

From the above it may be concluded that the use of windmills for pumping water in rural water supplies should be seriously considered. Satisfactory windmill operated supplies enable funds and manpower, otherwise used on existing supplies, to finance new supplies. They are a means to speed up considerably the spread of rural water supply, which has high priority in the Second Five Year Plan.

FIELD INVESTIGATIONS ON FRICTION LOSSES OF "SIMBA" PLASTIC PIPES

by

P.M. Todorov
Regional Water Engineer, Ministry
of Water Development & Power

I. INTRODUCTION

The friction losses along the water supply pipes are the basic element on which all hydraulic calculations are based. The discharge coefficient 'C', which is most commonly used for designing water supply, is based on experimental data. The possible deviation by using different formulas can be neglible in the comparison with the possible errors caused by a wrongly estimated friction coefficient.

While for the GSP those values are quite well established and properly used, this is not the case for the comparatively newly fabricated plastic pipes. This paper is intended as a modest contribution to the problem of producing more accurate values for the friction losses of "Simba" plastic pipes.

The presented data are the result of the field experiments carried out in W.D & I.D. depot at Tanga. The findings should not be treated as final, since the number of the pipes measured is rather small. Further investigations are still going on.

II. METHOD OF EXPERIMENTATION

For the field investigations, a simple experimental stand has been installed and used (see Fig. 1). The test plastic pipe has been connected to a water supply steel tank as a water source and the outlet of the pipe connected with a stop-valve, where the water discharged is to be measured by a V-notch spillway. Two transparent pipes are fixed and graduated at both ends of the test pipe to show the differences between piezometric level by varying the water discharge. Knowing the actual value of the water discharge and the hydraulic gradient, and with the relationship

$$i = \frac{\Delta h}{L} \qquad (1)$$

it is possible to draw graphs of the actual friction losses for different diameter pipes.

For the purpose of better analysis and discussion of the results, the Hazen - Williams formula has been used to calculate the actual values of 'C'. For this calculations the old "foot-cusec" system has been used:

$$V = 1.318 \times C \left(\frac{D}{4}\right)^{0.63} \times i^{0.54} \qquad (2)$$

$$\text{OR} \quad Q = 0.432 \times C \times D^{2.63} \times i^{0.54} \qquad (3)$$

As the logarithmic scale is most suitable for the case, the calculations of 'C' are made on the basis of:

$$Lg\ C = LgQ + 0.36453 - 2,63 LgD - 0541 gi \qquad (4)$$

The dimensions of 'C' are ft $^{0.5}$ x Sec $^{-1}$ or in the metric system $M^{0.5}$ x Sec $^{-1}$, and if we take the metric value of C:

$$C(M) = 0.3048 \times C_{(ft)} = 0.55210_{(ft)} \qquad (5)$$

For easier comparison the values in the table are given in the English system.

III. RESULT AND COMMENTS

The results are show in Table 1. An increase in the coefficient 'C' with pipe diameter can be observed. The result of the 3" pipe does not seem correct and it most likely not representative since only one pipe has been tested.

Table 1

PIPE	Nos. of pipes Experi-mented	Nos. of Experi-ments carried out	VALUE OF C (ENG. STANDARD)			PIPE-
			Actual average Exp. value	Reduced by 12.5%	Recomme-nded	
1" Class 'B'	2	12	171.1	149.7	150	1" (B)
1½" Class 'C'	3	12	172.6	151.0	150	1½"(C)
1½" Class 'B'	3	13	204.2	178.7	175	1½"(B)
2" Class 'B'	2	9	204.0	178.5	175	2" (B)
3" Class 'B'	1	6	167.5	146.5	145	3" (B)

For the practice a friction diagram with reduced values in recommend (ss Fig. 2). Here 12½% allowances are made, accounting for the imperfect pipelaying and the different fittings.

Unfortunately, no data for the change of the roughness of the plastic pipes with age are available; therefore such experiments are strongly recommended.

IV. CONCLUSION

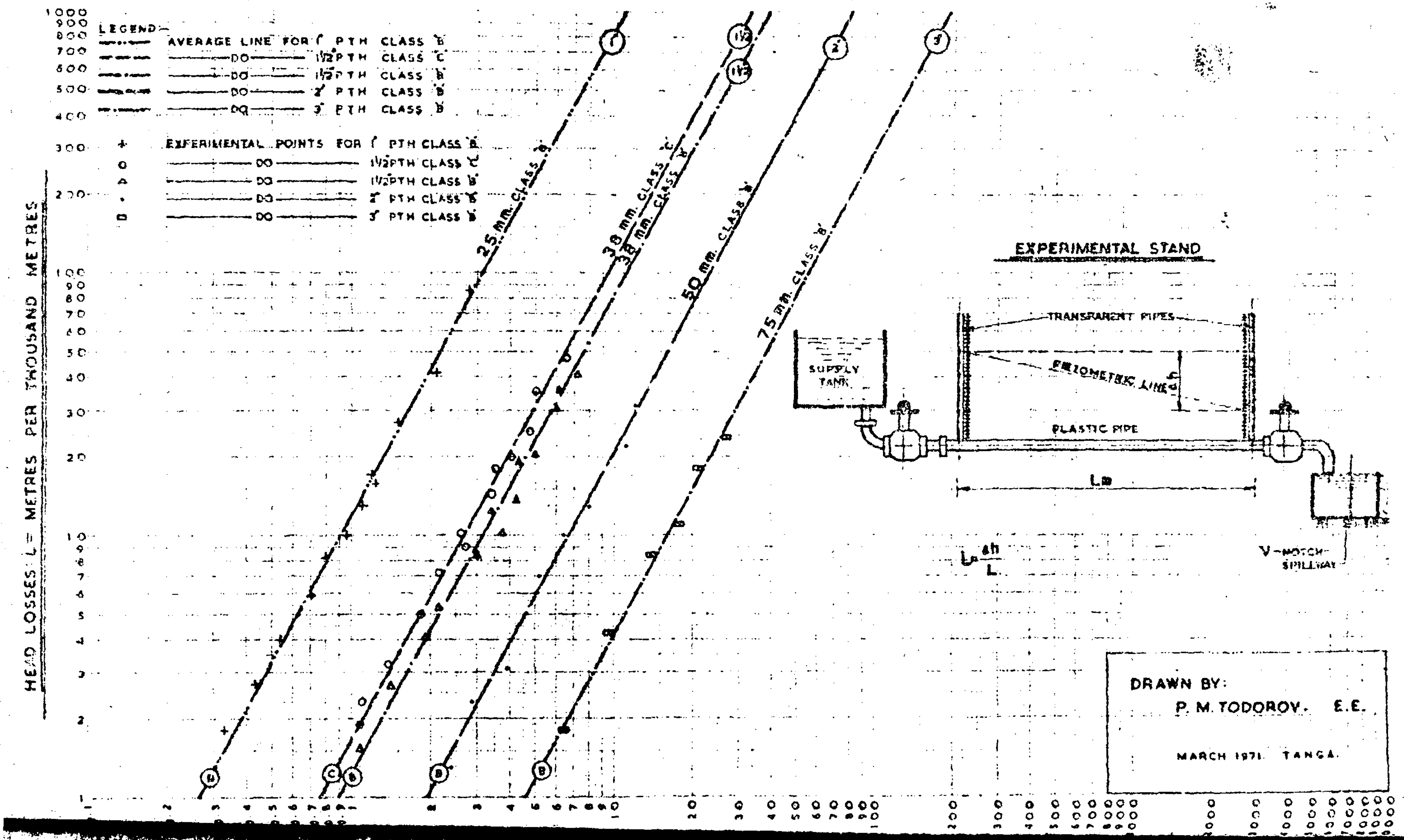
The use of available data for the friction coefficient 'C' could often result in wrong calculations, causing technical failures and economically unjustified projects.

Field experiments can produce the actual values of the friction losses, and such investigation are therefoer recommended for all new types of pipes.

EXPERIMENTAL FRICTION GRAPHS FOR "SIMBA" PLASTIC PIPE:

INVESTIGATIONS CARRIED OUT AT W. D. & I. D. TANGA

fig. 1



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PIPE—

1" (B)

1½" (C)

1½" (B)

2" (B)

3" (B)

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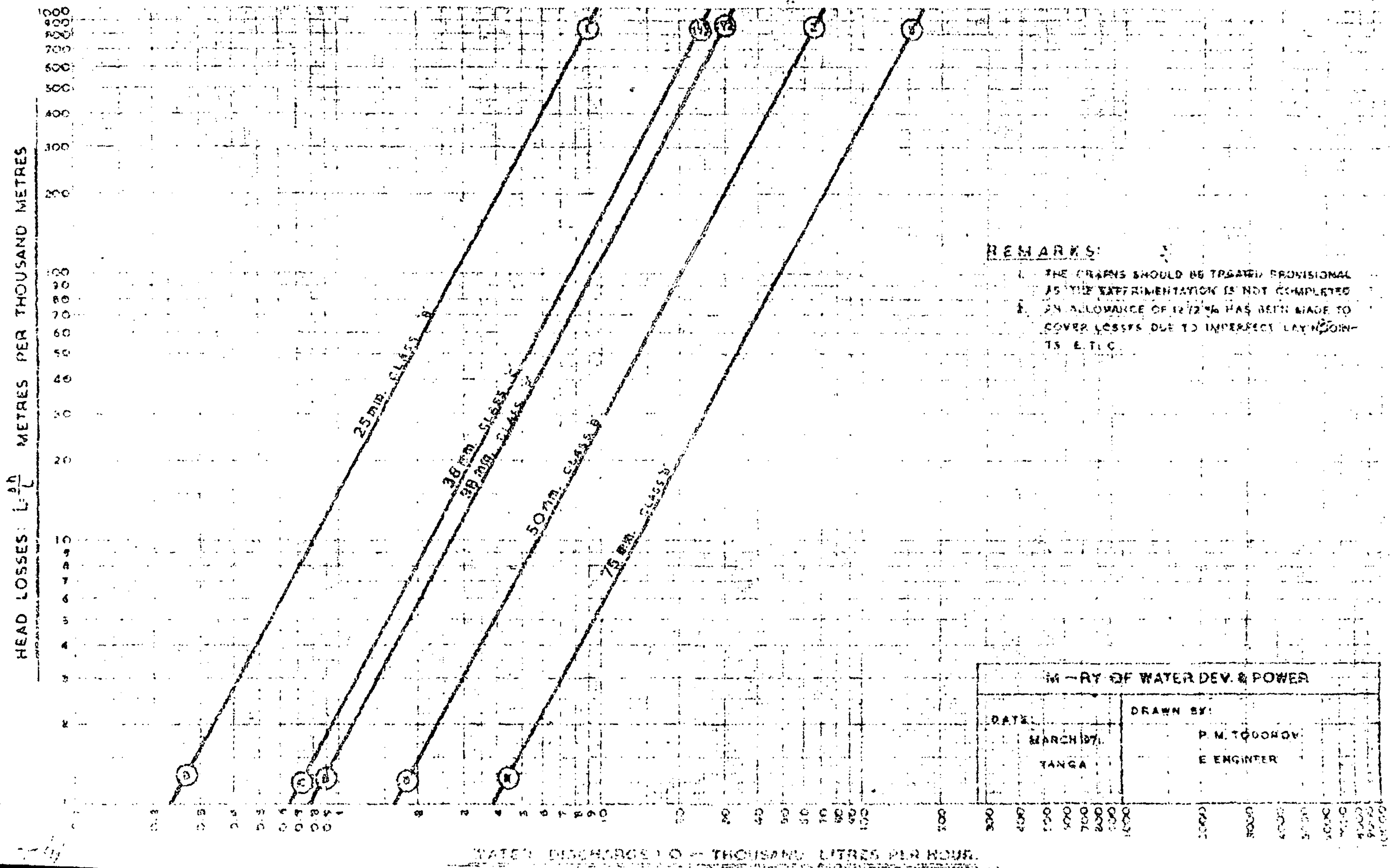
"SIMBA" PLASTIC PIPES FRICTION DIAGRAM (IN METRIC)

BASED ON EXPERIMENTAL DATA PRODUCED BY W.D.&I.D. TANGA.



APPENDIX A.

FINAL RECOMMENDATIONS[1]

Planning and Policy

(1) Considering the large number of regions for which water development master plans are to be prepared, the conference recommends that guidelines be established to standardize the approach to study teams engaged in the preparation of such master plans in order to facilitate the final decision making process. The standardization should include the design, and analysis of projects, as well as selection criteria, construction cost, maintenance cost, water quantity and quality standards, terms of finance, etc.

(2) The conference draws attention to the need for an inter-disciplinary approach in the preparation of national and regional master plans for the development of water resources, bringing in and strengthening a variety of institutions on the national and regional level. Furthermore, the preparation of regional master plans by various teams should be preceded by preparatory work, on an interdisciplinary basis, by the government of the respective country, so that the teams can be given uniform guidelines at the start of their studies.

(3) The conference recommends that intensified comparative research on the social, economic and health effects of water supply in different rural environments be undertaken on a national and international level.

Hydrology and Meteorology

(4) The conference notes the inadequacy of meteorological data in East Africa as reported in the Workshop on Rural Water Supply in East Africa, December, 1969, Dar es Salaam,[2] which is highlighted by the proceedings of this conference. Considering the urgent present and future needs for adequate and high-quality meteorological data for development planning, it is recommended to:

(a) bring the existing raingauge network to existing standards of operation,

(b) ensure a regular inspection and maintenance of all meteorological stations, at least twice a year for main stations and once in two years for rainfall stations,

(c) expand the raingauge network to meet needs for data sparse areas,

(d) install an adequate network of wind recorders (apart from its meteorological importance this would provide planning data for windmills and other engineering projects),

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[1] The recommendations were drafted by the workshops and approved in the final session of the conference.

[2] See D. Warner (ed.), Rural Water Supply in East Africa, proceedings of the workshop on Rural Water Supply, BRALUP Research Paper No.11, 1970.

(e) upgrade all main meteorological stations to Penman standards, and

/the (f) qualify the publication of meteorological data by indicating the date of last inspection and/organization responsible for it.

(5) The conference further recommends:

(a) placing greater importance on adequate maintenance of the existing hydrological network,

(b) expanding the network in areas lacking data, and

(c) giving particular attention to instrumentation and data collection in small catchments.

(6) The conference, noting that different types of instruments provided by different countries are presently in use in the meteorological and hydrological services now operating in East Africa, recommends that appropriate arrangements to be made by the responsible authorities in the meteorological and hydrological services to ensure standardization of instruments in use by these services. It also recommends the standardization of observing and maintenance procedures, and of staff training. This standardization should be effected by means of close liaison between the respective services, through cooperation between the IHD national committees, to become operative as soon as possible. The conference also recommends that the presentation and publication of data in these fields be standardized as far as possible.

Design, Implementation and Health

(7) Further research is needed to provide a better basis for the selection of design criteria, including per capita water consumption, water quality, length of design period, storage tank capacity, pump capacity, peak flow, and material of pipes. This research might be carried out by the countries' research institutes in conjunction with the respective departments of water development.

(8) Present policy in East Africa assumes that a large part of the health benefits from improved water supply can be obtained by providing standpipes. The evidence to support this assumption is not strong, and there is some evidence, relating to infectious diseases, hat suggests the contrary. The conference strongly recommends a comparative study in Tanzania's Ujamaa villages of the benefits and costs of designs in relation to health.

(9) The conference stresses the importance of continued emphasis on training of manpower on all levels in the field of water resource development. In particular, a major shortage of technical staff exists to work under the direction of professional engineers. The rural water supply programmes could be accelerated if more technitians were available. We recommend that, in collaboration with the Ministries of Education, an in-service training and advancement scheme be established to assure the promotion of specially able serving technical officers and works foremen according to their ability.

APPENDIX B.

Monday, 5th April

Introduction: Dr. I. Katoke, Associate Dean, Faculty of Arts and Social Science University of Dar es Salaam.

9.30

Opening Address: Dr. W.K. Chagula, Minister for Water Development and Power (delivered by Mr. F.K. Lwegarulila, Principal Secretary, on his behalf)

11.00 - 12.30

Planning - Master Plans

Chairman: F.K. Lwegarulila

Robert W. Kates, "Flexibility, Coordination and Choice in Water Resource Planning: The Utility of Recent Planning Innovations for Water Development in Tanzania"

Len Berry and Diana Conyers, "Planning for Rural Water Development in Tanzania"

Rushdhi Henin, "Determination of the Base Population of the Area and Future Population Size"

2.30 - 3.30

Planning - Policy

Chairman: Teshoma Workie

Ian Burton, "Towards a Rationale for Water Supply Policy in Developing Countries"

J.D. Heijnen and Diana Conyers, "Impact Studies of Rural Water Supply"

4.00 - 5.30

Planning - The Broader Context

Chairman: Hamisi Mwinyigoha

Hartmut Walter, "Educational and Ecological Aspects of Rural Water Planning"

Roger Woods, "Social Structure and Water Supply - Questions of Rural Development Strategies in Tanzania"

Tuesday, 6th April

9.00 - 10.30

Planning - Procedures

Chairman: G. Schultzberg

George W. Irvin, "Problems of Benefit Cost Analysis in Planning of Rural Water Supply"

Gerhard Tschannerl, "The Use of Mathematical Models in Water Supply Planning"

Andre Harlaut, "Investigations, Survey and Design of Rural Water Supplies"

11.00 - 12.30 — **Hydrology and Meteorology** (continued)

Chairman: H.T. Mørth

Elfatih A. Hasan, "Shallow Artificial Recharge of Groundwater"

R.L. Raikes, "Rural Water Supplies in Semi-Arid Conditions - Permeable Dams"

2.30 - 4.00 — Workshops (see below)

4.30 - 5.30 — Workshops

Thursday, 8th April

Morning — Visit to Kerege Ujamaa Village

2.30 - 3.30 — Reports from the Workshops

4.00 - 5.00 — Adoption of resolution and closing address

* *

WORKSHOPS — 3 groups meet concurrently in the afternoon of the 7th. They have the following themes.

GROUP 1 — PLANNING AND POLICY - ARTS SEMINAR ROOM B

Chairman: G. Dekker

GROUP 2 — HYDROLOGY AND METEOROLOGY - ARTS SEMINAR ROOM C

Chairman: U. Riise

GROUP 3 — DESIGN, IMPLEMENTATION AND HEALTH - ARTS SEMINAR ROOM D

Chairman: V.T. Kiossev

The chairmen report on the discussion in their group and draft the final resolutions.

APPENDIX C.

List of Participants

Airaksinen, Mrs. U.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Barting, Bo.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Bateman, Gordon H.
Department of Applied Physical Sciences, University of Reading,
England.

Bear, Eng. J.
Balashn and Jalon Consultant Engineers; 61, Haatzmauth Road,
Haifa, Israel.

Berry, Dr. Len
BRALUP, University of Dar es Salaam, P.O. Box 35097, Dar es Salaam.

Bower, Rod C.
National Water Resources Council; P.O. Box 9242, Dar es Salaam.

Bradley, Dr. David J.
Dunn School of Pathology, University of Oxford; South Parks Road,
Oxford OX1 3RE, England.

Buchanan, A.
Ministry of Water Development and Power; P.O. Box 9291, Dar es -
Salaam.

Bugaisa, Stephen L.
Mineral Resources Division, Dodoma.

Burton, Dr. Ian
Department of Geography, University of Toronto;
Toronto, 181, Ontario, Canada.

Chakraborty, T.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Chakraburtty, R.N.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Chagula, Dr. W.K...Minister
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Chambers, Dr. Robert
Institute for Development Studies, University of Nairobi,
P.O. Box 30197, Nairobi, Kenya.

Chande, S.J.
Howard Humphreys and Sons, Consultant Engineers; P.O. Box 2555,
Dar es Salaam.

Clark,
Ministry of Agriculture, Water Development Division,
P.O. Box 30521, Nairobi, Kenya.

Conyers, Miss Diana,
BRALUP, University of Dar es Salaam;
P.O. Box 35097, Dar es Salaam.

Csontes, K.
Ministry of Water Development and Power; P.O. Box 9291, Dar es Salaam.

Csongrady, K.
Ministry of Water Development and Power; P.O. Box 9291, Dar es Salaam.

Dekker, G.
Regional Advisor on Water Resource Development; Economic Commission for Africa, P.O. Box 3005, Addis Ababa, Ethiopia.

Dhalla, H.H.
Water Development, P.O. Box 174, Singida, Tanzania.

Dredsner, M.
Balasha and Jalon, Consultant Engineer; 61, Haatzmauth Road, Haifa, Israel.

Falu, J.
Ministry of Water Development and Power, P.O. Box 9291, Dar es Salaam.

Frank, H.
Society of Applied Geophysis Ltd; Eduard-Schmid-Strasse 3, 8 Munchen 90, W. Germany.

Hagan, Ivar.
Ministry of Water Development and Power; P.O, Box 9291, Dar es Salaam.

Harlaut, Andre
VBB Vattenbyggnadsbryan; P.O. Box 5038, S-102 41 Stockholm 5. Sweden.

Hasan, Elfatih A.
Hydrometeorological Survey of the Lakes Victoria, Kyoga and Albert; P.O. Box 192, Entebbe, Uganda.

Hay, Robert
East African Meteorological Department; P.O. Box 3056, Dar es Salaam.

Henin, Dr. Roushdi A.
BRALUP, University of Dar es Salaam, P.O. Box 35097, Dar es Salaam.

Heijnen, Dr. J.D.
BRALUP, University of Dar es Salaam, P.O. Box 35097, Dar es Salaam.

Hwakabisana, Principal,
Technical College; P.O. Box 2958, Dar es Salaam.

Irvin, George W.
Institute of Development Studies, University of Sussex; Brighton BN1 9RE, England.

Jalon, Eng. Z.
Balasha and Jalon, Consultant Engineer; 61, Haatzmauth Road, Haifa, Israel.

Jackson, Dr. [illegible]
Department of Geography, University of Dar es Salaam; P.O. Box 9291, Dar es Salaam.

Johansen,
Water Development Department, Ministry of Agriculture; P.O. Box 30521, Nairobi, Kenya.

Kamunvi, Dr. F....Secretary,
East African Medical Research Council; P.O. Box 1002, Arusha, Tanzania.

Kates, Dr. Robert W.
School of Geography, Clark University, Worcester, Massachusetts, 01610, U.S.A.

Kesseba, Dr. A.
Faculty of Medicine, University of Dar es Salaam, P.O. Box 20693, Dar es Salaam.

Khuti, R.
Ministry of Water Development and Power; P.O. Box 3030, Arusha, Tanzania.

Kiossev, V.T.
Ministry of Water Development and Power; P.O. Box 762, Mbeya, Tanzania.

Kukove, Mrs. Maria,
Technical College; P.O. Box 2958, Dar es Salaam.

Kuschel, H.
National Water Resources Council; P.O. Box 9242, Dar es Salaam.

Lucas, R.O.
Ministry of Water Development and Power; P.O. Box 9291, Dar es Salaam.

Lundquist, Jan,
BRALUP, University of Dar es Salaam, P.O. Box 35097, Dar es Salaam.

Lwegarulila, F.K....Principal Secretary,
Ministry of Water Development and Power; P.O. Box 9153, Dar es Salaam.

Lwelamila, A.J.
Ministry of Economic Affairs and Development Planning; P.O. Box 9242, Dar es Salaam.

Maier, A.D.
Bish and Patners, Consultant Engineers; P.O. Box 7040, NAIROBI, Kenya.

Mann, Dr. Georg
National Water Resources Council, P.O. Box 9242, Dar es Salaam.

Matango, R.R....Rural Development Officer,
District Development Office, P.O. Box 81, Lushoto, Tanzania.

Matteucci, A.
IFO Research Institute, Munich, Germany

Matteucci, Mrs. A.
University of California, Berkeley, California, U.S.A.

Mayerle, Dieter
LIDEP, P.O. Box 60, Soni, Tanzania.

Mbelwa, H.A.
Kibaha Education Centre; P.O. Box Kibaha, Dar es Salaam.

McKay, John,
BRALUP, University of Dar es Salaam; P.O. Box 35097, Dar es Salaam.

Meghji, M.H. (a)
Faculty of Agriculture, University of Dar es Salaam;
P.O.Box 643, Morogoro, Tanzania.

Mezer, Eng. A.
Balasha and Jalon, Consultant Engineers;
61 Haatzmauth Road, Haifa. Israel.

Mihalyi, L.
Department of Geography, University of Zambia,
P.O. Box 2379, Lusaka. Zambia.

Moller, H.C.
Ministry of Water Development and Power; P.O. Box 220, Iringa
Tanzania.

Moris, D.L.
Masailand Range Development Project; Kilimo, Arusha, Tanzania.

Moris, Dr. J.R.
Department of Political Science, University of Dar es Salaam:
P.O. Box 35091, Dar es Salaam.

Mörth, Dr. H.T.
East African Meteorological Department; P.O. Box 3056, Dar es -
Salaam.

Msimbira, H.K.
National Water Resources Council; P.O. Box 9242, Dar es Salaam.

Murray-Rust, Hammond
BRALUP, University of Dar es Salaam; P.O. Box 35097, Dar es Salaam.

Mwalwega, A.L.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Mwinyigoha, Hamisi,
Ministry of Agriculture, Food and Cooperatives;
P.O. Box 3092, Moshi, Tanzania.

Mzee, A.
Water and Drainage Division; P.O. Box 1878, Dar es Salaam.

Nieuwolt, S.
Department of Geography, University of Zambia;
P.O. Box 2379, Lusaka, Zambia.

Okot, P.C.
East African Meteorological Department; P.O. Box 3056,
Dar es Salaam.

Olsen, Alf
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

Patel, B.H.
Ministry of Water Development and Power; P.O. Box 9291,
Dar es Salaam.

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(a) Research Notes

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Reprinted June, 1969

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- Part 5a* I. Jackson, "Rainfall Stations in Tanzania", October, 1968
- Part 5b* I.D. Thomas, "Population Density in Tanzania"
- Part 5c "Bibliography of the Geology and Mineral Resource of Tanzania" to December, 1967. August, 1969
- Part 5d D. Conyers, "Forestry in Tanzania," October, 1969
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(b) Research Papers

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