THE ROLE OF HYDROLOGY AND HYDROMETEOROLOGY IN THE ECONOMIC DEVELOPMENT OF AFRICA

LE RÔLE DE L'HYDROLOGIE ET DE L'HYDROMÉTÉOROLOGIE DANS LE DÉVELOPPEMENT ÉCONOMIQUE DE L'AFRIQUE

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INTRODUCTORY NOTE

This publication (Volume II) contains papers for presentation at the Conference on Hydrology and Hydrometeorology in the Economic Development of Africa (Addis Ababa, from 13 to 23 September 1971). This volume was published before the conference. Volume I contains the actual proceedings, reports and recommendations of the conference.

NOTE D'INTRODUCTION

Cette publication (Volume II) contient des communications destinées à être présentées à la Conférence sur le rôle de l'hydrologie et de l'hydrométéorologie dans le développement économique de l'Afrique (Addis-Abéba, 13-23 septembre 1971). Ce volume a été publié avant la conférence. La Volume I, quant à lui, contient les comptes rendus, rapports et recommandations de la conférence.

HEAT AND WATER BALANCE STUDIES IN NIGERIA

by J.S. Oguntoyinbo

ABSTRACT

This paper reviews the major methods and problems associated with the study of heat and vapour fluxes in Nigeria. One major feature is the lack of the correct and appropriate data on the radiation fluxes in such an environment. This problem is being tackled but the scale and the scope need to be examined. Studies in radiation and evaporation need to be undertaken in different parts of the country especially as Nigeria straddles across the major climatic zones in West Africa. For this purpose, it is suggested that an agrometeorological set-up similar to the one operating in the Middle East should be built in West Africa to cope with the problem of data co-ordination and analysis, instrumentation and research and training of agrometeorologists. For the reasons stated Nigeria offers the best location for such a station.

RESUME

L'ouvrage passe en revue les principaux problèmes et méthodes liés à l'étude des flux thermiques et des flux de vapeur d'eau au Nigéria. Un élément majeur est l'absence de données pertinentes et exactes sur les radiations existant dans le milieu considéré. L'étude de ce problème est en cours, mais il y a lieu d'en accroître l'échelle et la portée. Il faut entreprendre des études sur la radiation et l'évaporation dans différentes parties du pays, compte tenu en particulier de ce que le territoire nigérian traverse les principales zones climatiques de l'Afrique de l'Ouest. Il est suggéré à cet effet de mettre en place dans cette sous-région une installation agro-météorologique semblable à celle qui fonctionne au Moyen-Orient et destinée à régler les problèmes de coordination et d'analyse des données, d'équipement en instruments, de recherche, et de formation d'agrométéorologistes. Le Nigéria, pour les raisons indiquées, constitue un emplacement idéal pour une station de ce type.

INTRODUCTION

In a tropical environment such as Nigeria, where temperature does not hinder crop cultivation at any season of the year, water supply constitutes the major resource for agricultural activity. Moisture supply (either directly from rainfall or by artificial irrigation processes) determines the types of crops and the length of the period of crop cultivation. The need to understand the complex processes of moisture utilization by plants is well illustrated in the literature by the various studies of heat and vapour fluxes relating to the problems of evaporation and evapotranspiration. This will not be discussed in this paper.

This paper is intended to review the results of the major agroclimatological research work undertaken in Nigeria within the last ten years and to suggest likely areas for the intensification of effort in this field bearing in mind the recent trends in agricultural development in the country. It is proposed therefore to discuss the major contributions in the field of evaporation and evapotranspiration (Garnier, 1956 and Davies, 1965a, Obasi, 1969) and in the field of radiation (Davies, 1965b, 1965c and Oguntoyinbo, 1970a, 1970b); these works represent the major contributions from which it could be possible to identify areas in which further research could be intensified.

DETERMINATION OF EVAPORATION AND EVAPOTRANSPIRATION

In most agricultural and hydrological problems involving a water budget it is the total water loss that is important; some of this loss comes directly from the soil and by interception from leaf surfaces (evaporation) while some comes indirectly from the soil through the plant (transpiration). The combined effect of this is known as evapotranspiration. When a crop is kept plentifully supplied with water, the rate at which the water is transported is dictated by the weather with plant and soil playing only secondary roles (Penman, 1948). The idea of water supply being a non-limiting factor has been termed by Thornthwaite (1948) as potential evapotranspiration (PE).

The various methods of estimating the PE are clearly described by Thornthwaite and Hare (1965). In his research studies at the University of Ibadan, Garnier paid great attention to the problem of evapotranspiration and the results of his work at this site are witnessed by the several notable contributions to the climatology of Nigeria and West Africa (Garnier, 1954, 1960). As a result of his observations, Garnier (1960) came to the conclusion that for Nigeria, Thornthwaite's (1948) empirical approach overestimated the potential evapotranspiration in the wet season and underestimated it in the dry season. He attributed the dry season disparity between the measured and the computed PE in the north of Nigeria to the effects of an extremely dry atmosphere, whereas in the south extremely moist air characterizes all seasons. Garnier also noted that during December, January and February the computed values showed a downward trend while the measured values rose sharply. Finding that (1) saturation deficit followed the same trends as the measured PE and (2) saturation deficit overestimated PE in the dry season, Garnier incorporated an aerodynamic term into the Thornthwaite method to reduce discrepancies between measured and computed values, viz:

$$x = T + S_d \text{ (day time)} \qquad \text{(1)}$$

where T = evapotranspiration computed by Thornthwaite's formula in mm/day,

and S_d = the mean saturation deficit in mm of Hg.

This summation is read into a regression formula

$$x = ay^b \qquad \text{(2)}$$

where a and b are constants which were found to be 0.675 and 2.198 respectively obtained from the data of Ibadan in the south and Samaru in the north.

When the results were plotted for the whole country (Fig.1), the isolines showed that the highest PE (60" p.a.) are observed in the extreme northeast and less than 50" p.a. in the coastal areas where the rainfall is highest. By comparing the results from Garnier's work with those obtained from applying the methods of other workers, Obasi (1969) observed amongst other things that the results obtained from the Garnier method are more variable than those obtained from either the Thornthwaite (1948) empirical approach or the Penman (1948) aerodynamic method. The result of such an exercise leads one to the conclusion that the problem of evapotranspiration still remains unsolved.

In his studies on radiation and evapotranspiration in Nigeria, Davies (1964) employed Garnier's existing installations for inquiry into the fundamental relationship between radiant energy and water loss, i.e. evaporation and evapotranspiration. But owing to a lack of data on solar radiation, Davies (1965b, 1966) had to approximate radiation from sunshine and cloudiness - parameters for which data were more easily available in West Africa. Davies noted the inadequacy of cloud observation as a parameter in such an exercise; he therefore checked his results against the records from a Gunn-Bellani net radiation integrator (Davies, 1965c).

The result of this study showed that there is a strong north-south gradient of radiation (Fig.1). In terms of annual totals the radiation level in the north (190 Kg.cal) is almost double the level in the south (110 Kg.cal). It was also observed that the radiation field can be divided into two at about lat. 9°N. To the north of this boundary the gradient is less and in the extreme north-east, it is negligible. This relative homogeneity was tentatively ascribed to the homogeneity of cloudiness and turbidity characteristic of the atmosphere which lies to the north of the ITD. To the south of lat. 9°N the gradient is much steeper; such a phenomenon was ascribed to moist surface southwest air stream which lies to the south of the ITD.

MEASUREMENT OF RADIATIVE FLUXES

In his estimation of insolation for Nigeria, Davies (1965b, 1966) noted the general lack of data on radiation, hence he had to estimate the values of insolation by indirect method which he himself regarded as not very satisfactory. In the measurement of radiative fluxes one important parameter to be measured in estimating the radiation and water balance of crops is the surface reflectivity. Seginer (1968) demonstrated theoretically that evapotranspiration can be reduced considerably by increasing the reflection coefficient (albedo). If such a method can be perfected the result will be a major asset to agriculturists in arid, semi-arid or seasonally dry areas such as are characteristic of the northern part of Nigeria. Data on the reflection coefficient (albedo) are hitherto not available for Nigeria (Davies, 1966). As a first step to rectify this anomaly, Oguntoyinbo (1970a, 1970b) undertook a countrywide series of observations (lat. 4° 40'N to lat. 13° 30'N) to determine the reflection coefficient (albedo) over a wide variety of natural vegetation and agricultural crop surfaces at different seasons in Nigeria. The weighted mean reflection coefficient value for the series of observation summarized in Table 1 was found to be .17$_8$.

As a sequel to this project a more detailed microclimatological study is at present being undertaken on the radiation balance of cocoa. Observations begun in February 1970 will last till January of 1971. These observations are being taken at two-weekly intervals in a cocoa research plot at Moor Plantation, Ibadan. The variables being measured above, within and below the canopy include the net (R_N), reflected (α), and total direct (S) and diffuse (s) radiation. The ultimate aim is twofold: to establish the microclimate of cocoa crop and also to develop a radiation balance formula which might be quickly applicable for the other crops for which the reflection coefficient term has already been determined.

Preliminary analysis of the data for the first six months of observation was discussed at a recent Conference in Accra (Oguntoyinbo, 1970c). The three main parameters of the radiation balance equation, reflection coefficient (albedo), heating coefficient and long-wave radiation, were derived from linear regression equation relating the measurements of the incident and reflected short-wave radiation to the measurement of radiation balance. The results show that for the period between February and July 1970, the daily totals of radiation ranged between a minimum of 195 $cal.cm^{-2} day^{-1}$ on a cloudy day in May to a high of 498 $cal.cm^{-2} day^{-1}$ on a bright sunny day in the same month. The daily total of the net radiation expressed as a percentage of the total incoming short-wave radiation was found to be 58% which compares favourably to the estimated value of 60% as the mean for summer conditions in the higher latitudes (Thornthwaite and Hare, 1965). The mean reflection coefficient for diurnal observations was found to be .18. The transmission coefficient (List, 1966) was 41% and the heating coefficient (β) (Monteith and Szeicz, 1961) was .26. There was also a high correlation between the heating coefficient (β) and the long-wave radiation (L_o) except when cloud cover is very high (Table 2). Of the total incoming short-wave radiation less than 15% reaches the base of the canopy where, in the case of cocoa, most of the fruits are borne. Such a lack of direct radiation coupled with a high relative humidity may be a major factor in the seasonal incidence of the swollen shoot and black pod diseases characteristic of the cocoa crop in this environment. Such a speculation requires further investigation.

The foregoing résumé highlights the achievements in the field of heat and water balance studies in Nigeria; it also reveals the areas in which further investigation needs to be carried on. Obasi (1969) showed that the Garnier method of calculating the PE is inconsistent; Davies also noted the lack of data on radiation in the process of estimating the PE for Nigeria. These studies require more careful investigation especially bearing in mind the rapidly developing scientific agriculture in Nigeria. In Nigeria, evapotranspiration is highest where the rainy season is shortest and most unreliable, consequently only one grain crop can be cultivated in one year in most parts of the north. However, the broad river valleys (fadamas in Hausa) subject to seasonal flooding provide large areas of potentially cultivable land in the dry season. These are being ineffectively utilized by peasants for the cultivation of certain crops like vegetables and rice. However, with the rapidly increasing population and the corresponding increase in demand for food and raw materials for industries, these tracts are being developed for large-scale irrigation schemes. The seasonal drought characteristic of the interior of the country where these broad valleys are located accounts for the fact that most of the recently developed schemes are to be found in the northern part of the country (Fig. 2). A typical example of this is the 8,000 acre Bacita Sugar Estate located in the River Niger fadama about 18 miles to the east of Jebba (Oguntoyinbo, 1965). Such large-scale irrigation projects constitute an innovation to Nigerian agriculture. Buchanan and Pugh (1955) observed that:

> "artificial and man-controlled irrigation as opposed to natural or flood irrigation for the dry season occupy a more restricted area" but that "through irrigation vast expanses of the sub-humid areas of the Middle Belt and the Sudan Zone could be made to produce specialized crops such as rice, sugar cane and vegetables and would reduce the seasonal character of the activities in the savannah environment."

The trend in the past decade has been the development of such large-scale irrigation schemes (Oguntoyinbo, 1970d) in which the problem of water management is of paramount importance. Most of these projects are preceded by pilot surveys in which greater attention is given to the details on soils, terrain and accessibility with less details on the microclimate. The risk run when a major project lacks details on microclimate of the environment was illustrated by the loss incurred at the Bacita Sugar Estate in 1967 season; this was alleged to be due to an unforseen drought (Sugar Cane Chronicle, 1968).

As a result of the rapidly expanding development of large-scale irrigation projects, it is suggested that detailed agroclimatological studies of major crops of interest should be undertaken to determine the heat and water balance of such crops. Reference can, in this respect, be made to the role of the Volcani Institute of Agriculture in Israel whose Division of Agricultural Meteorology is engaged in detailed research on the major crops - cotton (Stanhill and Fuchs, 1963 & 1968) orange (Kalma and Stanhill, 1969) and groundnuts (Stanhill and Fuchs, 1970). Efforts are made to interpret the results in such a manner as to be easily applicable by farmers (Fuchs *et al.*, 1963).

The role of the Meteorological Services cannot be over-emphasized in this respect; the Nigerian Meteorological Services need to expand the agrometeorological division both in scale and scope. Considering the size of the country and the amount of data that would be involved, one would advocate that a set-up similar to that located in the Meteorological Services at Bet Dagan in Israel whereby data processing is computerized, would be appropriate for a station located south of the Sahara. Nigeria offers the best location for such a set-up. The fact that its areal extent traverses all the major climatic zones in West Africa is an asset that cannot be claimed by any other country in West Africa. In order to reduce the cost of instrumentation, purchasing, repairs and calibrations, it is also suggested that an instrument workshop annexed to the central computing office would be a major advantage because such a workshop would reduce to a minimum the number of handicaps experienced by purchasing equipment from overseas.

With regard to the processes for estimating evaporation and evapotranspiration, it will be recalled that Davies (1965) and Obasi (1969) found that the Garnier (1956) method has a number of limitations. Davies (1965) suggested that a careful and detailed hydrological study of a large water body should be made to determine evaporation (E_o) from the water balance equation; Lake Kainji recently completed on the River Niger will provide a good location for such a study from which results obtained can be compared to those obtained from similar studies being undertaken elsewhere - for instance on Lake Tiberias in Israel (Stanhill, 1969a, 1969b).

Davies (1965) also suggested that owing to the inherent difficulties of measuring PE directly, the method of using lysimeters should be discontinued and replaced with the direct measurement of net radiative flux over green vegetated surface. This is being attempted, as has been referred to earlier on, but there is still a large amount of work to do. For example, (1) more of such agro-climatological research as reported earlier in this paper is required, especially in the seasonally dry belt of the northern part of Nigeria where irrigation is coming into vogue; (2) West Africa is faced with the unusual problem of atmospheric dust during the harmattan season; it will be of interest to study the impact of this on the radiation balance. One may again in this respect refer to the set-up at the National Physical Laboratory of the Hebrew University in Jerusalem where such a study is in progress and (3) with the greater refinement in lysimetry, it would be of interest to install more weighing lysimeters in different parts of the country to measure evapotranspiration directly.

In summarizing this paper, one can state that there is at present no standard agro-meteorological station in Nigeria. Such a station as is envisaged should be fully equipped for the measurement of the heat and vapour fluxes, the repairs, calibration and even manufacture of some simple instruments. In such a set-up facilities should be available for both research and for the training of workers to man the smaller stations.

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Table 1 - Mean Reflection Coefficient over different natural vegetation and agricultural crop surfaces in Nigeria (mid-day observations)

Vegetation Type	Reflection Coefficient	Crop Type	Reflection Coefficient
Swamp Forest	.12	Cocoa	.16
Tropical Rain Forest	.13	Kola nut	.13
Derived savanna and Fallow	.16	Cotton	.21
Guinea Savanna	.19	Sorghum	.20
Sudan Savanna	.20	Groundnuts	.17
Sahel Savanna	.21	Yams, Cassava, Tobacco	.19
Jos Plateau	.16	Maize	.18
		Sugar Cane	.15
		Swamp Rice	.11

Source: Oguntoyinbo, J. S. (1970b)

Table 2 - Linear regression of Net Radiation (R_N) versus Net short-wave radiation $(1-\alpha)(S+s)$ $Cal.cm^{-2}min^{-1}$

Date	S+s	R_N	$\frac{R_N}{S+s}$	α	(1-)(S+s)	a	b	β	r	L_o
7/2/70	.6122	.3504	.57	.15	.5185	.8343	-.36	.1986	.97	-.0843
20/2/70	.5230	.3036	.58	.17	.4320	.7912	-.12	.2839	.99	-.0793
5/3/70	.5379	.3019	.56	.13	.4653	.6792	-.03	.4711	.97	-.1432
19/3/70	.5807	.3690	.64	.14	.5006	.7812	+.012	.2801	.99	-.0984
2/4/70	.6347	.3999	.63	.16	.5357	.8454	-.10	.1828	.98	-.0716
24/4/70	.5974	.3744	.63	.23	.4624	.8968	-.03	.1150	.99	-.0447
9/5/70	.7217	.7917	.54	.23	.5579	.8621	-.11	.1600	.99	-.0655
21/5/70	.2825	.1449	.51	.20	.2263	.7014	-.18	.4258	.99	-.0606
4/6/70	.6329	.3513	.56	.19	.5118	.6974	-.10	.4339	.98	-.1430
18/7/70	.4674	.2618	.56	.19	.3885	.7786	+.022	.2844	.99	-.0691

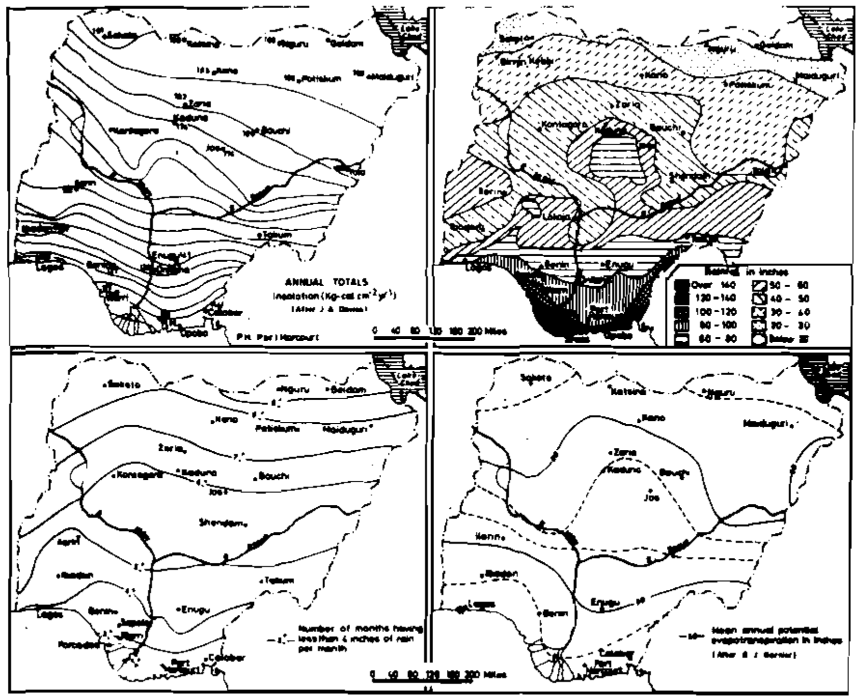

Figure 1 - Insolation, rainfall and evapotranspiration in Nigeria

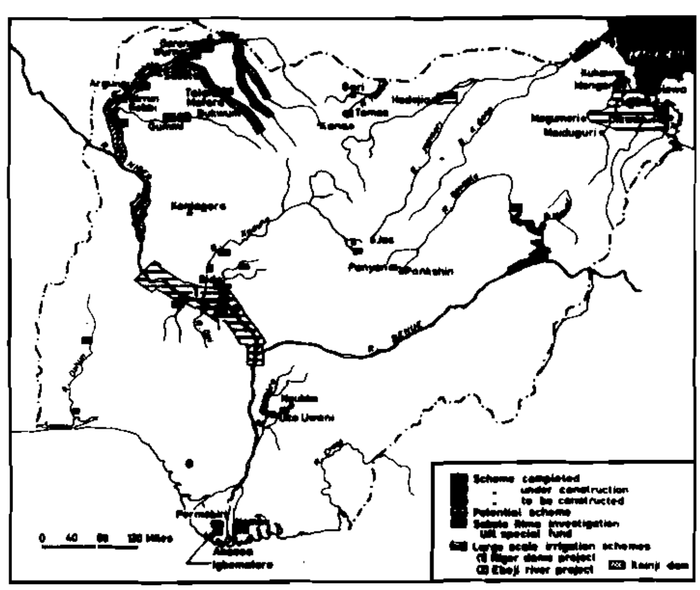

Figure 2 - Major irrigation projects in Nigeria, 1969

THE DEVELOPMENT OF INTERNATIONAL DRAINAGE BASINS

by Dr. Adetoye Faniran

ABSTRACT

The idea of integrated and co-ordinated study and development of river basins is not new; many projects have been carried out on almost all the drainage basins of Africa, aimed at this noble goal.

It is suggested here, as a way of possibly improving the existing system, that the Economic Commission for Africa sets up a Water Resources Committee, if it has not already done so. This body should consist of experts in the various aspects of the drainage basin, including geomorphologists, hydrologists, meteorologists, agronomists, ecologists, economists, engineers, and planners, and should be empowered to set up drainage basin authorities for Africa's major drainage basins, whose activities it will have to oversee and collate. In addition, the existing national and intra-state bodies should be linked, such that the activities of one are co-ordinated and controlled by a higher body. The ECA Committee on Water Resources should also store all available data on Africa's drainage basins, as well as keep an up-to-date record of all data-storing offices.

RESUME

L'idée d'intégrer et de coordonner l'étude et l'aménagement des bassins fluviaux n'est pas nouvelle; presque tous les bassins versants d'Afrique ont été l'objet de multiples projets orientés vers ce louable objectif.

Il est suggéré ici, comme un moyen possible d'améliorer le système existant, que la Commission économique pour l'Afrique institue, si elle ne l'a pas déjà fait, un Comité des ressources hydrauliques. Cet organisme serait composé d'experts des diverses disciplines intéressées par les différents aspects des bassins hydrographiques, c'est-à-dire de géomorphologistes, hydrologistes, météorologistes, agronomes, écologistes, économistes, ingénieurs et planificateurs, et il serait habilité à créer pour les principaux bassins hydrographiques africains des Commissions d'aménagement dont il aurait à contrôler et à analyser les activités. En outre, une liaison devrait être établie entre les organismes nationaux ou autres existant à l'intérieur d'un état de façon que leurs activités respectives soient coordonnées et contrôlées par une instance supérieure. Le Comité des ressources hydrauliques, institué à la CEA, devrait aussi recueillir et conserver toutes les données disponibles sur les bassins versants africains et tenir également à jour un fichier de tous les bureaux conservant des archives.

INTRODUCTION

The development of international drainage basins may be viewed from at least two perspectives. There are those who think of the river basin as perhaps one of the most suitable for most types of planning. These people advocate that the best form of planning is the comprehensive development of all the resources, natural and socio-economic, within given drainage basins. This idea is fully discussed in a United Nations publication (1955). The second approach to river basin development is called the integrated and multi-purpose development, which involves mostly the natural, especially water, resources. Integrated river basin development is also adequately covered by another United Nations publication (1958).

The distinction made here is mainly for convenience, since, according to a former school of thought, multipurpose and integrated development of river basins is only a stage in the evolution of the concept of river basin development. According to these people, the ultimate goal of all river basin development is the comprehensive type, involving all the elements of the basin and undertaken by a single body (cf. Faniran, 1970a).

There are problems, even with the second, less ambitious approach, arising mostly from the fact that political boundaries rarely coincide with drainage basin boundaries. The commonest case is for a river to flow across two or more countries, thus raising the difficult problem of international co-operation. Political problems can be so intractable that they can stop all forms of development. As such, the whole idea of using drainage basins as planning units of any time is not generally accepted.

This paper will not concern itself with the advantages or otherwise of drainage basins as planning units. Rather, it will (a) briefly review the present state of our knowledge of drainage basins, (b) consider the drainage basins of Africa and their international status, (c) discuss some of the existing examples of international co-operation based on drainage basins and (d) offer suggestions as to how to improve the existing system, especially in relation to data collection and storage.

THE CONCEPT OF THE DRAINAGE BASIN

The drainage basin is currently one of the most studied natural regions, being studied by the geomorphologist, the hydrologist, the ecologist, the conservationist, and even the socio-economist. The growing popularity of this land unit or land system is preferred for two main reasons: first, the drainage basin is a limited, convenient, usually clearly-defined and unambiguous unit area; and second, it represents an open system in equilibrium, in the sense that there is a sort of delicate balance between the input factors of precipitation, solar radiation, etc. To the geomorphologist, the drainage basin area can be readily traced on maps and its perimeter can be followed on the ground, along water divide or watershed, especially in accessible country. Moreover, it usually consists of a number of interrelated systems (tributaries), so that the basin can be readily broken down into its tangible components, each of which fits neatly into a nested hierarchy of sizes, based on the principles of stream ordering. Consequently, the drainage basin, following the pioneer work of people like Horton (1945), is now one of the most closely and quantitatively studied land units. The form and the processes operating within many drainage basins are now generally so well understood that we can speak of laws, such as the law of stream length, of stream numbers, of basin relief. Similarly, the hydrologist has in the drainage basin a handy area for the study of the interrelations of rainfall, water loss and consequently water balance. These factors are closely linked with plant and animal life, and so the study of drainage basins necessarily involves the co-operation of many disciplines. Examples of integrated or inter-disciplinary approach to river basin study abound in literature, but we are concerned here solely with the African continent, to which we need to restrict our discussion.

THE DRAINAGE BASINS OF AFRICA

Africa is blessed with a number of large and small rivers, including the Nile, the Niger, the Congo, the Zambesi, the Limpopo and the Orange. Some of these rivers mark international boundaries, e.g. between Congo Kinshasa and the Central

African Republic (the Ubangi River), or between Rhodesia and South Africa (the Limpopo), but the general situation is for the boundaries to cut across the various river basins. The number of autonomous states lying within the single drainage basins in Africa varies from two (in the case of the Southwest Coastal and the Southeast Coastal drainage basins to twelve in the case of the Coastal West African System). These examples are perhaps not the best, mainly because the systems consist of a number of small rivers. The situation is, however, not too different in single basins with the integrated river networks. While the Senegal basin comprises four states, the Congo basin comprises ten states and the Niger eleven states (cf. Figure 1, a, b, and c; cf. also Table 1).

The situation just described shows the gravity of the problem of international co-operation in Africa, especially with regard to integrated river basin development. If it took India and Pakistan many years to agree on the utilization of the resources of the Indus River, or the United States of America and Canada with respect to the Columbia River (cf. Beckinsale, 1969), the progress so far made in Africa needs not only to be mentioned but also to be praised.

AFRICAN EXAMPLES OF INTERNATIONAL DRAINAGE BASIN DEVELOPMENTS

The development of drainage basins may involve a single nation or a number of nations and Africa has examples of both. By far the most common drainage examples today are those undertaken by individual countries, for instance the many dam projects including the Volta (in Ghana) and the Kainji (in Nigeria). Nevertheless, there are examples of developments which involve two or more countries, from which lessons could be learnt. The earliest examples of these are those along the Nile and the Kariba dam on the Zambesi. The former concerns four countries - Uganda, Sudan, Ethiopia and Egypt and so involved the signing of international agreement (Barbour, 1957). The latter was built when the countries concerned belonged to the Central African Federation, a defunct political arrangement embracing Southern Rhodesia (Rhodesia), Northern Rhodesia (Zambia) and Nyasaland (Malawi). Nevertheless, there was need for agreement among the countries, which apparently has now been overtaken by events, following the breakdown of the federation and the still unresolved Rhodesia independence problem.

The more recent examples of international co-operation in the development of drainage basins in Africa are offered by West Africa. Since 1963, three regional subgroups based on drainage basins - the Niger River Commission, the Lake Chad Commission and the Organization of Senegal River States (OERS) - have emerged. These organizations are very important in themselves, since they epitomize the events in other parts of the world with regard to international co-operation. They are briefly described in what follows.

The River Niger Commission is an organization of the nine states, Mali, Guinea, Chad, Cameroon, Ivory Coast, Dahomey, Nigeria, Niger and Upper Volta, which flank the Niger and its tributaries. Formed in 1963, with its headquarters at Niamey, Niger, the main aim of the organization is perhaps best expressed by a one-time secretary of the group thus: "Each of the nine member states of the Commission has something in common. The Niamey Charter forces us to agree and to understand each other....." in order to benefit fully from the study and planned development of West Africa's greatest river (West Africa, 1967, p. 309). Already, the organization can boast of a number of achievements, especially on the scientific front. In August 1967, four of the members - Niger, Nigeria, Dahomey and Mali - signed "The River Niger Agreement" with the Dutch Government to study the navigational problems between Goa and Yelwa. The Lower Niger, within Nigeria, has also been studied, in connection with the Kainji Dam project (Nedeco, 1961) while scientists have been invited to study other sections of the river, especially in its upper reaches.

The Chad Basin Commission comprises Nigeria, Niger, Cameroon and Chad countries which lie within the Lake Chad Basin. The headquarters is at Fort Lamy (Chad), and its achievements are also in the field of scientific study which has involved a number of international bodies such as the Unesco (United Nations Educational, Scientific and Cultural Organization), the FAO (Food and Agricultural Organization) and the CDC (Commonwealth Development Corporation).

Finally, the Organization of Senegal River States (OERS), first established in March of 1964 as the Senegal River Committee and attaining its present form on signing a statute at Labe (Guinea) in March 1968, comprises Senegal, Mali, Mauritania and Guinea. Its headquarters is at St. Louis and its main aim is best summarized by quoting a one-time member of the organization, former President Modibo Keita, who once wished that the inter-state committee should work efficiently in order "to transform the regional sub-group...... into a system of unity based on real facts which will courageously face the problems raised by harmonization and unity" (West Africa, 1967, p. 1464). Its achievements so far include the study of the water resources and agricultural potentialities of the Senegal basin (begun in August 1969), the building of dams to improve navigation as far as Kayes, the planned improvement of port facilities at St. Louis, Rosso, Dagari, Podor, Kaedi and Matam, the signing of a trade agreement between Mali and Guinea abolishing duties on certain goods and the arrangement of industrial plants whereby each member specializes in one or the other of the major manufacturing industries.

Despite the various achievements of these organizations, they are beset by many problems. The Niger basin is perhaps too big (730,000 sq. miles / 1,118,000 sq. km.) and the states concerned too many for easy planning. The drainage basins are also inhabited by peoples with different languages, political and socio-economic backgrounds, mainly as a result of years of colonial rule. The ready availability of capital and of qualified personnel is another problem. Finally, and perhaps the most important, is the nature of the organizations themselves. In each of the three cases just cited in West Africa, the various governments are directly involved in the arrangements. This means that political problems, which are perhaps better left till a later stage after the basic studies of the resources, the costs of their development and the benefits derivable therefrom have been made, are being tackled first. Thus, with respect to the Senegal River states, the Guinean Head of State initially refused to co-operate fully with the others, but Guinea has now been replaced by Mauritania. Definitely, this is not the best way to develop international drainage basins, and the weaknesses in the set-up may have been responsible for the slow progress in many fields.

In contrast to the above situation, gigantic projects have been successfully launched by individual countries - e.g. the Volta and the Kainji schemes in Ghana and Nigeria respectively. However, one needs to assess the effects of these schemes in their widest contexts over the entire drainage basins before a reasonable auditing can be made. A recent study downstream of the Kainji Lake shows the untold hardships and losses the Lake has caused the local inhabitants, mainly because the authorities failed to recognize such problems (Adeniyi, 1970).

The problem of organizing the collection of data is also felt at the national level; for instance, in Nigeria, hydrological and related data are collected and stored by the various State administrations, many of which lack both the experience and the expertise. As a result, much valuable information has been wrongly filed, or even lost completely. Moreover, the hydrological stations, for instance, along the Kaduna river, which were established by the former Northern Regional Government are now shared among at least four states. This means that anybody looking for hydrological data on this small catchment area will have to visit four state capitals - Jos, Kaduna, Sokoto and Kano - probably only to be disappointed when the different authorities cannot locate the required information. What this all adds up to is the need for reorganization of the data-collecting procedure, so as to facilitate better co-ordination and centralization than hitherto.

SUGGESTIONS FOR IMPROVEMENT

There are many ways of improving the present set-up in various parts of Africa. The ideal situation is for a body to be in complete control of each of the main basins, as in the case of the Tenessee Valley Authority (TVA). Within the African context this will necessarily involve scientists and expert planners drawn from the various interested states and possibly also from the various international organizations with the necessary expertise. The main duty of a river basin authority, at least at the initial stages, will be concerned mostly with the collection of the necessary data on the various aspects of the basin, including geomorphology, hydrology, hydrometeorology, agrometeorology, climate, soil, vegetation, minerals and possibly socioeconomic and other aspects of the human geography of the basin. Should there be in existence a functional body, such as the River Niger Committee or the Organization of the Senegal River States, the final decision on the ordering, or arranging of, priorities will be left to this body.

The situation in Asia and the Far East, where a number of comprehensive drainage basin development schemes are already under way, clearly illustrates this last point. The Economic Commission for Asia and the Far East (ECAFE) has apparently played major roles with respect to data collection as well as in providing expert advice on the types of organizations that are needed for effective operation of plans. The present author quite recently wrote in this connection: "The Economic Commission for Africa (ECA) may also be encouraged and/or advised to do for Africa what its counterpart for Asia and the Far East has done, and is still doing, in the latter region in terms of river basin development" (Faniran, 1970a). The ECA seems to be in the best position to provide the incentive, framework, personnel and possibly also the finance for the co-ordination of both the scientific study and the planned development of Africa's major rivers. In order to do this, a system which encourages co-operation and co-ordination at varying levels of authority is very necessary.

The following system is suggested. The Economic Commission for Africa (ECA), perhaps in collaboration with other international (interested) bodies such as the Organization of African Unity (OAU), the United Nations Educational, Scientific and Cultural Organization (Unesco), the World Meteorological Organization (WMO), and the International Hydrological Decade (IHD) should set up a sub-section of the Commission charged with the responsibility of:

(a) Drawing up the "master plan" for the study and perhaps also for the development of Africa's water resources, in the best interest of all the countries concerned;

(b) Collating and co-ordinating the activities of the major (and possibly other) drainage basin bodies;

(c) Acting as a bank for all data (hydrological, hydrometeorological, agrometeorological, etc.) collected on the various drainage basins; and of

(d) Acting as a direct link with, among others, the International Hydrological Decade, the World Meteorological Organization and the Unesco.

The various river basin authorities, established perhaps initially for the six major drainage basins but eventually for all the others shown in Figure 1a, will be concerned with applying the "master plan" to particular drainage basins and effecting necessary modifications so as to be able to collect the data necessary for the most effective development of the resources of the entire drainage basins. These bodies will, of necessity, have to deal with a number of sovereign states, and their membership will need to reflect this. Furthermore, the various authorities will have to collate and co-ordinate the activities of the existing national bodies responsible for water resources, and serve as the link between them and the ECA's Water Resources Commission. The National Committees of the International Hydrological Decade may, with necessary changes, do the kind of jobs envisaged at this level. Some countries have regional or state authorities responsible for the water resources of each state. For instance, Nigeria has 12 state water corporations, ministries or departments responsible for the development of water resources in the state, apart from the Federal Inland Waterways. Forgetting for the moment the disadvantages of this system, and pending the time when a national policy on water resources will emerge as suggested elsewhere (Faniran, 1970b), the national water boards, perhaps in this case the various national Committees of the International Hydrological Decade, will collate and co-ordinate the activities of these various bodies. In some cases too, a river system may be subdivided, for purposes of convenience, as in the case of the River Niger (Figure 1, b and c). In that case, the activities of the various bodies in charge of the sub-sections will be supervised and controlled by the relevant river basin authority.

Finally, individual entrepreneurs and research workers may be interested in a section of a river basin. This arrangement makes it necessary for such workers to consult with the nearest water resources authority, which may be the intra-state or the national body. In effect, the scheme being suggested is a system of linkages, which may be represented roughly as follows, in a descending order of magnitude: the Economic Commission for Africa Commission on Water Resources, the various drainage basin authorities (e.g. the Niger Basin Authority), national water resources corporations (the various authorities or bodies responsible for sub-sections of large drainage basins; and the National Committees of the International Hydrological Decade also come at this level). Regional or intra-state water resources groups (to be disbanded as soon as practicable), and finally private entrepreneurs and individual research workers.

The above scheme, if developed at all, will certainly take time to emerge, therefore some type of "stop-gap" arrangement must be made. This may be in the form of close co-operation and constant consultation among countries, within a drainage basin, interested in the development of any part of that basin. In doing this, it is important to make sure that all relevant information is readily available, so that the possible effects of any schemes may be fully assessed.

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Table 1

AFRICA'S INTERNATIONAL DRAINAGE BASINS

Drainage Basins and Countries Concerned

(A) Integrated (single) systems

Chad - Chad, Niger, Nigeria, Cameroon, Sudan, Central African Republic, Algeria, Libya.

Congo - Congo Kinshasa, Congo Brazzaville, Central African Republic, Cameroon, Cabinda, Gabon, Rwanda, Burundi.

Niger - Senegal, Mali, Guinea, Niger, Nigeria, Dahomey, Upper Volta, Algeria, Cameroon, Chad, Ivory Coast.

Nile - Egypt, Sudan, Ethiopia, Uganda, Congo Kinshasa.

Orange - S.W. Africa, Botswana, Swaziland, Union of South Africa, Lesotho.

Zambezi - Angola, Zambia, Rhodesia, Malawi, Mozambique, Botswana.

Minor

Limpopo - Botswana, Rhodesia, Mozambique, Union of South Africa.

Senegal - Senegal, Guinea, Mali, Mauritania.

Volta - Mali, Upper Volta, Ivory Coast, Ghana, Dahomey, Togo.

(B) Unintegrated (coastal systems)

Mediterranean - Morocco, Algeria, Tunisia, Libya.

N.W. Coastal - Morocco, Spanish Sahara, Algeria, Mauritania.

Coastal West Africa - Senegal, Gambia, Portuguese Guinea, Guinea, Mali, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Dahomey, Nigeria.

Bight of Biafra - Nigeria, Cameroon, Central African Republic, Rio Muni, Gabon.

S.W. Coastal - Angola, S.W. Africa.

Southern Africa - Union of South Africa, Lesotho, Swaziland.

S.E. Coastal - Mozambique, Rhodesia.

East Coastal - Somali Republic, Ethiopia, Kenya, Uganda, Tanzania, Mozambique.

Suez Canal - Egypt, Sudan, Ethiopia, French Somali, Somali Republic.

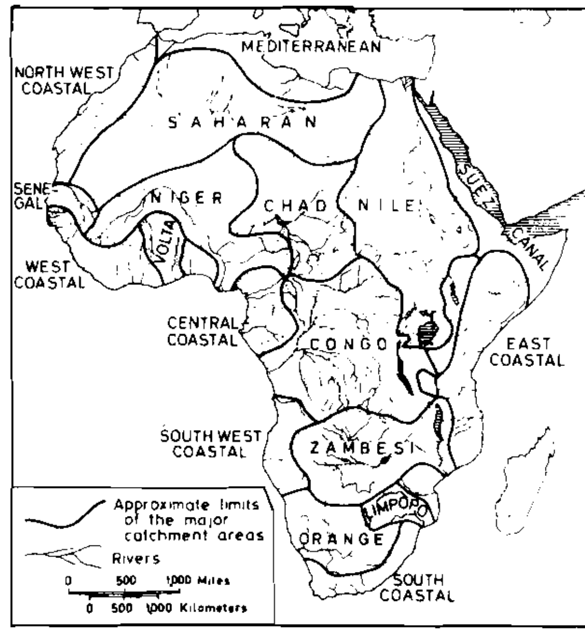

Figure 1 (a) - The drainage basins of Africa, modified from Unesco (1963, p. 182)

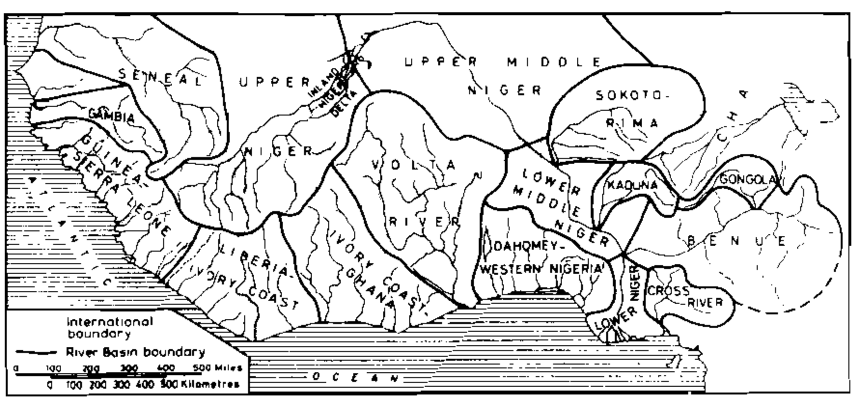

Figure 1 (b) - The drainage basins of West Africa taken from Faniran (1970a)

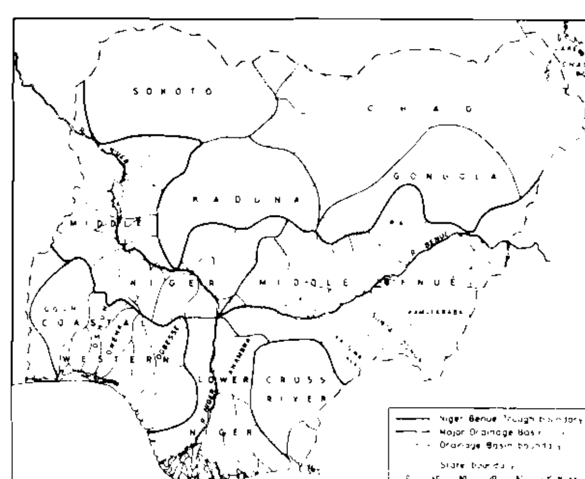

Figure 1 (c) - The drainage basins of Nigeria, taken from Faniran (1970b)

RELATIONSHIP BETWEEN CHARACTERISTIC FLOOD DISCHARGES AND CATCHMENT AREA

by Dr. G. Kovács

ABSTRACT

A relationship is derived between the flood discharges and the surface of the catchment area, based on specific discharges from catchments smaller than or equal to the surface area covered by typical storms. Numerical examples from East Africa and other areas are given.

RESUME

Une relation est établie entre les débits de crue et la superficie du bassin de réception, sur la base des débits spécifiques de bassins de réception d'une superficie inférieure ou égale à la surface arrosée par des orages typiques. Des exemples numériques provenant d'Afrique de l'Est et d'autres régions sont fournis.

INTRODUCTION

The characteristic flood discharges have a very important role among the design data for almost every type of hydraulic structure. The determination of these data causes, however, some difficulties, because only in a very rare case the hydraulic structure is situated at a gauging station with a long discharge record.

The calculation of flood discharges associated with various probabilities needs very long series of data. In other cases the determined value is not reliable. This is the reason why there are numerous scientists who prefer the use of genetic investigations, for example, calculating the maximum probable precipitation from climatic data. Using this method the determination of the height of precipitation or the flood discharge as the function of the catchment area in question is also necessary.

Where the density of the network of gauging stations with long records is sufficient, the required data can be determined by extrapolation from data of many stations. In this case, however, the knowledge of function between flood discharge and catchment area can also help the investigation. In developing countries, where there are only a very few stations with sufficiently long records this relationship is essential for the determination of design data. The purpose of this paper is therefore to determine the function relating flood discharges to catchment area.

PREVIOUS INVESTIGATIONS

There are several investigations in the literature dealing with this topic. Their results can be transformed into a common form:

$$q = f(A) \qquad (1)$$

where q is the specific value of a characteristic flood discharge in $\frac{l/sec}{km^2}$/1000 Q(A); A is the catchment area in km^2 and Q is the chosen characteristic flood discharge in m^3/sec.

The American code of practice recommends to determine this relationship for each catchment separately, using the data observed at different stations (Dalrymple, 1960). This method, however, can be applied only in the case when there are many gauging stations in the catchment with long records. The investigations resulting in mathematical formulae for describing this relationship are, therefore, more applicable (Csermák, 1965; Ryves equation in Camacho, 1967; Kovács-Takács, 1963; modified Myer's formula and Creagers' formula in Faiz, 1967).

The general form of the relationship determined in the papers listed previously can be given by the equation:

$$q = \frac{a}{A^n}; \qquad (2)$$

which represented in logarithmic co-ordinates gives the linear relationship:

$$\log q = a - n \log A. \qquad (3)$$

The characteristic specific flood discharges differ from each other in the various papers, because their authors use flood data with a given probability ($q_{3\%}$; $q_{2\%}$), the multiannual mean of the yearly maximum discharge (q_A), or the maximum probable flood calculated by various methods (q_m).

The factor 'a' in Eq. (2) is, naturally, the function of the climatic and runoff conditions of the area in question. It depends also on the type of flood data chosen for characterization. This is the reason why this factor is not comparable in the various papers. The 'n' value, which is the slope of the line in the logarithmic system, differs also considerably in the various methods: Ryves $n = 1/3$; Kovács-Takács $n = 0.44$; Csermák and Myer $n = 1/2$; Creagers $n = 1-0.894A$. If the 'n' value also depended on the local conditions, the various lines would give the required relationship for the investigated area. It seems, however, that the 'n' value is closely related to the size of the investigated area. In that case the various lines can be interpreted as an enveloping polinom of a continuous curve (Figure 1).

It was found in our previous investigation that the influence of the size of the catchment on the 'n' value was very important and that the effect of local conditions could be neglected (Figure 2), (Balogh et al., 1966). This is the reason why a continuous curve is recommended for describing the flood discharge versus catchment area in the logarithmic system instead of a straight line.

METHOD RECOMMENDED

The first results based on flood discharges of Hungarian rivers were followed by an investigation using hydrological data from East African catchments. First of all, it became clear that the flood data have to be divided according to the various characteristics of the flood-producing climatic conditions. This was easier in East Africa than in the moderate climatic zone where the floods from snow melt also have a very important role. In East Africa only the cumulative storms and the very extensive precipitations have to be divided. The former produce floods on small catchments, and the latter influence flood discharges from large areas.

On the basis of the second part of the investigations a general equation could be recommended for describing the relationship between specific flood discharges and catchment area:

$$\log q = \log 10 q_o - \sqrt{1 + \log^2 \frac{A}{A_o}}; \qquad (4)$$

where q_o is the maximum value of the variable specific discharge characteristic for catchments smaller than A_o km^2 (Kovács-Mörth, 1969).

The specific discharge is constant (q_o) when the area of the basin is smaller than A_o. Above this limit the former decreases continuously as the catchment increases.

The meteorological interpretation of the relationship expressed by Eq. (4) can be given as follows. The area A_o differentiates between the constant and the variable specific discharges, probably coincides with the typical areal extent of the flood-producing precipitation system. Areas smaller than A_o are likely to be wholly affected, and the precipitation depth is practically independent of the size of the catchment. Basins larger than A_o are only partly affected at the same time by a precipitation system and therefore the precipitation depth and the specific discharge vary inversely with the catchment area.

The examples shown in Figure 3 testify the existence of the two different flood-producing precipitation systems in East Africa. Small catchments on the Eastern slopes of high mountains are influenced by heavy rainstorms with high intensity but a limited areal extent (Tana and Pangani $A_o = 60 km^2$, $q_o = 300 \frac{l/sec}{km^2}$; Ruvu and Wami $A_o = 150\ km^2$, $q_o = 380 \frac{l/sec}{km^2}$; Rufiji $A_o = 60\ km^2$, $q_o = 400 \frac{l/sec}{km^2}$). It seems that the westerly slopes of the Ruvu and Wami basins are affected by the same precipitation system but it covers only a very small part of the catchment near the head-waters ($A_o = 15\ km^2$ $q_o = 380 \frac{l/sec}{km^2}$). In large drainage areas on the same slopes the floods are produced by more extensive but less intensive rainfall (Tana $A_o = 3000\ km^2$ $q_o = 100 \frac{l/sec}{km^2}$; Rufiji $A_o = 3000\ km^2$ $q_o = 200 \frac{l/sec}{km^2}$). Where the extension of the mountains in a North-South direction is relatively small this type of flood does not occur (Pangani, Ruvu, Wami). In this shadow of the great mountains extensive rainfall is also dominant, but its intensity is very small (Little Ruaha basin and the Western slopes of the Aberdares mountains $A_o = 3000\ km^2$, $q_o = 40 \frac{l/sec}{km^2}$).

It is likely that after collecting more information, relationships can be determined between the constants of Eq. (4) (A_o and q_o) and the meteorological data. Thus the A_o value can be calculated from the area-depth distribution of various precipitations and it seems that q_o of small catchments is related to the dewpoint observed at the foot of the slope in question.

The curves in Figure 3 were constructed from the specific value of the average of yearly maximum discharges (q_A). It was found that the same equation can also be used for describing other flood-characteristics as a function of the area. In Figure 5 of our previous paper (Kovács-Mörth, 1969) this relationship is shown for the observed maximum floods in the Tana catchment, and for the calculated maximum probable floods on different rivers in South-East Asia in Figure 6 of the same paper.

The latter indicates that the validity of Eq. (4) can be extended to other areas as well. The catchments investigated in connection with this figure are also from the tropical zone. In Figure 2, however, the curves describing Eq. (4) are also represented by dotted lines. It seems from the positions of the points and lines that Eq. (4) can be used in moderate zones as well. For testifying its general validity, however, more comparisons would be necessary.

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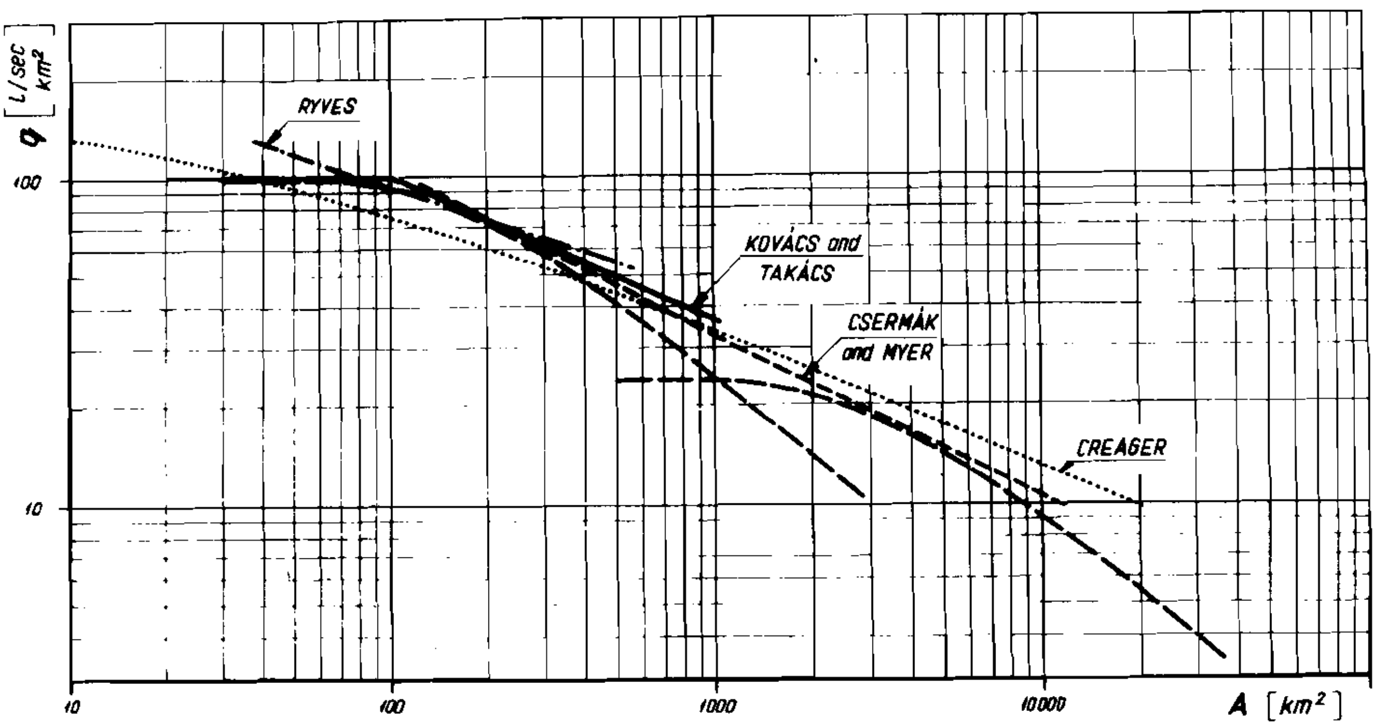

Figure 1 - Lines representing the various q=f(A) functions in logarithmic system

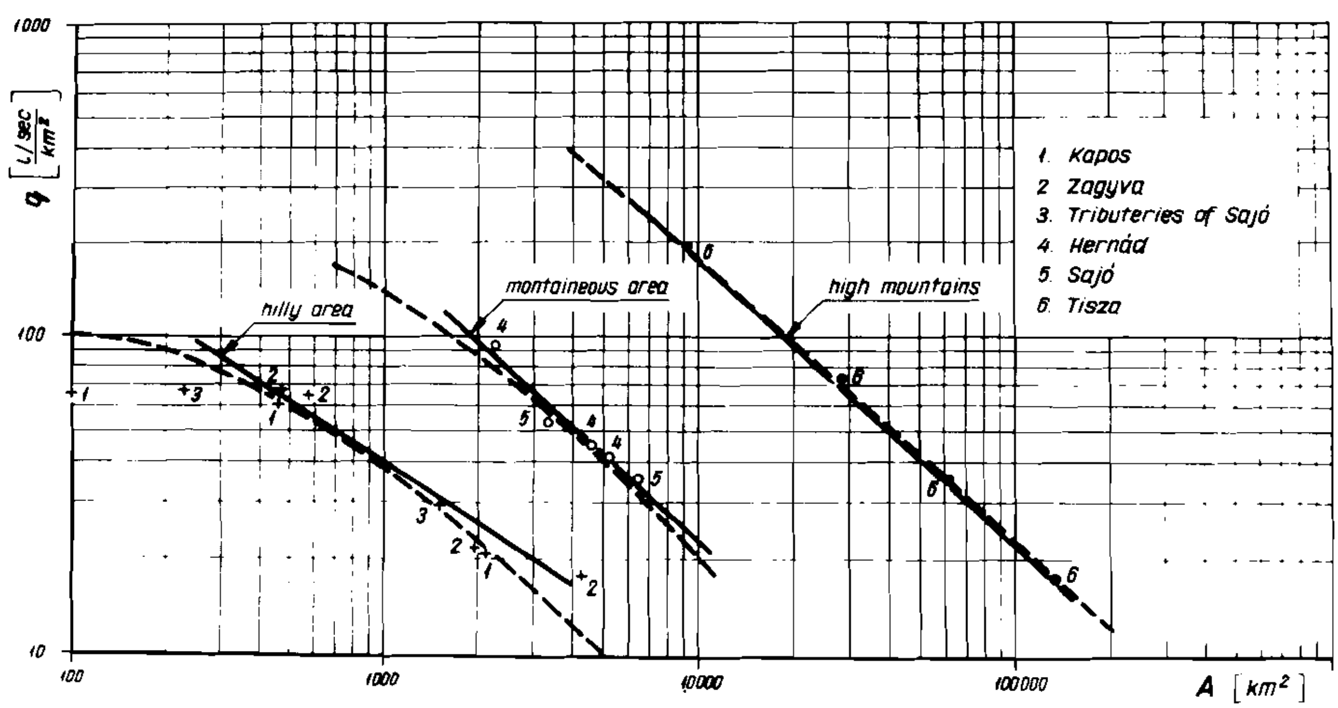

Figure 2 - The change of slope of the q=f(A) curve according to the extent of the catchment

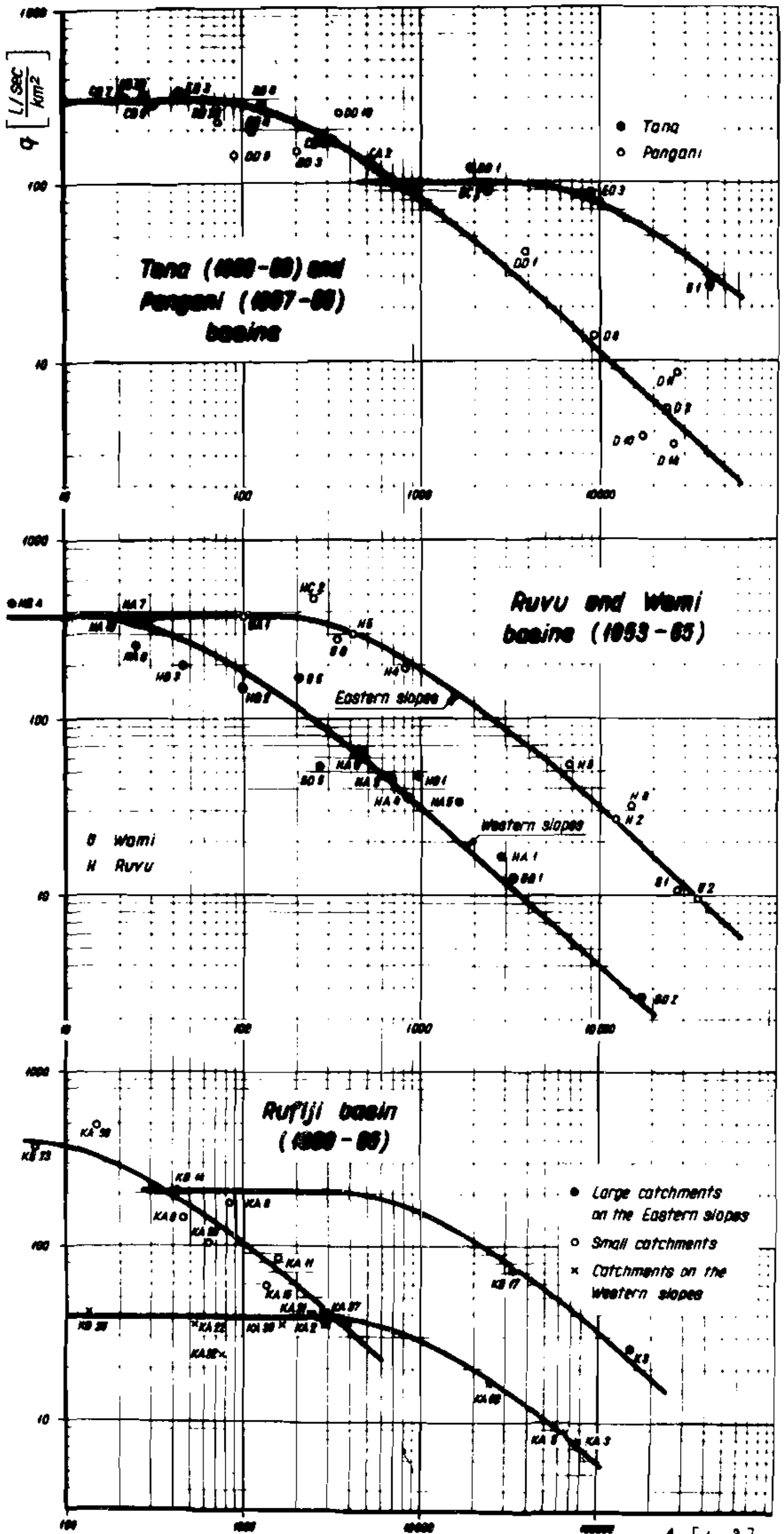

Figure 3 - Relationships between specific flood discharge and catchment area for various river basins in East Africa

AN ANALYSIS OF HISTORICAL SEQUENCES OF THE NILE MAXIMA AND MINIMA

by J. Andel, J. Balek, M. Verner

ABSTRACT

The mathematical-statistical analysis of the historical Nile maxima and minima observation dated back to A.D. 622 is provided. The autoregressive and hidden periodicities models of the Nile maxima and minima fluctuation are assessed as a source of information for long-term investment and planning. The significance of the number seven in the Nile history is discussed.

RESUME

L'analyse mathématique-statistique du débit maximum et minimum du Nil qui a été observé à partir de l'année 622 Apr.J.C. est décrite dans cette publication. Les modèles autorégressifs et les modèles de periodicités cachées des variations maximales et minimales du Nil sont composés comme une source d'information pour investissements et projets à long terme. L'importance du nombre sept dans l'histoire du Nil est discutée.

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Herodotus, the Greek historian, used probably the most appropriate parallel calling Egypt "Gift of the Nile". The relatively narrow strip of the inundated and therefore cultivated soil on both the banks of the Nile has always been surrounded by the desert in both the east and west. Since the end of the prehistoric times we can see in the so-called "inundated zone" an increased intensification of agriculture which marked a surprising leap at the beginning of the Old Kingdom (about 2800 B.C.).

Life in the whole country has depended on seemingly uncontrollable whims of this greatest river of Africa. Sufficient quantity of water has meant rich crops while water shortage has resulted in poor crops and famine. We cannot be far from the truth if we regard the effort to unify the disorganized system of water regulation and to build irrigation tracts as a very important or, conceivably, a decisive factor of the emergence and growth of the state power. A number of examples can be quoted regarding the immense importance ascribed to the Nile by the ancient Egyptians. The Nile, personified for the ancient Egyptians by God Hapy, represented a significant component of their religious imagery. Nile floods in particular served as a basis for complicated religious rites and theological doctrines as well as for a very intensive observance of all astronomic phenomena and the corresponding occurrences on the earth which were related to the floods.

The pragmatic Egyptians made promptly the best use of the results of their findings. It was the long and thorough observance of the Nile that enabled them to predict, for example, rich or poor crops, and on the basis of this prediction the ruler could regulate taxes, etc. At this end let us recall the Genesis (Chap. 41, v. 26-37) describing the famous biblical story of Joseph interpreting Pharaoh's dreams; we shall see later that number s e v e n does not occur in the Bible by accident but that it has a very specific meaning — no matter that it differs from the traditional interpretation. It would be equally interesting to give examples of the disastrous famines which were a result of poor crops (other catastrophes, e.g. political, were frequently another result); or to quote the text of the stela from the island of Sehel (even though the motives for engraving the stela by the priests were strictly propagandist and the date of described events was, therefore, deliberately ancient; it is interesting to note that even this text mentions that "the Nile has not come for seven years") (Barguet, 1953). Of great importance is also the fact that a number of records have survived which give the height of Nile floods as early as the ancient Egypt, e.g. from Semna and Kumma near the Second cataract (Reisner, 1960), or from Karnak (Legrain). The data are not comprehensive enough, however, to help us ascertain the periodicity of the river and some other phenomena. The height of Nile floods was measured by means of a nilometre; the most famous of them was situated on the island of Rauda (Borchardt, 1906). There have been polemics among the Egyptologists concerning the question whether the famous Rauda nilometre comes from ancient Egypt or whether it was constructed only after the Arab conquest of Egypt. It was the island of Rauda that the German Egyptologist Kurt Sethe considers "to have been the so-called Pr-Hapy - the House of Hapy", i.e. the sanctuary of the God of the Nile. According to him, the origin of the Rauda nilometre should be sought in pharaonic Egypt, and for many years this view was shared by other Egyptologists. Later, however, the British Egyptologist Allan H. Gardiner (1947) gathered all historical and geographic texts relating to this area and arrived at a different conclusion than K. Sethe. In his work, however, Gardiner failed to take into consideration religious texts on the basis of which the French Egyptologist Etienne Drioton (1953) has recently confirmed Sethe's hypotheses of the nilometre originating in ancient Egypt. As already mentioned, there must have existed many nilometres but only a few have been historically documented. Omar Tusun (1925) enlists thirty-one in his study. It is conceivable that (as in the case of the Rauda nilometre) a number of them were built by the Arabs to replace the older Egyptian ones. In any case, the Arabs increased the number of nilometres and they seem to have set a better order into the annual records concerning the stage of the Nile. Various known records dating back to the Pharaonic Egypt are too fragmentary for any statistical analysis; however, we cannot exclude the fact that more ancient Egyptian records of this kind have not been preserved and that more will be discovered later on.

This study draws exclusively on statistical surveys compiled on the basis of data found in the manuscripts of Arab historians. The most important of them undoubtedly are Abu El-Mahasin Yusuf Ibn Taghri Birdi and Ahmad Ibn Al-Hijazi. Al-Hijazi's data were used particularly by Omar Tusun in his comprehensive tables on the Nile maxima and minima; he supplemented the missing data essentially with the figures of Ibn Taghri Birdi. Omar Tusun's statistics, being the most complete, are most frequently used. For this reason they have been used in this study. W. Popper (1951) has raised several objections against the way in which Omar Tusun compiled his tables. According to W. Popper, Omar Tusun was of the opinion that all data must correspond to the scale engraved on the nilometre, dividing all cubits into twenty-four fractions. Al-Hijazi and Ibn Taghri Birdi give, however, altogether 62 cases of the minima in which the number of fingers (added to the number of cubits between 1 and 11) is 24, 25, 26 and 27. Omar Tusun regarded these data as erroneous; therefore he changed all the minima under review to correspond to the 24 - finger scale (e.g. 5 cubits and 27 fingers changed to 6 cubits and 3 fingers). For this reason, W. Popper comes up with a comprehensive table in which he assembles all Tusun's corrections of Al-Hijazi's figures (1951). All objections of Popper stem from his findings that there was never a uniform scale for measuring the Nile's level; however, between 641 and 1522 A.D. (i.e. the period examined and documented by both Al-Hijazi and Ibn Taghri Birdi two scales were in use: between 1 and 11 cubits, one cubit had 28 fingers (1 cubit equals 0.539 metre and 1 finger equals 0.0192 metre). Apart from the above-mentioned disunity of scale, the compilation of Nile statistics is complicated by the so-called leap year. Arab historians used to date all events according to the Mohamedan lunar calendar which contains 354 days (Brockelmann, 1953). Besides this, however, the solar calendar was used for fiscal and agricultural purposes. Thus, in 33 years, the difference between the lunar and solar calendars amounted to one year, referred to as "leap-year" (Wüstenfeld 1854). Correction of this inconsistency (i.e. the leaving out of one year after a 33-year cycle) was always an important decision and only the Caliph and later the Sultan was authorized to make it. Nevertheless, the historians who gathered data about the Nile differed on the choice of "leap years". Sometimes they adhered to Caliph's edict (when there was any), sometimes they did not leave out any Muslim year at all. Even Ibn Taghri Birdi whose data are used in the checking tests of our study, made this kind of error. Except for a few cases, this historian does not mark down "leap years" and gives 33 sets of data for 32 solar years. For this reason, W. Popper compiled a comprehensive table (1951, Tab. 8) in which he gathers duplicated data found in the work of Ibn Taghri Birdi (as well as those of Al-Hijazi and Ibn Aibak). There are over fifty duplicated data in reference material under review. Whenever they appear in the period in which a "leap year" may have occurred, one can assume that one should substitute an omission or draw attention to the fact that one set of solar-year data refers to two lunar years.

The data contained in the sequence of both authors may also be influenced by the permanent increase of the Nile bed. The rate of that increase was estimated at 0.234 metre per century (Popper, 1951). Willcocks (1889) found that the rate was 0.132 metre per century and a similar value was obtained by Lyons (1906) for the cross-section at Rauda. Thus, a certain trend produced by the increase of the river bed could be expected, even though one should not disregard the fact that the increase was probably calculated from an average and thus the existence of a periodical component could not be eliminated.

According to Popper, a systematically written record of the Nile level had to exist because at the time of flood culmination the river level was announced in the city streets together with that of the preceding year. Nevertheless, both authors presented the sequence in quite a different manner. Some of the differences may have occurred in course of data copying, even though this explanation cannot be considered as satisfying for the whole set.

A series of statistical tests was applied to all the sequences in an attempt to separate periodical and random components. The method, as described by Andel and Balek (1969 a,b), is based on the presumption that the occurrence of more periodicities existing in a sequence is not detectable by standard tests at the same level as it is in the cases in which the sequence contains one periodical component only.

The test of significance of the correlation coefficient serves as the basic source of information:

$$R = \frac{\sum_{t=1}^{N} x_t x_{t+1} - N\bar{x}^2}{\sum_{t=1}^{N} x_t - N\bar{x}^2}$$

where $\bar{x} = \sum_{i=1}^{N} x_i$; $x_{N+1} = x_1$

t is the number of the year and N is the number of the sequence $x_1 \ldots\ldots\ldots x_N$. The test was described by Anderson

(1942) and determines whether the sequence is formed by independent random variables with the same distribution. A following test by Fisher (Hannan, 1964) examines the possibility of the existence of periodical components in the sequences. Basic information on the occurrence of periodical components is supplied by the periodograms defined in the following way:

$$I(\lambda) = \frac{1}{2} C_o + 2 \sum_{t=1}^{N-1} C_t \cos \lambda \qquad , 0$$

where

$$C_k = \frac{1}{N} \sum_{t=1}^{N-k} (x_{t+k} - \bar{x}).(x_t - \bar{x}) , \quad k = 0,1 \ldots\ldots N-1$$

Another source of information is the determination of spectral density calculated by Parzen's formula (Granger, Hatanaka, 1964). The order of autoregression is determined by Whittle's tests enabling to trace even the autoregression of higher degrees (1952). Five of the Nile sequences have been analysed (see Table 1 below).

Table 1

1.	Annual maxima based on Tusun (since 622 A.D.).
2.	Annual minima x) based on Tusun (since 622 A.D.).
3.	Annual maxima based on Taghri Birdi (since 622 A.D.).
4.	Annual minima x) based on Taghri Birdi (since 622 A.D.).
5.	Average annual discharge volume from cross-section Assuan (since 1871 A.D.).

x) the so-called "old-water"

CONCLUSIONS

The minima sequence of Tusun was analysed together with other sequences even though according to Popper at least six per cent of the sequence members may be inaccurate because of the facts discussed above; the other sequences appear to be more reliable. By applying the described tests, hidden periodicities on various levels of significance and the lags significant for the autoregressive model were traced. An analysis of the lags has provided further information concerning sequence formation.

Appropriate ranges of validity were ascertained for respective periods, the main criteria being both the length of the sequence and that of the periods. In this way, following information was arrived at (Table 2).

Table 2

Hidden periodicities in years

Author	Taghri Birdi				Tusun				Hurst	
Value	Min.	Range	Max.	Range	Min.	Range	Max.	Range	Mean	Range
Unit of seq.	m		m		m		m		mld m^3	
Profile	Rauda		Rauda		Rauda		Rauda		Assuan	
No. of members	663		849		849		849		84	
Calculated periods & related ranges	663	>440	849	>556	849	>556	849	>556	84	56-120
	221	189-265	282	242-339	282	242-339	282	242-389	22.6	20.5-32.2
	6.6		141	151-332	106	89-113	141	132-151	7.3	
			14.1	14-14.2	77	74-82				
					18.4	16.2-18.3				

The longer periods in all the sequences may indicate some trends, for example one produced by an increase of the river bed. As regards the length of the sequences, the existence of longer periods in the sequences is disputable; even some periods longer than those ascertained by calculation might be signalized in this way. However, as very interesting can be considered the shorter periods indicated by the periodograms of all the sequences except for Tusun's maxima.

A number close to seven appears to play a certain role in the formation of all those sequences. Thus, for example, the periods of 7.3 and 22.6 in Hurst's sequence may be related to the periods of 6.6 and 14.1 in Taghri Birdi's sequences. A certain relationship may also exist with the period of 77 years in Tusun's minima, while the period of 18.4 years may be influenced by several doubled values as discussed above.

In Figs. 1 and 2, there are drafted the sequences of minima and maxima presented by Taghri Birdi together with the models drawing on a mathematical and statistical analysis of those sequences. The equation of the minima model is:

$$f(t) = 10.803 - 0.434 \sin 0.0095\, t + 0.257 \cos 0.0284\, t + 0.407 \sin 0.0284\, t - 0.069 \cos 0.9572\, t + 0.157 \sin 0.9572\, t$$

and that of the maxima model:

$$f(t) = 16.992 + 0.172 \cos 0.0074\, t - 0.266 \sin 0.0074\, t + 0.089 \cos 0.0222\, t - 0.242 \sin 0.0222\, t - 0.039 \cos 0.0444\, t - 0.159 \sin 0.0444\, t - 0.079 \cos 0.4440\, t + 0.076 \sin 0.4440\, t$$

Another source of information is the lags significant for the composition of the autoregressive models on the 90 per cent level of significance (Table 3)

Table 3

Auther	Taghri Birdi		Tusun	
Value	Maxima	Minima	Maxima	Minima
Lags	1	1	1	1
	2	2	2	2
	3	3	3	3
	4		4	4
		5	5	5
	6	6	6	6
	7		7	7
	8		8	
	9		9	
	10	11		
	13	13		
			15	
	17			

Obviously, the events of at least 6 - 9 previous years play an important role in the formation of the value valid for the year that follows. Even some of the years from a previous decade were found important. The equation of the autoregressive model of Taghri Birdi's sequences for minima is:

$$y_t = 0.42y_{t-1} + 0.10y_{t-2} + 0.06y_{t-3} + 0.10y_{t-5} + 0.02y_{t-6} + $$

$$+ 0.04y_{t-11} + 0.11y_{t-13} + \mathcal{E}_t$$

where

$$y = x - 10.80$$

are the differences from the mean value.

The autoregressive model of maxima has the equation

$$y_t = 0.20y_{t-1} + 0.07y_{t-2} + 0.09y_{t-3} + 0.06y_{t-4} + 0.04y_{t-6} +$$

$$+ 0.02y_{t-7} + 0.05y_{t-8} + 0.08y_{t-9} + 0.06y_{t-10} +$$

$$+ 0.10y_{t-13} + 0.09y_{t-17} + \mathcal{E}_t$$

where again

$$y = x - 16.99$$

are the differences from the mean value.

Apart from the first members of the equations, also remarkable are the members apertaining to the lag of 13 because they are obviously more significant in the model than the others. Thus, together with the calculated value, again the number of 14 is obtained.

A comparison of the simulation of the sequences by the periodical and autoregressive models can be based on the values of variance in Table 4.

Table 4

Author	Taghri Birdi		Al-Hijazi		Hurst
Sequence	Maxima	Old water	Maxima	Old water	Volume of mld m^3
No.of members	849	663	849	849	84
1st year of observation A.D.	622	622	622	622	1871
Mean value	16.99m	10.80m	17.64m	11.54m	92.7mld m^3
Cyclical cor. coefficient	0.408	0.553	0.395	0.552	0.362
Variance	0.400	0.768	0.193	0.830	391
Variance in autoregressive model	0.285	0.445	0.137	0.528	278
Variance in hidden periodicities model	0.297	0.570	0.150	0.655	202

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This study draws mainly on the information contained in the manuscripts of the Arab historians Abu El-Mahasin Yusuf Ibn Taghri Birdi and Ahmad Ibn Al-Hijazi. Other works of Arab authors concerned with the observation of the Nile were used by editors of the manuscripts, and several of them are important for studying the development of the observation of the Nile. The list of them can be supplied by the authors of the paper on request.

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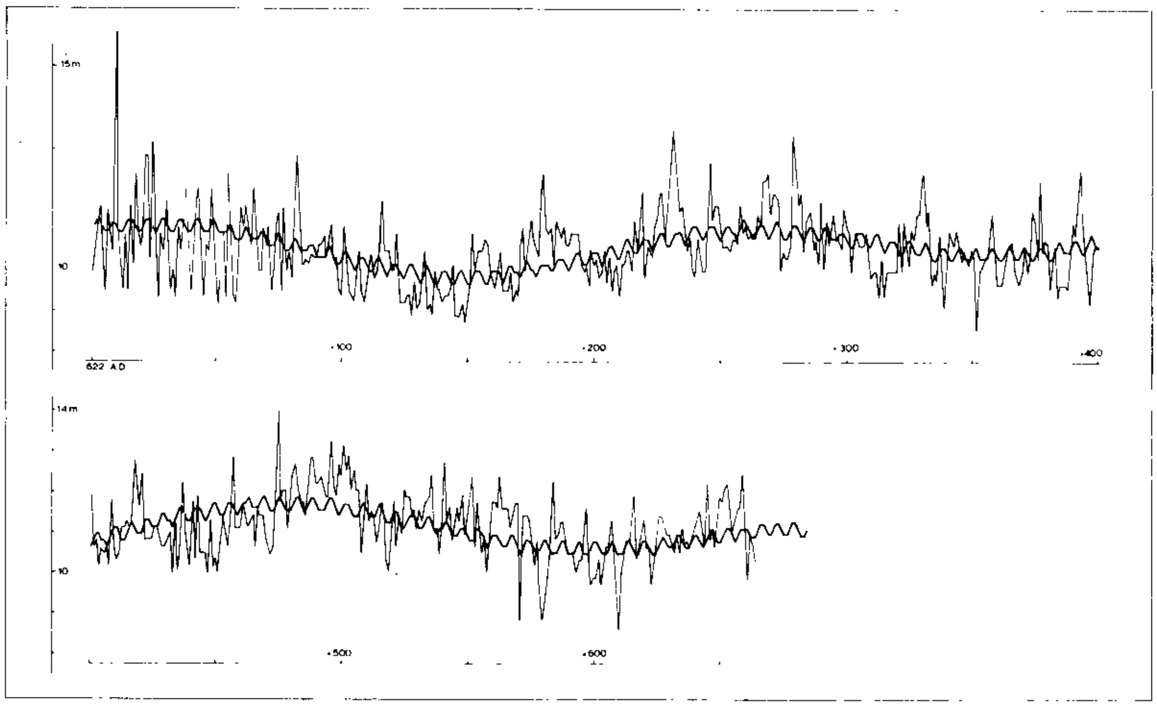

Figure 1 - Nile minima sequence according to Taghri Birdi and the modelled sequence

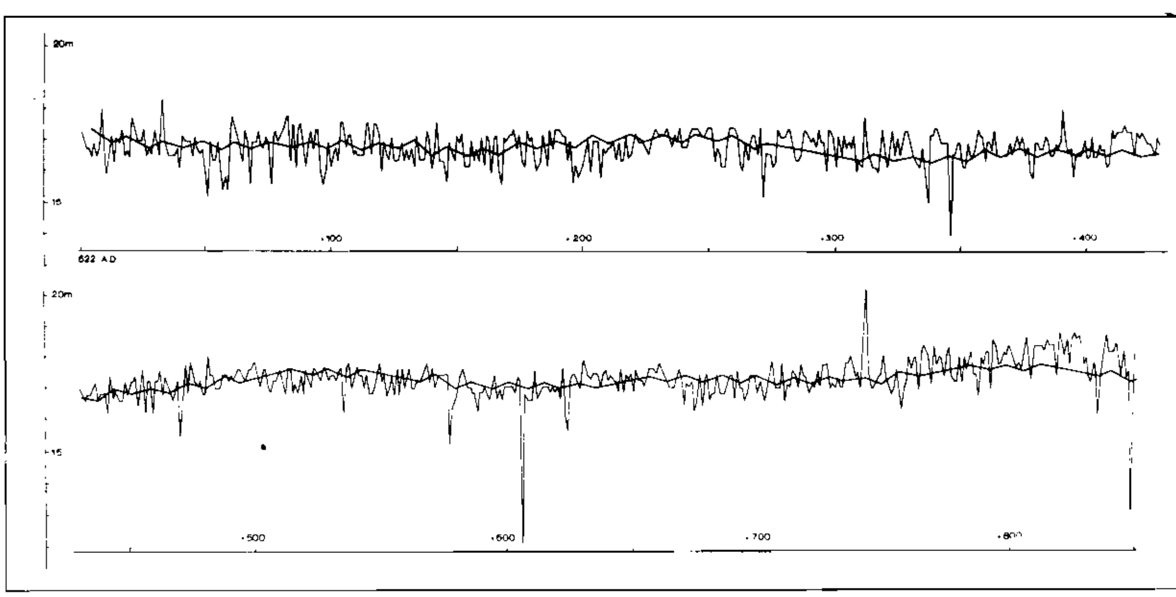

Figure 2 - Nile maxima sequence according to Taghri Birdi and the modelled sequence

HYDROLOGICAL DATA FOR THE UPPER ZAMBEZI
AND UPPER CONGO HEADWATERS

by Jaroslav Balek

ABSTRACT

The hydrological water-balance calculation applied to the upper Congo and upper Zambezi headwaters is described. Graphs are presented to show some of the basic hydrological characteristics and to serve as comparative figures for other African regions. A proposal is made for the calculation of water-balance data on a wider regional scale.

RESUME

Le calcul de la balance hydrologique appliqué aux sources du bassin du Congo et à celles du Zambèze est décrit dans cette publication. Les graphiques sont présents pour montrer les caractéristiques des principes hydrologiques et pour servir de référence dans les autres régions africaines. Une proposition est faite en vue du calcul de la balance hydrologique dans d'autres régions africaines.

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Rapid industrial and agricultural development of the African countries requires a very intensive investigation of all natural resources and their economic exploitation. Water is one of the most important natural resources of any country, however, it differs from other resources by the time variability of the total amount available for exploitation, and thus the time factor must always be taken into account. Non-uniform seasonal distribution of precipitation, runoff, groundwater and soil moisture storage plus the non-uniformity of these fluctuations from region to region, from basin to basin, and from catchment to catchment make the planning of the economic use of water resources extremely difficult.

Very often industrial and agricultural projects require immediate hydrological data and the hydrologist is unable to prepare the required information properly on the basis of the natural hydrological laws of the whole environmental area. Instead of the calculation of the hydrological data based on the detailed knowledge of the hydrological behaviour of all surrounding river networks, data are prepared separately for random cross sections chosen solely by the requirements of the project designers and frequently by using formulas whose validity has been proved for entirely different areas. To obtain more reliable results, the basic network of mutually fitted data for a given region, or at least for a main basin, should be known before any local hydrological data are issued and used for technical or agricultural purposes.

The following is a system for the preparation of such a water-balance network for the whole of Zambia.

Zambia can hydrologically be divided into two main drainage areas (Fig.1). The larger area, approximately of 217,000 sqm, is drained by the Zambezi system; the smaller area of 65,000 sqm by the Congo system. The Zambezi drainage area in Zambian territory can be divided into the three main basins: The Upper Zambezi Basin, Kafue River Basin and Luangwa River Basin. The area drained into the Congo Basin consists of two parts, the main one formed by the Chambeshi-Luapula system and the minor one drained through Lake Tanganyika. Obviously, Zambian territory forms a very important part of both the Zambezi and Congo headwaters. Swamps play a very significant role in both areas (Debenham, 1952). The Bangweulu Swamps transform the discharges of the Chambeshi river and create the entirely different hydrological regime of the Luapula River (Balek 1970). The Kafue Flats and Lukanga Swamp in the Kafue Basin serve a similar function. The fluctuation of the water yield between the headwaters and mouth of the rivers of the Luangwa Basin and Lake Tanganyika tributaries is less pronounced because those basins do not contain swamps of significant size.

As in other African countries, there exists a very limited number of hydrometric cross sections supplying the observations necessary for water balance calculations. Thus in the Kafue Basin there have been found 13 stations producing usable data over ten years, in the Zambezi Basin 5 stations over 7 years, in the Chambeshi-Luapula system 19 over 5 years and in Luangwa basin 3 stations over 5 years. As everywhere, the lack of records is due mainly to indirect reasons, such as inadequate communication, financial problems or the lack of qualified observers. The presently existing network is much more dense; nevertheless, several years of observation will be necessary for further refinement of the water balance figures.

Even with the limited amount of data presently available it is possible to produce reasonably accurate balance figures if all those data are taken into account and processed simultaneously. Positive factors for the water-balance calculations in Zambian basins are the observations of several small catchments and the limited number of long-term records that can be traced back almost seventy years.

The choice of data to be calculated is the first step. There exist varying types of hydrological data to be produced according to the special requirements of various projects; however, all of these data are secondary, being developed from more basic data such as mean annual precipitation, mean annual runoff, the difference between those two values (sometime called "the loss" but more or less representing mean annual evapotranspiration), runoff coefficient, water yield, mean annual discharge, and flood frequency.

Generally, even in the developed countries, the periods of hydrographical observations and hydrometric measurements are shorter than the periods of existing meteorological, particularly rainfall, records. Thus, the figures of long-term mean annual precipiation can serve as a common denominator for the water balance calculation based on the shorter hydrometeorological records. Within one main basin, however, only the hydrometeorological records having the same period of observation should be used. This sometimes requires the elimination of even much longer records from a few basic stations. Such a step may appear illogical, it is nevertheless unavoidable if the influence of the fluctuations of the groundwater and soil moisture storage is to be eliminated from the water balance calculations. The longer records can be used as guiding figures, however, when the basic rainfall-runoff relation developed for the short-term period of common records is extended by using the longer precipitation records.

Empirically, five years of discharge observations are sufficient to obtain reliable basic data if there have not been two or more extremely dry or wet years within that time period.

Fig. 2 shows the basic rainfall-runoff relationships that were developed as basic curves to supply information on the hydrological behaviour of the main basins*. The curves of Wundt's diagram (1953) serve as guiding lines to demarcate the limits for basins of tropical and subtropical zones. Even if some tropical rivers extend beyond the limits given by Wundt, the general direction of the curves is correct.

Fig. 3 presents a family of similar curves, this time developed only for the rivers of Luapula basin. Here the basic rainfall-runoff relationship has been determined even for smaller watersheds (the area of the smallest one being less then 40 sq.mi. These curves indicate the variability of the behaviour of partial watersheds within the main basin. Obviously, the calculation of the hydrological data for local surface water resources exploitation would supply very unrealistic results if based only on the observation of the main river.

The principles of hydrological analogy have been used for the calculation of the basic balance data of the unobserved basins. It would be difficult to define briefly the basic principles based mainly on the field investigation and complex analysis of the all available data. In general, they consist of tracing the development of the mean annual precipitation from the spring to the mouth of the main river and comparing the "mean annual loss" with the precipitation and meteorological, morphological and vegetational parameters. The influence of the

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* The figures for the upper Zambezi itself were not yet available when this paper was written.

swamps must also be taken into account. All deviations from the smoothed rainfall-runoff curves have to be satisfactorily explained. Also the development of the runoff coefficient and water yield within a basin should usually have a smooth trend. The mean annual discharge figures have to be well balanced for each main cross section above and below the significant tributary and with respect to the hydrological régimes of neighbouring interbasins.

Finally, the figures characterizing the distribution of the discharge within the year have to be in a balance similar to that of mean annual discharges. Calculation of these figures is not always an easy task, especially with regard to the variability of the characteristic duration curves (Fig. 4). An example of the tabled balance figures of the upper Chambeshi Basin is given in Table 1.

The relationship between the size of the drainage area and peak discharge of the floods repeated once in a hundred years is plotted in Fig. 5. The lines 4 and 5 indicate the limits obtained for the Kafue Basin. The lower line characterizes the flood régime of the swampy basins, where a significant part of the flood peaks is retarded by the flats and swamps. The upper curve characterizes the flood régime of hilly impermeable watersheds with rather poor vegetational cover. A great variety of curves, each characterizing a certain particular watershed very likely exists within those limits. Tracing them, however, is very difficult because of the lack of reliable data. Most of the records are shorter than 20 years, and only one sequence consists of almost 70 years of continuous records. Line 6 characterizes the flood régime of the Luapula river, with an even more pronounced influence of the swamps. The flood peaks of the Luapula tributaries reach much higher values and can be traced somewhere within Kafue limits. For a comparison the representative lines developed for some of the rivers of Tropical West Africa and middle and southern Europe have also been plotted.

As an example of the variety of flood régimes, the flood probability curves characterizing the flood régime of different main basins are plotted in Fig. 6. These curves have been developed as a combination of the statistical and empirical methods and serve for the calculation of the floods for any probability of occurrence.

CONCLUSION

The estimation of water-balance figures based on the comparison of long-term precipitation records with short ones for which discharge records exist can servd as a useful tool for obtaining immediate hydrological data where required.

The basic hydrological water-balance data were calculated originally as a contribution to Zambian industrial and agricultural development, preferably in those areas that depend on the exploitation of local surface water resources. However, these data together with the environmental characteristics of the appertaining watersheds and basins, could serve as analogical hydrological figures for areas in which hydrographical and hydrometrical measurements have not been obtained.

Very likely, similar hydrological water-balance data calculated by using the uniform methods will be needed for the main African regions and basins. The Water Resources Laboratory in Lusaka, operated jointly by the National Council for Scientific Research and by the University of Zambia, is prepared to undertake such studies. However, these studies exceed the boundaries and financial resources of a single country and would require co-operation of the international organizations concerned with the African hydrological research.

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UPPER CHAMBESHI WATER BALANCE	DRAIN AREA	MEAN ANNUAL RAIN-FALL	MEAN ANNUAL RUN-OFF	MEAN ANNUAL LOSS	RUN-OFF COEFF	WATER YIELD	MEAN ANNUAL DIS-CHARGE	DISCHARGE LIKELY TO BE EXCEEDED				
								20	40	60	80	[illegible]
								% OF THE YEAR				
	SQM	IN	IN	IN	-	CFS/ SQM	CFS	CFS				
1	2	3	4	5	6	7	8	9	10	11	12	13
CHAMBESHI-CG8 x)	1580	46.0	10.70	36.30	0.233	0.789	1245	2855	1370	560	162	31
INTERBASIN CHAMBESHI CG8 ABOVE WIWA KALUNGU	673	42.0	8.33	33.67	0.198	0.613	413	965	455	190	55	10
CHAMBESHI CG8 ABOVE WIWA KALUNGU	2253	44.8	10.00	37.80	0.223	0.756	1658	3820	1825	750	215	43
CHOSI CG7 x)	849	43.1	8.70	34.40	0.202	0.640	544	1250	600	245	0	14
INTERBASIN CG7 - WIWA KALUNGU	1215	39.9	7.00	32.90	0.175	0.515	626	1440	690	255	30	15
CHOSI MOUTH TO WIWA KALUNGU	2064	41.2	7.70	33.50	0.187	0.566	1170	2690	1290	500	150	29

x) UNDERLINED ARE THE OBSERVED CROSS-SECTIONS

Table 1

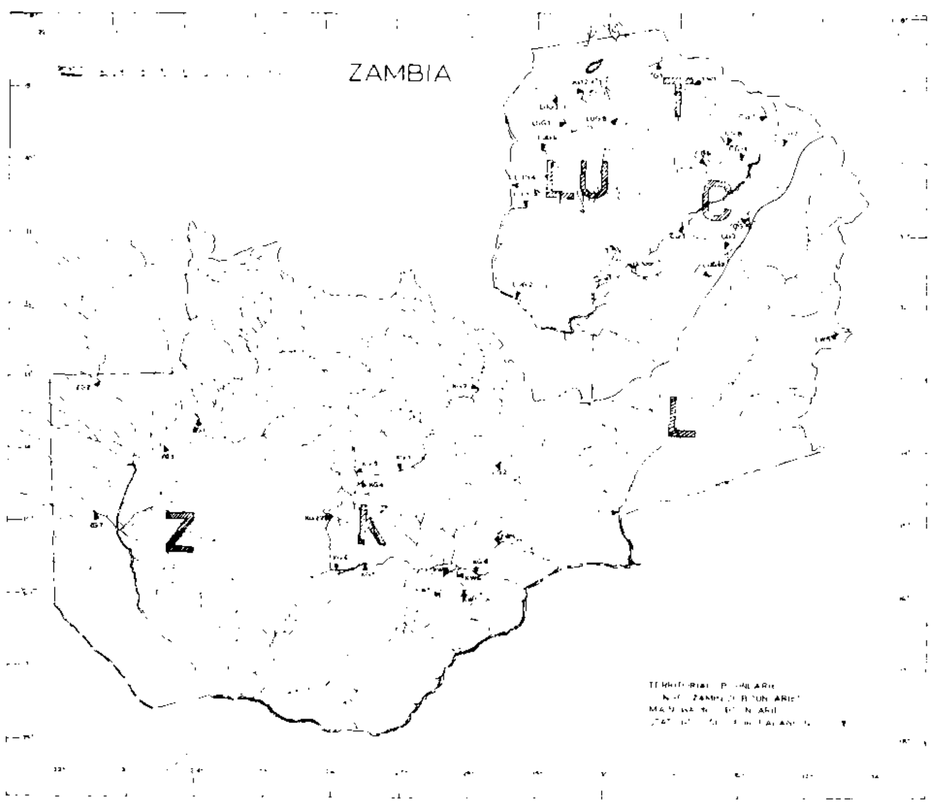

Figure 1 - Main basins of Zambia

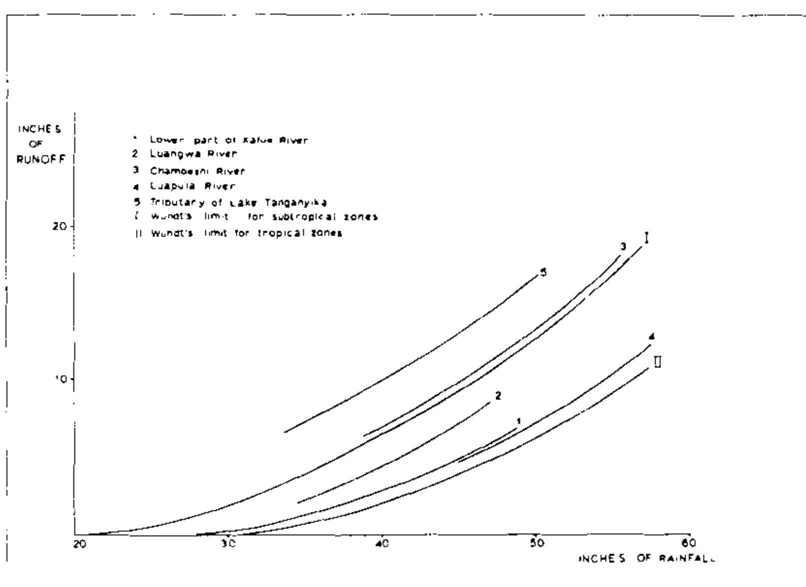

Figure 2 - Rainfall-runoff relations for main Zambian basins

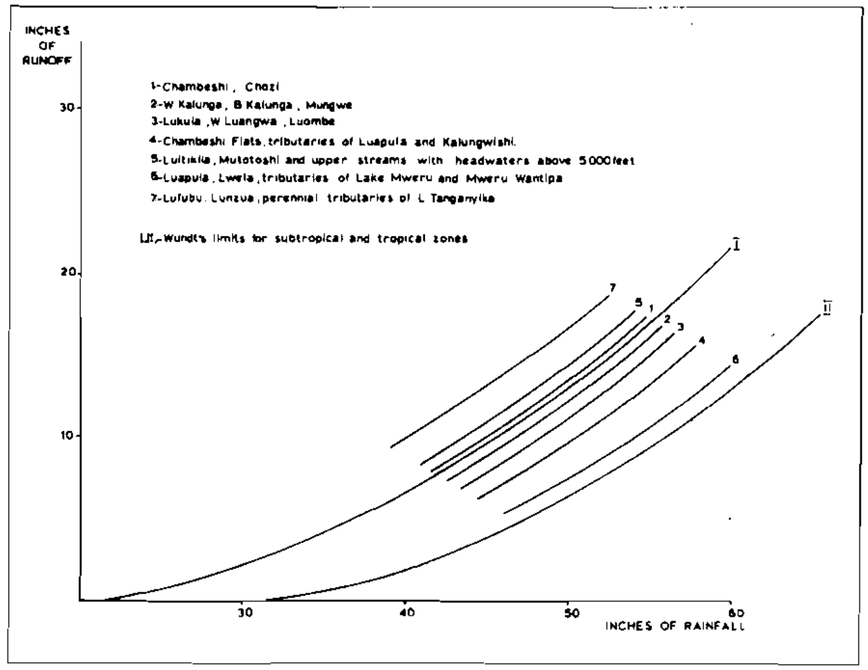

Figure 3 - Rainfall-runoff relations of the rivers in Chambeshi-Luapula basin

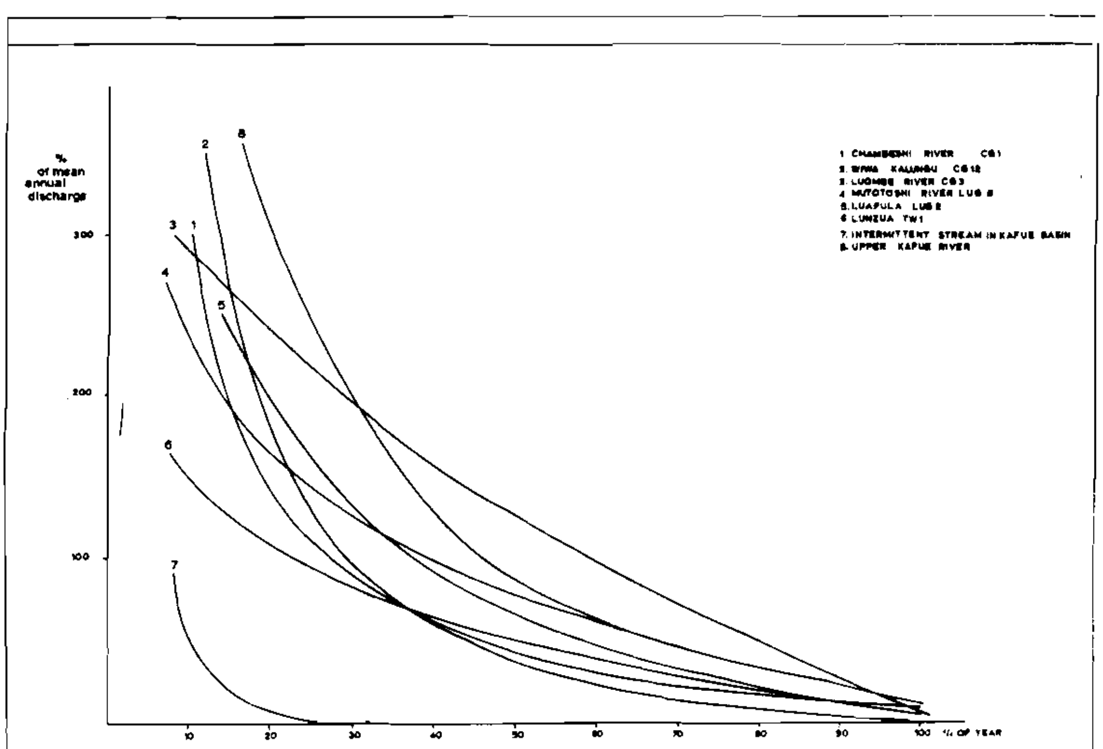

Figure 4 - Characteristic duration curves of some Zambian rivers

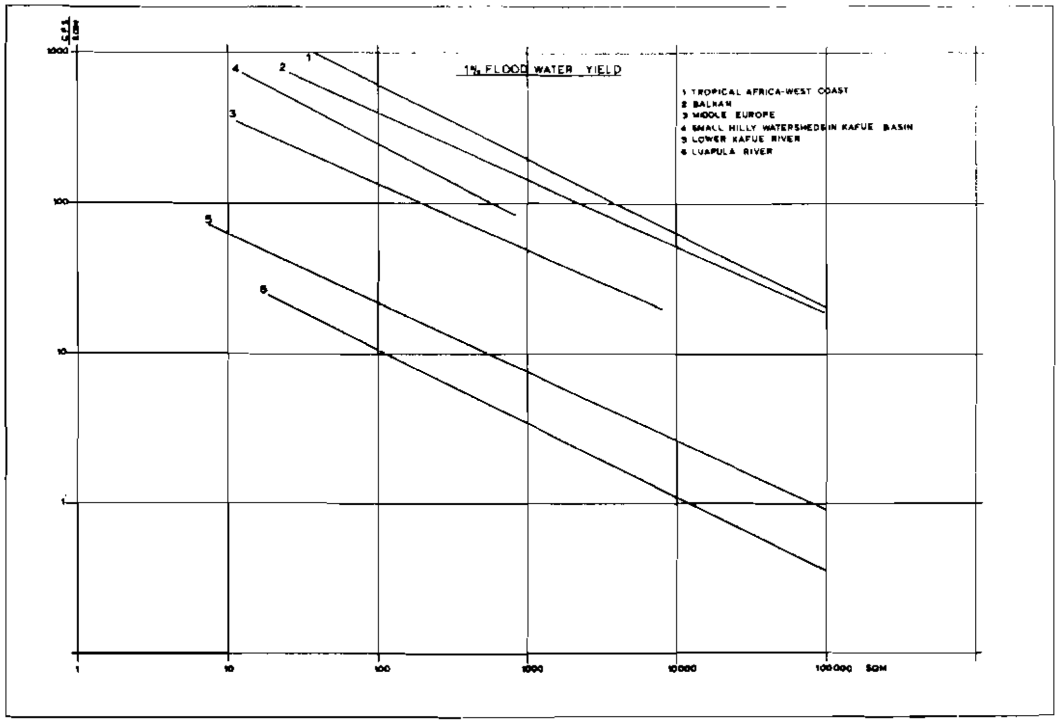

Figure 5 - Relation between the drainage area and 100-year return period floods

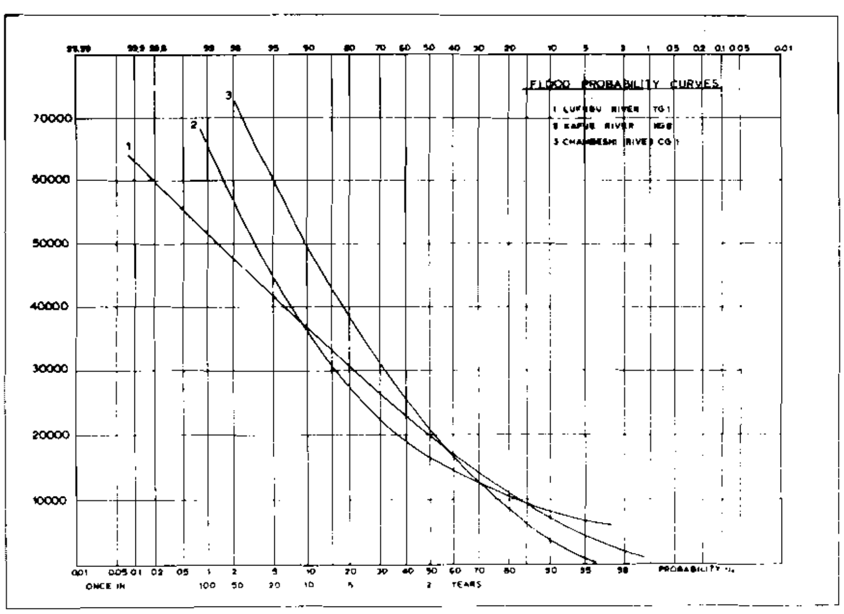

Figure 6 - Flood probability curves for some Zambian rivers

APPLICATIONS DE L'HYDROMETEOROLOGIE AU DEVELOPPEMENT ECONOMIQUE ET SOCIAL DES PAYS AFRICAINS

par W. Mandengué Epoy

RESUME

Les pays Africains disposent de grandes ressources hydrauliques, mais dont la mise en valeur rationnelle ne pourrait se faire qu'avec le concours des données hydrométéorologiques. Or nos Services Météorologiques sont, pour la plupart, dépourvus de moyens matériels et de cadres appropriés pour apporter une assistance efficace dans ce domaine. Il y a donc lieu d'attirer l'attention des Autorités sur les avantages d'ordre économique réalisables grâce aux données météorologiques et hydrologiques. Les champs d'application des données hydrométéorologiques sont multiples :

1°/- Par exemple, nous avons des projets de mise en valeur en commun de certains cours d'eau qui traversent les territoires de plusieurs de nos pays. La mise en valeur des ressources qu'ils offrent requiert une connaissance des données hydrométéorologiques sur leurs bassins versants.

2°/- Certains de nos territoires se trouvent en zône aride ou semi-aride. Pour promouvoir le développement économique de ces territoires, les données hydrométéorologiques sont nécessaires pour résoudre des problèmes d'approvisionnement en eau pour toutes sortes d'usagers; constituer des réservoirs de retenue pour des fins d'irrigation et autres.

3°/- Les inondations ont souvent provoqué des dommages importants chez nous. On comprend combien seront nécessaires les renseignements météorologiques afin de les prévenir. Il en est de même des problèmes d'évacuation des eaux de pluie dans les centres urbains.

4°/- Les données hydrologiques et hydrométéorologiques sont également indispensables dans tous les travaux de construction d'ouvrages hydrauliques; la détermination des ressources hydrauliques potentielles en diverses parties d'un bassin versant; l'étude des déversoirs et des réservoirs d'accumulation pour résister aux crues maximales et calculer la taille des barrages et la capacité des réservoirs tant pour assurer l'évacuation ou garder le surplus d'eau; etc...

5°/- Les données hydrométéorologiques constituent en outre le paramètre essentiel à l'agriculture, la plus importante source d'eau pour les plantes étant la pluie. Il est donc nécessaire de connaître les quantités d'eau de pluie disponibles, leur répartition régionale, etc..., avant d'entreprendre toute culture extensive.

De plus, les méthodes modernes de calcul de l'évapotranspiration potentielle pour la détermination du volume d'eau nécessaire pour l'irrigation rendent de grands services à l'agriculture.

Ces quelques domaines de l'application des connaissances hydrométéorologiques et hydrologiques devraient permettre aux Autorités d'avoir une idée assez précise de la contribution que les services météorologiques et hydrologiques peuvent apporter pour le développement économique et social de nos pays, si ces services sont suffisamment équipés.

ABSTRACT

The African countries have vast water resources, but these can only be utilized with the assistance of hydrometeorological data. Our Meteorological Services are often short of material and appropriate staff to give effective assistance in this field. There is therefore need to draw the attention of authorities to the economic advantages which are gained from meteorological and hydrological data. The fields of application of hydrometeorological data are numerous:

1. There are joint development projects for rivers which cross the territories of several countries. The utilization of the resources they offer requires knowledge of hydrometeorological data from the catchment areas.

2. Some of the territories are in the arid or semi-arid zones. In order to promote the economic development of these territories, hydrometeorological data are necessary to resolve the problems of water supply for all kinds of uses; to construct dams, reservoirs for irrigation purposes, etc.

3. Floods have often caused serious damage in some countries. Meteorological information is necessary in order to forecast the floods. This also applies to the problem of rainwater drainage in towns.

4. Hydrological and hydrometeorological data are equally essential for all water projects to determine the potential water resources in various parts of a basin; to study inflow and outflow of reservoirs to withstand maximum floods and to calculate the height of dams and the capacity of reservoirs, as well as to ensure drainage or conservation of the excess water, etc.

5. Hydrometeorological data are also essential to agriculture, the most important source of water for plants being rain. It is therefore necessary to know about such aspects as the quantities of available rainfall, its regional distribution, before undertaking any extensive cultivation.

Moreover, modern methods of calculating potential evapotranspiration for the determination of the necessary volume of water for irrigation are useful to agriculture.

These applications of hydrometeorological and hydrological knowledge would allow the authorities to have a precise idea of the contribution that meteorological and hydrological services can bring to the economic and social development of our countries, if these services are sufficiently equipped.

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INTRODUCTION

Les Pays Africains disposent d'énormes ressources en eau inexploitées et dont l'inventaire n'a jamais été fait. Ceci est dû au manque de moyens matériels et humains pour assurer cet inventaire.

Il est arrivé, du fait de la colonisation et par la conjoncture du second conflit mondial, que les Services Météorologiques africains n'ont connu de développement que du point de vue aéronautique. Si nos Gouvernements ont osé accorder un certain intérêt à la météorologie, il ne se limitait qu'aux Réseaux des Stations Synoptiques et aux Télécommunications météorologiques. Ceci a eu pour conséquence une désaffection générale des autres branches de la Météorologie, dont l'Hydrométéorologie, qui sont pourtant d'une importance capitale pour le développement économique et social de nos Pays.

Cela a également créé une stagnation, voire même la régression des Réseaux extensifs d'observation au sol des éléments climatiques fondamentaux.

Les responsables actuels des Services Météorologiques et Hydrologiques doivent donc, dès maintenant, conjuguer leurs efforts pour changer la mentalité de nos Gouvernements afin de les amener à une meilleure appréciation des avantages que nos pays peuvent retirer de nos Services Météorologiques, si ces Services disposent des moyens matériels et humains suffisants.

C'est dans ce cadre que nous aborderons ici un examen sommaire de quelques domaines d'application de l'Hydrométéorologie, qui présentent un intérêt certain dans les Projets de développement économique de nos pays.

DONNEES HYDROMETEOROLOGIQUES POUR DES INVESTISSEMENTS A COURT ET A LONG TERME

Certains de nos pays ont des Projets de mise en valeur en commun des cours d'eau qui traversent leurs Territoires. C'est le cas, par exemple, pour le Cameroun, des Bassins du Lac Tchad et du Niger.

Pour évaluer et mettre en valeur les Ressources qu'offrent ces Cours d'eau, tant au stade de planification, de la réalisation des aménagements projetés, que de leur exploitation à des fins multiples, les données hydrologiques et hydrométéorologiques sont nécessaires pour :

- L'estimation correcte des précipitations sur les Bassins versants,

- L'Evaporation probable dans les Réservoirs projetés,

- Les Prévisions à long terme de la durée de l'intensité des Saisons sèches et humides, et celles qui concernent la distribution des probabilités maximales et minimales des Précipitations et des Débits de ces cours d'eau.

MISE EN VALEUR DE LA ZONE SEMI-ARIDE DU NORD CAMEROUN

- Le Nord Cameroun, par exemple, est situé dans une Zône semi-aride. Pour promouvoir le développement économique de cette zône, les problèmes d'eau y ont encore une importance particulière. Le recensement de ses disponibilités en eau est donc indispensable, surtout encore que la pluviosité n'y est pas partout uniforme, les régions montagneuses étant plus avantagées sous ce rapport que celles des plaines.

Pour l'irrigation saisonnière des régions de plaines fertiles, mais desséchées pendant la saison sèche et dont l'approvisionnement en eau provient des Régions montagneuses, il est nécessaire de disposer d'un grand nombre de types de renseignements hydroclimatiques.

Pour constituer des réservoirs d'eau de pluie qui tombe de ces régions montagneuses, des prévisions faites plusieurs mois à l'avance permettent de planifier l'affectation des Terres pour chaque saison. Et pour établir ces prévisions, on doit disposer d'une longue série d'observations pluviométriques, et de mesures d'intensité.

Ces prévisions concernant l'approvisionnement saisonnier en eau intéressent généralement tous les usagers, mais notamment les responsables de l'irrigation : les précisions sur la durée, la fréquence et la hauteur des précipitations minimales étant indispensables pour des études de systèmes d'irrigation -

Par ailleurs, pour établir la relation entre l'eau du sol et les quantités d'eau disponibles en surface, il faut avoir des renseignements sur la répartition saisonnière et régionale, ainsi que sur la distribution des fréquences de pluie.

PREVENTIONS CONTRE LES INONDATIONS

Les cas d'inondation sont fréquents chez nous, surtout dans le Nord du pays. Et les dommages causés sont souvent importants. Des renseignements météorologiques sont, dans ce cas, nécessaires pour définir les risques d'inondation dans les régions inondables, y compris les zônes qui se trouvent en dehors de la protection des digues ou de tous autres ouvrages. En outre, pour que le zônage des champs d'inondation soit efficace en vue d'une occupation intermittente des gens et des biens, il est nécessaire de prévoir quel sera le régime des cours d'eau qui traversent ces régions. Cette prévision, bien entendu ne coûte qu'une petite fraction des sommes qu'elle permet d'économiser.

La défense contre les inondations, y compris l'évacuation des eaux dans les centres urbains, est un des aspects du domaine d'application de l'Hydrométéorologie et de l'Hydrologie.

Des réservoirs de toutes sortes, qu'ils soient destinés à la défense contre les inondations ou à l'approvisionnement en eau, et que cette eau soit utilisée dans le cours même ou en dérivation, doivent être en mesure de recevoir le trop-plein. Les calculs de tels réservoirs ne seront fondés que sur l'évaluation des précipitations : fréquence et intensité des pluies.

CONFECTION DES OUVRAGES HYDRAULIQUES

Les données hydrologiques et hydrométéorologiques sont indispensables dans tous les stades de confection d'ouvrages hydrauliques : planification, projets, travaux de construction et l'exploitation même de ces ouvrages.

a) Stade de Planification : Au stade de planification d'ouvrages hydrauliques sur un bassin fluvial, on procède à l'inventaire des ressources hydrauliques potentielles en diverses parties du bassin ; on détermine les déperditions d'eau par évaporation et évapotranspiration ; etc.. Les données de base pour toutes ces études sont du domaine de l'Hydrométéorologie : Pluies, Evaporation, Evapotranspiration, etc...

b) Stade des Projets : Les déversoirs de dérivation et les réservoirs d'accumulation sont conçus de façon à résister aux crues maximales et de manière à permettre l'écoulement normal de la rivière - La connaissance de la hauteur des précipitations est indispensable dans ce cas.

Dans les projets de barrages et de réservoirs, la détermination de la taille et de la capacité des ouvrages, la prévision des installations pour évacuer ou garder le surplus d'eau, etc... sont liés au régime des pluies à déterminer par l'hydrométéorologie.

c) Stade des Travaux :

Au cours de la période des travaux de construction d'ouvrages hydrauliques, il faut dériver le cours naturel au fleuve, ériger des digues pour prévenir l'inondation du chantier, protéger le matériel et les ouvriers. Pour effectuer tous ces calculs et en arriver à bonne fin, il est indispensable de disposer de prévisions de pluies et des niveaux d'eau pouvant en résulter.

d) Stade de l'Exploitation -

Une fois la construction de l'ouvrage terminée, on doit formuler une méthode pour la régularisation des réservoirs compte tenu des tendances des précipitations dans le bassin versant en amont de l'ouvrage. La méthode doit permettre de transformer les eaux de pluie en débit fluvial qui influe sur le niveau d'eau du bassin de retenue, et doit considérer la quantité d'eau à écouler régulièrement par les déversoirs, les turbines de génération d'énergie, etc... Pour parvenir à ces fins, il faut exploiter un réseau de postes pluviométriques au-dessus du point de contrôle, rassembler et communiquer les données sur les chutes de pluie, élaborer et transmettre les prévisions de pluviosité.

Toutes ces opérations relèvent de l'Hydrométéorologie.

Le Météorologiste est conscient du fait que la planification de la construction de barrages et d'usines hydro-électriques, en général, implique nécessairement une connaissance approfondie du régime des précipitations et des conditions d'évaporation qui prévalent dans la région concernée.

Ne pas tenir compte de cette nécessité lors de la construction de barrages, pourrait entrainer des risques parfois désastreux si le niveau des précipitations atteignait une hauteur imprévue. Il est pourtant facile de dénombrer que les sommes que l'on pourrait dépenser pour l'observation des précipitations et de l'évaporation dans le bassin versant considéré, même si les observations doivent se poursuivre pendant un certain nombre d'années, sont relativement faibles par rapport au coût d'un barrage ou d'une usine, sans parler de ce que pourraient être les pertes si une catastrophe se produisait.

DONNEES HYDROMETEOROLOGIQUES COMME PARAMETRE ESSENTIEL A L'AGRICULTURE

On sait bien, pour les cultures, que l'équilibre entre la perte de chaleur et l'absorption d'eau détermine en partie la croissance des plantes. Or pour les plantes, la plus importante source d'eau est la pluie. Il est donc nécessaire de connaître les quantités d'eau saisonnières disponibles, la répartition et la régularité des pluies avant d'entreprendre toute culture extensive. C'est cette connaissance qui permettra de résoudre, selon les exigences de chaque espèce de culture, les problèmes de :

- Choix de Cultures et de Méthodes d'élevage ;
- Détermination des périodes favorables pour l'ensemencement, la fenaison et la récolte ;
- Protection des Cultures contre la chaleur
- Planification du reboisement et de l'irrigation pour remédier à l'insuffissance des précipitations, ou pour accroître le rendement des Cultures ;
- Emmagasinage et transport des produits agricoles,etc...

Par ailleurs, les méthodes modernes de calcul de l'Evapotranspiration potentielle pour la détermination du volume d'eau nécessaire pour l'irrigation sont encore une source d'importantes économies réalisables grâce aux données hydrométéorologiques.

Il appartient donc à nos Gouvernements de pourvoir leurs Services Météorologiques en Cadres et en Matériels techniques adéquats si nous voulons tirer le maximum de profits de la Science hydrométéorologique et hydrologique pour le développement économique et Social de nos pays .

THE VOLTA RIVER BEFORE AND AFTER IMPOUNDMENT

by E. Nyame Kumi

ABSTRACT

The effect of the Volta reservoir on the annual flow of the Volta River at Akosombo is discussed.

RESUME

Un examen de l'influence du bassin de retenue de la Volta sur la crue annuelle de ce fleuve à Akosombo.

INTRODUCTION

For successful exploitation or utilization of water resources by man, methods have been devised to ascertain the dependable quantity of available water. Due to the variable nature of the elements involved, many years of data are usually compiled, studied, and analysed. In the case of a river development scheme, analysis of records obtained from river gauging stations near the development area is normally carried out to choose a dependable flow for the design of the system.

Barely twenty years ago, in Ghana, attention was drawn to the vast potentialities of the Volta River in the area where it cuts a gorge through the edge of the plateau to enter the Atlantic Ocean. Fortunately within the stretch of the gorge there was a gauging station with reliable flow records since 1936. When the project for harnessing the river for the generation of electricity crystallised in 1958 there were 23 years of river flow records available for the designer of the hydraulic systems involved.

In brief, a dam was to be built across the gorge to form the fourth largest man-made lake, and a certain dependable outflow was to turn the turbines for the intended purpose. In choosing the flow, consideration was given to the loss of water through evaporation, and the gain of water from rainfall on the surface of the reservoir. The effect of the proposed reservoir on the flow of the river was not considered; and the purpose of this paper is to discuss the effect of the reservoir on the flow of the river as recorded at the same observation point.

HYDROMETEOROLOGY OF THE VOLTA BASIN

The whole basin of the Volta River lies in a region which is exposed to overhead passages of the intertropical front or belt; this front may be regarded as a discontinuity or a boundary formed between two air masses originating from the Northern and Southern Hemispheres. The main cause of precipitation in the rainy season over the entire basin is a frontal-wave phenomenon closely associated with the tropical front. The front is neither stationary nor static, but rather fluctuant or migratory. In the months of December through February the front lies across the Gulf of Guinea, just north of the Equator. In March it begins to migrate northwards and continues in this direction until July. The northward migration produces the frontal wave phenomena, accompanied by thunderstorms with violent electric discharges. During August the front begins to retreat southwards and continues until November when it returns to its position astride the Guinea coast. The southward thrust tends to disintegrate the front. Any location which is crossed by the front twice each year enjoys two maxima of energetic inter-tropical front weather. The interval between the two maxima decreases with higher latitude until there is but one maximum at the high latitude limit of the fronts migration.

As higher latitudes are approached the ratio of the amount of precipitation in the months of March through July, to the amount for August through November decreases, which feebly supports the fact expressed in the last sentence of the previous paragraph. The amount of precipitation in any particular year depends on two factors: (1) the mobility of the front and (2) the depth of air mass involved at the vicinity of the front.

The average annual precipitation for the entire Volta basin is estimated to be about 43 inches, and the surface runoff caused by this amount of precipitation is observed to be slightly over 15 million day-sec.-ft. (1 day-sec.-ft. = 0.03719 inch per sq. mi.) as long-term average.

VOLTA BASIN: PHYSICAL CHARACTERISTICS

The catchment area of the Volta River basin above the dam site is 152,090 square miles, of which 61,590 square miles are in Ghana and some 90,500 square miles lie in Upper Volta (66,090), Togo (9,868), Dahomey (5,250), Mali (4,800) and Ivory Coast (3,820).

The main streams of the Volta River are the White Volta, the Black Volta and the Oti, with catchment areas of 40,445, 57,535 and 28,100 square miles respectively. There are other streams in the south such as Afram, Obosum and Sene. In general the catchment area within Ghana is low-lying, undulating with a general level of between 100 and 700 feet above the sea. Geological explorations have indicated that there is little ground water storage.

RUNOFF

Before the impoundment and after, the runoff for the catchment of the Volta River was recorded daily at or near the dam site. The lowest and highest figures recorded during the period 1936 to 1964 were 5 and 37 million day-sec.-ft., the annual average standing at 15.9 million day-sec.-ft. As table 3 indicates, the annual average has been gradually increasing prior to the completion of the dam.

The long average runoff coefficient for the entire basin is 9 per cent. Several sub-catchments, however, have different coefficients of runoff. The Oti, though only 18 per cent of the total catchment contributes on an average 30 per cent to 40 per cent of the annual total runoff of the entire basin. The reason for this is that the catchment of this river is the most hilly and mountainous in the whole basin.

The wide variation in the monthly runoff bears no direct relation to the monthly rainfall. The lowest monthly runoff recorded is 0.017 million day-sec.-ft. while the highest is 12.027 million day-sec.-ft. The lowest was in April 1958 and the highest in September 1963.

The rainy period which begins in March does not bring any detectable increase in runoff until June. The explanation is that a large portion of the rainfall is lost to the soil-moisture complex as a recharge, because the catchment is sucked and sapped dry by the dry continental harmattan wind prior to the rainy season, that is, from December through February to the permanent wilting point or the zero point of soil moisture. The early rainfall or precipitation recharges the soil moisture until it reaches a maximum value, or its field capacity. The whole recharge is a permanent loss of precipitation to runoff.

The ratio of total runoff for the period March to July, to that for the period August to November ranges from 0.04 to 0.27, while the ratio of total rainfall for the same period ranges from 1.06 to 1.55. The indication here is that the soil-moisture recharge for the basin as a whole is considerably large.

Before the project had commenced the basin soil-moisture or its field capacity was not under any influence. The creation of the 3,275 square miles reservoir by the construction of a 370-ft. dam should surely cause a change in soil moisture conditions in the shallow basin of the reservoir area. The change should effect a reduction in the loss of precipitation, thus increasing runoff.

The loss of precipitation to runoff through evaporation is almost equal to the gain due to rainfall on the surface of the reservoir during the months of August, September and October. Furthermore, the runoff for these months constitutes 80 per cent of the total annual runoff. Therefore these three months have been considered to discuss the effect of the reservoir on runoff.

EFFECT OF VOLTA RIVER DEVELOPMENT PROJECT ON RUNOFF

Before the project, the peaks of Volta River hydrographs always occurred between September 15 and October 22. Two factors are recognisable from the shape of the hydrographs.

(a) The whole or greater portion of the basin is contributing just before or during this period.

(b) The soil moisture deficiency is completely eliminated before the peak flows. That is, the field capacity of the soil moisture has been reached, and that there is very little loss of precipitation to runoff through the soil moisture complex.

The effect of the project on the first factor is nil, but not on the second factor. The impoundment has raised the surface of the river about 120 to 230 feet in a reach of 250 miles. In the process, some amount of water was lost to the surrounding areas; changing the soil moisture complex of these areas. The extent of the affected area is difficult to determine. The period affected by the change, however, is easily discernible.

For the peak to occur as it does, the recharge should be completed before the end of the second week of September, with plus or minus ten days. From this and considering the three months, namely August, September and October, there should be no appreciable change in runoff in October after the impoundment. There should, however, be increases in the other months especially August, for the period under consideration.

An examination of the pre-project flow records from 1936 to 1963 (Table 2), gives an average of 2.05, 5.08, 5.46 million day-sec.-ft. for August, September and October respectively. Assuming the years 1964 and 1965 as transition period when the reservoir was being formed, the post-project period is reckoned from 1966. The post-project flow records give as averages for August, September and October, 3.94, 7.60 and 5.46 million day-sec.-ft. respectively. (Table 1).

It should be conceded here that the post-project records are of short duration. Nevertheless the argument holds and is sustained by the following facts:

(a) The October runoff is not expected to be affected, and it has not been.

(b) For the months under consideration August runoff is expected to be affected most, and it has. There is an increase of 1.89 million day-sec.-ft. or 92 per cent.

(c) The increase in September runoff is 2.52 million day-sec.-ft. that is almost 50 per cent increase over pre-project runoff.

(d) In 1968 when the whole of the southern catchment received copious precipitation following the pattern of 1941, 1942 and 1949 rainfall, August inflow exceeded October inflow for the first time, and by over 40 per cent.

(e) August runoff recorded its highest in 1968, a post-project year. Parenthetically, so also July and June.

CONCLUSIONS

The above analysis demonstrates that there is more water available for utilization for generation of hydro-electricity than was conceived by the designers, due to the effect of the project itself. This was hard to conceive during the design stage.

For the period discussed the increase amounts to 4.41 million day-sec.-ft., about 30 per cent increase over the average flow of 17 million day-sec.-ft. chosen as dependable for the design of the hydraulic components. In terms of installed capacity of the project, the analysis has indicated there is water for two more turbines, to make the total eight instead of six as planned.

Moreover, the Volta Lake sub-catchment proper, which has an area of about 30,000 sq.mi. and which lies wholly in the low land basin, is going to exert considerable influence on the runoff of the Volta River as a whole in the post-project days. As the influence is inclined to increase runoff of the River, consideration should be given to how best to utilise this increase instead of discharging it through the spillways as surplus waste.

SUMMARY

The runoff of the Volta River has been found to have increased about 30 per cent since 1966. The increase is attributed to the creation of the large man-made lake. The lake or reservoir lying in a shallow basin has caused a change in the soil moisture complex: the recharge to soil moisture has been reduced, thus a reduction in the loss of precipitation to runoff.

Table 1

Recorded runoff in thousand day-sec-ft. after impoundment

YEAR	MONTH		
	August	September	October
1966	2,930	5,720	4,750
1967	3,050	5,480	5,500
1968	8,350	10,810	5,860
1969	3,280	8,030	6,040
1970	2,110	8,000	5,180
AVERAGE	3,944	7,608	5,466

Table 2

Recorded runoff in thousand day-sec-ft, before impoundment

YEAR	MONTH		
	AUGUST	SEPTEMBER	OCTOBER
1936	1248.90	3403.30	5605.80
1937	1196.70	4987.40	5589.50
1938	1198.10	3400.00	4007.60
1939	2039.00	5365.70	6280.20
1940	1558.30	4211.60	4262.60
1941	3013.00	6935.60	3706.50
1942	960.25	3105.90	1278.70
1943	1074.40	3310.60	4176.80
1944	1963.00	5170.20	4232.80
1945	3079.80	6936.10	7045.70
1946	715.05	2121.20	4768.90
1947	3085.60	8510.70	6723.40
1948	1321.70	4932.80	3349.30
1949	4014.30	8797.60	4904.80
1950	1196.90	2509.89	2819.20
1951	1500.20	5384.60	8256.80
1952	1617.30	4885.60	9440.30
1953	3310.60	5195.30	5575.80
1954	755.30	3671.80	4951.50
1955	4581.60	7224.10	8037.90
1956	504.60	2909.70	3993.70
1957	2946.80	6874.40	8954.20
1958	323.60	1835.30	1533.30
1959	1025.00	4371.00	4863.00
1960	2170.50	4994.00	7206.10
1961	1882.20	2630.11	3205.80
1962	2809.75	6624.00	7293.00
1963	6283.00	12027.00	10706.00
AVERAGE	2049.12	5083.05	5456.04

Table 3

Progressive average annual runoff in million D.S.F.

YEAR	RUNOFF	PROGRESSIVE AVERAGE
1936	13.2	13.2
1937	14.1	13.6
1938	11.7	13.0
1939	17.2	14.1
1940	13.1	13.8
1941	16.4	14.3
1942	7.5	13.3
1943	11.4	13.1
1944	13.3	13.1
1945	19.5	13.7
1946	10.4	13.4
1947	21.0	14.1
1948	11.9	13.9
1949	20.7	14.4
1950	8.1	14.0
1951	23.0	14.5
1952	20.3	14.9
1953	19.2	15.1
1954	12.5	15.0
1955	25.1	15.5
1956	8.9	15.2
1957	26.8	15.7
1958	5.0	15.2
1959	12.7	15.1
1960	16.8	15.3
1961	9.3	15.0
1962	22.0	15.2
1963	37.2	16.0
1964	12.10	15.9

HYDROMETEOROLOGICAL FACTORS IN THE LAKE NASSER DEVELOPMENT PROJECT

by M.H. Omar

ABSTRACT

A brief account is given of the hydrometeorological factors which are important to the Lake Nasser Development Project. These factors include evaporation from the lake, evapotranspiration from crops which will be planted round the lake, and wind, waves and water temperatures for fishing and navigation. The steps that have been taken or that are planned to be taken to meet the requirements of the Project for these hydrometeorological factors are also given.

RESUME

Un bref compte rendu a été donné sur les facteurs hydrométéorologiques qui sont importants pour le Projet du Développement du Lac Nasser. Ces facteurs comprennent l'évaporation du lac, l'évapotranspiration des plantations autour du lac et le vent, les courants et la température de l'eau pour la pêche et la navigation. Les mesures qui ont été déjà prises ou qui sont à prendre pour subvenir aux besoins du projet pour ces facteurs hydrométéorologiques sont aussi donnés.

INTRODUCTION

The development of Lake Nasser is one of the most important projects in the United Arab Republic. The lake can provide the source of various resources and industries of large economic benefits, and the opportunity for developing and exploiting the potential of the lake for recreation, tourism and settlement. The Lake Nasser Development Centre Project, which is responsible for research and planning related to the development of the lake, is executed with the co-operation between the Food and Agriculture Organization of the United Nations, and the Government of the UAR. The UAR Meteorological Department supervises the technical side of the meteorological work in the Project.

Hydrometeorological factors play an important role in the Lake Nasser Development Project. This role is related to hydro-electric power, irrigation, agriculture, transport and fishing. It is the aim of this lecture to give a brief account of the hydrometeorological factors which are important to the project, and the steps that have been taken, or that are planned to be taken, to meet the requirements related to these factors.

EVAPORATION

A knowledge of evaporation from the lake is important for the proper management of water resources. It will hold particular promise for further progress as concerning irrigation and water and power supply. While high lake levels are desired for power production and irrigation, the increased size of the lake surface would lead to rapid increases of evaporation at higher lake levels. At 160m and 180m levels the estimated areas are 2580 and 5240 km^2 respectively. For optimum benefits from the lake it may be advisable to determine that lake level which gives the best balance between high power production and irrigation against reduced loss of water from evaporation.

Evaporation is difficult to measure accurately (see e.g. WMO Technical Note No. 83, 1966). This is especially so in the case of a lake like Lake Nasser, of irregular configuration, surrounded by rugged areas and with a variable maximum depth depending on the flood cycle.

Preliminary estimation. Until direct measurements of evaporation from the lake are made, it was thought worthwhile to attempt to estimate evaporation from the lake on the basis of the available data, using the results of recent research on lake evaporation made elsewhere, e.g. in the USA, Australia and Japan. This attempt was made by Omar and El-Bakri (1970). Three different approaches were used: evaporation pan (Kohler et. al., 1955), combination (Penman, 1948, Slatyer and McIlroy, 1961) and Dalton. The data used for the estimation included a class 'A' pan and climatological observations at Aswan, water temperature at Aswan reservoir (Sutton, 1946), and estimated values of climatological elements over the lake. The results by the different methods were close to each other and indicated that evaporation from the lake averages about 8 mm/day, assuming that advected energy and change in energy storage are negligible. On this assumption the evaporation rate varies between about 4 mm/day in January and 11 mm/day in June. The estimated annual evaporation from the lake is about 8 per cent higher than the estimated annual net radiation. That evaporation is higher than net radiation is due to the downwind sensible heat flux as the cool water surface is heated by the warm air. Evaporation is about 58 per cent of Class 'A' pan evaporation, which would be expected for a very warm and arid climate, on the basis of the findings by Kohler et. al. (1959). It is noteworthy that the estimated average evaporation is about 30 per cent higher than the average evaporation at Lake Mead which lies in a warm and arid area in Nevada, USA. Average evaporation at Lake Mead was about 6.0 mm/day (Harbeck et. al. 1958). The higher evaporation at Lake Nasser than at Lake Mead may be explained by higher global radiation, larger air temperatures and lower humidities at the former than the latter lake. Taking into account the average depth of Lake Nasser and the results of work on lake evaporation in Japan (Yamamoto and Kondo, 1968) and in USA (Harbeck et. al., 1958) it appears that evaporation from Lake Nasser is probably at a maximum about September and at a minimum about February.

The estimated evaporation from Lake Nasser is about 3 m/year. This represents a net loss of water due to evaporation from the lake of about 15 billion cubic metres per year at the 180m level. This would represent approximately 18 per cent of the average flow of the River Nile.

Measurements over the lake. It is necessary to confirm the results of the estimation described above, with actual measurements over the lake. The water budget method cannot be applied as seepage is not accurately known. The suitable methods are probably the energy budget method, coupled with measurements by the Dalton or bulk aerodynamic method. The measured evaporation should be correlated to Class 'A' pan evaporation placed at representative stations round the lake so that they may be used later for the estimation of short period, e.g. monthly, evaporation. It is planned to have the services of an expert in evaporation in deciding the most suitable procedures for measuring evaporation from the lake.

EVAPOTRANSPIRATION

Preliminary surveys have shown that about 300,000 acres above the lake level would be available for irrigated farming. To use the water available for irrigation in the most economic way it is necessary to know evapotranspiration which determines the water needs of crops. While a knowledge of evapotranspiration enables us to use the extra water to irrigate new crops in newly irrigated areas, it also helps to get the best yield as too much irrigation or too little irrigation will have harmful effects on the crop yields.

An accurate weighed lysimeter with a large monolith soil-block (2m x 2m x 2m depth) on a high capacity simple strip-pivot balance of accuracy to the nearest 0.05mm of evaporation has been under construction by the workshop of the Meteorological Department at Cairo, and is now near finalization. It is based on a design by Mr. I.C. McIlroy, of the CSIRO Division of Meteorological Physics, who has been in Cairo as a WMO expert during 1967. Parallel with lysimetry, work has been going on to construct an energy partition evapotranspiration recorder (EPER). This is a fully automatic portable instrument using electric signals simulating the energy balance equation, and is also based on a design by Mr. McIlroy. Final tests of the functioning of a pilot-model EPER are now being made. It is intended to use lysimeters and EPER instruments to measure crop evapotranspiration at the principal agrometeorological station at Abu Simbel (Lat. 23° 20'N, Long. 31° 36'E) which will be established as soon as preparations for the agricultural farm there are finalized.

In addition to these accurate and rather complex methods, simpler methods will be used to estimate evapotranspiration. These include the McIlroy combination method (Slatyer and McIlroy, 1961), and correlations between measured evapotranspiration and routine climatological data and evaporation from pan readings. Class 'A' pan evaporation, as measured with the pan well inside the crop and with its rim at crop top level, has been found elsewhere to be highly correlated with evapotranspiration. Such simple methods will be useful to estimate evapotranspiration at a number of stations round the lake where lysimeters and EPER measurements are not available.

HYDROMETEOROLOGICAL FACTORS AFFECTING THE SAFETY AND OPERATIONS OF NAVIGATION AND FISHING INDUSTRY

Wind and waves. The safety of navigation on Lake Nasser depends greatly on the conditions of wind and waves. As there are no navigational beacons or radio aids, compasses or radar, visual navigation alone is used. The shoreline that gives guidance for navigation may very well be hidden by blowing sand, dust or haze. Haze and dust conditions obscure water eddies that warn of hidden rocks. Dust and sandstorms therefore force all navigation to take shelter. Waves of one-half metre are a serious threat and all boats must avoid them. Waves may grow to two metres or more at the downwind end of the larger khors. Strong winds that arise with the arrival of cool air masses in winter or that are associated with the onset of khamsin depressions in spring are dangerous to all navigation.

Navigational operations are planned assuming that satisfactory conditions of winds and waves will occur. Reliable weather forecasts would lead to considerable economic benefits and convenience as they would enable to cancel, delay or change plan. for later travel.

Winds and waves are occasionally hazardous to the safety of fishermen and their property. Conditions are worst in the open waters of the khors. At present the fishermen live along the shore and fish mostly in wind-protected small khors where there are no large waves. When fishermen venture out in the lake they are exposed to the hazards of storms. Storms of blowing dust or sand, which often occur suddenly, stop all fishing and are hazardous to the safety of fishermen.

Weather conditions have a great influence on fishing operations. Fishing nets are damaged by strong winds which drag and tangle them, and sometimes the anchor ropes are broken and the nets are lost. Waves over one-half metre in height interfere with the delivery of fish to carrier boats, and of supplies to the fishermen. Losses and shortages might be avoided if fishermen were warned in advance of high waves, strong winds duststorms and sandstorms.

<u>Water temperatures</u>. Water temperatures control the movement and location of those fish which prefer specific temperatures. These fish move out to deeper, cooler levels in the lake when the surface water gets too warm. The catch of the different species, therefore, varies through the year. The relationship between the movement of fish and the air and water conditions, especially water temperatures, should be studied with the aim of providing a day-to-day advisory on the probable location of the different fish species in the lake. This would lead to considerable economic benefit.

<u>Forecast and warning services for the lake</u>. Due to the importance of provision of storm and weather advisory for the safety and welfare of fishermen and navigators, the Food and Agriculture Organization of the United Nations, under its expanded programme of technical assistance, appointed a marine meteorologist (Mr. K.T. McLeod) for 5 months in 1970. According to his recommendations it is intended, as soon as possible, to start a weather warning and forecast service for Lake Nasser. The forecasts for 24 hours period will include wind speed and direction, visibility, temperature, waves and surface water temperature. They will be issued by the Meteorological Department twice daily, to be available for radio broadcast at times suitable for the fishermen. Warnings will be issued as soon as it becomes evident that conditions dangerous to, or of importance to, fishermen and navigators will affect the lake within the next 30 hours.

NETWORK OF HYDROMETEOROLOGICAL STATIONS

During the mission of the marine meteorology expert a station was established in the town of Abu Simbel. The station will be transferred later to the area planned for agricultural development, as soon as farming activities are under way. The observations of the station will be a useful aid to weather forecasting in the area of the lake as before its establishment no observations for forecasting were available between Aswan airport and Dongola, 550km to the south. Observations at Abu Simbel station are taken at 06,09,12 and 15 UT and they include air temperature and humidity at screen level, wind speed and direction at 2½m, soil temperatures at 2,5,10 and 20 cm depths, pressure, clouds, rainfall and visibility. Observations are also made at a lake station at the harbour, using portable equipment, at 06,09 and 15 UT. They include air temperature and humidity and wind speed and direction at 1½m, and water surface temperature.

Climatological data are needed for navigation, fishing and other purposes. These data will be obtained by a combination of mobile and fixed observing stations. As for mobile stations a series of combined meteorology-limnology observing survey trips are being arranged at monthly periods. The data observed include air and water temperature, wind, relative humidity, visibility and wave conditions. The network of fixed stations will include both shore and lake stations. The shore stations will be established at representative locations on the east and west sides of the lake. It is intended that the lake station network will consist of buoy type automated stations first in mid-lake, and later about ½ to 1 km east of the harbour of Abu Simbel.

As Aswan is the focal point for Lake Nasser activities, a weather and climate advisory service has been established there. It has been staffed by a meteorologist who was seconded from the Meteorological Department to the Project, and two technician observers. Two observers work at Abu Simbel station. The staff for hydrometeorological work in the project will be increased when evaporation measurements are started and new stations are established. It is hoped that progress of hydrometeorological work will be rapid for the benefit of the important Lake Nasser Development Project.

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NUCLEAR TECHNIQUES IN GROUNDWATER EXPLORATION

by Bryan R. Payne

ABSTRACT

The principles of the use of environmental isotope techniques, depending upon the natural variations of deuterium, oxygen-18, tritium and carbon-14, are described. Examples of applications are drawn from studies on the African Continent.

RESUME

Les principes déterminant l'emploi des techniques des isotopes naturels dépendant des variations naturelles du deutérium, de l'oxygène-18, du tritium et du carbone-14, sont décrites. Les exemples de ces applications proviennent d'études faites sur le Continent Africain.

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INTRODUCTION

Nuclear techniques are one of the recent technological developments in hydrology which can help solve hydrological problems and contribute to a better understanding of hydrological phenomena. The wide range of techniques available to the hydrologist are discussed in a guidebook (IAEA-1968) which outlines the principles of application to specific hydrological problems. In groundwater studies the techniques include the use of nucleonic instruments and injected radioactive tracers and the use of a group of techniques based upon the natural variations of environmental isotopes in waters of the hydrological cycle. Nuclear logging methods fall in the first group and have been used in the petroleum industry for some time, but relatively limited use has so far been made by the hydrologist. It is hoped that a recent report (IAEA-1971) will generate interest in the use of these methods.

Environmental isotope techniques are already being used in a number of UNDP Special Fund projects in countries on the African continent, mainly by co-operative arrangements between IAEA and FAO, UNESCO and WHO. Bearing this in mind and the limitations on length, this paper is limited to a brief discussion of the principles of application of these relatively new methods.

Environmental isotopes may be defined as those isotopes, both radioactive and stable, which occur in the environment in varying concentrations and over which the investigator has no direct control. At present, the commonly used environmental isotopes are the stable isotopes deuterium and oxygen-18 and the radioisotopes tritium and carbon-14. The first three isotopes are part of the water molecule and as isotopic tracers constitute the only real water tracers available to the hydrologist. All other water tracers are present in a dissolved form and, therefore, are subject to loss by precipitation, adsorption and exchange.

Environmental isotopes have two immediate advantages over the use of injected radioisotope tracers. First, there are no problems of health and safety, and second, since the waters of different parts of the hydrological cycle are labelled with these isotopes, it is possible to make much larger scale studies than are possible with injected radioisotopes. Many applications are available and there is a continuing refinement and development of techniques.

OCCURRENCE OF STABLE ISOTOPES IN NATURAL WATERS

Deuterium and oxygen-18 occur in the oceans in concentrations of about 320 p.p.m. and 2000 p.p.m. for the molecular species HDO and $H_2{}^{18}O$ respectively. In practice, the isotope ratios D/H and $^{18}O/^{16}O$ are measured in a mass spectrometer; the data being expressed as per mil deviations (δ_D, δ_{18_O}) from a standard. The accuracy of measurement is about $\pm 2‰$ and $\pm 0.2‰$ for deuterium and oxygen-18 respectively.

Owing to the difference in vapour pressures and diffusion velocities in air of the different isotopic species of water, fractionation takes place when water changes state. Water vapour in equilibrium with liquid water is depleted in the heavy isotopic species with respect to the liquid phase. Thus, precipitation and, therefore, river waters and most groundwater are depleted in deuterium and oxygen-18 as compared with the isotopic composition of the oceans. This isotopic depletion becomes more marked with increasing latitude, distance from the sea and altitude due to the continuous removal of the heavier isotopic species by precipitation.

In a given region, a seasonal variation of the isotopic composition of precipitation is seen which closely parallels the variation in air temperature, so that precipitation in winter is more depleted in the heavy isotopes than in summer. However, these seasonal variations are soon smoothed out during passage to the groundwater table. This is due to the dispersion taking place during movement through the unsaturated soil zone and also to the fact that not all precipitation reaches the groundwater system due to run-off and evapotranspiration which is not uncommon in arid and semi-arid areas.

Craig showed that the isotopic composition of precipitation at a large number of stations in the world approximately obeys the following relation:

$$\delta_D = 8\,\delta_{18} + 10 \qquad (1)$$

Water which has been subjected to evaporation does not plot on the line given by equation 1. When water is subjected to evaporation the isotopic composition changes so that the remaining water is enriched with respect to the heavy isotopic species. However, the relative change for the deuterium and oxygen-18 is different from that in condensation processes so that a slope of 4 to 6 is observed.

OCCURRENCE OF TRITIUM IN NATURAL WATERS

Tritium, the radioisotope of hydrogen, has a half-life of 12.26 years and is a soft beta emitter (E_{max} 18 kev). Its occurrence in precipitation arises from two sources. The first, a natural one, is the production by cosmic radiation. Estimates of the concentration in precipitation vary, but are of the order of 10 T.U. (1 T.U. = $T/H \times 10^{18}$). The second source is man-made and is derived, since 1952, principally from the detonation of thermonuclear devices. This production has swamped the former by injecting periodic pulses into the atmosphere which has resulted in the labelling of waters of the hydrological cycle with an amount of tritium which can easily be measured. Tritium concentrations in precipitation reached a maximum in 1963 in the northern hemisphere.

The concentration of tritium in precipitation at any given location varies with season and exhibits a maximum in late spring and early summer. Knowledge of this variation is necessary when estimating the tritium concentration of water which is effective in recharging an aquifer. Tritium concentrations are also dependent upon geographic location. At a given time the concentrations are greater at higher latitude and more continental locations.

OCCURRENCE OF CARBON-14 IN GROUNDWATER

Carbon-14 has a half-life of about 5,730 years and, like tritium, is produced by cosmic radiation and from thermonuclear devices. The carbon-14 is oxidized to carbon dioxide and mixes rapidly with the atmospheric carbon dioxide reservoir. Any material that uses or reacts with carbon dioxide will contain a constant amount of carbon-14 as long as the material is in equilibrium with the atmospheric carbon-14 reservoir. After removal from contact with this reservoir, the carbon-14 content of the material will be subject to radioactive decay.

The carbon in groundwater is present in the form of dissolved carbon dioxide, bicarbonate and carbonate, bicarbonate being the predominant form at the pH of most groundwaters. In order to obtain a true age from the measurement of the carbon-14 content of a sample of groundwater, it is necessary to know what proportion of the total dissolved carbon species is derived from soil-air carbon dioxide which contains carbon-14. The remaining proportion is derived from non-biogenic carbon which contains no carbon-14 so that the radiocarbon age of a water sample will be falsely greater than its true age.

The $^{13}C/^{12}C$ adjustment technique permits an estimation of the carbon derived from soil-air by measurement of the $^{13}C/^{12}C$ ratio of the dissolved carbon species.

$$CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^- \qquad (2)$$

In the above equation 2 which represents the solution of limestone, the carbon in the soluble bicarbonate is partly derived from the carbon dioxide derived from soil-air containing carbon-14, and partly from the carbon-14 free carbonate. The relative proportions may be determined from the $^{13}C/^{12}C$ ratio of the bicarbonate if the isotopic ratio for both limestone and soil-air carbon dioxide are known. Values for limestone are known quite well and a number of measurements of the other parameter indicate the range of values to be expected.

APPLICATION OF ENVIRONMENTAL ISOTOPE TECHNIQUES

Before a discussion of the various uses it should be emphasized that the optimum benefit is obtained if the isotope techniques are used in conjunction with conventional hydrological methods, as is the case in the Special Fund projects mentioned earlier. Isotope techniques are often very valuable in substantiating a hypothesis based on hydrological data, or even deciding between alternative hypotheses.

The stable isotopic composition of a groundwater sample is valuable for classification and providing information on the origin of the water. Although there is a marked seasonal variability in the stable isotopic composition of precipitation, considerable smoothing occurs during infiltration through the soil and during transit through basins. Consequently, groundwater usually has a fairly consistent isotopic composition characteristic of its origin. This is true for granular aquifers, but not necessarily so when the flow is through fractures and tubular openings such as in karst and volcanic rocks, when some of the seasonal variability may be retained. An illustration of the value of stable isotope data is provided in a current UNDP project, executed by FAO, in Hodna, Algeria, where the stable isotope composition of the phreatic and artesian aquifers was found to be different, which excluded the hypothesis that the artesian aquifer was recharging the phreatic aquifer by leakage.

The change in isotope composition induced by evaporation of surface waters is of value in studying the relation of surface water to groundwater. An application of this type has been made on the border between Kenya and Tanzania (Payne, 1970). The isotope composition of Lake Chala which straddles the border was completely different to springs in the area. These results refuted the hypothesis that the springs received a significant proportion of their recharge from the lake. This type of application is particularly valuable when competing demands for the water are under consideration.

The hydrology of Lake Chad and the surrounding area is also being investigated by isotopic methods (Fontes et al.). The enriched stable isotope composition of the lake water owing to evaporation has demonstrated that leakage to groundwater is limited to areas quite close to the lake where mixing also takes place with rain water recharged on the sand dunes. The stable isotope data also demonstrate the stratification of water in the phreatic aquifer and the influence of flood water from the Chari river, the major source of supply to the lake, on the neighbouring phreatic aquifer.

The half-life of tritium limits its use in groundwater studies to shallow aquifers or in fractured rocks where movement is relatively rapid. The presence of thermonuclear tritium is a unique tool for testing hypotheses related to recharge. Investigations in arid and semi-arid areas often pose the question as to whether or not active recharge is taking place. In the example of the Hodna project cited earlier the highest tritium concentrations in the phreatic aquifer were observed near wadis, thus confirming that these are probably the major source of recharge to the aquifer. Elsewhere in the aquifer the tritium concentrations were rather low indicating that direct recharge by precipitation is probably rather low. The same technique is being applied in a UNDP project executed by WHO in Senegal. Tritium has demonstrated the existence of recharge in a number of the aquifers under investigation.

Attempts to interpret measured tritium values in terms of the time since recharge of the water sampled is complicated for two principle reasons. Firstly there is uncertainty in the tritium value to be used at the time of recharge and this is particularly so in the cases of water recharged since the early 1950's owing to the production of tritium by thermonuclear devices. Secondly, from the hydrological standpoint, a sample of water most likely represents a mixture of waters of different ages owing to the dispersive and mixing processes which have taken place since recharge. Therefore the dynamics of the aquifer are better considered in terms of transit time rather than age. In practice quantitative data require a time series of observations which are then matched with computed tritium concentration curves derived from different models postulated for the system.

Clearly the use of environmental tritium is limited to systems having relatively short transit times. Thus in studies in semi-arid and arid areas and particularly in confined aquifers, we find that carbon-14 measurements are required. Such studies are currently being made in a number of countries on the African continent, including Algeria, Chad, Senegal, Sudan and Tunisia. The carbon-14 data are normally interpreted in terms of groundwater velocity from which a figure for the regional mean permeability may be derived. It is considered that estimates of the latter parameter are more realistic than the extrapolations to a given area from pumping tests.

Carbon-14 data have also been used in a study of an artesian aquifer on the south coast of South Africa (Vogel). The low flow rate of 0.7 m/y estimated is presumed to be due to the fact that very little water can escape through the confining layers to the ocean. The same author has also estimated groundwater velocities in two aquifers in the central arid region of southern Africa where the water is in crystalline and consolidated rock covered by a thick layer of Kalahari sand.

CONCLUSIONS

Nuclear techniques provide the hydrologist with a powerful tool not only to solve routine problems, but also problems for which no solution was known before. Environmental isotope techniques, which are the subject of this paper, depend upon the fact that water can be identified by its composition thus giving the hydrologist a whole range of potential applications only some of which have been briefly touched upon. For example, no mention has been made of the use of stable isotope data in determining the source of salinity in saline waters, a problem which is difficult to resolve without recourse to isotope data.

Although nuclear techniques are not being used as yet as widely as their potential indicates, the number of studies in Africa has reached the stage where data from one study is also of benefit to other studies in the area. In addition to the work of the IAEA in co-operation with other specialized agencies there are probably about seven other groups actively engaged in isotope studies in Africa. These efforts will no doubt contribute to a wider awareness of the capabilities of these techniques and thus to their wider use as an additional tool for the hydrologist.

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DESIGN AND OPERATION OF HYDROLOGICAL AND HYDROMETEOROLOGICAL NETWORKS IN AFRICA

by Dr. Adetoye Faniran

ABSTRACT

The accelerated rate at which African countries are undertaking water resources development projects suggests that it is time we made a thorough appraisal of the methods of collecting and storing hydrological and related data. This is not only because of the failings of existing systems but also because of the additional advantage of using the data to estimate the continent's over-all water resources situation as well as to gain a better knowledge of the continent's hydrological cycle.

To this end the standardization of the method of designing and operating the stations in representative basins is suggested. A representative basin is defined as one which is sufficiently homogeneous in terms of relief, climate, hydrology, soil, vegetation, land-use etc., and whose major characteristics are repeated in a number of other places within a given area. The selection of these representative basins in Africa is best done by a group of interested specialists charged with this responsibility. The use of aerial photographs and simple cheap instruments is discussed. A centralised system of storage is advocated, with one major centre for all records and sub-stations for basins within individual countries.

RESUME

Le rythme accéléré aquel les pays africains entreprennent l'exécution de projets d'aménagement des ressources hydrauliques permet de penser que le moment est venu de procéder à un examen critique approfondi des méthodes de rassemblement et d'emmagasinage des données hydrologiques et des données connexes. Cet examen n'est pas seulement opportun en raison des faiblesses des systèmes existants, mais aussi du fait de l'avantage supplémentaire résultant de l'utilisation de ces données pour évaluer la situation générale du continent à l'égard des ressources hydrauliques, ainsi que pour parvenir à une meilleure connaissance de son cycle hydrologique.

Il est suggéré de recourir, à cette fin, à la normalisation du mode de conception et d'exploitation des stations de bassins représentatifs. On désigne ainsi des bassins suffisamment homogènes du point de vue du relief, du climat, de l'hydrologie, de la nature du sol, de la végétation, de l'utilisation des terres, etc., et dont les principales caractéristiques se retrouvent dans un certain nombre d'autres endroits d'une zone donnée. La meilleure façon de choisir ces bassins représentatifs en Afrique consiste à confier le soin de ce choix à un groupe de spécialistes s'intéressant à la question. L'utilisation de photographies aériennes et d'instruments simples et peu coûteux est également étudiée. Il est recommandé d'adopter un système centralisé d'archivage, comportant un centre principal où toutes les données seraient rassemblées et des sous-stations pour chacun des bassins intéressant les différents pays.

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INTRODUCTION

Many African countries are today concerned more than ever before with rapid economic development. Of the projects being undertaken in this respect the development of water and other resources of drainage basins is apparently the most important. This is because almost all the projects involve water in one form or another; for instance, urban development, industries, hydroelectricity and so on. It is therefore not surprising that dams and barrages can be found on almost all the important rivers of the continent, while many more are being built or are in the planning stage.

In spite of these, or rather because of them, there is a great need for a thorough appraisal of the methods of collecting, storing and analysing the necessary data for these water resources development projects. In the first place there are vast areas in Africa for which neither hydrological nor hydro-meteorological information is available, either for lack of capital or for lack of technical know-how, or both. Secondly, the situation in the continent until recently has been that individual countries or parts thereof have studied and kept the records within their borders; such records are generally inaccessible because of their scattered nature, because of border restrictions and also because of the variations in recording and storage methods. In this respect the efforts currently being made in the Nile, Senegal, Niger, Chad and Orange basins to standardize recording methods and to centralize data storage are to be appreciated. Thirdly, experience from the computed projects shows that the studies which preceded them were not sufficient in scope and time to minimize side effects. Finally, the efforts made so far have mostly been focused on the collection of data for particular development projects (see the Nedeco report in respect of Nigeria's Kainji dam (1961) or the FAO reports in respect of agricultural developments in the Senegal Valley). The result is a patchy hydrological and hydrometeorological network, from which few if any valid statements can be made about the over-all water balance and hydrological cycle, whether of individual drainage basins or of the continent as a whole. In short, there has so far been no conscious effort to obtain 'representative' data capable of providing a reliable estimate of the continent's over-all water sources.

This paper discussed two possible approaches for improving this situation. First, it advocates and elaborates on a system of representative basin-sampling in addition to the present national and other networks of hydrological and hydrometeorological stations; secondly it discusses the role of applied geomorphology, particularly the use of aerial photography and geomorphological mapping as possible sources of additional information. This last point is considered very important because it is relatively simple to undertake and involves relatively low costs.

THE PRESENT SITUATION

One of the most spectacular developments in Africa in the last ten years has been the accelerated study and development of river basins. This has taken two main forms. Individual African countries have undertaken studies for water resources development projects within their borders, such as the Volta dam in Ghana and the Kainji dam in Nigeria. The second type of study involves international co-operation among the countries within a drainage basin. Notable examples are the development projects along the Nile basin and the activities of the Senegal, Niger and Chad basin commissions in West Africa. Both types of study are useful but the latter has obvious advantages, as elaborated elsewhere (Faniran 1971, in press). Among other things, the second type of study takes the drainage basin for what it really is: that is, an organic unity as well as an integrated system in equilibrium, where the repercussions of changes in any part of the system are felt all over the basin (Chorley, 1969). Moreover, there are advantages in having all records kept at one place rather than scattered over three or more centres. For example, in the case of the Senegal basin, all available records formerly kept in Paris, Dakar, Conakry, Bamako, Nouckchott, etc. are now kept at the Organisation of Senegal River States (OERS) headquarters in St. Louis, Senegal. This is the ideal to be aimed at in all river basins.

The latest reviews of the literature and works on the hydrological and hydrometeorological situation in Africa are those by UNESCO (1963) and by Ledger (1964). The situation has of course changed considerably, at least in some areas, since then. It is useful in this respect to compare Ledger's (1964 p. 82) map with Figure 1 of this paper. Comparison shows that many more river gauging and other stations have been established in Nigeria since Ledger published his work. The Western sector of Nigeria is a particularly good example with quite a marked increase in the number of river gauging stations. This area may be special and perhaps exceptional, but it reflects the accelerated rate at which rivers and river basins are being studied.

Ledger (1964) using the then available data has produced a map of the "hydrological regions of West Africa" (p. 88). This is a very useful document, especially in connection with the possible acceptance of the representative basin approach for the evaluation and/or estimation of Africa's hydrological-cycle situation and water balance. It will be interesting, however, to see whether Ledger's boundaries will change and by how much, when the additional available data are considered or when more objective (statistical) analyses are employed. Reference may be made to a paper by Fagbemi and Okulaja (1970) which uses the space correlation technique to Nigeria's rainfall data and as a result recognises a few more climatic zones than hitherto. It is not the aim of the present paper to do anything of this nature. Rather the concept of hydrological regions is accepted and used in the following discussion of representative basin ideas.

THE REPRESENTATIVE BASIN CONCEPT FOR AFRICA

The concept of the representative basin has been accepted by many authorities. Among these are the World Meteorological Organization (WMO) (1965), UNESCO (1969) and the Australian Water Resources Council (1969). According to the WMO Guide to Hydrometeorological Practices (1965) the study of representative catchments (or basins) helps to make up partly for deficiencies in short periods of observation and the low density of recording stations.

The definition adopted by the Australians is: "a catchment which contains within its boundaries a complex of land forms, geology, land use and vegetation which can be recognized in many other catchments of a similar size throughout a particular region." (Australian Water Resources Council, 1969, p. 5). In addition the Australians have used the precipitation index or pattern as a classifying medium.

The mere idea of adopting a system of representative basins in Africa raises a number of technical, economic and political problems. On the technical side very few countries have sufficient trained personnel or an adequate coverage of reliable maps on large enough scales. Even a country like Nigeria has not covered the entire country on either the scale of 1:50,000 or of 1:100,000. The available smaller-scale maps (1:250,000, 1:500,000), although covering large parts, do not in some cases have contours; they also fail to give sufficient information necessary for classification purposes. With respect to the economics of the idea, there is little doubt that many people will brand it as a luxury or prestige one, having no obvious utilitarian (applied) values. Consequently Africa cannot really afford any such projects at the present time, given the present level of her economy. Finally there are political problems such as who should choose the basins to be studied, and in which countries they are to be located.

Although these are serious problems which should not be underrated, there are many advantages to be derived from co-operation and integrated planned development, and many of these problems are not as difficult to solve as they seem.

The problem of maps is not so serious. The Australians have used maps of 1:5,000,000 scale and Africa has maps on this and larger scales. The Institut

Géographie Nationale in Paris has produced structural and relief maps at larger and comparable scales which can be used with climatic, vegetation, soil and other information to produce natural regions or land systems from which the representative basins can be chosen. One of the positive outcomes of a recent UNESCO Seminar on Applied Geomorphology and Integrated Surveys of Drainage Basins (Dakar, 9 November - 4 December 1970) is the decision to produce a geomorphological (resource) map of Africa at the scale of 1:500,000. This map when produced is likely to be a great boon in this respect. Alternatively, the method used by Ledger (1964) with some modifications may be applied; in which case, the representative basins are chosen from hydrological regions. Finally the basins may be chosen by a simple random process from, say, a map of drainage basins such as the one recently produced by the author for Nigeria (Faniran 1971, in press).

The economic arguments against the project are also not as strong as they seem. The concept of a representative basin is likely to considerably lower the cost of designing and operating a network because the method provides a satisfactory basis for the extrapolation of the obtained information to ungauged catchments in areas for which the studied catchment is representative. In a place like West Africa, it may be enough to study one or two of the coastal streams (Ledger's, 1964, region I, p. 88) in order to understand the catchment characteristics of the entire region. Moreover, the project need not be separate from the existing network. Most likely the basins to be chosen would be under study previously. In that case, only some additional installations need be considered.

The political problems are being overcome, especially through increasing international co-operation in the development of drainage basins in Africa such as in the Nile basin, and in the Senegal basin. In addition, a setup whereby the study of river basins in Africa is centralised and integrally co-ordinated should considerably ease the political problems.

According to this last scheme, an international body should be set up by either the Economic Commission for Africa (ECA) or the Organization of African Unity (OAU), charged with the over-all control of the study of Africa's river basins. This body (to be called the Water Resources Council or some similar name) in co-operation with the various river basin authorities and national bodies should be able to resolve any political problems (Faniran, 1970).

Finally, the concept of a representative basin is advantageous from the point of view of objective analysis of data. The data collected from such basins are amenable to statistical analysis by the computer. The predictive values of the results of such analyses are also considerably enhanced, since they have been obtained according to some pre-determined and standard procedures.

THE SELECTION OF REPRESENTATIVE BASINS

For selecting the representative basins for any areas it is preferable to set up a committee. Such a committee should include people who have special knowledge of the areas concerned, including geomorphologists, pedologists, geologists, climatologists, land-use experts, hydrologists and other practising scientists with interest in drainage basins. The following suggestions are offered as guidelines; they may have to be modified according to particular situations.

(1) Africa, because of its size, needs to be broken into a number of sub-regions, such as West Africa, North Africa including the Nile basin, Eastern Africa,

Central Africa and South Africa. The boundaries of these sub-regions should be marked by major watersheds, so that no drainage basin is divided between two or more sub-regions.

(2) Attempts should be made to produce for each sub-region, natural regions based on structural, geomorphological, hydrological, pedological, climatic, vegetational and land-use criteria. The method adopted by Ledger (1964) may be used initially, in which case hydrological regions form the basis for the selection. However, hydrological records are not available for vast areas, so that such a selection is not possible. Moreover, in this approach little or no consideration is given to relief, land forms, or to other physical parameters of landscape. The best basis for selection of representative basins therefore is a composite map showing the interrelationships of all the visible and measurable attributes of the landscape. For the Australian example relief, land form and rock types are taken as the basic factors, while rainfall and evapotranspiration are superimposed. A detailed study by the body charged with this responsibility will be necessary in order to decide which of the various landscape parameters are of hydrological importance.

(3) Care must be taken about the size of the basins to be chosen. A very small basin tends to sample recurring patterns of the region it is meant to represent, in which case it is not a representative basin. Conversely, very large basins may be too complex both in ground characteristics and in climate: as such they become regions in themselves, and not representative of any other basins. Uniformity of rainfall, evaporation, groundwater recharge and river discharges also need to be considered. The Australian experience suggests that drainage basins with the desired characteristics and suitable for analytical purposes fall generally in the range of 10 to 100 square miles. In terms of order of magnitude, these will be between second and fourth order basins.

(4) All available records for chosen basins should be collected and kept at one place for analysis.

(5) Installations for obtaining the following information are necessary in each representative basin:

(a) Surface water information:

(i) primary measurements, e.g. stage and discharge; and

(ii) secondary measurements, e.g. water quality, water temperature, stream load (suspended and bed load).

(b) Meteorological information:

(i) primary, e.g. rainfall depth, rainfall intensity, snowfall (where applicable); and

(ii) climatological measurements, e.g. temperature, humidity, wind, sunshine, radiation, cloud cover, air pressure, evaporation.

(c) Soil and groundwater:

Soil moisture, soil temperature, and if possible study of the groundwater characteristics.

SOURCES OF DATA FOR THE REPRESENTATIVE BASINS

The instruments required to obtain such information are not easily available to many african countries because of high cost, problems of suitability for use, and problems of personnel and maintenance. Although the most sophisticated instruments should ultimately be used to obtain hydrological and hydrometeorological data the local conditions call for makeshift measures at the initial stages. These measures should minimise cost and be both fast and sufficiently accurate. The use of aerial photographs and the method of Vigil Networks using simple, cheap instruments and devices, is considered suitable in this respect.

Aerial photographs and hydrological data. A wealth of information can be obtained from aerial photographs which are of immense importance in the hydrological study of river basins. Virtually all aspects of the drainage basin including geometry, discharge, flow velocity, and erosional processes can be studied from aerial photographs (Meyerink, 1970).

The general method of obtaining hydrological information from aerial photographs is through the medium of hydrogeomorphological maps. The most commonly followed procedures are as follows:

(i) A hydrogeomorphological map of the drainage basin is prepared showing the channel networks and orders, watershed, flow characteristics, river bed characteristics, sediments, etc. In addition, geomorphological features of hydrological interest (slope, country rock, etc.) may be shown. The procedures and examples of these maps are given by Verstappen (1970) among others. Different maps may be produced for different purposes, for instance, the flood protection maps of Japan, or maps showing irrigation possibilities.

(ii) The forms and dynamics of river basins can be studied from sequential or successive aerial photographs especially the large-scale types. Previous studies on such photographs have shown some diagnostic characteristics which have hydrological significance. For instance, if vegetation is growing on the bed of a river, the velocity of flow in that partof the channel may be taken to be less than 1 m/sec., under normal conditions. Moreover, the behaviour of flow to obstacles is also indicative of velocity. If the flow separated by an obstacle rejoins after the obstacle the velocity may be taken as about 4 m/sec., otherwise, the velocity is much less (Verstappen, pers. comm.).

(iii) The most important contribution of a hydrogeomorphological map to the study of basin hydrology is in terms of the established relationship between basin morphometry and fluvial processes and characteristics. The relevant basin parameters are many and only a few of them are discussed below.

Stream order: There are various methods of stream ordering, each having its own advantages. Strahler's (1952) modified form of Horton's (1945) system has the advantage of being simple and logical, and is recommended for use here. However, for more accurate hydrological studies, Shreve's (1969) system seems to be more appropriate. Stream order is related to and has implications on stream length, valley size, discharge, etc.

Drainage intensity: This factor combines drainage density (total length per unit area) and stream frequency (total number per unit area) and seems to reflect landscape texture; it is also correlated among other things with volume of removal, valley-side slope etc., (Faniran, 1969).

Drainage basin size: This can be readily measured from aerial photographs and provides valuable information about basin discharge. A linear relationship is established between basin area and discharge, that is, the larger the drainage basin the higher the discharge, all other things being equal.

Drainage basin shape: There are various ways of describing the shape of a drainage basin one of which is the circularity ratio. Whichever way it is expressed, the shape of a drainage basin influences the form of runoff hydrograph, especially with respect to flooding. Generally speaking the more integrated a drainage system is (that is the higher the bifurcation ratio ($\frac{Nu}{Nu + 1}$) where Nu is the total number of streams of a given order and Nu + 1 is the total number of streams of the next higher order) the higher the likelihood of early flooding in the trunk stream).

Average slope of basin: This is another measurable parameter from aerial photographs and which is expressed in a number of ways. The parameter is an important indication of basin velocity and discharge. In general terms steep valley-side slopes mean steep gradients, high velocities and the possibility of early flooding.

Vigil networks. Aerial photographs alone are not sufficient; they have to be supported by field checks and observations. One way of doing this in Africa where resources are scarce is the use of simple, cheap and easy-to-operate instruments. This approach is generally described as Vigil networks and is increasingly becoming popular throughout the world. Vigil networks have been described by many workers including Miller and Leopold (1963) and High (1970), and so are not described in detail here.

In brief, Vigil networks involve the use of simple techniques to observe morphological changes on slopes and in channels. The techniques used include monumented cross sections which are surveyed at regular intervals to record changes; pins for recording rates of bank recession; chains as indicators of bed scour; use of painted pebbles on river beds; and of stakes to measure soil creep or mass movement. Only those having direct hydrological significance need to be set up in a given drainage basin.

In addition, runoff plots can be cheaply set up within a representative basin. These may involve mostly improvised materials such as planks to mark the plot's boundary, some cement for the apron and waterproof materials to retain water and sediment collected in pits dug at the lower end of the plot. The average cost of a runoff plot according to the Nigerian experience is about £6, and a number of them established at the International Institute of Tropical Agriculture (IITA) site near the University of Ibadan are now providing very useful information among other things on the relationship of rainfall, runoff and vegetation cover. The Department of Geography of the University of Ibadan also hopes to start one very shortly. Where necessary funds are available, sophisticated instruments such as automatic raingauges and H-Flume and/or Coshocton runoff gauges should be used. Information from all such sources will definitely go a long way in further defining the already established close correlation between the various elements of an area including the climatic, geomorphological and biotic factors which are of great hydrological significance.

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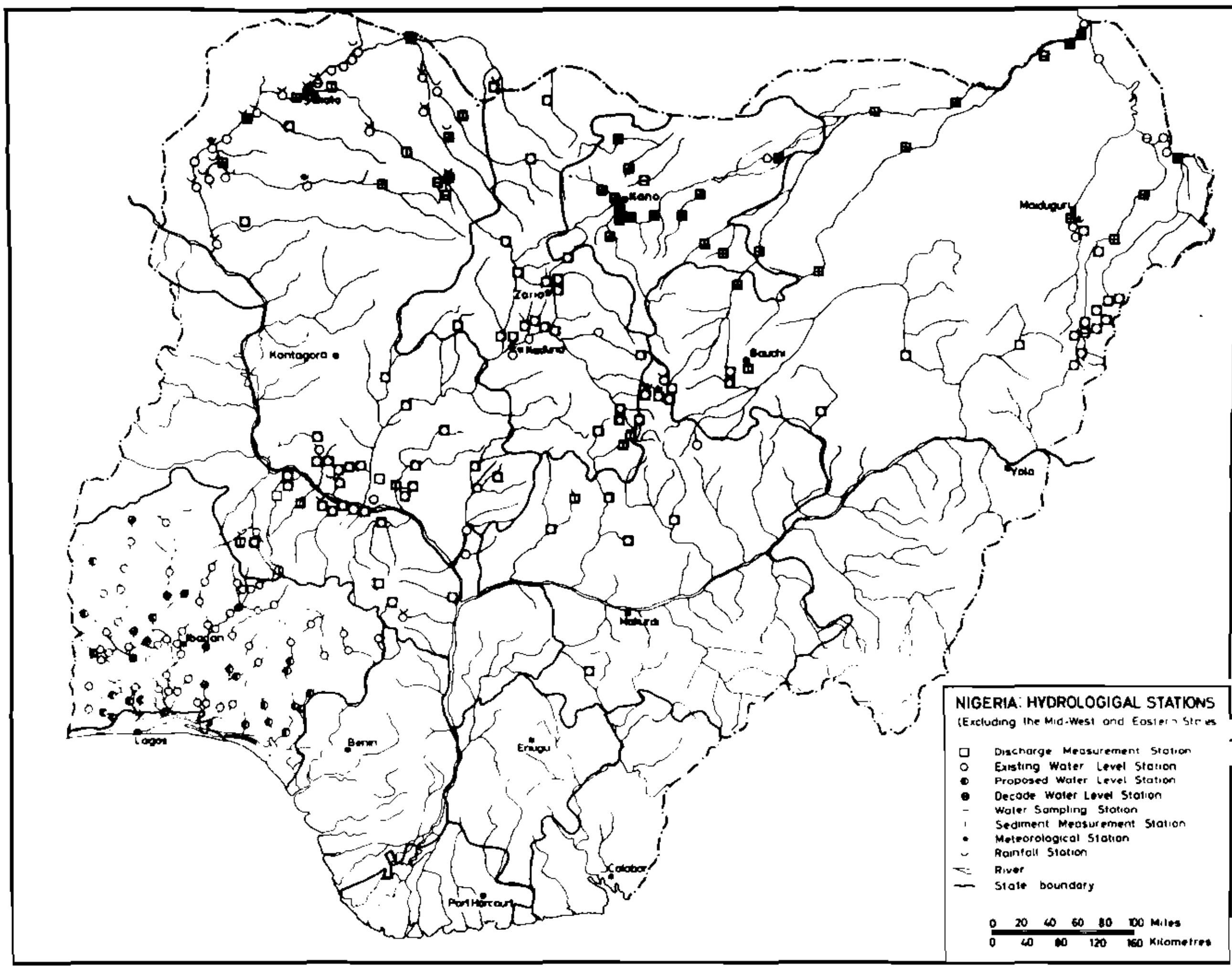

Figure 1. Nigeria: Hydrological and hydrometeorological network. (Information for the Northern States was obtained up to 30 September 1967, and for the Western States up to July 1970. No information was available for the Western and Mid-Western States at the time of compilation of the map.)

DESIGN OF HYDROLOGICAL AND HYDROMETEOROLOGICAL NETWORKS

by Ivar Hagen

ABSTRACT

This paper outlines general principles for the planning of a hydrological network. Four types of stations and their purposes are defined. They are: primary station, secondary station, water-level station and hydrometeorological station.

These types should form the basic stations of the network. The facilities used and practical procedure are described. The distribution and the density of stations are considered. The equipment and the ratio between primary and secondary runoff stations are discussed. The programme for construction work, financial estimates and the publication of the plan are described.

RESUME

Le présent mémoire contient un exposé des principes généraux à appliquer en matière de planification d'un réseau hydrologique. Quatre types de stations et leurs objectifs y sont définis. Ce sont: station principale, station secondaire, station de jaugeage et station hydrométéorologique.

Les stations de ces divers types sont supposées constituer les stations de base du réseau. On trouve également dans ce mémoire une description des moyens et installations utilisés et des procédures pratiques appliquées en la matière ainsi qu'un examen de la question de la distribution des stations dans la région et de la densité du réseau. Le mémoire traite de l'équipement et de la proportion entre les stations principales et les stations secondaires de mesure de l'écoulement. On y trouve également une description du programme des travaux de construction, les prévisions financières et la publication du plan.

INTRODUCTION

During the last two decades efforts have been made to define general principles for designing a hydrological network for obtaining the basic data. The task, however, is very complicated, and often the results of the endeavours have so far been of little importance to the hydrologist. The great topographical variations on the earth also create differences in climate. The irregularity of geological formations further complicates the problem. Therefore, the first step for the hydrologist designing a hydrological network is to carry out a comprehensive study of the physical conditions within the district, region or country. Such information forms the basis for estimating the required number of hydrological stations and their distribution within the area.

This paper aims to describe a practical procedure for planning a hydrological network (surface runoff only).

Hydrological textbooks, guides and manuals give different definitions and designations of stations which form the concept "Hydrological Network". In this paper 4 categories of stations are defined and classified according to their respective purposes.

RUNOFF STATIONS

Hydrological investigations consist of records of runoff variations in time and space. The variation in time, or the time parameter, reflects the short- and long-term climatic variations. The variation in space, or the space parameter, reflect the variations of runoff within a certain area caused by topographic and geological differences.

The climatic variations occur in fairly regular cycles depending on the position of the sun and the sunspots. But these periods also undergo changes of which we know very little. The only thing to do is to obtain observations over sufficiently long periods, thus acquiring satisfactory statistical data.

The changes in runoff caused by the topographical and geological conditions are usually independent of climatic variations in a climatically homogeneous area. Theoretically any two observation points within such an area are therefore recording similar variations in runoff or are producing runoff data of high correlation.

Hydrological stations recording the time parameter usually keep recording continuously at the same site for an indefinite period. This should be borne in mind when the hydrologist evaluates the sites for establishing such stations. Moreover, it is important that the site has a stable control for all stages and a well-defined stage-discharge relation. Such stations should be referred to as Primary Stations. The minimum period of observation for satisfactory analysis of data on which technical and economic development can be based is generally estimated at 15-20 years.

The hydrological stations recording the space parameter are usually operated at the same sites for a limited period of time, 5-10 years, and then shifted to a new site. Stable control is also essential for such stations. The number of such stations is by far the largest in a network of runoff stations. These stations should be referred to as Secondary Stations. Data from such a station may be applicable for technical purposes after 3 or 4 years providing it is operated in conjunction with a representative Primary Station.

WATER LEVEL STATION

Such stations are usually established in lakes. Where the lake's catchment is of international interest, or where the lake is of national economic importance, the station should be kept permanently.

HYDROMETEOROLOGICAL STATIONS

These stations are established to observe such climatic elements as precipitation, temperature, wind, radiation, humidity and evaporation. The variations in these elements are dependent on time. Therefore, the station should be operated at the same site indefinitely. The representativeness of the stations is highly dependent on topography, and the instruments are very sensitive to local disturbances. Therefore, the sites have to be carefully selected.

The meteorological data have an extensive application in practical and theoretical hydrology. One of the most important applications of such data is in the assessment of the consequences of major water development projects. The artificial reservoirs built in connection with water power or irrigation projects usually change the normal conditions of the river. Water is stored in the wet season when the evaporation is insignificant, groundwater level is at or near its maximum and the soil moisture is high; i.e. when the river is susceptible to flooding. However, depletion of the reservoirs occurs in the dry season when the contrary conditions prevail. Such circumstances interfere with the natural régime of the water resources. The prediction of the consequences must therefore be based on recorded climatic data.

The four types of stations mentioned above procure the basic surface runoff data and may be referred to as Basic Stations.

NETWORK DESIGN

The national hydrological network should be designed to obtain general information, independent of planned or potential technical water projects, because of the following two main reasons:

(a) Independent of special demands, it is possible to select the best sites and the most favourable distribution of the stations in order to obtain reliable and representative data.

(b) The fact that a basic network needs a long period of observation before economical output is possible puts such projects in a difficult position concerning the availability of necessary funds. The limited amount of funds allocated therefore necessitates very careful planning. On the other hand, where a satisfactory hydrological network exists, stations necessary for special projects need only 3 or 4 years' period of observation to provide the additional data for economic and technical planning. This period usually corresponds with the time used for the preliminary survey of such projects, and additional hydrological investigations are therefore a logical part of such a survey.

Homogeneous climatic areas. The first practical step for network planning is to study the geography of the area concerned. For this purpose contoured maps of 1:50,000 scale are most suitable. Independent of the specific topography, the area between 3 or 4 equidistant contours should be drawn with different colours. This will make the main features of the topography more visible, thus simplifying the location of homogeneous climatic areas. Where meteorological data such as precipitation and evaporation are available, these should be represented by isolines on the maps. If meteorological observations are not available, study of the topography will give a satisfactory idea about the location of those areas.

Primary stations. As mentioned before, the station-sites must be very carefully considered before they are accepted. The control must be stable and the cross-section or channel section must be well defined for all stages. Geological maps may provide valuable information concerning the location of sites, and details can also be studied very closely on aerial photos.

It is very difficult to set up general rules concerning the density of such stations. Theoretically it should be sufficient to have one primary station within every homogeneous climatic area, and this rule may be taken as a general guide for practical use.

In the case of more than one alternative, the site which has the best control should be preferred even if the access to it may not be the best. Furthermore, the planning of hydrological stations must always be determined by the demand for stations, and not by what is economically possible at the time. The realisation of the plan may be done step by step.

Secondary stations. The object of these stations is to procure data for evaluating the distribution of runoff within individual catchments or extensive areas. As for the primary stations, good control is important, however; because of the relatively short observation period, a strategically correct position of the site must be considered as more decisive. As mentioned earlier, these stations have to be shifted to new sites after 5 to 10 years; i.e. only a part of the designed network operates at the same time. Therefore, a reasonable distribution of the "first-turn-stations" has to be considered. The aim must be to obtain the best output of data at any time.

Primary stations/secondary stations. The number of secondary stations is by far the largest of the total of various types of runoff stations. A general figure for this ratio is difficult to assess and depends on the individual properties of the area concerned. However, in order to give an idea reference is made to actual figures from a project designed in Tanzania. This project, "Hydrometeorological Survey of western Tanzania", involves the construction of approximately 100 runoff stations and 30 hydrometeorological stations within an area of 260,000 km^2. The primary stations will form about 30 per cent of the total. Almost no previous hydrological investigations of this area exist. After 5 to 10 years of observation it is expected that this figure will be reduced to 20 per cent. The selection of primary stations will then be done by using regression analysis based on the collected data.

Water level stations (see above)

Hydrometeorological stations. As a general rule, at least one hydrometeorological station should be established within each homogeneous climatic area and if possible near its centre. If the area is 10,000 km^2 or more, at least 2 stations should be established. On the other hand, stations should not be established on or close to defined climatic boundaries (see above).

Other categories of stations. Very often hydrological stations are established for special projects. In such cases the choice of station sites depends on the location of the planned constructions. If the sites are acceptable from a hydrological point of view, they may be considered as secondary stations and included in the National Network. If not, such stations are of little use for the general hydrological investigations.

EQUIPMENT OF HYDROLOGICAL STATIONS

A primary station should be equipped with an automatic recorder and a cableway. At least 50 per cent of the secondary stations should be equipped with automatic recorders and all of them should have cableways.

PROGRAMME OF CONSTRUCTION WORK

When the number and sites of stations are fixed, the programme of construction work has to be considered. This estimate also includes a calculation of staff requirements. Staff includes temporary construction staff and permanent staff for running of the stations. Construction staff may be organised from the employees of the agency responsible for the National Hydrological Service and should work as a team as long as the construction work continues. Organising permanent staff may often be a most serious problem to solve. Such staff consists of technical assistants and gauge readers. The assistants should have a certificate from a technical college or similar courses. The gauge readers are supposed to have primary-school education.

In Tanzania the problem is solved through close co-operation with the Technical College in Dar es Salaam which every year provides hydrology as a special subject for a certain percentage of the students. The number of students is fixed according to the estimated need of technical assistants in the Water Development and Irrigation Division. Special courses of 3 weeks' duration are organised for training gauge readers.

It is obvious that the realisation of such projects depends largely on the rate of recruiting new staff and this rate is decisive for the programme planned for the construction.

If the project needs more than one year to complete, a construction plan for each year should be prepared. The annual expenses could then be included in the annual budget of the national hydrological investigations. For this, tables for each year indicating the amount of construction work and employment of staff, and maps showing the station sites, should be prepared.

The work programme is the basis for estimating the cost of the project. If the programme is worked out as outlined above, the expenses are easy to calculate. This calculation should be summarised in a clearly arranged table showing the cost of equipment, construction work and salaries of staff per annum and the total.

PUBLICATION

When the design work is completed all essential information should be collected in one handy publication. The problem of financing belongs to the government and very few of those dealing with financial tasks are experts in this special subject. Therefore, the publication must not be overloaded with technical details. The financial authorities want to get a general impression of the technical side of the project, the demands to be covered and a clear tabular presentation of the estimated cost. Therefore the publication should contain a brief geographical description of the area, and information on the necessity of the project besides tables and maps as background to the estimate and a short explanation of the tables. The publication should have a summary as an introduction and a summary table of the expenses at the end.

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THE USE OF DIGITAL COMPUTERS IN THE HYDROLOGICAL SERVICE IN TANZANIA

by Bo Wingard

ABSTRACT

Processing, analysis and publication of hydrological and hydrometeorological data by electronic computers started in Tanzania in 1966. The systems used in processing the data and storing them in files on magnetic tapes are described. The files form the basis for publication and analysis of data.

RESUME

Le traitement, l'analyse et la publication de données hydrologiques et hydrométéorologiques à l'aide d'ordinateurs a débuté, en Tanzanie, en 1966. Les systèmes utilisés pour le traitement des données et leur enregistrement sur bandes magnétiques sont décrits dans le présent mémoire. C'est sur la base de ces fichiers que les données sont publiées et analysées.

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INTRODUCTION

Hydrological services started regularly in 1950 in Tanzania when the Hydrological Section was established. Since then, about 680 water level stations have been established, of which about 240 are in operation today. The kind of data collected and processed are river flow data and water quality data.

The Section also collects data from meteorological stations, normally referred to as hydrometeorological stations. Of 34 stations established, 33 are still in operation. The kind of data collected are precipitation, temperature, humidity, wind, sunshine, radiation and evaporation. In addition 205 precipitation stations were established of which 85 are still in operation.

To illustrate the amount of data collected, a convenient unit of "observation year" may be used, i.e. 1 year of observations from 1 station is 1 observation year. For water level observations the total number is about 2,000 observation years, for the meteorological elements it is about 2,200. The demand for hydrological data and analysis is expected to increase considerably in the future. In order to meet the requirements, it is decided to process, analyse and publish these data by digital computers.

Here the processing and publication of the data which are collected routinely on a continuous or periodic basis are described.

COMPUTER PARTICULARS

The machine processing of hydrological data started in 1966. The Section has bought computer time from the Computer Project at the Ministry of Finance. Up to 1968 ICT with 4 magnetic tape stations, card reader, line printer and paper tape reader was used. Then it was replaced by an ICL 1902 with a core store of 16 K words, 6 magnetic tape stations, card reader, line printer and paper tape reader. The programming language used is 1900 Fortran. The reason for using this language instead of Algol, Cobol or Plan, which are also available on the 1900 series, is that Fortran is the most commonly used scientific language within East Africa, and also widely used in hydrological data processing in hydrometeorological institutions abroad. The only problem encountered with this programming language is the lack of flexibility of the printing routines. This seriously affects the printing of observation tables. For the sake of clarity, missing observations are represented with a horizontal bar. To do this in Fortran takes a relatively long time. Special Plan sub-routines for printing purposes are therefore necessary in order to decrease the cost of computer time. Since the end of 1970 the Section has been equipped with one card puncher and one card verifier of ICL make. These machine installations are expected to remain unchanged for the next 2 to 4 years.

INSTRUMENTATION

Only the hydrological instrumentation is described here.

Water level is observed on staves, which are rapidly being replaced by those with metric units. This is also the case with all other instruments the Section has installed.

Automatic analog water level recorders are installed at about 30 stations. No manual system for digitizing and storing information from the recorder charts on a medium readable by a computer has yet been introduced. The process in the future will probably be to digitize instantaneous water levels by a system indicating the period of observation and frequency of values. Then both high frequencies (for example values every 15 minutes in flood periods) and low frequencies (values every day in dry periods) could be represented in the same codingform. These data will probably only be stored on punched cards, and extracted when special analyses are required.

Recorders which digitize the data on either magnetic tape or paper tape have not yet been introduced. Instruments for digitizing the analog recorder hydrographs will not be introduced at present mainly due to the fact that no equipment is yet offered together with simple computer programmes which enable a quick and effective digitization of the hydrographs.

Discharge measurements are made by recording the point velocity of water with propeller-type current meters. Such measurements are made whenever a station is visited, normally every month or every second month. Special flood ratings are made at selected stations during the rainy season.

Sediment samples are taken by the depth integration method. Samples are taken each time a discharge measurement is made, and later analysed to calculate suspended sediment load.

HYDROLOGICAL DATA

The policy is to store all water level data and all converted discharge data in magnetic tape files. The data are stored chronologically in increasing order of the station identification number. Each observation year is stored as a block of 370 INTEGER 24 bit words (5 identification words — 1 numerical station code number, 2 alphanumerical gauge station numbers, observation year, storage unit — and 365 mean daily observations). The observation from the leap year day is not stored.

All data are coded in special forms, punched on cards and verified. After card listing, the data are checked manually before they are stored in tapes. Some logical tests are incorporated in the storing process in order to ensure correctness of the stored data. Examples of such tests are: station code number, year and month number must be within certain ranges; the number of observations for each month must be equal to or a whole multiple of the number of days in the month: a manually computed month sum and a machine computed sum must not differ more than say 1 per cent. Whenever an observation year is transferred to tape, the data are also printed on line printer. A checking of these printed data is the last control.

The data are processed in two slightly different ways, pre-1965 data published in "The Rufiji Basin Tanganyika Basic Data Records" Volume II, part 2 (1960),"Hydrological Yearbook 1950-1959" (1963) and "Hydrological Yearbook 1960-1965"(1967) are referred to as "historical data", and treated differently from "new data" observed since 1965.

Processing of historical data

The manually computed mean daily water levels are coded in specially designed coding forms, manually checked, punched, verified and listed. The card listing is checked against the observation forms or the publications if the data have been published before and are stored in the magnetic tape file for historical water level data.

When a rating curve can be established, the corresponding rating curve equation or rating table forms the basis for a conversion by computer of the water-level data to discharge data. The values of the rating curve equation or rating table are punched on punch cards, and fed to the computer just before the punched water levels. The discharges are stored in the magnetic tape file for historical discharge data. Such a computer conversion is carried out if discharge data have not been converted before, either manually or by computer.

When discharge data are computed manually (Yearbook 1950-1959) or by computer (Yearbook 1960-1965) they are coded and treated in the same way as the water-level data and stored in the magnetic tape file for historical discharge data.

Processing of new data

The frequency of observation is normally 1, 2 or 3 readings of water level each day. These data are coded, punched and checked and fed to the computer. When a rating curve equation or rating table can be established, the data for each day is converted to discharges and the mean daily value is computed as the mean of all the instantaneous values.

The mean water level is similarly defined as the mean of the instantaneous water levels, and cannot usually be associated directly with the mean daily discharge as the rating curve is not linear.

The instantaneous maximum and minimum values for each month are computed, together with their date and hour of occurrence. These values are stored as an appendix to the usual "historical" 370 word observation year block. With additional 4 words for each month (2 extreme values and 2 time values (date x 100 + time in whole hours)) the observation year record for the "new data" file is 418 words.

Both water level and discharge records are stored according to the same principles as the historical data. When the data are published, it is assumed that the last 48 extreme words are of little interest for further analysis. The first 370 words of the "new data" record is then transferred to the historical file. The reason for this is to save storage on magnetic tape, and to reduce the mean access time to the data. It will be relatively simple to create an "instantaneous extremes file" later if a demand for special analysis of such data is expressed. The "new data" file will be updated, say, every half year. The maximum age of the data is then one year. Yearbooks may then be published just over one calendar year after the data are observed.

METEOROLOGICAL DATA

Most of the meteorological observations are made in co-operation with the East African Meteorological Department (EAMD), as most of the stations are incorporated in their network. The Hydrological Section maintains the stations and the equipment and is responsible for the daily reading, and sends copies of the observations to EAMD, which takes care of the publication. As the data will be used in the Section for hydrological analysis, the aim is to store them in files on magnetic tapes.

A precipitation file is already established. The rainfall data are coded in specially designed forms and processed and stored in a way similar to that of the hydrological historical data. Out-prints of the daily observations are made only when manual analysis is required.

It has not been decided yet how the data from the meteorological stations will be stored. As the number of stations is small, and in order to reduce the number of files, all the observations from each meteorological station for each year will probably be stored together. The elements to be stored will be precipitation, mean daily temperature and dew point temperature, wind speed, radiation, evaporation and sunshine. The storing sequence will be the same as for hydrological data. Out-prints of daily observations will be made whenever data is read from cards and stored on tape.

In addition to these files, a file for rainfall intensities where an automatic rainfall recorder is installed (maximum precipitation - date and amount - for each month in 1, 3, 6, 12, 24 and 72 hours) will be created. When EAMD gets their observations stored in a similar way, the transfer of data will be greatly simplified, and the subsequent analysis can be expanded to a greater extent than is possible today. The main difference in EAMD's and Hydrological Section's ways of storing data is the storing sequence: EAMD stores the data from all the stations from one year together instead of all the years from one station.

RATING TABLES

A special file will be created, containing the discharge rating tables for each station. When the "new data" file is updated, only water levels are read to the computer from cards. The rating table is read from the magnetic tape file. The storing of the tables in a special file also enables publication of these important data whenever required. Special programmes are made for computation of rating curve equations when pairs of water level and discharge are available. Segments of the curve are then mathematically expressed.

$$q = k(h + \Delta h)^n,$$

where q is discharge, h water level, Δh height to flow level, k and n constants. A rating curve is normally described in full detail by 1 to 3 segments.

A programme for computation of discharge from current meter measurements is made in order to simplify and standardize this time consuming work. The programme works out velocity profiles of the measured point velocities, and computes the total discharge as the integral of the resulting mean velocities.

As the collection of sediment data from the river gauging stations is just recently introduced on a regular basis, no system for processing these data has yet been adopted. Existing programmes, slightly modified, can be used for equations or tables resulting from manually prepared sediment rating curves, which will enable quick and reliable conversion of discharges to daily, monthly or yearly yield of suspended sediments. These data can, if required, be stored in a similar way as for other hydrological data.

GAUGE LIBRARY

A file is created, storing information about the gauging stations. Such information is date of installation and closure, altitude, drainage area, geographical co-ordinates, types of station, quality of station and measurements, kind of recorder, date and magnitude of observed extremes of water level and, if available, discharge. This gauge library file will be most useful in publications. Our aim is to publish particulars of the basic stations in the yearbooks as has been done up to now, in addition to information which can be extracted from the gauge library file. Such information is necessary for different statistical analysis.

PUBLICATION

Computed discharges from calibrated stations are published on a 5-year basis. Mean daily values together with monthly extremes are read from the "new data" file and printed together with computed monthly sums and means. The daily values together with the identification values are transferred to the "historical data" file. The gauge library file is updated with respect to extremes and the results printed when data for all 5 years for each station has been processed.

Water levels will be published only for important stations for which rating curves cannot be established (i.e. inland drainage, swampy areas, etc.).

As mentioned before, meteorological data is already being published by EAMD for a majority of the stations.

FUTURE PLANS

By a variety of different computer programmes, analysis of the hydrological data will be carried out, both on a national and local basis. The standard analysis will be made for magnitude frequency summaries, probability, low flow variability, basic characteristics, runoff maps, etc.

The library will also contain programmes made for analysis other than pure hydrological, such as water power and irrigation. In this way, the Section can provide service for numerous organisations requiring the use of different analysis and data.

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DESIGN AND OPERATION OF THE HYDROLOGICAL NETWORK IN THE OKAVANGO DELTA, BOTSWANA

by M.J. Norman

ABSTRACT

A short description is given of the Okavango River and its delta. Mention is made of previous investigations leading up to the establishment of a four-year Project in 1968 with the setting up of a national hydrological service for Botswana as a major objective.

The purposes for which hydrological data on the delta are required are set out and the development of the network required to provide this data described, together with details of the equipment used and some of the operational problems encountered.

In the analysis of the hydrology of the Okavango delta two approaches become apparent and a brief description of these is given.

RESUME

Le fleuve Okavango et son delta font l'objet d'une brève description. Mention est faite des recherches antérieures qui ont conduit, en 1968, au lancement d'un programme quadriennal ayant pour principal objectif la création d'un service hydrologique national au Botswana.

On indique les raisons pour lesquelles des données hydrologiques sur le delta sont nécessaires en même temps qu'on décrit l'aménagement du réseau requis pour obtenir ces données et qu'on donne des détails sur le matériel employé et sur quelques-uns des problèmes d'exploitation rencontrés.

L'analyse des caractéristiques hydrologiques du delta de l'Okavango fait apparaître deux manières possibles d'aborder la question, et toutes deux sont brièvement décrites.

1. INTRODUCTION

The Okavango River rises, at an elevation of some 1800 metres, in the summer rainfall region of the Angola Highlands, where it is known as the Cubango, and flows in a southerly direction to the border with South West Africa. Here it deflects eastward forming the border for a distance of 400 kilometres and is joined by the Cuito, which also rises in the Angola Highlands, before again turning south across the Caprivi Strip and entering Botswana at Mohembo. At this point the river has a mean annual discharge of 11750×10^6 m^3 and is Southern Africa's second largest river, being exceeded only by the Zambezi with a mean annual discharge at Livingstone of 37500×10^6 m^3.

After entering Botswana the Okavango flows southwards for a distance of 140 kilometres in a valley some 10 to 11 kilometres in width, where it breaks up into a number of channels prior to entering the wide expanse of swamps forming the head of the large inland delta known as the Okavango Swamps.

The delta is roughly triangular in shape covering an area of some 16,000 sq. kilometres. The flow patterns within this area are complex with flow passing from one channel to another through permanently and seasonally flooded areas choked with aquatic vegetation. The attached diagrammatic sketch shows the salient features of the system consisting of three main branches, the Taoge, the Boro and the Ng-gokha/Santantadibe, which eventually discharge into the Thamalakane and Lake Rivers lying at the base of the triangle, along a fault line. The Thamalakane at low flows discharges southwards into the Boteti River but at higher flows also spills into the Lake River towards the west.

The level of the Okavango River is at its lowest, at Shakawe at the head of the delta, in September/October. Thereafter the effects of the rains in Angola become apparent and discharge increases to reach a peak in early March or April. These floodwaters move down the Ng-gokha and Taoge into the permanent swamps at the head of the delta, which cover an area of some 2,000 sq. kilometres, and then overflow from these towards the south and north-east following the general slope of the land. Flood waters entering the head of the delta normally take four to five months to reach Maun, levels in the Thamalakane beginning to rise in July or August. From the Ng-gokha, not far below its point of separation from the Taoge, floodwater may spill north-eastwards over the plains and make its way along a gently sloping depression known as the Selinda spillway to reach the Chobe and eventually the Zambezi.

2. PREVIOUS SURVEYS AND RECORDS

Although Livingstone first discovered Lake Ngami in 1840 it was not until Captain A.G. Stigand produced his "Sketchmap of Ngamiland" in 1922 that any maps of the swamps were available. Meanwhile Professor Schwarz had aroused much interest in the vast quantities of water in the Okavango and Chobe Rivers by propounding, among other things, that by restoring the lakes of the Kalahari the evaporation therefrom would very soon permanently increase the rainfall over much of Southern Africa, and a survey was arranged by the then Union Government which resulted in Dr. A.L. du Toit's valuable "Report on the Kalahari Reconnaissance" in 1925. In 1937, J.L.S. Jeffares undertook further surveys in the swamps described in his report on the Ngamiland Waterways Surveys.

W.G. Brind carried out a remarkable and extensive survey in the swamps during 1953-1955 and put forward suggestions of a practical nature for further investigations and possible developments and improvements in his report "The Okavango Delta".

During the late 50's attention shifted from the Okavango to the more urgent needs of the population concentrated in the eastern part of Botswana, generally in the Limpopo catchment, and from 1961 efforts were made to obtain international aid to set up a permanent national hydrological service. In 1968, this bore fruit in the commencement of a four-year programme for the "Surveys and Training for the Development of Water Resources and Agricultural Production" under the management of F.A.O., the Project being financed by the Special Fund of the United Nations Development Programme and the Botswana Government. It had always been appreciated that in any future development of Botswana the water resources of the Okavango must play a major role and because of this the setting up of an hydrological network in the swamps was included in the Project programme. Recent mineral discoveries and the opening of the diamond mine at Orapa, which draws its water from the lower Boteti River, have provided a new stimulus for the investigation of ways of developing and utilizing the resources of the Okavango.

3. HYDROLOGICAL NETWORK

The first problem to be faced in designing a network from scratch for such a vast and complicated area as the Okavango Delta is to define the purposes for which the information is to be collected. It is relatively easy to fall into the trap of collecting vast amounts of unrelated data on the basis that all data is valuable knowledge which may be of use in solving future problems. By increasing the costs of setting up and operating the network this aggravates the problem of persuading Government to allocate funds on which there are many other calls, and may result in failure to collect data relevant to immediate needs, so casting doubts on the value of the whole programme.

Within the immediate future there are a number of questions for which answers will be required. These are:-

(a) What would be the effect on the Okavango-Boteti system if at some future date the Angolan and South West African authorities undertook water control and diversion works in the upper catchment of the river?

(b) What measures can be undertaken to increase the outflow from the swamps to ensure a firm yield to the lower Boteti for the existing mining activities at Orapa and possible future mining and domestic requirements in the south-west of the country?

(c) To what extent will these measures to decrease inflow and increase outflow affect the present water supply position in the Taoge, Kwaai and Lake Ngami areas, where there is potential for irrigation, fishing and game development respectively, and on the areal extent of the swamps generally?

(d) To what extent may polder cultivation be practised within the delta, particularly in the Shorobe area, and what would be the hydrological effects?

Answers to these questions can only be based on an understanding of the hydrology of the delta and the problem therefore was

(i) to accurately measure the inflow and the outflow of the swamps;

(ii) to determine the proportion of the outflow discharged to the Boteti and Lake River systems respectively;

(iii) to find a method of forecasting the outflow hydrograph;

(iv) to measure the flow patterns within the swamps with a view to devising means of increasing the outflow and monitoring the effects of any channel clearing operations which may be carried out in the future, and

(v) to determine whether the losses in the swamps are due to evapotranspiration only, or whether there are any appreciable seepage losses.

Before an hydrological network could be designed it was necessary to determine the flow patterns within the delta and to identify the courses of the major channels. Brind had made use of the 1951 air photography of the Okavango Delta in his surveys, but as this was carried out in a relatively dry season it showed neither the full extent of the flooding nor the actual channels at the base of the delta. The only other photography available was of some of the northern and western areas of the delta flown in 1944 and from oblique strips of the main channels flown for Jeffares in 1937. It was therefore decided to re-fly the whole delta during the flood period in August 1969. Consideration was given to carrying this out in normal black and white, colour and infra-red. Because of the cost of producing colour prints and the ability of infra-red to show flooded areas even when covered with vegetation, it was decided to carry out the photography in infra-red at the same scale, 1:40,000, as the 1951 survey.

At the same time a reconnaissance of the swamps was made by boat, staff gauges were established and spot gaugings taken. This confirmed the accuracy of Brind's work and provided useful data on the distribution of flow in the various channels. It had always been thought that the channels within the swamps were unstable and subject to frequent blockages and changes of course. Comparison of the various aerial photographs, however, showed that these channels were in fact remarkably stable and showed very little alteration over the years.

The Okavango swamps are situated in the north-west corner of Botswana in a remote area, difficult of access and virtually undeveloped. Much of the aura of mystery surrounding these swamps in the past can be attributed to their isolation and, even today, the only all-weather road is that connecting Maun to the railhead at Francistown some 480 kilometres away across sparsely inhabited country. Travel within the swamps proper can only be undertaken by boat and even this is difficult due to the shallow depth of many of the channels which are frequently choked with weed growth and subject to blockage by floating debris. Furthermore, tsetse fly are present throughout the greater part of the swamps and, because of this, most of the indigenous population live in villages located along the fly-free western and southern margins of the delta.

Although changes in stage occur only gradually, as the flood wave travels through the delta, the difficulty of access and the impossibility of stationing personnel in the tsetse fly areas for prolonged periods dictated the use of automatic recorders at the key stations within these areas.

The only established stations were the staff gauges at Shakawe and Maun, a synoptic meteorological station at Maun and raingauges at Shakawe, Seronga, Gomoti and Kwaai; all these stations being on the periphery of the delta. Based on the findings of the initial reconnaissance within the delta, 27 staff gauges were established on the major channels during 1968 and 1969 and this was followed by an intensive programme of gauging during the 1970 flood season. After evaluation of the data obtained, sites were chosen for the installation of four recorders at Khihum, Xakue, Ng-gokha blockage and Txaba. Automatic rainfall recorders were also installed at these sites to complete the raingauge network over the delta.

The importance of the inflow and outflow data and our experience of the general unreliability of locally employed gauge readers was considered sufficient justification for the use of recorders at Shakawe to record the inflow and at Toteng, Maun, Ghantsang and Samadupi to record the distribution of the major components of the outflow.

4. INSTRUMENTS AND EQUIPMENT

Because of the difficulty of access and isolation of many of the stations within and around the swamps, automatic recorders capable of continuous operation unattended for long periods were required. Consideration was given to using punched tape recorders which have the advantage that a computer may be used to process readings. However, because of the high cost of the equipment required and its complexity, which would have posed a serious maintenance problem, they were finally rejected in favour of Leupold and Stevens, type A.35, recorders which have a thoroughly proved reliability in other parts of the world. These recorders are fitted with beaded float lines and weight drive, with strip charts giving three months' continuous operation. Natural controls are used because of the virtual impossibility of constructing any satisfactory form of artificial control. Rating is carried out by wading or boat using S.I.A.P. current meters, type ME-4001, a propeller type meter with an electronic digital counter, very similar to the Ott meter. S.I.A.P. pigmy current meters, type MP, have also been used in the smaller channels. Because of the effects of channel vegetation, mainly Cyperus Papyrus, Phragmites, and Vossia Cuspidata, rating will have to be continuously checked and very pronounced hysteresis patterns have already been encountered as the flood wave passes.

Measurement of rainfall at the four points within the swamps is being made using S.I.A.P., type UM-8150, monthly rainfall recorders and these recordings will be compared with the established stations at Maun and Shakawe for which there are fairly long-term records.

For travel within the swamps 14ft. and 18ft. aluminium boats powered by 20, 25 or 35 H.P. outboard motors fitted with weedless propellers are being used and have proved very satisfactory. These boats, together with inflatable rubber dinghies, have also been used for carrying out current metering.

The metric system is used throughout for all observation and measurements.

5. NETWORK OPERATION

The headquarters of the national hydrological service will be located in the Botswana capital, Gaborone, and a divisional office has been established at Maun under the control of an hydrometrist, to operate the network in the Okavango Delta. This office is provided with stores, facilities for the maintenance and repair of the outboard motors, bulk fuel storage and the base radio station. All readings and measurements taken in the district are checked and processed in this office before being passed on to the head office in Gaborone where the hydrological data processing unit will be established during 1971.

During the 1970 flood season, from March to September, three gauging teams equipped with boats, outboard motors, current meters and radio transmitters were operating continuously in the swamps. Each team, which normally consisted of two hydrological assistants and a boatman, remained within the swamps for a month before being replaced by a relief team from Maun. The three teams were based at Kwihum, Txaba and Xakue.

The Kwihum team looked after the northern area of the delta and carried out current meter gaugings twice a week at Kwihum, Boro inflow, cross channel and Duba, and once a week at Gaenga and Ng-Gokha blockage. The Txaba team carried out gaugings twice a week at Txaba, Lopis and Monachira, while the Xakue team was responsible only for gauging the Boro at this one point.

Gauging teams also operated from Maun carrying out weekly gaugings at Maun, Boro, Samadupi and Santantadibe, and occasional gaugings at Tsau, Kwaai and the Selinda spillway. Finally, a team was stationed at Toteng to gauge the Kunyere daily and read the gauge in Lake Ngami once a week.

The hydrological assistants, who were recruited from inhabitants of the delta area, were of a relatively low educational standard and were therefore taught to carry out a rigid gauging procedure in which measurements were taken at 0.6 of the depth, at one metre intervals across the river. In practice this method worked well and good curves have been obtained for all the lower gauging stations. Some difficulty has been experienced with stations at the upper end of the delta but this is attributable to the small variation in gauge height with discharge and the fact that there are no defined banks, the channel being bounded on one or other side by papyrus swamps. The current meter measurements were computed in the field and the Maun office informed of the results every second day by radio. The hydrologist in charge of the operation was thus in continuous contact with all field parties and could query any anomalies while there was still time to take check readings.

As a result of the experience gained during this period of intensive gauging it became evident that the costs and difficulties of maintaining teams within the swamps for extended periods would be beyond the capacity of the proposed national hydrological service. A further problem was the risk of staff contracting trypanosomiasis. However, the data obtained from this single season was sufficient to give an assessment of the hydrology of the swamps and from this four key stations within the swamps were chosen as recorder sites. In future these four stations will be visited at monthly intervals when gaugings will be taken, and the gauges at the remaining staff stations read en route. The gauges around the periphery of the swamps do not present the same problems and will continue to be operated as before.

6. ANALYSIS OF DATA

Data on inflow and outflow of the swamps was available for differing periods. Inflow data was available for the 37 years from 1932 to 1969 without a break, while outflow at Maun was available from 1933 to 1947 and 1951 to 1960 (see Table I). This data indicated that although there was little correlation between the inflow and the outflow the mean annual discharge at Maun was approximately 5% of the mean annual inflow at Shakawe.

Analysis of the available data reveals that outflow from the swamps is more closely correlated with rainfall than with inflow. It also reveals that in 1953 there was a sudden change in regime which has persisted to the present day. Brind mentions in his report that the Boro began to flow in 1953, whereas previously the bulk of the flow reached the Thamalakane via the Santantadibe and earlier via the Gomoti. During 1952 the area experienced no less than 22 earth tremors in the 5-6 magnitude range, with epicentres located in the upper Santantadibe-Ng-gokha area. The sudden change in regime may therefore have been caused by earth movements along the major rift faulting of the Ngamiland trough over which the swamps are located.

In the analysis of the hydrology of the Okavango delta two approaches are apparent and detailed consideration has been given to both. The first is a deterministic model using physical laws, in particular the law of conservation of energy and the law of conservation of mass, and the second is to assume that the swamp is a 'black box' which transforms an input into a set of outputs using parameters which must be determined.

The value of a deterministic model is clear as it is based on very definite principles. It has the great advantage over the 'black box' approach inasmuch as one is enabled to simulate the effect of physical changes (drainage, diversion, reclamation) within the swamp and determine the resultant effect of these. A detailed examination of such a model has been carried out by Chidley (1970) and the theoretical structure developed. However, to develop fully such a model a considerable amount of further field survey work is required far beyond the present manpower and time limits of the present project. It is hoped, however, that as more and more data is accumulated in the future, it may be possible to operate the model.

For practical purposes of predicting the total volume and peak rate of outflow at the base of the swamps, resort has had to be made to the 'black box' approach and, using the 11 years of records since 1952/63, a series of regression equations has been developed through the application of multiple correlation techniques utilizing a local computer (Pike 1970). These equations assume little or no detailed knowledge of the components or relationships within the cycle and interest is entirely focused on inputs (inflow and rainfall) and outputs (outflow) and in establishing some direct functional link between them. In this case up to eight input variables have been utilized: maximum and minimum inflow of the previous year, maximum inflow of the current year, minimum outflow just prior to the arrival of the annual outflow rise and the rainfall/evaporation ratio or effective rainfall over the swamps for each of the months from December to March.

While the resulting equations are somewhat inelegant, the coefficient of determination is in the region of 95% and provides a reasonably accurate means of predicting total outflow volume and peak flow to be expected each year. An added advantage is that the prediction can be made each year at the end of March, allowing a six-week interval before the onset of the annual flood at the outlet of the swamps.

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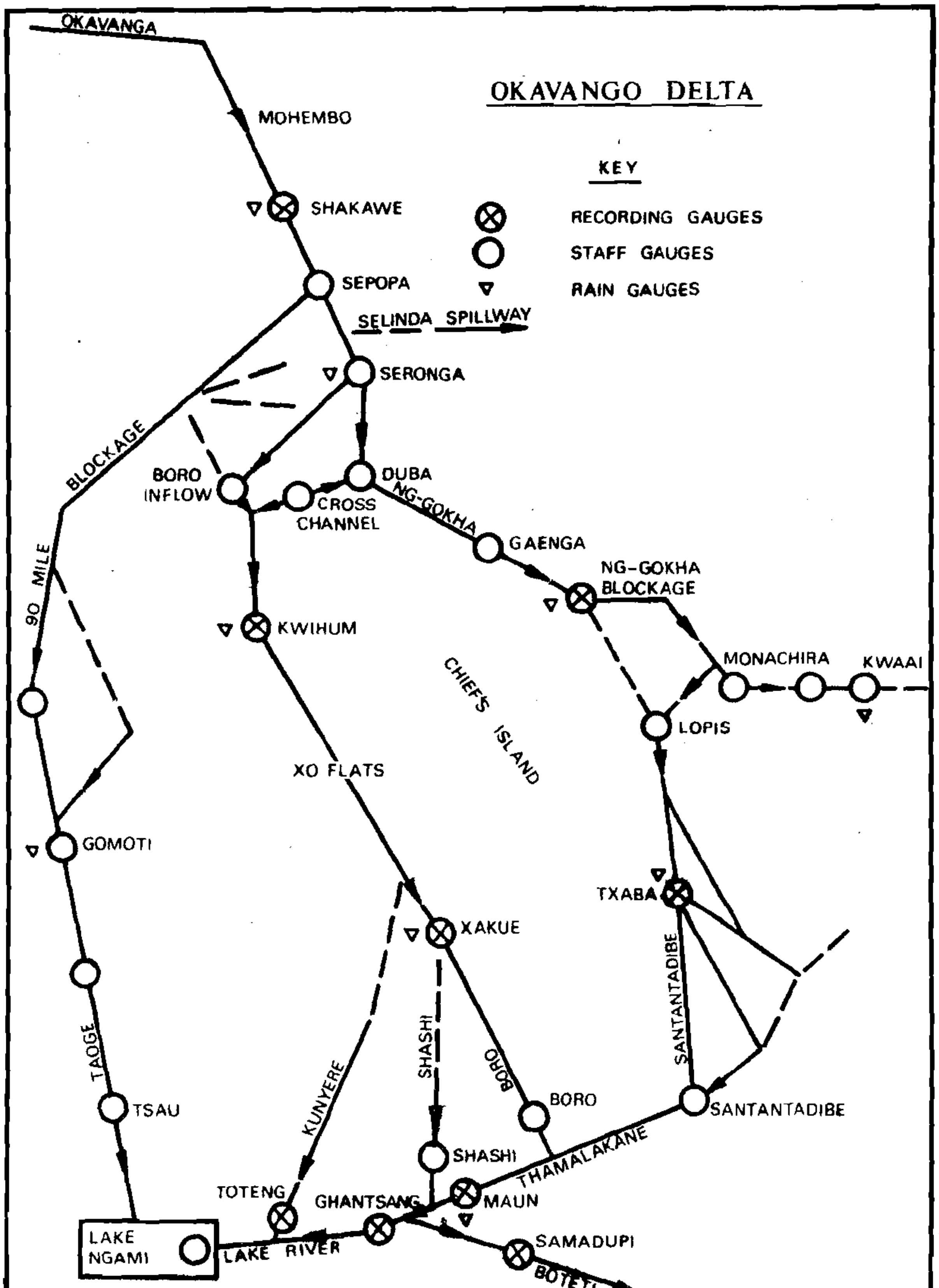
Table 1

Okavango Delta - Annual Inflow at Mohembo
Outflow at Maun and January-March rainfall at Maun

YEAR	Outflow $m^3 \times 10^6$ (Apr.-Mar.)	Inflow $m^3 \times 10^7$ (Oct.-Sep.)	Rainfall mm (Jan.Feb.Mar.)
1933/34	2.6	1520	35
1934/35	24.1	1940	278
1935/36	5.8	1490	146
1936/37	40.5	1150	424
1937/38	128.1	970	268
1938/39	35.7	1240	204
1939/40	89.7	1030	323
1940/41	252.7	1240	204
1941/42	7.4	710	211
1942/43	NIL	640	257
1943/44	18.6	1200	141
1944/45	400.2	1560	511
1945/46	76.1	1070	222
1946/47	20.1	765	475
1947/48	64.7	1300	237
1948/49	261.4	916	518
1949/50	125.0	849	218
1952/53	278.7	1025	210
1953/54	264.4	1131	332
1954/55	1046.5	1639	325
1955/56	693.3	930	429
1956/57	585.1	1221	252
1957/58	295.2	910	269
1958/59	448.0	954	444
1959/60	224.3	954	270
1960/61	84.3	982	124
1968/69	898.4	1597	295
1969/70	603.7	1310	319



OKAVANGO DELTA
KEY
RECORDING GAUGES
STAFF GAUGES
RAIN GAUGES
OKAVANGA
MOHEMBO
SHAKAWE
SEPOPA
SELINDA SPILLWAY
SERONGA
BLOCKAGE
BORO INFLOW
DUBA
CROSS CHANNEL
NG-GOKHA
GAENGA
NG-GOKHA BLOCKAGE
90 MILE
KWIHUM
MONACHIRA
KWAAI
LOPIS
CHIEF'S ISLAND
XO FLATS
GOMOTI
TXABA
XAKUE
SANTANTADIBE
TAOGE
KUNYERE
SHASHI
BORO
TSAU
SANTANTADIBE
THAMALAKANE
SHASHI
TOTENG
GHANTSANG
MAUN
SAMADUPI
LAKE NGAMI
LAKE RIVER
BOTETI

NEED OF HYDROLOGICAL AND HYDROMETEOROLOGICAL DATA FOR LARGE-SCALE, LONG-TERM INVESTMENT AND GENERAL ECONOMIC AND SOCIAL PLANNING

by D. Jovanovic

ABSTRACT

Economic development of a country depends on its water resources. Planning and construction of hydraulic structures based on inaccurate or insufficient hydrometeorological data certainly leads toward losses in the overall economy. For this, several examples are given.

There are indications that in Ethiopia there exist regions with different rainfall distribution, during a year or from year to year. For confirmation of this, additional field and office work is required. If the idea is to be confirmed, substantial saving in storage water reservoirs can be obtained if an interconnected power system is built.

RESUME

Le développement économique d'un pays dépend de ses ressources en eau. Un projet et une construction de structures hydrauliques basés sur des données hydrométéorologiques imprécises et incomplètes méneront certainement à des pertes s'étendant à l'ensemble de l'économie. Nous donnerons plus tard quelques exemples.

Des indices existent qu'en certaines régions de l'Ethiopie la distribution des précipitations diffère au cours d'une année ou d'une année à l'autre. La confirmation de ceci exige un travail complémentaire sur le terrain et au bureau. Si l'idée est confirmée une grande économie en réservoirs d'accumulation pourrait être faite en construisant un système de production d'énergie hydraulique composé de plusiers éléments reliés entre eux.

* *

The possibility of industrial and economic development of a country depends very much on its water resources. Cheap water power is always the base for industrial development. But water power reservoirs will, at the same time, serve as multipurpose structures aimed primarily at supplying water for irrigation, navigation, etc.; hence the dependence of economic development of a country on its water resources. As the flow of rivers fluctuates during the year, it is essential in any planning to know the relation of these fluctuations to the time, in order to know the quantity of water available at any moment. The availability of water at any time of the year may be determined by processing hydrometeorological data.

If such data do not exist; if the period of record is not sufficiently long, or if the data are not accurate enough, then, investment in economical development will be larger than necessary, or there will be less production than is economically possible due to the smaller size of plant. In both cases the result will be loss in overall economy.

Examples:

(1) Flow hydrograph and mean annual flow: Assuming that the observation and recording of data was done perfectly but with the period of observation being short, then the main annual flow, which is the base of all planning, may differ from the mean annual flow corresponding to that of the long period of observation. This difference may be positive or negative depending on the cycle to which the observed period belongs (the cycle of wet or the cycle of dry years).

In this case, the storage reservoir built for a certain degree of flow regulation, will be either over-sized or under-sized, depending on the error made in the estimation of the average flow. As the creation of a reservoir usually requires the construction of a dam, the dam height will also be wrongly chosen, as it is directly variable with the storage capacity.

(a) Assuming that the calculated mean annual flow is underestimated (lower than the actual long-term average value):

Determined storage capacity will be smaller than it should be, and hence the required degree of regulation cannot be achieved. This will directly affect production of hydro-electric power, regulation for irrigation, and navigation etc., all of which depend on the storage capacity of the dam. Power production will be less than planned and more irregular; power plant will not be able to cover peak loads which, in turn, would call for the construction of more expensive thermal power. Also, a smaller area than expected would be irrigated, and for the best yield of crops the available water would be insufficient.

When the inadequacy of the reservoir size is recognized, it would be necessary to increase the dam height to obtain the required storage capacity, thus incurring more expense than would have been the case if it had been done initially. This often requires stoppages and creates difficulties in production as well. The worst effect of such correction will be on conduits. The size of canal might be increased, but if the conduit is a tunnel, then, the size of the tunnel being usually practically impossible to increase, a new one should be drilled otherwise the plant will remain with smaller capacity than is economically justified.

(b) Assuming that calculated mean annual flow is overestimated (greater than the long-term average value), then, in this case too, all structures will be overestimated.

Dam height will be more than is necessary, and the reservoir will very seldom be as full as the foreseen normal water level.

Since the hydro-electric power plant will be installed on bigger capacity than is possible, all structures, power house, conduits, etc., will be of larger size than required. Production of power will be below the planned target, and some machines will either stay idle or work with low efficiency.

For planned irrigation schemes there will not be sufficient water to irrigate the whole area and the channels and other structures will be of excessive sizes.

In all these cases the excess of money spent is a permanent loss.

(c) The required degree of flow regulation for a given sector of the river can be obtained by building a storage reservoir of corresponding capacity. If the flow hydrograph does not for some reason or other represent the average condition of a rather long period of years, the size of the reservoir will be wrongly determined, which effect will be felt after several years of operation, and therefore the required degree of regulation will not be achieved.

(2) Floods: It is much more difficult to estimate flood flow than it is to estimate normal streamflows. Frequencies of peak floods, determined on the probability theory based on a short period of observation, can be several times lower than the actual value. Also, other methods do not give more reliable data, except probably, the unit hydrograph method. But unfortunately, the unit hydrograph incurs more expense since the establishment of a number of gauging stations and at least one or two years of observation are necessary. However, when applying even the unit hydrograph method, one cannot be absolutely certain that estimated flood discharge will not be surpassed in the future.

Overestimation of flood discharge involves unnecessary expense in the construction of over-sized spillways and other related structures. Underestimation of flood, on the other hand, may have much more serious consequences such as the complete destruction of the dam, resulting not only in very high material losses, but also in possible loss of human lives which is beyond any material equivalence. For this reason, full attention should be given to peak flood determination, which totally depends on the accuracy of the hydrometeorological data.

If losses and gains from a well-established hydrometeorological network are set against the lack of one, it will be found that in the long run the cost of establishing and running enough hydrometeorological stations will be much less than the losses involved in hydraulic structures designed on inaccurate data.

When designing and establishing an hydrometeorological network, full attention should be given to the kind of instruments that should be installed. Automatic recording instruments certainly do have higher initial costs and, eventually, operating costs. Records obtained from such instruments are not only more reliable and accurate, but they also give continually recorded data which are very useful in the correct determination of hydrological occurrences. Sometimes they are the only means of obtaining data. Initial cost of non-automatic gauging stations read once or twice daily by observers is certainly cheaper. The operation cost may probably be cheaper also, but it does not give a continuity of occurrence (intensity of rainfall, flood peaks etc.). Furthermore, if the number of gauging stations is installed without the observers being sufficiently educated and reliable to make correct registration, the recorded data will have no value, in which case the money allocated for the purpose could be considered as completely wasted.

Unfortunately, money spent on establishing an hydrometeorological network and running and maintaining it, does not give immediate and visible benefits. Therefore the importance of such work is not always clear to higher authorities on whom the budget approval depends. Especially in underdeveloped countries such work is more or less neglected or at least subordinated to organizations which are likely to provide immediate and obvious benefits.

The UN and the ECA can help a lot in persuading different governments to recognize the importance of hydrometeorological records by repeatedly suggesting the ideas and demanding some kind of pertinent regular reports from member countries.

All that has been mentioned above is more or less generally applicable to all countries. To mention certain problems related to Ethiopian conditions:

Ethiopia consists mostly of three different regions as far as altitude is concerned. Namely the highland, the lowland, and the intermediate zones between these two.

Of these the regions of highland and lowland differ not only in altitude but also on hydrometeorological occurrences. While the highland's main characteristics are lower temperatures and higher rainfalls, the lowland's characteristics are the reverse, i.e. higher temperature and lower rainfall.

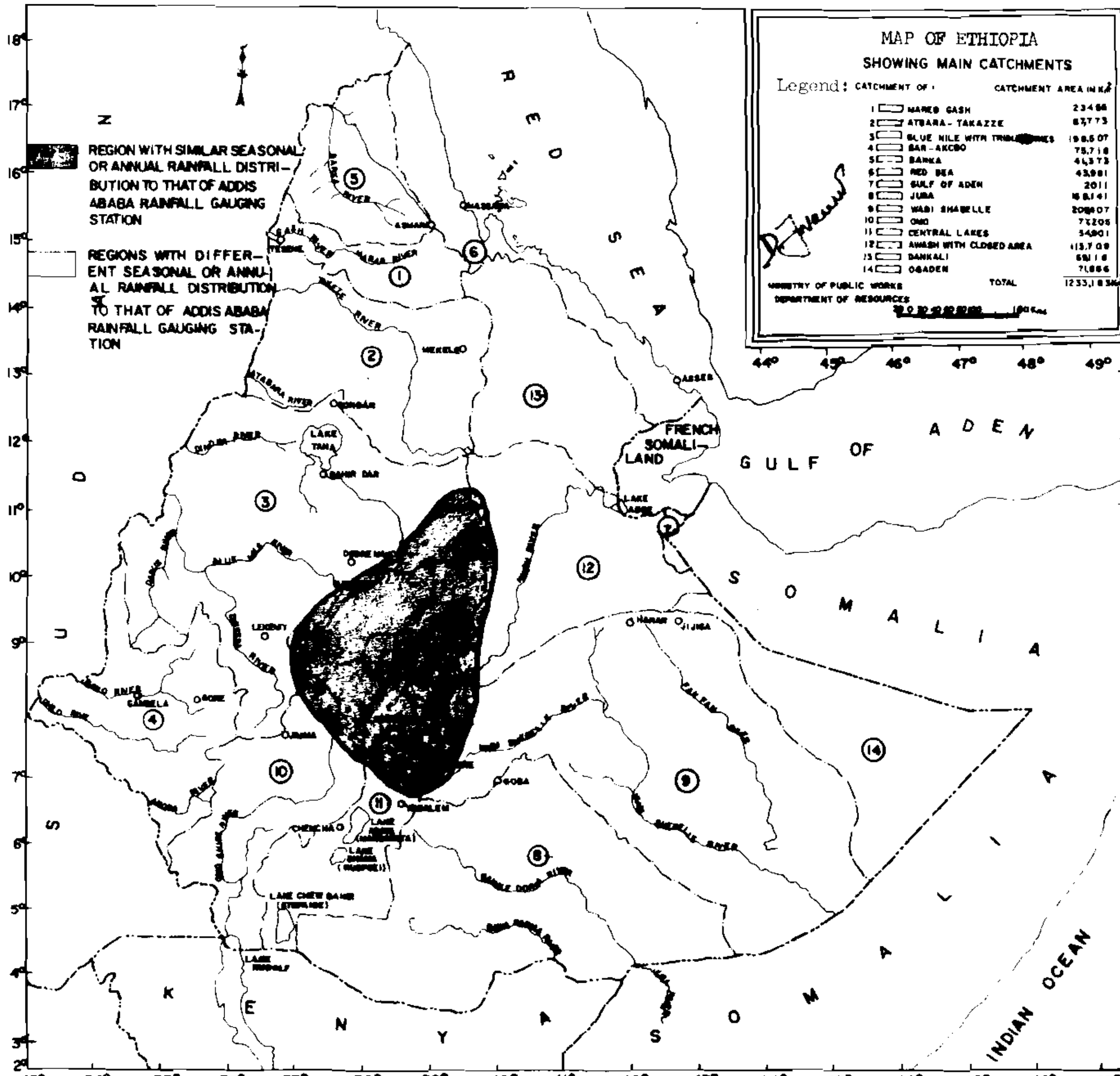
The need of supplementation between these two climatically different regions is obvious. On the highland most of the water from precipitation should be stored, and thence the impounded water will be used for irrigation in the lowland areas where fertile land is in abundance. In addition to that, differences in elevation between the highland and the lowland should be utilized for hydro-power production.

As for total power regulation, it is not even required to have a total water flow regulation, the storage capacity required will greatly depend on the interconnexion between different power plants within a system. If, within the system, regions with different seasonal or annual distribution of discharges exist, further saving in storage capacity and installed power can be achieved. Ethiopia, unfortunately, has not been studied from this point of view.

Today electricity from large water-power stations in the world is transmitted at higher voltage for distances of over 800-1,000 km. If such an interconnected high-voltage system is built, Ethiopia can benefit from differences in seasonal and annual water distributions within the different parts of the country.

Based on the rainfall records, it is possible to identify regions with differences in the distribution of rainfall. Most probably the discharge of rivers stemming from these regions will also be subject to diversity of low-and flood-discharge occurrences. It is, however, necessary to continue ths study by processing existing flow records and making new flow measurements. This will require several years of field and office work and, of course, financial means too.

The map below should be considered as a first approximation to determine regions with seasonal and annual diversity of rainfall. Further study based on discharge will either confirm or reject this analysis. If this idea can be confirmed, further economical and water studies should give an answer on the economical degree of interconnexion between different regions of the country. It is worthwhile investigating this situation since benefits, in favourable cases, will be very high.


MAP OF ETHIOPIA
SHOWING MAIN CATCHMENTS
Legend: CATCHMENT OF: CATCHMENT AREA IN KM²
1 MAREB GASH
2 ATBARA - TAKAZZE
3 BLUE NILE WITH
4 BAR - AKOBO 75,716
5 BARKA
6 RED SEA 43,981
7 GULF OF ADEN 2011
8 JUBA
9 WABI SHABELLE
10 OMO
11 CENTRAL LAKES 54,901
12 AWASH WITH CLOSED AREA 113,709
13 DANKALI
14 OGADEN
TOTAL
MINISTRY OF PUBLIC WORKS
DEPARTMENT OF RESOURCES
REGION WITH SIMILAR SEASONAL OR ANNUAL RAINFALL DISTRIBUTION TO THAT OF ADDIS ABABA RAINFALL GAUGING STATION
REGIONS WITH DIFFERENT SEASONAL OR ANNUAL RAINFALL DISTRIBUTION TO THAT OF ADDIS ABABA RAINFALL GAUGING STATION
RED SEA
GULF OF ADEN
FRENCH SOMALI-LAND
SOMALIA
KENYA
SUDAN
INDIAN OCEAN
LAKE TANA
MEKELE
GONDAR
BAHIR DAR
ASSAB
HARAR
JIJIGA
GOBA
GAMBELA
GORE
JIMMA
LEKEMTI
CHENCHA
ATBARA RIVER
LAKE CHEW BAHIR (STEPHANIE)
LAKE RUDOLF
33° 34° 35° 36° 37° 38° 39° 40° 41° 42° 43° 44° 45° 46° 47° 48° 49°

MULTIPLE-PURPOSE DEVELOPMENT OF WATER RESOURCES

by Teshome Workie

ABSTRACT

Full and complete utilization of water resources is an economic and social advantage to all members of a society. The water resources potential of most developing countries is practically untouched, and their systematic and wise development is of paramount importance for enjoying the maximum possible benefits.

This paper indicates that, although a multi-purpose development may not give the maximum benefit for one purpose, by including other purposes it provides an optimum use of water, thereby achieving a better overall economy. It also points out the conflicting requirements of various functions and the difficulties they pose in the design of multi-purpose projects.

The paper summarizes some of the current practices of cost allocations to various functions of the multi-purpose development and calls for greater support to multi-purpose projects in developing countries than that at present.

RESUME

Le plein et complet emploi des ressources en eau constitue un avantage économique et social pour tous les membres de la société. Dans la plupart des pays en voie de développement, ces ressources sont pratiquement inutilisées et leur mise en valeur systématique et rationnelle revêt une importance capitale si l'on veut en tirer le maximum de profit.

Cette étude fait remarquer que bien qu'une mise en valeur orientée vers plusieurs buts ne rapporte peut-être pas un profit maximal dans un domaine particulier, elle assure néanmoins une utilisation optimale de l'eau et par là une meilleure économie générale. Elle souligne également les exigences opposées de différentes fonctions ainsi que les difficultés qui en résultent pour esquisser des projets à des fins multiples.

Cette étude résume quelques-unes des méthodes utilisées actuellement pour la répartition des coûts entre différentes fonctions d'un projet de mise en valeur à fins multiples et demande qu'une plus grande assistance soit accordée à des projets à fins multiples dans des pays en voie de développement.

INTRODUCTION

Water is one of the most basic resources in a country. Some resources, like minerals, can be preserved in their natural form and can be saved until required. If a mineral resource is little exploited by the present generation, it can wait undiminished for the next generation. Water is a flowing resource and, like time, it waits for no man. Unlike the mineral resource, it cannot be preserved for coming generations. Any water unused today is lost forever. Each year the development of water resources is delayed, the potential value of water diminishes. Delay means waste and loss of potential wealth. Most of the African countries are rich in water resources. The waste of these resources is inexcusable in these countries where agriculture for balanced food supplies and power for industries are greatly needed.

Water resource development is concerned with the use of water and related resources for better living. Planning must be directed toward the present and the future needs of the society to be served. An appraisal of water resources must consider surface as well as ground water supplies in terms of location, quantity and quality. It should include all main elements in water resources development, such as domestic, municipal and industrial uses, irrigation, hydropower, flood control, navigation, pollution abatement, watershed management, fish and wild-life conservation and recreation. In plan formulation, emphasis must be made on a project objective. The basic objective should be to provide the best use, or combination of uses, of water and related land resources to meet all foreseeable short-term and long-term needs. All purposes of development should be given full consideration. Many water resources projects are potentially useful for more than one of the above basic purposes. By designing and building them to serve more than one purpose, greater overall economy can be achieved.

MEANING OF MULTI-PURPOSE PROJECT

There is a difference of opinion among engineers as to the meaning of a multi-purpose project. There are engineers who consider any reservoir used, or capable of being used, for more than one purpose as a multi-purpose reservoir.

An irrigation project, solely designed for irrigation as an objective, may provide other incidental benefits. An irrigation project producing power for pumping irrigation water is a good example of this type, and some engineers take this as a multi-purpose project.

This paper follows the definition given by the committee of the American Society of Civil Engineers on multi-purpose development. The committee defines multi-purpose projects as "projects designed and operated to serve more than one function and should exclude those projects whose design and operation are controlled by one function, even though other benefits accrue as by-products".

EVOLUTION OF MULTI-PURPOSE DEVELOPMENTS

In many countries, especially developing ones, the control of a river subject to disastrous floods, the exploitation of a river for power generation, the improvement of a river channel for navigation, the regulation of surface water and the exploitation of the groundwater for irrigation, domestic, municipal and industrial use, the disposal of sewage and industrial waste, or any other use or control of water have been treated until very recently as isolated problems. This disorderly and unintegrated development of water resources has neglected the maximum utilization of the available water. Single-purpose development has created, and is still creating, a lot of waste of flowing wealth. Many single-purpose projects already constructed have occupied sites that could have been used for multi-purpose projects, thereby providing optimum benefits from the available water.

The rapid growth in multi-purpose development stems mainly from a realization that maximum use should be made of existing water resources. The start of the evolution of multi-purpose development of water resources is the recognition of the multi-purpose concept itself. This began in the USA with the intimation of the relationship between navigation and flood control, first; between irrigation and flood control, second; between watershed management and flood control, navigation and irrigation third. This led to the laying down of the broad fundamentals of the multi-purpose concept.

River basins are the natural sub-divisions of water resources. The river-basin concept is another factor that revolutionized multi-purpose development. This recognizes the interrelation of resource elements. A drainage basin is to be considered as an economic unit and a dynamic and organic system. Multi-purpose development can, in the river-basin concept, make the maximum utilization of the water of the basin in an integrated development of the entire basin.

The new idea of a comprehensive programme of development, the new concept of social benefits and costs as applied to region, and the new concept of a unified control (TVA in the USA., Damodar V.P. in India, etc.) have made the multi-purpose approach of water resources development the most attractive and beneficial one.

FUNCTIONAL REQUIREMENTS IN MULTI-PURPOSE PROJECTS

In multi-purpose projects, the success of using storage space for different functions depends on the extent of compatibility of these functions. Reviewing their requirements indicates the existence of conflicts among them. Analysing these conflicts calls for co-ordination and reconciliation among various uses. That the requirements of reservoir operation in multi-purpose projects are fundamentally conflicting is indicated below:

1. Regulation for flood control is best accomplished when reservoirs are kept empty to reduce the flood peaks and to store the flood waters for release according to the capacity of the channel downstream.

2. Conservation for domestic, municipal, industrial or irrigation use requires that flood waters be held in storage during the flood season, sometimes over a period of years in the arid and semi-arid regions, and that the release of water be in conformity with seasonal demands.

3. Regulation of streamflows for the generation of hydro-electric power requires that reservoirs be kept as nearly full as practicable, that they never be emptied, and that the release of water be made in accordance with demands for power and energy.

4. Reservoirs for slackwater improvement of streams for navigation must be limited in height because of the need for locks, and hence can not have large storage allocations for other purposes.

5. Conservation of fish and wild-life may require maintaining a stable reservoir level and in no event may such a reservoir be emptied.

6. Recreational use preferably requires the reservoir to remain nearly full during the recreation season.

Flood control with its requirements for empty storage space is the least compatible of all uses. Because conservation of floods and regulation of releases are essential over an extended period of time for both irrigation and power, there is less conflict between them than between either of them and flood control. Co-ordination of the requirements for fish and wild-life conservation and for recreational uses of reservoirs with the requirements for either flood control or irrigation is almost impracticable; this is because flood control reservoirs are subject to rapid changes in level, and irrigation reservoirs must be emptied of all water whenever it is needed. Without compromise it is only superimposition of capacities that would avoid the conflicting requirements of flood control and irrigation, or of flood control and power generation. If pyramiding is carried out, the component parts could be operated in effect as separate reservoirs.

DESIGN OF MULTI-PURPOSE PROJECTS

The design of any multi-purpose project is basically an economic problem. The basic factor in multi-purpose design is a compromise. The structural features (dams, spillways, sluiceways, gates, water conductors, power-plants etc.) are more or less the same for single-purpose as well as for multi-purpose projects. The most important point in multi-purpose design is the selection of the physical works and a plan of operation to provide effective co-ordination and reconciliation among the various uses.

If a reservoir of a given capacity is to serve several purposes, its value for any one purpose can not be the maximum possible for that purpose. The reservoir operation must be planned in such a way that operation for all purposes is included. This would probably reduce the maximum possible benefits from one purpose in order to include other purposes. The sum of all the benefits from the services should be the optimum and this should exceed the maximum benefit from any one function. Detail and systematic studies of benefits and costs for different capacities of reservoirs, different types of dams and the inclusion or exclusion of each of the several purposes must be made in order to obtain this optimum economic and physical balance.

ECONOMICS OF MULTI-PURPOSE PROJECTS

Economics in river developments are frequently made possible by formulation of a balanced and comprehensive plan involving a combination of purposes and a combination of facilities and measures. Multi-purpose projects permit more complete use of the physical potentialities of individual reservoir sites and fuller utilization of project facilities than single-purpose projects. Multi-purpose programmes further the realization of optimum beneficial values from the available water resources.

In the design of any project intended to serve more than one purpose, the conflicting requirements of these purposes must be compromised unless there is to be a pyramiding of capacities and costs. There is a need to consider the relative values involved before any compromise of conflicting requirements can be made intelligently. Compromise of such conflicting requirements will depend on evaluation of each direct and indirect benefit that will actually be realized in the operation of the project. The sum of all such benefits must be substantially more than the costs of construction and operation.

Benefits arising from the construction of any multi-purpose project approach an upper limit as the capacity provided in the reservoir is increased. Costs of construction become tremendous whenever the size of the reservoir exceeds the limitations of the site. If typical curves are plotted showing the relations between benefits and reservoir capacity, and between costs and reservoir capacity, these curves intersect at two points. Below some small capacity the costs will exceed the benefits, and beyond some much greater capacity the benefits again become less than the costs (see the attached figure).

For any reservoir capacity between 0.3 unit and 8.3 units, the benefits (1) exceed the costs (2). The maximum difference between benefits and costs occurs for a reservoir of 3.3 units in size. This is 40 per cent of the upper limit where the costs become as great as the benefits. The maximum ratio of benefits to costs (3) occurs for a reservoir of 1.9 units capacity, which is only 23 per cent of the same upper limit. With available water, the reservoir capacities corresponding to the last three values determined in this illustration must be given consideration in the design of any multi-purpose reservoir. In any such comparison of costs and benefits of multi-purpose reservoirs, the benefits deemed to arise out of the reservoir must be as tangible as the costs themselves.

COST ALLOCATIONS FOR MULTI-PURPOSE PROJECTS

Cost allocation is the process of assigning to each purpose of a multi-purpose project an appropriate share of the total multi-purpose cost. There is not as such a very satisfactory method of cost allocation that would be equally applicable to all projects and that would yield allocations which are equitably correct. There is usually no difficulty in identifying the costs of facilities used for one specific purpose; the problem is to apportion costs of joint-use facilities. Generally, any method of allocation must first set aside the separable costs which are clearly chargeable to a single project function, such as the cost of power-house, navigation locks, irrigation canals, or fish ladders. Many methods have been used, usually to favour some particular use over others. Some consideration to basic philosophies rather than exhaustive treatment is presented here.

Use of facilities

Purposes making the same type of use share in proportion to their use.

Priority of use

If there is favoured principal user compared with other users of project, the priority user may be considered to pay the basic costs and incidental costs; or adjustment can be made for differences in use arising from the application of priority treatment over equal treatment.

Benefits

If one beneficiary derives a greater benefit than another for the same use, that user may be expected to pay a greater amount.

Alternative justifiable-expenditure methods

This approach is an indirect method based on the assumption that no beneficiary should be required to pay more than he would be required to pay for equal service from the cheapest alternative providing equal benefit.

Separable costs/remaining benefits method

This method calls for allocating to each purpose the separable costs of including that purpose in a project plus a share of the "joint costs", which are the difference between the total project costs and the sum of the separable costs for each purpose. The joint costs are allocated to each purpose in proportion to their "remaining benefits", which are the difference between separable cost of a purpose and the benefits to that purpose or the alternative costs of obtaining those benefits whichever is less. This method has been widely used and generally found adaptable and acceptable in most situations.

MULTI-PURPOSE PROJECTS IN DEVELOPING COUNTRIES

In developing countries, the concept of multi-purpose development does not seem to be given the appropriate attention. There are many water resources projects being undertaken for single-purpose developments without possible consideration for other uses. Immediate demands, without a little forethought for future consequences, may press on piecemeal developments. Usually, major water-control structures, once built, can be altered either not at all or only with difficulty and substantial expense. If the suitable dam sites are already appropriated for single purpose projects, the opportunities for economic multi-purpose developments are considerably reduced or even eliminated. This type of undertaking, even though it gives a temporary solution to the problem then prevailing, would not only undermine the optimum use of water but also create a waste of available resources.

Therefore, plan formulation should be directed towards full development and complete utilization of the available water resources. This, from the national point of view, will lead to comprehensive river-basin or regional development as an essential means to obtaining optimum use of water. Comprehensive river-basin study would help identify water resources projects and put them in priority order of development, taking into consideration relative economic and social attractiveness without favouring any particular use of water. Thus comprehensive river-basin study gives impetus to multi-purpose development schemes.

SUMMARY

Water is a very precious natural resource. The method of exploitation of this resource, until very recently, has not made use of the maximum utilization of available water. Multi-purpose development of water resources permits optimum use of water in the basin, thereby achieving greater overall economy.

Different uses of multi-purpose development have conflicting interests. Because of conflicting requirements, the design of multi-purpose projects is mainly a compromise among the various uses and is basically an economic problem.

The cost allocation procedures for various functions of the multi-purpose projects appear to be sound in principle but subject to questions when applied. The main objective for cost allocation among purposes is to achieve mutually agreeable division of costs. The existing procedures, even though used in the absence of better ones, are not found to be equitable.

In developing countries, multi-purpose development should be given greater support than at present, and planning for water resources should be directed towards optimum use of water. Therefore, great care must be exercised so that promising sites are used to their best advantage from the standpoint of all requirements that can be served.

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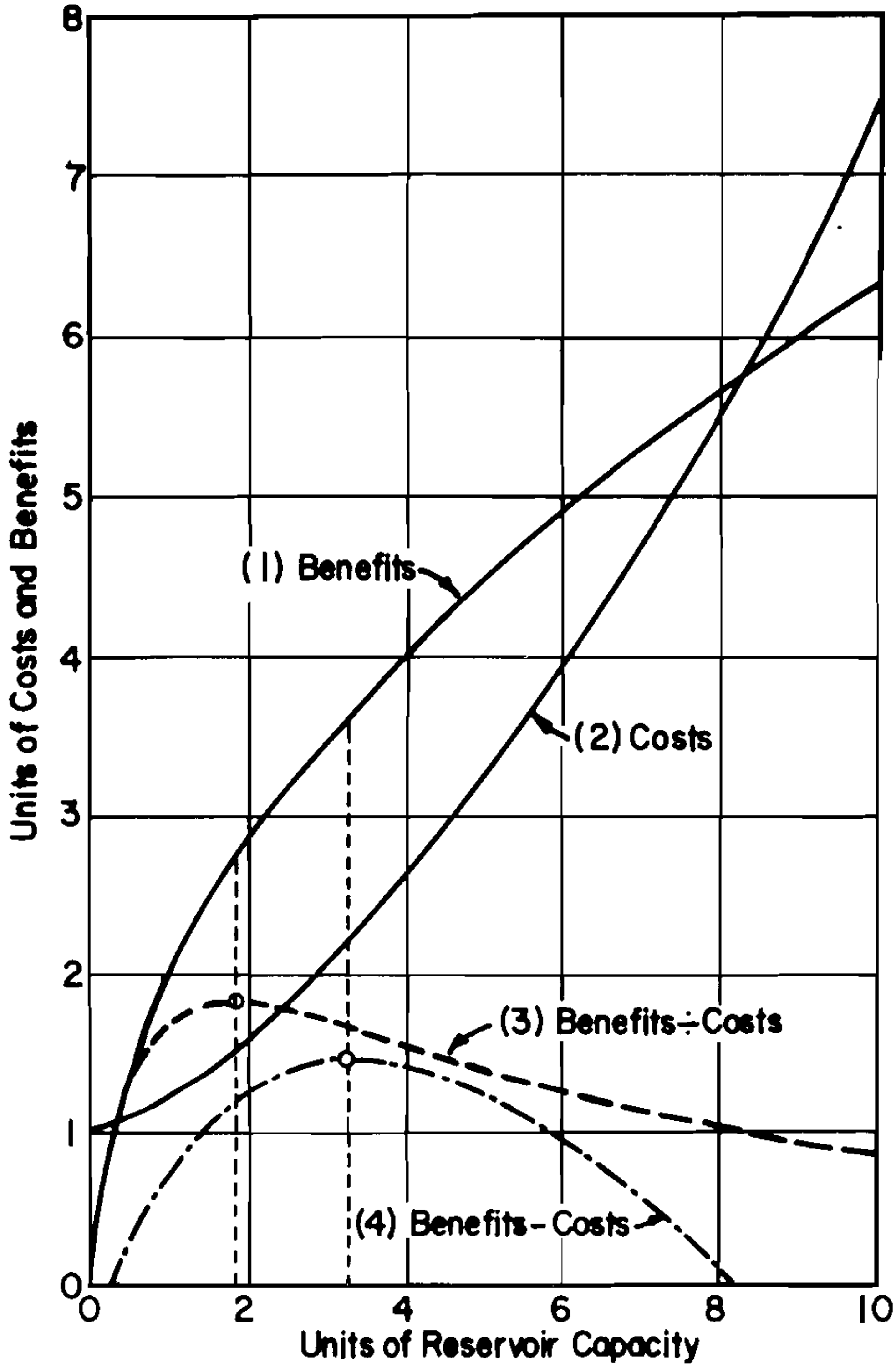


RELATION BETWEEN BENEFITS AND COSTS OF MULTIPLE-PURPOSE RESERVOIRS

WATER RESOURCES INVENTORY

by D. Jovanovic

ABSTRACT

It is suggested to standardize the method of Water Resources inventory and to establish a common Institute for Water Resources for the whole African Continent.

As the most convenient method to make Water Power Inventory is the method proposed by prof. V.Yevdjevitch (Colorado State University) which gives all necessary information with minimal field works. In his method prof. Yevdjevitch suggested **a method** to establish probable upper and lower limits for installed power as well as upper and lower limits of annually available energy. Actually produced energy will be somewhere between those two limits and it can be determined only by studying the basins in more details.

The present stage of water studies in Ethiopia is also described.

RESUME

Il a été suggéré d'unifier la méthode d'un inventaire des ressources en eau et d'établir un Institut commun pour les ressources en eau en ce qui concerne toute l'Afrique.

La méthode la plus facile pour faire un inventaire des forces hydrauliques est celle proposée par le professeur V. Yevdjevitch ("Colorado State University") donnant toutes les informations nécessaires avec des travaux sur le terrain minimes. Dans sa méthode, le professeur Yevdjevitch suggère d'établir les hautes et basses limites probables pour les forces installées ainsi que les hautes et basses limites pour l'énergie annuelle disponible. L'énergie effectivement produite se situera en quelque sorte entre ces deux limites et ne pourra être désignée qu'après une étude des bassins plus detaillée.

L'état actuel des études sur les ressources en eau en Ethiopie y figure également.

* * *

Six topics are proposed for discussion under question No. 6. As all topics are to a certain extent interconnected, it is very difficult to treat them separately. Therefore problems related to the question No. 6 will be discussed together regardless of the subdivisions.

The most important use of water is to support the life of living organisms on the earth, but its use is not restricted only to this. Water is used for many other purposes aimed at raising the living standard of humanity, as in, for example: irrigation, water power, navigation, etc. However, for whatever purpose the water is used, its use changes the annual balance or modifies the distribution of the runoff.

Thus, the use of water for irrigation and drinking purposes consume most part of the used water without returning it to the stream or the source from where it was taken. The use of water for water power & navigation, on the other hand, utilizes water without considerable change in the balance of discharge.

Natural river flow is usually irregular, following mostly the sequence of rainfalls. Such flow fluctuations scarcely correspond to fluctuations of water demands. To regulate such river fluctuation, storage reservoirs are built, with the main objective of storing the water in excess of the demand and releasing it when the required flow is higher than the natural flow. By building reservoirs, overall runoff balance is reduced due to increased evaporation and eventual deep percolation.

To determine the relation between the river flow and the water demand, a knowledge of the river flow related to the time is essential. Based on this the economical size of reservoir for required degree of flow regulation can be designed.

For a single hydroelectric power plant or for irrigating a single plot of land a flow hydrograph at one point, i.e. at the point of intake, is required. But, if the development of regions or of the country as a whole is to be studied, water resources inventory of all rivers within the region or the country is needed. The water resources inventory should contain sufficient data for the determination of the flow at any one time, as required in the planning of irrigation, water supply, navigation, etc.

Planning of water power requires one more parameter: the head of differences in elevations along the river course.

Industrial development of a country, especially these fields of electro-metallurgical and electrochemical industries, depends highly on the possibilities of electricity production. At present the main sources of electric power are fuels and water. Atomic energy has not yet reached the full stage for economical production. Based on these, production of electric energy can be classified in three groups, depending on natural reserves and possibilities of exploiting water and fuel.

1. Where hydro-energy is predominant;
2. Where fuel or thermal energy is predominant;
3. Where thermal and hydro-energy are in certain proportion.

Hydro-electric power production depends on hydrological characteristics of water sources. Therefore the greater part the hydroelectric energy has in the total power production, the bigger the influence of water resources characteristics should be. In the second case where thermal power is predominant the influence of water resources characteristics on the total power production is smaller than in the first case, and similarly the accuracy of hydrological data is less important.

In accordance with the available information on natural resources, Ethiopia must base its power production mostly on water, since fuels are not yet discovered in large quantities. Although there are very promising possibilities of geothermal power, industrial development can not be based on the source of energy whose reserves can never be determined in advance with enough certainty.

Another basic element in the development of the country is agriculture based on irrigation. This will not only secure the necessary food for population, but will also support and encourage agro-industrial development.

Having in mind the fact that both of these two elements of industrial development are based on water, the preparation of water power resources inventory, as described before, is the utmost and urgent task of Ethiopia.

Such inventory also offers the possibility of deciding priority areas of the country where studies should be concentrated and to determine the criteria of project investment for afforestation, reclamation and other soil conservation works directed at improving the existing potential.

For location of industrial centres, however, water power resources inventory alone can not be sufficient. It is only a first step in the study. Accordingly if errors in planning are to be avoided a complete, integrated river basin development study is required, which should include planning of development not only of water power, but also of industry, agriculture, communications, etc. Water power and water resources inventory being the base of such integrated study, they must be prepared well in advance since the time required for their preparation is very long, especially where **an** adequately long period of reliable records **is** lacking. Fluctuation in river flows is a **well-known** fact and it requires at least a decade of observation to get data for any planning.

There are several methods for preparation of water power resources inventory. We shall describe here only two, the second one being more practical and recommendable for Ethiopia or in general for African conditions.

METHOD PROPOSED BY PROFESSOR M. PECINAR

This method which was proposed to the world Power Conference before the Second World War consists of:

- The study of the whole basin of a given river including all tributaries up to a limiting potential of 15 HP/km
- Water flow and water power determined for 5 characteristic flows obtained from flow duration curves (Q1; Q9; Q6; Q3 and average annual-Qav.), (Q1 - Q9 are the flows of one to **nine** months' duration.)
- A **monographic** presentation describing various factors of water régime and economical and social relations for every river.

Division of river courses into sectors of already exploited (constructed power plant or under process of construction) and sectors potentially available for further development.

Such method of water power resources inventory offers nearly all the necessary data for studying water power development, but as it does not give chronological distribution of flow it is not much use in flow regulation studies. This method requires more extensive investigation work than necessary to estimate water resources as a source of hydropower.

METHOD PROPOSED BY DR. V. YEVDJEVITCH

Based on this method Prof. **Yevdjevitch** prepared water power resources inventory of Yugoslavia, which was submitted to the World Power **Conference.** His method solves the problem **in** more practical **ways.** The basic principles of his method are:

(1) <u>Instead of dividing available water power in 3 groups as is commonly used, he divides it only in 2 groups.</u> i.e.

- Theoretically available water power; and
- Economically exploitable water power.

He dismissed the third group "technically possible" as being meaningless in the light of today's technical development. Today, dams and power plants may be built **at almost any site,** but they must be economically justifiable. Thus the technical aspect is automatically identified as identical with the second "economically exploitable" group.

<u>Theoretically available water power</u>

This is the power of all water flow across a catchment area for all available gross heads, without deduction of losses in conduits and equipment. This power is equivalent to the power produced by regulated water up to the last drop impounded in the reservoir. It is, however, practically impossible to use all this power.

<u>Economically exploitable water power</u>

Such power is variable with time. Some structures which may be economically unjustfied today, may be considered justified after a few years. Therefore this term should be related to a certain period of development, which means that the cost of energy produced from the hydro-electric power plant in question should be less than the highest cost of energy produced at that time.

(2) <u>To express available power and energy of a given river by two limits</u>: upper and lower limit. This proposal is quite acceptable since the possible energy production from the river depends on 2 factors:

Installed capacity of the power plant; and

Possibility of constructing storage reservoirs and degree of river flow regulation which can thus be obtained.

This method involves the determination of only two characteristic river flows while the method of prof. Peciner required five. These two characteristic flows are:

Q_{av} = average annual flow for longer period of time

$Q_{m.b.a}$=mean flow of all flows bellow Q_{av}. for the same period of time.

From the above two values it is possible to determine both upper and lower limits of probable installed power and annually produced energy.

<u>As the probable lower limit of installed power (P_{min})</u> in hydroelectric power plant, Dr. Yevdjevitch proposed the power installed on Qav for the following reasons:

Today it is a rare practice to install power on less than Q5, and very often it goes up to Q3. Duration of these two flows is on most rivers between 15% and 25%. As the duration of Qav. is very often 35% - 45%, most hydropower plants will be installed on a flow above Qav. Also considering the fact that today all power plants are interconnected in one system, it is justified to consider power installed on Qav. as a lower limit.

<u>The upper limit of installed power</u> ($P_{max} = n \times P_{min}$) must be always several times higher than the lower limit. The factor "n" depends on the degree of water regulation possibility, on the type of hydro-electric power plant and on the role the hydro-plant has in the interconnected system (base-load or peak-load plant). Its value varies from 1 to 7.

<u>The upper limit of annually available energy</u> (E_{max}) is the energy produced by the total annual flow of the river. It can be calculated by multiplying Pmin with 8,760 hrs. ($E_{max} = P_{av} \times 8{,}760$) i.e. as the river flow is completely regulated to give throughout the year a constant average flow (Qav). This energy is the maximum possible energy obtainable from the river and is equal to the total area of the power duration curve for the average year.

<u>The probable lower limit of annually available energy</u> (E_{min}) is the energy obtained by using all the water below the flow on which the lower limit of the power is installed (Qn.b.a.). It is equal to the imaginary power Pn.b.a. which corresponds to the Qn.b.a. multiplied by 8,760 hrs. or $E_{min} = P_{n.b.a.} \times 8{,}760$.

Relation between the average annual discharge Qav, and the mean discharge for all flows below Qav., gives at the same time the relation between the upper and lower limits of the annually available energy.

$$\alpha = \frac{Q_{av.}}{Q_{n.b.a.}}$$

This parameter is very important for water power study and is also very simple to be determined.

Thus both probable installed power and available energy are framed between two limits. The installed power and produced energy for every particular plant will be somewhere between these two limits. Exact values can be found only by studying the catchment area in more detail.

Thus:

If the construction of large storages is economically justifiable and if the capacity is installed on flows exceeding Qav, and if all sectors of the river can be utilized economically, average power and available energy produced by hydro-electric power plant will be near the upper limit.

If only smaller storages are economically justifiable and if capacities are installed on the flow values nearer to Qav and if all sectors of the river can be utilized, average power and available energy will be nearer to the lower limit.

Available energy can be less than lower limit only if storages are not economical, and if the power is installed on about Qav or below it, and if there are certain sectors of the river which can not be utilized.

Dr. Yevdjevitch proposed to include in water power inventory, synthetic flow hydrograph based on the records from the same long period of observation as for Qav., since from such diagram it is possible to study power variation with time, whereas it is not possible to do it from a duration curve.

The determination of the sizes of storage reservoirs for required degree of flow regulation is possible only from synthetic hydrograph.

This synthetic hydrograph represents idealized average flow fluctuations, which scarcely occurs in nature. It is a very useful diagram since actual values of dry and wet years oscillate around it. The representative average year from a given period of observation is chosen among years having the same annual flow as average, and at the same time displaying the most similar flow fluctuations to those of synthetic hydrograph.

The description of the method proposed by Dr. Yevdjevitch to obtain synthetic hydrograph is beyond the scope of this report.

* * *

There is no Research Institute in Ethiopia for studying water resources. It is the responsibility of the Water Resources Department Ministry of Public Works, but so far no work on such studies has been started. Few integrated river basin development studies were done with the help of some developed nations, but these studies are far from being complete and comprehensive. Studies on many tributaries of the main streams are missing in those works and only the most economical sites for dams and power plants have been investigated.

Some stream flow measurements, rainfall, evaporation etc. are continously recorded by Water Resources Department on some rivers. These records may be useful at a later stage when study of water resources inventory may start. However, the number of gauging stations and the period of records are not sufficient for the preparation of an inventory that could cover the whole country.

The main obstacle in developing the proper network of hydro-meteorological stations is the lack of funds and lack of understanding by higher authorities on the importance of such a work.

The Water Resources Department has in its programme water resources inventory study, which may be started as soon as the financial means are secured.

During the first and second year of this study sufficient skilled personnel should be found in order to cover 1,200,000 sq.km area of the Empire with gaugings network. The personnel should be recruited from secondary school graduates, who should be able to follow successfully theoretical and practical courses of at least 6 months in hydro-meteorology.

CONCLUSIONS AND RECOMMENDATIONS

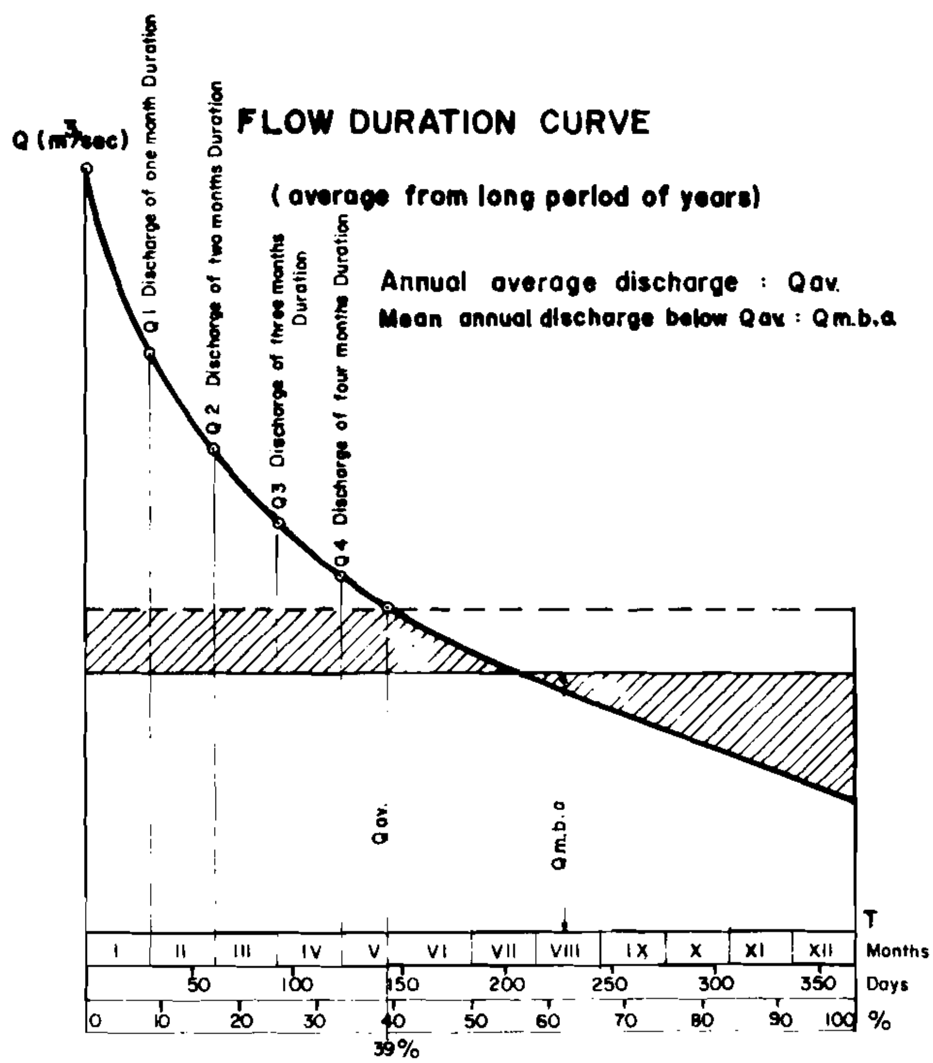
(1) It is recommended to standardize the method of water power inventory for the whole of Africa such that data from different countries can easily be compared and integrated in one common inventory for the whole continent. This is especially important for international rivers like the Congo, Senegal, Nile and similar rivers. It should be remembered that the African continent is the richest in water power with its approx. 24 % of the total available water power of the world.

(2) It is recommended to accept as the standard method for the whole continent the method proposed by Dr. Yevdjevitch since with only a minimum field work the method is capable to give the best evidence of the available water power and water resources potential.

(3) The formation of a nucleus of Water Resources Research Institute for Africa, which may be either directly under E.C.A. or under some other international organization and which could after few years of organizational period develop into a full-scale Institute for the continent.

The duty of such an **Institute**, apart from carrying out current studies, would be to prepare proposals for standardization of hydrometeorological services as well as establishing criteria of approach for the different terms such as, for example, the determination of the year that could be considered as an average year from a given period of years (mean, mode or median), etc.

The personnel for this Institute should be selected from the best qualified hydrometeorologists of the different countries of the continent. As this **Institute** shall be purely a technical organization, the head or the manager should be a highly qualified and experienced hydrotechnical engineer and not a professional politician.



THE ROLE OF WMO IN THE DEVELOPMENT OF HYDROLOGY AND HYDROMETEOROLOGY IN AFRICA

By the Secretariat of the World Meteorological Organization

ABSTRACT

The paper falls into three main parts. Firstly, the role and responsibilities of WMO in hydrology and hydrometeorology are described in general, including the definition of "operational hydrology". Relevant WMO programmes and activities, particularly those which concern Africa, are discussed. The second part of the paper treats in detail the technical guidance and the material published by WMO on hydrological and hydrometeorological networks and instrumentation, data processing, data analysis for design purposes, and hydrological forecasting. Finally, the implications of the WMO World Weather Watch Programme are outlined. The WMO Programme of Technical Co-operation in Africa is discussed in a separate paper.

RESUME

La présente communication se divise en trois parties principales. La première décrit en termes généraux le rôle et les responsabilités de l'OMM dans le domaine de l'hydrologie et de l'hydrométéorologie et comprend la définition de l'expression "hydrologie opérationnelle". Elle passe en revue les divers programmes et activités de l'OMM, en particulier ceux qui concernent l'Afrique. La deuxième partie traite en détail des directives techniques et de la documentation publiées par l'OMM sur les réseaux et les instruments hydrologiques et hydrométéorologiques, le traitement des données, l'analyse des données pour l'étude et la conception de projets, et la prévision hydrologique. Enfin on trouvera un exposé des incidences du Programme de la Veille météorologique mondiale de l'OMM. Le Programme de Coopération technique de l'OMM en Afrique fait l'objet d'un autre communication.

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INTRODUCTION

International co-operation in meteorology and among meteorological services is an absolute necessity, especially in view of the development of global systems such as the World Weather Watch (WWW) and the Global Atmospheric Research Programme (GARP).

The need for international co-operation in hydrology, although perhaps not as great as that involved in meteorology, is universally recognized for the more efficient development and management of water resources, particularly in the developing countries. In view of the fact that the World Meteorological Organization's operational activities in meteorology are in many respects

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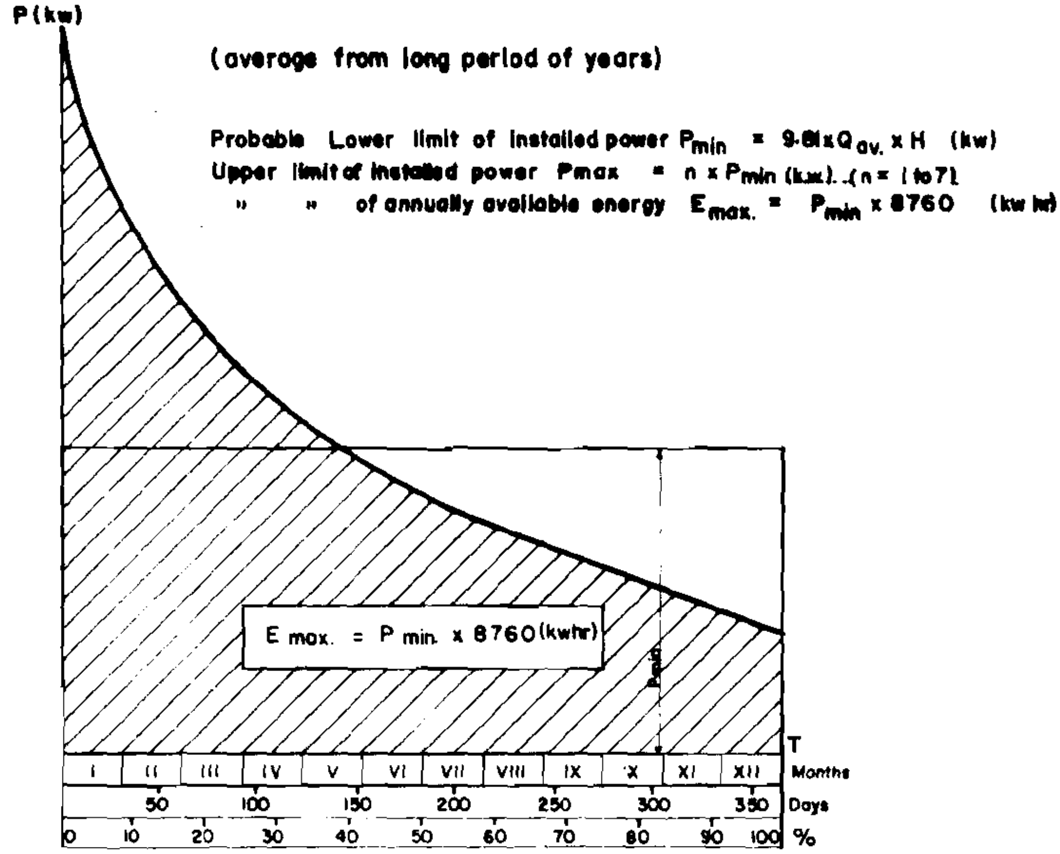
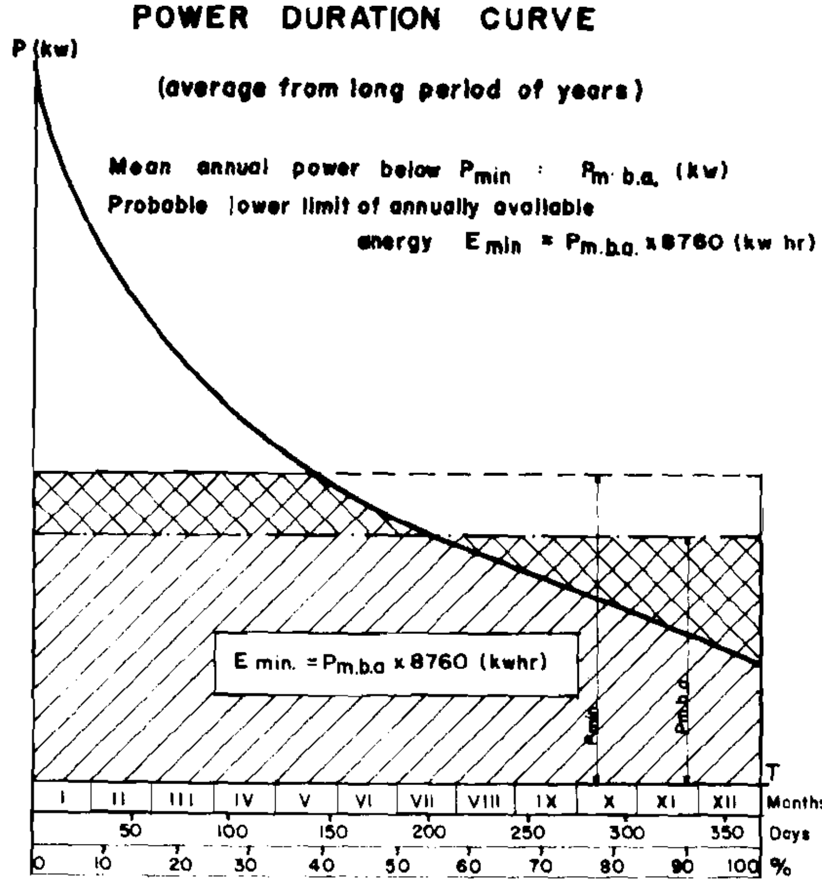


POWER DURATION CURVE



similar to the international activities required in the field of operational hydrology, WMO has accepted responsibility for giving guidance and organizing international co-operation in this field, mainly through its Commission for Hydrology. Such co-operation is necessary for promoting exchange of information and data for the benefit of developing countries which cannot afford or are for other reasons unable to indulge in expensive hydrological research projects. This paper reviews WMO's role and responsibility in international co-operation concerning (a) design and operation of meteorological (hydrometeorological, agrometeorological) and hydrological (surface-water) networks, (b) basic data processing, co-ordination of acquisition (networks) and of services, and (c) analysis for computation of surface-water design data for operational use in projects.

OPERATIONAL HYDROLOGY

In addition to its primary responsibilities in the field of meteorology, WMO is concerned with those aspects of hydrology and hydrometeorology which have been termed as "operational hydrology".

The field of operational hydrology, as defined by the WMO Technical Conference of Hydrological and Meteorological Services (Geneva, September-October 1970)(51), and approved by the Sixth WMO Congress (April 1971), comprises:

(a) Measurement of basic hydrological elements from networks of meteorological and hydrological stations; and collection, transmission, processing, storage, retrieval and publication of basic hydrological data;

(b) Hydrological forecasting;

(c) Research on and development and improvement of methods, procedures and techniques in:

  (i) Network design;

  (ii) Specification of instruments;

  (iii) Standardization of instruments and methods of observation;

  (iv) Data transmission and processing;

  (v) Supply of meteorological and hydrological data for design purposes;

  (vi) Hydrological forecasting.

The above activities are usually performed on a day-to-day basis by national Hydrological Services or appropriate equivalent organizations.

In promoting international co-operation in operational hydrology, as defined above, WMO deals with the following elements (with particular reference to surface water):

(a) Precipitation;

(b) Snow cover;

(c) Evaporation from lakes, river basins and reservoirs;

(d) Temperature and ice régime of rivers, lakes and reservoirs;

(e) Water level of rivers, lakes, reservoirs and estuaries;

(f) Water discharge of rivers;

(g) Sediment discharge of rivers;

(h) Soil moisture and depth of soil frost;

(i) Quality of water;

(j) Groundwater.

WMO PROGRAMME IN OPERATIONAL HYDROLOGY

The strengthening of the WMO programme in operational hydrology was discussed by the above-mentioned WMO Technical Conference of Hydrological and Meteorological Services. The conference considered the manner in which the WMO Technical Regulations(37) should be supplemented to include the present responsibilities of WMO in the field of hydrology so as to best serve the needs of both meteorological and hydrological services. A large majority of the participants, particularly delegations of developing countries, expressed the need for Technical Regulations in the field of hydrology. On the recommendation of the Conference, the revised draft chapter on Technical Regulations was adopted by the Sixth Congress of WMO (April 1971) under the title "Technical Regulations in Operational Hydrology". These regulations will, apart from their technical aspects, facilitate the creation and improvement of hydrological networks, co-operation in international river basins, promotion and achievement of conformity in international exchange of hydrological data, and assistance in the establishment and expansion of national Hydrological Services, particularly in developing countries.

The conference also gave consideration to the ways in which the WMO programme of World Weather Watch can be planned and developed to be of maximum benefit to Hydrological Services of Members, particularly in the field of hydrological forecasting; and to the ways in which WMO should strengthen its efforts in carrying out its present responsibilities in the field of hydrology. It confirmed that WMO had fully proved its ability to contribute to the science and application of hydrology and that it is the appropriate international agency for co-ordinating the activities in operational hydrology according to government requirements. Accordingly the Sixth Congress of WMO (April 1971) has formally approved that WMO should undertake the responsibilities in the field of operational hydrology.

WMO ACTIVITIES IN METEOROLOGY RELEVANT TO HYDROLOGY AND HYDROMETEOROLOGY

The technical and scientific activities of WMO fall into four programmes: World Weather Watch, the WMO Research Programme, the WMO Programme on the Interaction of Man and His Environment, and the WMO Technical Co-operation Programme.

The implementation of the Technical Co-operation Programme in Africa is being described in detail in another paper being presented to this conference, and World Weather Watch is described in section 10 of this paper. The first three programmes are being carried out mainly through the activities of the eight Technical Commissions of WMO. In addition to the Commission for Hydrology, at least three other Commissions make substantial contributions to the development of hydrology and hydrometeorology. The work of the Commission for Agricultural Meteorology, for example, includes the study of questions relating to the observation, measurement, evaluation and suitable presentation of single and complex factors of weather and climate as they affect soils, plants and animals; combating unfavourable influences of weather and climate on agriculture; and the use of weather forecasts and warnings for agricultural purposes. The Commission for Special Applications of Meteorology and Climatology deals inter alia with the application of climatological data to man, his comforts and his activities which include the needs of hydrology and water resources development. It is guiding work on the production of regional climatic maps with the ultimate aim of compiling a World Climatic Atlas which will also include hydrological maps. Similarly, the Commission for Instruments and Methods of Observation is actively occupied in promoting development, improvement, international comparison and standardization of instruments and methods of observation.

Very close collaboration amongst the Technical Commissions is maintained in common fields of activity.

ROLE OF THE REGIONAL ASSOCIATION FOR AFRICA

All WMO programmes are co-ordinated at the regional level by its six Regional Associations. The WMO Members in Africa are grouped to form Regional Association I (Africa) which, like the other Regional Associations, meets regularly to examine and plan co-ordination of activities in the Region in pursuance of the resolutions of the Congress and the Executive Committee. The idea of holding this particular conference was proposed by this Association in 1969.[43] The Association has established a Working Group on Hydrometeorology which studies and advises the Association on matters referred to it and assists in the implementation of action required in co-operation with the UN Economic Commission for Africa (ECA). Matters considered by the working group include hydrological and hydrometeorological networks, use of meteorological data and forecasts for hydrological purposes, and preparation of hydrometeorological maps.

A very important role has been attached to the Regional Association and its Working Group on Hydrometeorology in the approved programme for the strengthening of WMO efforts in the field of operational hydrology. In addition to having representatives of Hydrological Services included in the delegation of Members to the Congress and in the Commission for Hydrology the Congress has established an "Advisory Committee for Operational Hydrology". This Committee would be composed of directors of Hydrological Services or national representatives of agencies responsible for hydrological services. For this Committee to be fully effective it has been decided that a procedure for co-operation among national Hydrological Services be developed within the framework of WMO Regional Associations, in order to provide liaison of the Committee with national Hydrological Services.

Such regional co-operation should also lead to improved lines of communication for technical assistance programmes, thus greatly benefiting countries in Africa, and to a more satisfactory treatment of regional water resources problems. Co-operation in this respect would be strengthened and close co-ordination ensured with the relevant activities of ECA and bodies responsible for operational hydrology in international basins.

GUIDANCE BY WMO IN OPERATIONAL HYDROLOGY

WMO's interest and activities in the establishment and improvement of hydrological and hydrometeorological networks in Africa can be traced over many years. The first comprehensive report on networks and hydrological data in Africa, however, was prepared jointly by WMO and ECA, and published in 1966[28], followed by a joint Seminar on Hydrometeorological Instruments, Observations and Networks in Africa (1967)[29]. In the light of the results of these activities the two organizations undertook practical steps to provide guidance and assistance to develop hydrological and hydrometeorological networks according to the requirements of individual countries and to prepare a master plan for the development of such networks in Africa. WMO has seconded to the ECA Secretariat an expert hydrometeorologist to assist in carrying out this programme.

Recognition of economic importance of hydrological data for all water resources development projects in particular, and for national economies in general, has led many countries in Africa to embark on extensive programmes for the improvement of the collection and handling of data. Besides actually executing a number of national and international technical assistance projects for establishing comprehensive hydrological and hydrometeorological networks, e.g. the Hydrometeorological Survey of Catchments of Lakes Victoria, Kioga and Albert, which are described in more detail in another paper presented to this conference, WMO provides technical advice and guidance in different forms to most countries.

Most of the technical guidance stems from the activities of WMO's Commission for Hydrology under which eight working groups and nine rapporteurs are currently engaged on studies concerning a wide range of subjects in operational hydrology. These topics include: Guide[1] and Technical Regulations[37], instruments and methods of observation, hydrological aspects of World Weather Watch, machine processing of hydrometeorological data, hydrological forecasting, hydrological design data for water resources projects, network design, training in hydrology, maximum floods, terminology, and maps and mapping techniques in hydrology.[24]

Nearly all of these topics are related to the collection and analysis of hydrological data for design purposes. The results of the Commission's work are made available through a number of publications of which the WMO Guide to Hydrometeorological Practices[1] in particular has achieved universal recognition.

Of all the WMO publications in this field, this Guide has become an internationally recognized standard reference book for all operational Hydrological Services. In addition, the WMO "Guide to Instrument and Observing Practices"(35) and the "Guide to Climatological Practices"(36) include material closely related to hydrology and hydrometeorology. All of these Guides are a step towards standardization.

Numerous scientific papers are published each year dealing with hydrology and hydrometeorology, and it is very difficult for practising hydrologists to take account of all of them when establishing and operating a network. The "Guide to Hydrometeorological Practices" provides clearly, precisely and in a convenient form information about practices, procedures and instrumentation for the successful implementation of their work. It discusses the functions and organization of Hydrological and Hydrometeorological Services and the importance of their co-operation with Meteorological Services. It provides guidance and basic information on processing of hydrological data and quality control, preliminary analysis and publication of observations on a regular basis, as well as practical methods for hydrological analysis for design purposes, and applications to water management.

Members of WMO are invited to follow or implement the practices, procedures and specifications recommended in the Guide in the operation of their Hydrological or Hydrometeorological Services.

Under the supervision of the Commission, eminent scientists and technical experts continually work to improve, extend and keep the Guide up to date. New material, suggestions and comments are received from other WMO bodies as well as from various research and scientific institutions from all over the world. Work has already commenced on a complete revision for a new edition of the Guide.

NETWORKS AND INSTRUMENTATION

(a) <u>Networks</u>

Measurement of basic hydrological elements from networks of meteorological and hydrological stations is the primary element of operational hydrology. The establishment of basic hydrological networks and the improvement of existing networks in order to provide the fundamental data needed for water resources development are therefore two of the major objectives of WMO. In fact, WMO has undertaken the responsibility for the subject of network design within the IHD programme.

There are inadequacies in both length of record and number and distribution of instruments in hydrological networks, especially in the developing countries of Africa. It is realized that many factors such as population density, economic activity, climate etc. influence the density of networks. However, an energy consumption per capita index appears to contain an element of most of these factors including that of development of water resources. When an energy consumption per capita index is plotted against the density of rainfall stations for each country (Figure 1), the relative position of countries in Africa is clearly revealed. An arbitrary grouping places Africa at the bottom, Asia and Latin America in the middle and Europe at the top.

Very generalized guidelines on network design are given in the WMO Guide to Hydrometeorological Practices. At this stage, however, it is extremely difficult to demonstrate the value of scientific design in defining and classifying hydrological networks or even to establish clear and concise objectives. Methods of network design(4) apply the concepts of regionalization, mapping and system analysis, but the most sound design criteria are economic ones, and these cannot be employed because there are no relevant economic data from networks. The nature and scope of these problems, the difficulties facing the developing countries and the problems of fixing a money value to the benefits accruing from scientifically designed networks are highlighted in a WMO report entitled "Hydrological Network Design - Needs, Problems and Approaches"(23) which was contributed to the IHD programme.

WMO is at present preparing a casebook of examples of networks, together with explanatory notes on objectives and principles applied. The examples are being selected from various geographic and climatic zones in countries in different stages of water resources development. Such a casebook should prove very useful and practical for most developing countries. The casebook has been divided into five main sections, as follows:

Section A. Characteristics of hydrological elements that relate to network design;

Section B. Examples of techniques of network design;

Section C. Examples of operating networks;

Section D. Networks in problem areas;

Section E. Future developments in network design and operation.

(b) Instruments

It must be borne in mind that a network can be no better than the instruments of which it is composed. In 1966 WMO published a Technical Note on "Instruments and measurements in hydrometeorology"(7) which describes new developments in the field of hydrological instruments and methods of observation. Taking into account the latest developments in this field and considering the problems of comparison and standardization of instruments and methods of observation, WMO is conducting special studies for the benefit of Members through its Commission for Instruments and Methods of Observation(25) as well as through two working groups of the Commission for Hydrology.

Information collected from nearly all countries on the proven reliability of various hydrological and hydrometeorological instruments has been analysed and is being incorporated in a Technical Note which will also include up-to-date information on available automatic equipment for observing and transmitting hydrological and hydrometeorological elements.

In view of the fact that there are serious problems concerning the accurate measurement of precipitation, WMO is implementing a project for an international comparison of all types of precipitation gauges with a standard reference gauge of "pit" type.

In 1966 WMO published a Technical Note(5) which contains a comprehensive review of the evaporation instruments used in many countries of the world, international comparisons made among them, and the many different methods at present in use for deriving evaporation losses. Further critical study of the subject was made and a report containing useful guidance has recently been published(41).

WMO publications providing detailed guidance on specific methods and instruments for measurement of different hydrological elements are listed in the bibliography. The implications of the WWW Global Observing Station (GOS) on observational networks are discussed in section 10(a).

DATA PROCESSING

Data processing involves a systematic procedure through which basic information is transposed into more accessible and more directly usable forms. It comprises collecting, editing, organizing, storing and retrieving data for various practical uses. Manual data-processing methods still satisfy the simple requirements of small collections. But an immense amount of hydrometeorological data has accumulated over the years and the rapidly increasing rate of production of such data makes it necessary to introduce various degrees of automation, ranging from small-scale punch-card machines to large electronic computing systems, in order to satisfy the ever-growing demand for information and the accelerating development of observing techniques.

The rational planning of activities related to the development of water resources requires facilities for the analysis of past hydrometeorological data in all possible scales of time and space. These data must be safely stored for long periods and in forms suitable for quick, effective and economic retrieval and analysis.

Aware of the lack of suitable detailed guidance material on processing of hydrological and hydrometeorological data, and bearing in mind that future development of operational and also scientific hydrology depends, to a large extent, on the utilization of data-processing systems, the WMO Working Group on Machine Processing of Hydrometeorological Data prepared a comprehensive Technical Note(11) on this subject.

The Technical Note is an assessment of the present state of the development and practice of collection, editing and conversion of data; of information storage and retrieval; and of the publication and analysis of hydrometeorological data by machine methods. The advantages and drawbacks of the different data-processing machines and methods are described in relation to their application in countries at various stages of development.

The publication concentrates on the processing of data concerning the main elements of the hydrological cycle, precipitation and streamflow in particular. However, references are also made to other elements of the cycle, such as the meteorological data needed for hydrometeorological studies, groundwater levels, soil moisture, sediment transport and water quality.

In order to illustrate the principles involved, an annex has been prepared which contains a practical example of hydrometeorological data processing, ranging from data collection to their publication. The implications of the WWW Global Data-Processing System (GDPS) for hydrological data processing are discussed later (see section 10(b)).

DATA ANALYSIS FOR DESIGN PURPOSES

Without an adequate supply of necessary data of sufficient accuracy, design calculations cannot be carried out. Raw hydrological and hydrometeorological data are studied in order to ascertain whether they fulfil the requirements and are then shaped by analytical techniques into forms suitable for application to the design of water resources projects. Some of these techniques can be used to estimate missing data, to generate synthetic sequences and to derive estimates for ungauged areas. In this regard meteorological data can be of great importance in complementing or replacing hydrological information.

A major portion of the analytical work required in designing river works is devoted to the specification of the design flood or floods. This can often involve the use of such techniques as depth-area-duration analysis, the estimation of probable maximum precipitation and the application of one of the many rainfall-runoff models that have been developed. Recently WMO published a "Manual for Depth-Area-Duration Analysis of Storm Precipitation".(3) The first part of the manual describes depth-area-duration analysis by standard methods and the second part describes an experiment in depth-area-duration analysis by computer. Similar manuals on rainfall frequency analysis and on probable maximum precipitation are under preparation.

The design flood can be estimated from a flood-frequency analysis if the necessary streamflow data are available. A WMO working group recently prepared a Technical Note on "Estimation of Maximum Floods."(8), the preparation of which was an exercise in international collaboration because examples of computations were sought from as many different countries of the world as possible. The Note describes methods used in different countries of the world (including some in Africa) for estimating the extremes of rainfall and snowmelt on the basis of physical analysis, and methods of converting these into estimates of extreme flows. It treats statistical methods and their application to storm and flood events and outlines techniques used in flood-frequency analysis and the use of meteorological data in flood-frequency estimation.

An earlier Technical Note on "Measurement of Peak Discharge by Indirect Methods"(6) details the procedures involved in applying hydraulic theory to the post facto measurement of peak flood discharge in streams. Most of the WMO projects on design data are related to the activities of its Working Group on Hydrological Design Data for Water Resources Projects. Among other tasks, the group has to examine all material published or prepared by WMO bodies and containing guidance material on selection of hydrometeorological series in specific cases, statistical analyses of hydrometeorological variables, correlation methods for hydrometeorological variables, synthesis of hydrometric data, depth-area-duration analyses, design flood studies, flood-frequency analyses, flood-routeing procedures, utilization of flood forecasting techniques for design.

In many parts of Africa, inadequacy of direct observations of data is a major problem for planning and designing water resources projects in those areas. However, indirect methods using rainfall and other hydrometeorological data have been devised to improvise design data for such areas. The use of index (experimental, representative) catchments also plays an important role in this respect. Guidance material on this subject is being prepared by the WMO Working Group on Representative and Experimental Basins.

The WMO publication on evaporation, mentioned in the previous section, also contains guidance for assessing potential and actual evaporation on an areal basis. In addition, a report on the comparison between pan and lake evaporation is to be published shortly.

Associated with the problems of evaporation assessment is the question of soil-moisture estimation on an areal basis. A report(39) on this subject has recently been published by WMO.

Hydrological forecasting

The analysis of past streamflow and precipitation data is used as a guide to the floods that can be expected to occur on a river in the future, and provided these data are of a reasonable standard they provide the most important guide for use in designing any training or regulating works. Nevertheless, if these works contain any elements that can be operated and are not fixed, such as sluice gates, the characteristics of their operation and the operating policy to be followed will have a great influence on the efficiency of the whole project. Such factors should therefore be taken into consideration at the design stage, and may legitimately be considered as design data. They will include details on the ability of the operating agency to forecast accurately the characteristics of future floods some time in advance. The higher the standard of such forecasts, the lower the capital cost necessary to protect surrounding areas from the effects of flooding.

A symposium on this subject was organized by WMO jointly with Unesco and the Federal Government of Australia in 1967, and the proceedings have since been published.(26) A large number of the papers deal with the use of mathematical models in forecasting floods, using either hydrometeorological or purely hydrological data as input. This was a reflection of the importance of such models in forecasting and WMO is now engaged in further studies on the subject and has started an international programme of intercomparison of hydrological models.

The design of a hydrological forecasting service must include a detailed account of the data and forecasts required and suggest how they can best be obtained. Successful operation could depend very much on the degree of sophistication of the local meteorological agency and on the extent to which it is prepared to co-operate in setting up and operating the service.

In the past, the urgent need for rapid methods of converting meteorological data into hydrological forecasts had led to the widespread use of very simple forecasting techniques. These are usually based on the correlation that exists between rainfall amount and river stage. No attempt is made in such methods to simulate the physical characteristics or response of the actual catchment, and for this reason they suffer greatly from a lack of generality and are notoriously unreliable for the prediction of extreme events. The perfection of computers, both digital and analogue, has now made it possible to attempt a simulation of the actual behaviour of the catchment. This requires the use of a conceptual model, designed to simulate the mechanisms involved in converting rainfall to runoff. WMO has taken a leading role in the formulation and dissemination of hydrometeorological forecasting procedures, and is at present investigating the application of conceptual models in operational hydrological forecasting.

Some of the forecasting systems are extremely complex, and would require a very large capital investment if they were to be made operational. The question arises as to whether an investment in a forecasting service is economically justifiable in general, and in particular with respect to the alternative forecasting systems that may be available.

A state-of-the-art report on this subject has been prepared by a consultant of WMO. It was noted that, as many nations progress towards a more formal process of planning river basin development, the economics of each segment of the programme become important. Three factors are particularly important with regard to a flood-damage reduction programme, quite apart from the engineering works or the magnitude of the flood. These are: the length of warning time, magnitude of reducible damage, and efficiency of response to warning. In theory, by considering the influence of such factors on flood damage, one can arrive at an estimate of the benefit produced by each, and thereby permit decisions to be taken with regard to the whole flood-prevention scheme on economic grounds. However, such an anylysis requires a considerable quantity of information, not only on the topographic, hydrological climatic and hydraulic nature of the river basin, but also on its social and economic characteristics, including the organization and forecasting capability of the agency responsible for flood protection. In practice it is very difficult to make accurate overall cost/benefit assessments. One has therefore to be extremely cautious about the cost/benefit situation before embarking on an expensive and complex project of instituting a hydrological forecasting system on any river basin.

Implications of WWW for hydrological forecasting are treated in the next section.

WMO is also carrying out studies on the incidence and spread of drought, which are a serious handicap to development.[13] The main aim is to assess droughts with respect to their effects and to find practical methods of forecasting droughts for medium and long-range periods in order to help in planning and designing water projects which would in turn prevent serious water and flood hazards.

IMPLICATIONS OF WMO WORLD WEATHER WATCH PROGRAMME

The previous three sections on networks, data processing and hydrological forecasting have special significance and are integrated within the hydrological aspects of the WMO programme of World Weather Watch (WWW).[15][52] This programme involves the development of a world weather system which will ensure that modern scientific and technological advances, such as artificial satellites and electronic computers, are utilized to the maximum to improve our knowledge of atmospheric processes, and that the benefits of the system are made available to all countries. The WWW, by its very nature, contains elements of direct interest and use to hydrology and water resources development even in the developing countries in spite of difficult conditions particularly of an economic nature.

There are three main elements of WWW which have a direct bearing on our subject and are discussed below.

(a) Global Observing System (GOS): The major component of this system is the setting up of adequate basic meteorological networks on the Earth and the use of aircraft and meteorological satellites in order to obtain more reliable and accurate data. The Regional Association for Africa has set up targets to meet these requirements through the co-operation of individual countries. Members are encouraged to use automatic stations, especially in problem areas, including at least one Automatic Picture Transmission (APT) station and ground weather-radar stations. The integration of hydrological and hydrometeorological stations would considerably increase the accuracy of hydrological analysis, particularly for hydrological forecasting purposes. Judicious design of networks equipped with suitable instruments compatible with GOS should therefore be given special attention now in order to save valuable time and expense in the future.

(b) Global Data-processing System (GDPS): The Global Data-processing System[54] operates through a system of World, Regional and National Meteorological Centres, which collect, prepare and make available to Members processed meteorological information on a global or regional scale. GDPS could also ensure the processing of data for climatological and, at a later stage, for hydrological purposes, as well as the storage of data in such a way that they would be readily available.

In view of the fact that many national and even sub-national enterprises have accumulated hydrological and hydrometeorological data, often from an extremely dense network of stations, a WMO Executive Committee Panel on the Collection, Storage and Retrieval of Data recently examined in detail the facilities and organization of the GDPS in order to help the hydrological activities of Members, particularly on regional and national scales. Most probably the hydrological data developed from the GOS and the GDPS will be archived within the WMO system. A preliminary list has been proposed of the following types of hydrological data for inclusion in the system:[55]

(i) Data for the study of water and energy budgets (i.e. streamflow, evaporation, etc.);

(ii) Remote-sensed data related, among other things, to hydrology;

(iii) Snow and ice data on a regional scale;

(iv) Soil temperature and humidity, and air-trajectory information.

(c) Global Telecommunication System (GTS): This system[53] is capable of collecting and distributing raw observational data through National, Regional and World Meteorological Centres and, subsequently of distributing the resulting processed information to other WMCs, RMCs, and NMCs. GTS will make available pictorial and numerical data that have been obtained by remote sensing techniques, covering large areas of the Earth. The analyses and application of these data for hydrological and water resources purposes will permit higher accuracy, greater speed and better co-ordination of both short- and long-term hydrological forecasts, in addition to the benefits that will accrue through their use for hydrological research purposes.

Application of the essential elements and objectives of WWW to operational hydrology, however, requires close co-operation between Hydrological and Meteorological Services at national, sub-regional, regional and world-wide levels in a number of technical aspects of the three systems. It also requires uniform codes for the exchange of data, and research. WMO has already initiated action to promote these activities.

As its name implies, the WWW is designed to be operated on a global scale. Its value for the acquisition and transmission of data for use in the design and operation of river-regulating works will therefore be greatest with regard to very large catchments. In particular, the establishment of efficient international links for the transmission of data will greatly improve the rational development of international river basins, including the regulation of their rivers and flood plains.

CONCLUSION

In addition to its general programmes and the Programme of Technical Co-operation, WMO has an important role in Africa in many specific hydrological aspects in addition to its paramount role in meteorology. With the long-standing close and effective co-operation between WMO and ECA steps are being taken to satisfy the urgent need for the establishment of adequate hydrological and hydrometeorological networks in Africa. On the basis of the analysis and evaluation of the deficiencies of networks on a national and regional basis, a master plan is to be drawn up to assist governments in organizing and expanding their operational hydrological services and in formulating technical assistance programmes for conducting systematic hydrological and hydrometeorological surveys of river basins. Such surveys are essential for further development and rational use of national water resources which form an essential factor for socio-economic progress.

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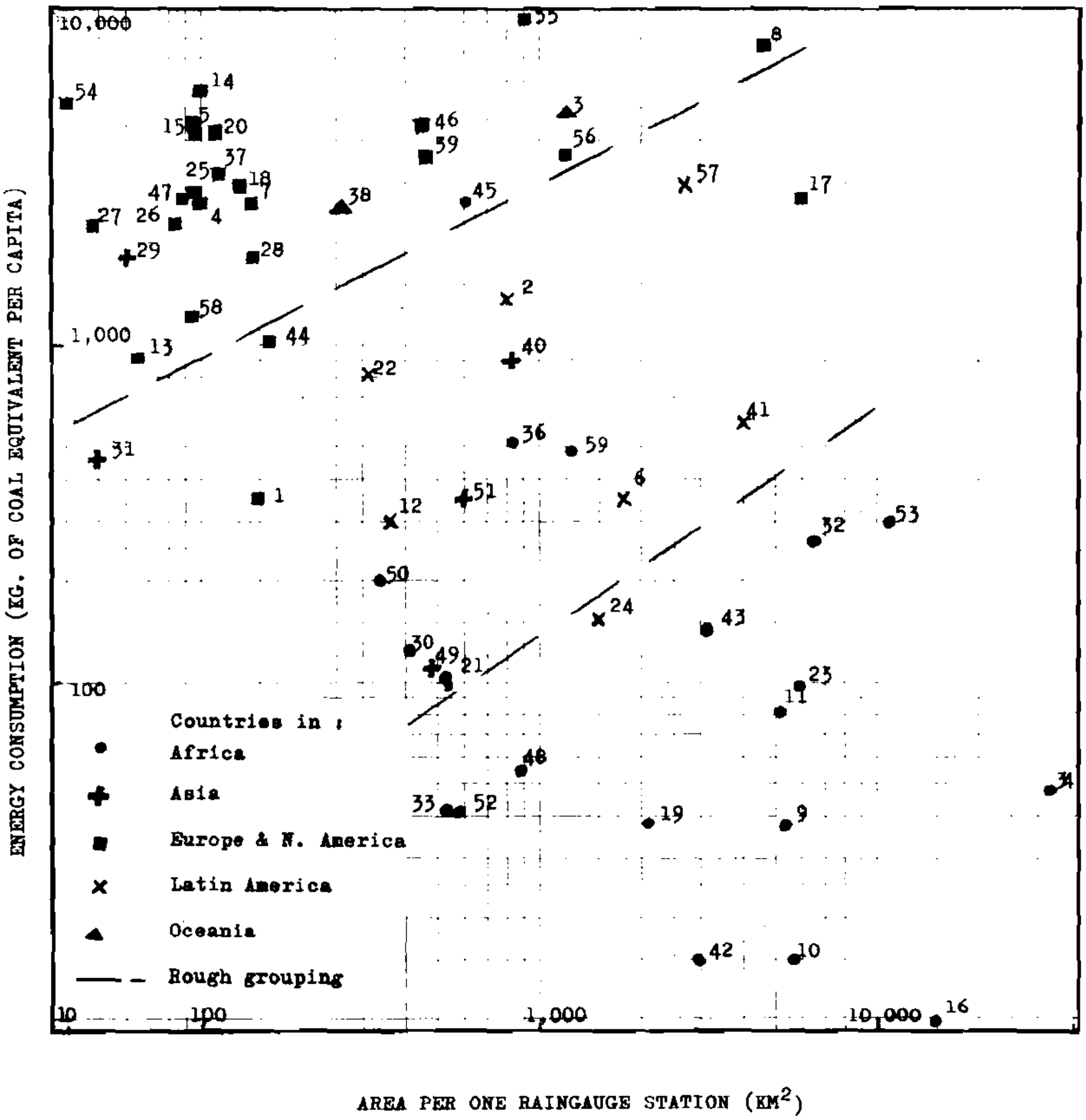

FIG. 1. Density of raingauge network related to an economic index.

Countries: 1 Albania 2 Argentina 3 Australia 4 Austria
5 Belgium 6 Brazil 7 Bulgaria 8 Canada 9 Central
African Republic 10 Chad 11 Congo (D.R.)
12 Costa Rica 13 Cyprus 14 Czechoslovakia
15 Denmark 16 Ethiopia 17 Finland 18 France
19 Gambia 20 Germany (F.R.) 21 Ghana 22 Guatemala
23 Guinea 24 Honduras 25 Hungary 26 Ireland
27 Isreal 28 Italy 29 Japan 30 Kenya 31 Korea
32 Liberia 33 Malawi 34 Mauritania 35 (not shown) 36 Morocco
37 Netherlands 38 New Zealand 39 Norway
40 Pakistan 41 Peru 42 Rwanda 43 Senegal
44 Spain 45 South Africa 46 Sweden 47 Switzerland
48 Tanzania 49 Thailand 50 Tunisia 51 Turkey
52 Uganda 53 U.A.R. 54 United Kingdom 55 U.S.A.
56 U.S.S.R. 57 Venezuela 58 Yugoslavia 59 Zambia

HYDROLOGICAL AND HYDROMETEOROLOGICAL DATA AS ESSENTIAL PARAMETERS FOR DESIGN OF ECONOMIC DEVELOPMENT PROJECTS

By Richard D.A. Hill

ABSTRACT

This paper describes the operation and problems confronted in the hydrological and meteorological programme in the Republic of Liberia.

RESUME

Le présent mémoire contient un exposé sur les opérations et les problèmes que doit confronter le programme hydrologique et météorologique au Libéria.

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In the Division of Meteorology-Hydrology of the Department of Public Works, the Government of Liberia controls and is regarded as the central agency for the establishment of hydrological and hydrometeorological stations and also for the compilation of data. However, it can be well noted that the first rainfall station and the first river gauging station were established by two private agencies. These early stations have contributed largely to the development of hydrology and hydrometeorology in Liberia. At present, considering all stations in operation (government, concessions and missions), there are approximately 40 rainfall stations in existence in Liberia, resulting in approximately one station per 1075 square miles. However because of inaccessibility only about 50 per cent of these are producing continuous records. There exist 25 river gauging stations and 75 per cent of these are in good operation. Each of the nine counties into which Liberia is divided has some hydrological and hydrometeorological stations operating on a daily basis.

In order to collect systematic and unbroken records adequate and continuing financing is all important. Many of the established stations in Liberia are facing great difficulties in surviving. The Government agency does not have sufficient available funds for the accomplishment of the great amount of work required in connection with the nationwide collection of hydrological and hydrometeorological data or with the necessary knowledge of local and regional needs related to these data to enable it to act satisfactorily alone. Pooling of funds, information and effort therefore is very important to accomplish this work, but there has not been agencies other than the Government to co-operate until a few years ago. This has affected the progress of hydrology and hydrometeorology considerably. However, with the records obtained from our establishment in Liberia, other places have also benefited.

Previously agriculture was practised on a seasonal basis. The planting was done in the rainy season or winter because at this time the ground is always wet or moist with a moderate temperature suitable for the growth of plants. There was not much planting done in the summer because it was felt to be a waste of time. Today, through the aid of data collected from hydrological and hydrometeorological observations, agriculture is carried on throughout the year by irrigation. No extensive research is being conducted with regard to the quality of water used for the purpose of irrigation.

The water in the streams of Liberia has been found to be good enough for crops and it does not contain harmful chemicals that would retard the growth of vegetation except for low areas very close to the coast. However, because of the long dry season, it is necessary to have sufficient data to assure a continuous flow of the stream used for irrigation during this period.

The dry season lasts for about four months beginning in December and ending in April, and is a time of high temperatures and intensive sunshine. The Liberian rivers and smaller streams form such a network that there is almost no need for investigation regarding the water quantity and quality for inland fisheries, wild life, tourism and recreation, etc., at present. The man-made lakes in this country are usually made by expanding certain points of small streams which generally flow throughout or for most part of the year; hence there is very little danger of these lakes running dry in the summer when the rate of evaporation is high.

In referring to data need for hydro-power projects in particular for design capacity of plants and availability of storage, it must be noted that Liberia's prime objectives in the entire programme of water resources are water supply and hydroelectric development. Much can be said on this point but it is my desire to give a brief and clear view of this phase of hydrology and hydrometeorology as conducted in Liberia. To begin with, I wish to stress on the establishment and operation of gauging stations as carried on in Liberia.

The early set of gauges installed on the large rivers of the country were chiefly for the development of hydroelectric power plants. Later, other gauges were installed for study of water supply and in some instances for irrigation. Staff gauges were used initially at all gauging sites. They were selected because they could be made locally and were simple to install. The earliest installations were made using two inch galvanized pipe for backing to which were attached aluminium strips marked with feet and tenths of a foot. Later installations were made using steel channels for backing and standard five feet lengths of porcelain enamel gauge. On bridges they were attached vertically to piers. At other locations one gauge was installed sloping up the river bank while the other gauge was installed vertically on top of the river bank. A table was made to convert the sloping gauge height to vertical gauge height. As the programme progressed wire weight gauges were used to supplement staff gauges at bridge sites.

Attempts were made to locate all gauges at sites where the physical chacacteristics of the channel were favourable for accurate discharge measurements and when the relationship between stage and discharge would be permanent. Unfortunately, this was not always possible because of the inaccessibility of the major portion of Liberia. For this reason most of the gauging sites were selected primarily because they were accessible. Consequently their channel characteristics were not always as favourable as they should have been for a precise determination of discharge.

The operation of gauging stations involves four principal objectives: (1) the collection of systematic records of stage; (2) measuring dischage for the development of a station stage-discharge rating curve; (3) periodically instructing the local observer regarding his duties, giving special attention to his success or failure in understanding and performing those duties; and (4) maintaining in proper condition the installations and equipment. The statement of objectives is simple, but there are many difficulties in attaining them. The continuous or periodic records of stage and discharge must at least theoretically be equally reliable for all stages of the stream, for all conditions of flow, and for all changes in the stage-discharge relation.

Change in the stage-discharge relation may be due to a variety of conditions, including shifting controls and variations in the cross section of the channel caused by shifting bed and banks. This is very usual in Liberia because of the sudden rise of the river stage as a result of high intensity of precipitation. Temporary and seasonal changes may be caused by the accumulation of drift, the jamming of logs and up-rooted trees of the high forests or by aquatic vegetation in the channel.

Added to the difficulties related to the physical conditions at and near the gauging station are problems related to travel and transportation, human inefficiencies, lapses, and errors, faulty operation of instruments and wild sudden variation in temperature, precipitation and wind, with corresponding sudden fluctuations in stage and discharge. The difficulties vary at all times at different gauging stations.

To measure stream flow the Price current meter has been used in all areas of the country and they have been found to be quite appropriate.

Two major projects which elaborate the practical application of data collected from streams have been constructed within the past five years. These are the 22,000 kw hydroelectric power plant (costing approximately twenty-seven million dollars) and a water filtration plant with a capacity of about eight million gallons per day (costing about seven million dollars). Both of these projects are located on the St. Paul River, about 15 and 12 miles respectively from the Atlantic Ocean. This is the largest river that lies within Liberia and has a drainage area of about 8,360 sq. mi. with an average annual stream flow of about 13,464,000 acre-feet.

Because of the rapid development of Liberia, within two years after the completion of the hydroelectric plant it was discovered that electric power was in great demand and it became necessary to make additional surveys for expansion. This preliminary suvey revealed that two of the major tributaries of the St. Paul River were capable of being used as storage reservoir and therefore could facilitate expansion that could be equal to the present power output. The two locations are very inaccessible, yet they are the only solution thus far to our power expansion.

Because of the urgency of the power requirement, only six year period of data was used and this was all that was available at that time. Considering these aspects, it is very apparent that long-term hydrological and hydrometeorological data are of prime necessity for a better use of water resources. Liberia has not experienced severe floods as have other parts of the world; therefore very little attention has been given to flood control. Studies are conducted however for highway designs and constructions. There are several sizable rivers in Liberia, but most of them do not provide more than 10 miles of navigation. Hence, except for sporting and fishing, there is very little inland water transportation.

Since some amount of water is necessary for any development, knowledge of the availability of an adequate supply is essential for local or regional planning purposes. Without such knowledge, a project which involves the use of considerable quantities of water cannot be properly evaluated. Since such information must cover a sufficient period of time to show the approximate limits of high, low, and average flows, stream gauging on the proposed source or sources of water supply must be carried out continuously for several years before a project can be successfully and honestly promoted.

In Liberia very few studies are being conducted for the purpose of collecting data for urban or rural water supply; however, plans are being made to conduct a survey that will aid in the study of urban and rural water supply, sewage and sanitation design and effects of pollution.

DESIGN AND OPERATION OF A HYDROMETEOROLOGICAL NETWORK IN THE CATCHMENTS OF LAKES VICTORIA, KIOGA AND ALBERT

by Gerald H. Morton

ABSTRACT

This paper reviews the criteria used in establishing a hydrometeorological network for the catchments of Lakes Victoria, Kioga and Albert, and the accuracy the network may be expected to produce. Discussion is also made of the difficulties encountered in the operation of the network, and major deficiencies in the network are discussed.

RESUME

Le présent mémoire contient un exposé sur les critères utilisés pour la mise en place d'un réseau hydrométéorologique dans les bassins versants des lacs Victoria, Kyoga et Albert, et sur la précision que l'on peut attendre des données fournies par ce réseau. Il y est également question des difficultés rencontrées dans l'exploitation du réseau ainsi que des principales lacunes de celui-ci.

OBJECTIVES OF THE PROJECT

The objectives of the Project of the Hydrometeorological Survey of the Catchments of Lakes Victoria, Kioga and Albert are "the collection and analysis of hydrometeorological data of the catchments in order to study the water balance of the Upper Nile. The data collected and the study are expected to assist the countries in the planning of water conservation and development, and to provide the groundwork for intergovernmental co-operation in the storage, regulation and use of the Nile".

ESTABLISHING A NETWORK TO MEET THE OBJECTIVES

In order to achieve a reliable water balance, and to supply adequate data and make preliminary studies for future development of water resources of the Upper Nile Basin, it was necessary to consider the requirements for meteorological and hydrologic networks separately, and then to integrate these considerations in order to achieve a practicable and workable network.

In the design of the meteorological network, the following are some of the major considerations which were taken into account:

(a) Establishing first order meteorological stations: As different areas of the project show considerable variation in rainfall and other meteorological factors it was desirable to sub-divide the area into zones of fairly homogeneous climatic régimes. The project area was divided into twelve zones and the adequacy of existing first order meteorological stations in each zone was analysed in order to ascertain the number and location of additional stations required. The existing network of twenty-nine first order meteorological stations was augmented by an additional twenty-five stations giving an over-all network density of one station per 6,300 square kilometres. The additional twenty-five stations include five stations established on islands in Lake Victoria, and one of these, Nabuyongo Island, is a fully automatic station as it was not possible to place an observer at this site.

(b) Establishing a raingauge network: The establishment of an adequate raingauge network for the project was based on three aspects; firstly, designing the network in the project area as a whole; secondly, in individual sub-catchments to facilitate hydrological studies for the various sub-basins that constitute the project area; and thirdly, in index catchments to facilitate a more intensive study of the rainfall runoff relations for application to other parts of the project area. In the first two cases, the existing network was studied with a view to locating the gaps to be filled in. In examining the network the principal criteria were that 5 per cent relative error represents an ideal network and 10 per cent relative error may have to be acceptable. The project area was divided into 10 minute squares as a density of one station per 10 minute square (or 342 sq. km.) gives a relative error of approximately 5 per cent. It was found that in Kenya each 10 minute square contained more than 10 stations, whereas, in the project area as a whole, approximately 50 per cent of the 10 minute squares did not have any raingauge stations. Therefore, wherever practicable, at least one station was established within a 10 minute square. In many cases, in remote and uninhabited regions, this involved the installation of storage gauges which are read on a monthly basis by project personnel.

For Lake Victoria proper it was not possible to achieve this density, and raingauge stations could only be established on the islands which perimeter the Lake. The additional 150 raingauge stations established by the project increased the number of raingauge stations within the project area to 870 or an average density of one station per 386 square kilometres. The aforementioned figures are exclusive of raingauges established within Index Catchments. The raingauge network within Index Catchments was designed on a basis of one station per 50 square kilometres in order to facilitate the required detailed studies of rainfall runoff relationships.

(c) Establishing a hydrometric network: As the project was divided into different climatic zones for the purpose of augmenting the meteorological network, it was divided into different hydrologic zones for the purpose of reviewing the existing hydrologic network, and identifying and strengthening the gaps. These zones were then analysed on a sub-catchment basis, and including the three lakes there were 35 sub-catchments which were analysed. The following points were taken into consideration in the analysis of each sub-catchment:

(i) As much as possible of the existing network is utilized.

(ii) All major streams discharging into or out of the Lake systems are gauged in their lower reaches.

(iii) Stations are provided at or near sites of potential development.

(iv) The density of discharge stations conforms to international normals, and all streams with a catchment area exceeding 5,000 square kilometres are gauged.

An evaluation of the existing network revealed that to meet the requirements of the project an additional 51 stream-gauging and 12 lake-level stations would be required. At stream gauging stations where rapid variations in stage were expected, which were designated as index catchments, or which were key stations for potential development, it was necessary to install automatic water level recorders. In addition, improved methods for obtaining discharge measurements were introduced and these included self-propelled cable cars, a motor-driven cable car, bank operated cableways, and portable cableways.

(d) Measurement of other elements: In addition to the three major aforementioned networks it was necessary to make an accurate assessment of a number of other elements. Some of these elements and the criteria followed in establishing this auxiliary network are as follows:

(i) Index catchments: In order to determine runoff from ungauged areas and to facilitate detailed rainfall-runoff studies it was necessary to establish seven representative index catchments within the project, and their selection was based on the criteria; that they would facilitate the estimation of runoff from ungauged areas; they conformed to natural watersheds of small independent basins; and were distributed to reflect the diversity of features within the project area.

(ii) Topographic and hydrographic survey: In order to provide accurate information on changes in volume relating to changes in lake level which will provide a basis for planning future regulation of lake levels, and to facilitate hydrometric studies, the following tasks were defined and implemented: the survey and mapping of critical flat shore areas; hydrographic survey of Lake Kyoga; and relating the gauges at all project stations to precise level network.

(iii) Measurement of evapotranspiration: In view of the extensive areas under swamp in the project area it was desirable to obtain an evaluation of the potential evapotranspiration from these areas. Two lysimeters of the compensation type have been installed in typical swamps in order to facilitate the study of this phenomenon.

(iv) Sediment and quality of water surveys: Although the measurement of these elements is not a direct factor in the water balance study of the Lakes, it was recognized that they are a very important part of a hydrometric survey, and a knowledge of these elements will be useful for future design of reservoirs, irrigation projects, and water supplies. Sixteen sites were chosen as observation stations, and these sites were the seven index catchments and nine key sites which offer possibilities for future development or at which problems presently exist. The density of this observational network is 9 per cent of the total stream-gauging stations within the project area.

(v) Instrument shop and laboratory: Due to the specialized nature of equipment used in hydrometeorological surveys it is usually not possible to have repairs made locally, and in the case of the project the shipping costs to a suitable agent and the time delays involved in shipping made the establishment of an instrument shop essential in order to ensure an uninterrupted collection of data. Also experience by other agencies has indicated that chemical, sediment and similar types of analysis can best be facilitated with in-project facilities, and thus a laboratory was established to complement the instrument shop.

DIFFICULTIES IN OPERATION OF THE NETWORK

The difficulties which have arisen, and the manner in which they are being dealt with, are as follows:

(a) Standardization procedures: As the project is composed of a large international staff there is an inherent diversity of disciplines. Furthermore, the various participating governments were following different field and office procedures. To overcome this the project prepared Field and Office Manuals which were formulated on recommended international procedures.

(b) Planning field trips: As the hydrometric network is comprised mainly of new stations the stage-discharge relationship, and the stability of the control at these sites, are unknown. Therefore, if a standard programme of weekly measurements was followed it would be extremely expensive and in many cases unwarranted; similarly in many cases a monthly programme would be inadequate. To overcome this problem a Technical Memorandum on Frequency of Measurements was prepared, and on the basis of regular discharge measurements the status of each station is constantly reviewed in order to ascertain if the measurement programme for that particular station should be revised.

(c) Processing of data: One of the major tasks of the project involves the collection, computation and publication of all meteorological and hydrological data for all stations within the project, commencing with 1967 data. This assignment was rather straightforward for the meteorological sector as it primarily consisted of reproducing computer cards from the East African Meteorological Department and then devising an output format suitable for publication. However, putting this task into action in the hydrological sector posed a difficult problem, as the three East African governments have commenced on a programme of computerizing their hydrological data, and as the formats of these programmes conflicted it did not facilitate interchange of data. This necessitated formulating a policy to set up a working group in order to standardize procedures.

ACCURACY OF STUDY

The accuracy of the study as considered from a water-balance aspect is at present difficult to assess due to the varying degrees of accuracy to which the various components of the hydrologic cycle are being determined. Also the accuracy of the water balance for each of the three lakes varies considerably. Therefore, at present, the accuracy of the study can only be considered in a general sense, and this is best facilitated by considering various aspects of the hydrologic cycle and the three lakes separately.

(a) Surface runoff: Of an average annual estimated runoff of 22 milliards into Lake Victoria, 90 per cent of this is measured by stream-flow stations, and the remaining 10 per cent can be determined fairly accurately by using index catchment results; rainfall stations and adjacent gauged streams with similar basin features. The outflow from Lake Victoria is measured directly and therefore the only error in this quantity is the inherent error in this particular station.

The Victoria Nile provides 90 per cent of the inflow into Lake Kioga, and almost all of the remaining 10 per cent is gauged directly. The outflow from Lake Kioga is gauged directly.

The average annual estimated inflow into Lake Albert is 27 milliards, and 95 per cent of this is gauged directly. Most of the remaining 5 per cent arises in Congo Kinshasa and thus only a rough estimate of this quantity can be made.

The outflow of Lake Albert is gauged directly; however, in the past errors at this site may have been as great as 10 per cent, but recent improvements are expected to reduce this error to the status of normal station accuracy.

(b) Change in storage: With the existing maps available, surveys in low-lying areas presently being conducted, and the network of water-level recorders around Lake Victoria, the change of storage can be estimated to within 1 per cent.

On Lake Kioga a complete hydrographic survey is being conducted and therefore the accuracy should also be within 1 per cent.

On Lake Albert the area lying within Congo Kinshasa cannot be surveyed, and at present there is no provision for surveying the mouths of the Kioga Nile and Semiliki Rivers. Therefore, errors in determining the change of storage may be as much as 3 per cent.

(c) Groundwater: For the purpose of this study it is assumed that in the systems of all three lakes there is no influent or effluent seepage. This assumption is based on a few observations of groundwater wells, and a general knowledge of the geological conditions around the lakes. It is recognised that errors could be introduced into the water balance if these assumptions are incorrect; however, it is felt any errors arising from an incorrect assessment of groundwater conditions will be negligible when included in the over-all survey.

(d) Evapotranspiration: There are a number of arguments against the use of lysimeters for determination of evapotranspiration, and these arguments are predicated on the basis that difference may exist between the lysimeter and natural conditions in soil profile, soil moisture régime, plant rooting characteristics, methods of water application and the net energy exchange. Also the evaporation studies being conducted within the project do not take cognizance of the varying climatic zones, or the different types of growth.

(e) Evaporation: Although the network of first-order meteorological stations has been substantially increased and upgraded it is still inadequate in density for determining the evaporation from a large body of water. The two methods presently available to the project for computing evaporation are the Penman and Evaporation Pan methods.

Both of these methods have their limitations as the Penman method requires a measure of the surface temperature of the body of water, and this is very difficult to obtain, and the evaporation pan has inherent errors such as the temperature of the water in the pan fluctuating closely with the air temperature and splash-out or overflow during intense rains.

(f) Precipitation: Although the raingauge network in and around the periphery of Lake Victoria has been almost doubled from the original network of 33 stations, it is still estimated that the relative error in determination of rainfall over the Lake may be as great as 13 per cent. As the area of the Lake is 69,000 sq. km and the mean annual is estimated at 1,400 mm this could produce a maximum error of approximately 12.5 milliards.

The relative error in precipitation for Lake Kyoga is approximately 5 per cent, and in terms of volume this is equivalent to maximum error of approximately 0.4 milliards.

Also for Lake Albert the precipitation network provides reliability to within 5 per cent, and therefore the maximum error would be approximately 0.2 milliards.

DEFICIENCIES IN NETWORK AND METHODS FOR IMPROVEMENT

(a) The inaccuracy in the determination of rainfall over Lake Victoria is obviously one of the major deficiencies in the present network. At present the only solution to this problem appears to be observing rainfall by radar techniques. However, this method has two major drawbacks; firstly the initial capital cost of approximately $2,000,000 and annual recurrent cost of $500,000, and secondly the point that radar techniques give a qualitative rather than a quantitative result. Therefore, it is not considered justifiable to recommend an approach for further funds to acquire radar, and until new and financially feasible methods are developed it will be necessary to permit this deficiency to remain.

(b) Although the raingauge network in the project area was designed to produce results within 5 per cent relative error, the density of the network in some of the hydrological subcatchments previously mentioned is much less than one station per 342 square kilometres. This deficiency will limit future studies in these basins and therefore, especially in the case of major sub-catchments, this deficiency in the network should be rectified. As these deficiencies generally occur in sub-catchments which are uninhabited and inaccessible during various periods of the year, storage gauges should be installed and read on a monthly basis by project personnel.

(c) The personnel engaged in field observations of hydrometric and meteorological phenomena are as a general rule only trained in the basic fundamentals. Therefore, when an unusual event such as an extreme flood occurs, when equipment malfunctions, or when a matter requiring an on-the-spot decision or action arises they are unable to cope with it. Furthermore, without being involved in the processing and analysis of the field data these personnel do not realize the value of their work and consequently lose interest in their duties. The project has conducted two seminars in hydrology, and these have provided some fruitful results. Additional seminars are required at the ground-root level in both meteorology and hydrology; however, implementation of these seminars has been delayed due to senior personnel being fully involved in other major programmes, and they will continue to be involved in these programmes during the duration of the project. Therefore, at present the most satisfactory solution appears to be gaining additional funds to bring in suitable lecturers for approximately three man-months, for if this goal is not met, it will ultimately leave a serious gap in the operation of the network.

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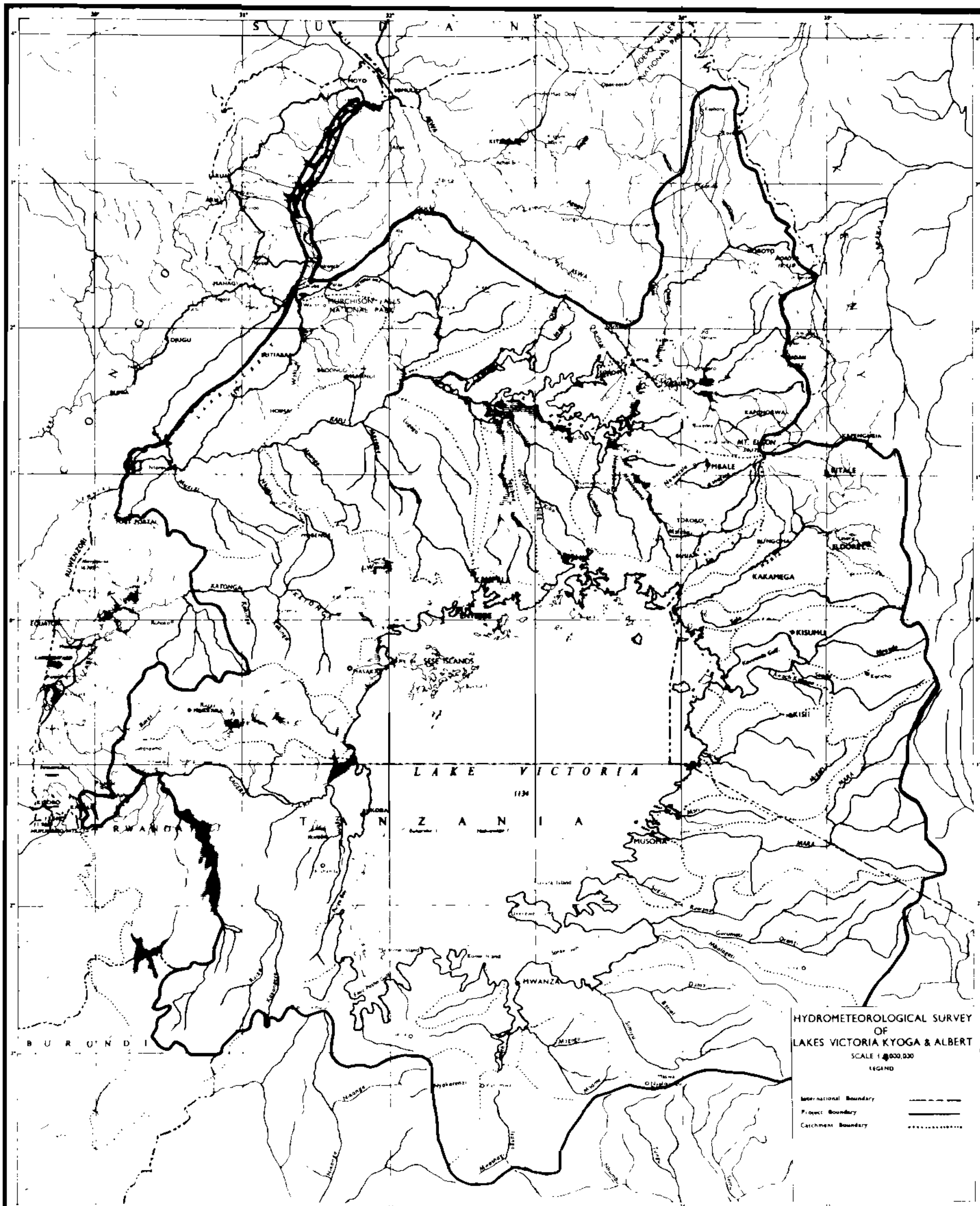
S U D A N
CONGO
LAKE VICTORIA
TANZANIA
RWANDA
BURUNDI
KENYA
MURCHISON FALLS NATIONAL PARK
SESE ISLANDS
MWANZA
MUSOMA
KISUMU
KAKAMEGA
KISII
MBALE
TORORO
KITALE
ENTEBBE
FORT PORTAL
HYDROMETEOROLOGICAL SURVEY
OF
LAKES VICTORIA KYOGA & ALBERT
LEGEND
International Boundary
Project Boundary
Catchment Boundary

PROSPECTION DE L'EAU SOUTERRAINE EN AFRIQUE

Par Robert E. Dijon

RESUME

Cet article expose d'abord comment la prospection de l'eau souterraine en Afrique s'est développée, surtout depuis la période de l'après guerre et l'accession de nombreux pays africains à l'indépendance. Les diverses méthodes sont brièvement passées en revue avec des exemples de leur application en Afrique: reconnaissance hydrogéologique - y compris observations géomorphologiques et préparation de cartes, inventaire des ressources en eau avec report sur fiches, prospection géophysique, forage d'eau, pompages d'essai et interprétation, analyses chimiques, traceurs, et techniques nucléaires. Ce développement est suivi de quelques considérations relatives aux services specialisés dans la prospection des eaux souterraines en Afrique, et aux principes dont l'organisation de ces services devrait s'inspirer. En conclusion certaines recommendations sont proposées, en vue de la simplification, de la normalisation, et de l'adaptation, aux conditions africaines des méthodes et matériels de prospection d'eau souterraine.

ABSTRACT

This paper shows at the outset how the prospection for groundwater in Africa has soared, especially since the post-war period, and since the accession to independence of many African countries.

A brief discussion of the various prospection methods is offered and their uses in Africa illustrated including: hydrogeological reconnaissance, encompassing geomorphological observations and the preparation of maps; inventories of groundwater resources including the preparation of index cards; geophysical prospection; water-well drilling, as well as pumping tests and their interpretation; water quality analyses, tracers and nuclear techniques.

In addition, some remarks are offered concerning governmental services specialized in the prospection of groundwater resources, and the main principles for the organization of such services.

In the conclusion, the author puts forward a number of recommendations concerning the simplification, the standardization and the adjustment to African conditions of the methods and equipment used for groundwater prospection.

Introduction, Historique

La plus grande partie du continent à l'exception des parties Nord et Sud est formée de pays plats et humides où les eaux superficielles sont presque partout présentes, notamment sous forme de mares à la saison sèche.

L'eau étant considérée comme un don du ciel - et un don relativement abondant - il n'est pas étonnant qu'elle n'ait guère été recherchée dans le sous-sol, à l'exception des alluvions des cours d'eau, lorsque ces derniers tarissent à la saison sèche. En fait, avant la Seconde Guerre mondiale le forage d'eau n'était guère développé en Afrique, sur un plan régional. Un essor véritable s'est manifesté après la deuxième Guerre mondiale grâce au développement des techniques existantes, et à l'apparition d'autres entièrement nouvelles. La réalisation systématique de "couvertures" de photo aérienne a eu de nombreuses applications et d'abord l'établissement rapide de cartes topographiques et de cartes géologiques. L'importance des besoins de l'Europe en hydrocarbures à la fin de la guerre a déclanché un vaste mouvement de recherche petrolière en Afrique, aussi bien dans les bassins sédimentaires du Nord que dans les bassins côtiers. Dans les régions arides la recherche d'eau souterraine a constitué un préalable à la réalisation des forages pétroliers souvent très profonds (Sahara). C'est ainsi que la connaissance des eaux souterraines a largement progressé dans les régions désertiques. En certains cas, des forages artésiens spéctaculaires ont été réalisés, l'eau constituant en quelque sorte un "sous-produit" du pétrole. De même, les méthodes de prospection géophysique se sont largement développées à la fois en perfectionnements techniques et en diffusion.

C'est à une époque relativement récente que les méthodes modernes quantitatives d'hydrologie souterraine ont été utilisées en Afrique: au Maroc, en 1954 et dans le "New Valley" en République Arabe Unie à la même époque.

Le perfectionnement des méthodes d'analyses d'eau notamment par spectrophotomètre à flamme ou par absorption atomique n'a pas eu en Afrique de grandes répercussions, car les appareils concernés sont coûteux, d'un maniement et d'un entretien délicats; l'usage des isotopes radioactifs en hydrologie souterraine a connu un développement limité dans les années 60 et tend à se développer. Celui des modèles analogiques et mathématiques en est à ses débuts.

L'ensemble des méthodes utilisées en Afrique pour la prospection des eaux souterraines est très sommairement énuméré ci-après et illustré par quelques exemples. En conclusion on trouvera quelques recommandations relatives à l'utilisation de ces méthodes, sur le continent africain.

1. Reconnaissance Hydrologique

Le support fondamental de toute reconnaissance hydrogéologique est la carte géologique. Les hydrogéologues ont dû assez souvent dresser des cartes géologiques, avant toute opération. Ce fut le cas, en particulier, pour beaucoup d'études locales pour l'alimentation en eaux des villes, qui nécessitaient l'exécution de levés de détail à grande échelle (ex: Dakar, Lusaka).

Lorsqu'un pays est couvert par une carte et des études géologiques de base, le travail de reconnaissance de l'hydrogéologue consiste à repérer les strates, zones, ou structures favorables à l'emmagasinement en suffisance d'eaux souterraines de bonne qualité, notamment celles susceptibles de recueillir des eaux d'infiltration - de pluies ou de ruissellement, et aussi surtout celles favorables à la construction de captages et de puits productifs. Par exemple en pays de socle cristallin c'est la présence des zones de fractures, de filons, et d'inclusions dans un contexte géomorphologique favorable qui oriente la recherche des zones de captage; en Afrique occidentale et orientale la photographie aérienne a été largement utilisée dans ce but. En pays de bassin sédimentaire où le recouvrement argilo-sablonneux est épais et d'une structure complexe, la reconnaissance consiste surtout à détecter par le moyen de tarières à main la présence de nappes ayant leur siège dans des lits ou lentilles de sable (cas du bassin Tchadien). Enfin en pays de calcaires karstiques, la morphologie est un facteur essentiel.

Au cours de ces reconnaissances un premier inventaire partiel des points d'eau les plus importants est dressé: sources, mares permanentes ou temporaires, cours d'eau, et, s'il y a lieu, puits, drains, forages d'eau. Certaines données telles que: profondeur du niveau piézomètrique par rapport au sol, débit des sources, composition chimique des eaux, ainsi que les fluctuations de certaines de ces valeurs fournissent des indications essentielles sur les ressources en eaux souterraines, la recharge et la vidange des réservoirs.

L'ensemble des renseignements recueillis est parfois porté sur des cartes hydrogéologiques dites "de reconnaissance", ou "d'orientation de la recherche" des eaux souterraines.

Parmi les cartes hydrogéologiques de reconnaissance à petite échelle établies pour l'Afrique il convient de citer:

1950 et 1957	Madagascar	SW	1/500.000
1961	Ghana (totalité du pays)		Echelle 1/1.000.000
1962	Sénégal: Ferlo Nord		1/500.000
1962	Mauritanie	SW	1/500.000
1964	Libye		1/1.000.000
1964	Niger	SW	1/1.000.000
1964	Côte d'Ivoire		1/1.000.000
1964 - 1968	Tchad (Les 2/3 du pays, au Sud en plusieurs feuilles)		1/500.000
1965	Sénégal en 4 feuilles		1/500.000
1965	Niger	SW	1/1.000.000
1967	Carte hydrogéologique des terrains métamorphiques et cristallins d'Afrique occidentale		1/2.000.000

2. <u>Inventaire des Ressources Hydrauliques</u>

L'inventaire des ressources hydrauliques est une opération qui consiste à reporter sur fiches et cartes tous les points d'eau, caractérisés par un numéro et par un indice, ce dernier correspondant à une feuille de la couverture cartographique. Les fiches, outre un croquis de position, la désignation, le nom et les coordonnées du point d'eau mentionnent: la profondeur de l'ouvrage et de l'eau, le débit, les caractéristiques chimiques et physiques des eaux, la nature et les caractéristiques des aquifères, les résultats des essais de débit ou de pompage, la description des aménagements existants ou à prévoir; les débits prélevés, etc..... Les fiches de forages comprennent en outre un croquis et une description de la coupe géologique des terrains.

Un nombre considérable de points d'eau a ainsi été inventorié en Afrique du Nord et en Afrique Occidentale. C'est ainsi que 7000 points d'eau étaient déjà recensés au Niger en 1964 sur un total estimé à 20,000; en Mauritanie 3000 (en 1966); au Maroc 25,000; au Nord Cameroun 2500. En Haute Volta 1500 villages ont été fichés (sur les 5000 du pays)(1969). L'abondance des renseignements ainsi collectés permet de traiter certains problèmes par ordinateur.

Les projets "Eaux Souterraines" des Nations Unies en Afrique ont également parmi leurs objectifs l'organisation, la réorganisation ou la poursuite de tels inventaires. C'est ainsi qu'au Togo l'inventaire a porté sur 1700 villages et 2262 points d'eau dont 1447 dans le bassin sédimentaire côtier.

3. <u>Prospection géophysique des nappes d'eau souterraines en Afrique</u>. Elle utilise plusieurs méthodes et techniques dont des exemples d'application sont donnés ci-après.

<u>Méthode des Résistivités</u>

<u>ALGERIE</u>: Etudes de la vallée du Chelif, de la Mitidja, des Hauts Plateaux.

<u>MAROC</u>: Etude structurale du substratum des plaines atlantiques (Rharb, Sais, Doukkala, Souss).

Bassin Sédimentaire <u>MAURITANIE-SENEGAL</u> Etude Structurale: La carte des résistivités apparentes donne une idée de la profondeur du substratum imperméable.

<u>MALI</u>: Cuvette nigérienne et détroit soudanais: étude des fosses d'effondrement.

<u>TCHAD</u>: Bassin sédimentaire: repérage des niveaux sablonneux pour implantation de forages urbains et pastoraux.

<u>SENEGAL</u>: Etudes structurales de détail dans la région du Cap Vert notamment Sebikotane-Pout en vue de la détermination des ressources en eau souterraine disponibles pour Dakar.

REPUBLIQUE ARABE UNIE: Haut-Nil: Etude des possibilités aquifères des grès nubiens.
CAMEROUN: (Nord) Etude de "biseaux secs", étroite bande de territoire sédimentaire dépourvue d'eaux souterraines en bordure d'une zone d'affleurements du socle.
TOGO - SENEGAL - COTE-D'IVOIRE: Etude d'invasions d'eaux marines dans les aquifères des bassins sédimentaires côtiers.
NIGER - OUGANDA: Etudes de nappes alluviales.
MAURITANIE - HAUTE-VOLTA - GHANA - COTE-D'IVOIRE - TOGO - DAHOMEY - TCHAD - KENYA - OUGANDA - MALAWI - AFRIQUE DU SUD etc... Etudes de l'épaisseur et des possibilités des formations d'altération recouvrant le socle cristallin granito-gneissique et des zones filoniennes.
MAURITANIE: Délimitation de la nappe douce lenticulaire de Bennichab, environnée de terrains salés ou gypseux.
ZAMBIE - BOTSWANA - NIGERIA: Etudeslocales (points d'eaux pastoraux).

Carottage Electrique

Ce procédé a été largement employé dans les investigations à caractère régional et local dans la plupart des pays africains et particulièrement en Afrique anglophone; parmi les travaux les plus récents il faut mentionner au Nord Cameroun l'étude des sédiments de la cuvette tchadienne par carottage électrique dans des forages profonds (1967-68). La méthode se justifie surtout pour l'étude d'un assez grand nombre d'ouvrages groupés dans une région. Elle n'est ni pratique ni économique pour l'étude d'ouvrages isolés ou dispersés.

Autres Méthodes Electriques - Elles sont emplyées beaucoup moins fréquemment que les précédentes:

- Mesure des "différences des potentiels superficiels"

  (phénomène d'électrofiltration) exemple: arènes granitiques de COTE D'IVOIRE.
- "Electromagnétisme", utilisant le courant alternatif à basse fréquence, souvent employé par les sociétés scandinaves. Ces procédés ont été parfois utilisés en prospection aéroportée dans les régions sahariennes (Mauritanie).

Sismique

La méthode sismique est souvent jumelée avec l'électrique, notamment en pays de socle cristallin recouvert de formations d'altération relativement épaisses. Elle donne souvent dans ce cas de meilleurs résultats que l'électrique. Elle est également utilisée pour détecter des structures de roches dures sous des formations de remplissage.

Exemples de prospection mixte électrosismique:
MAURITANIE: Alimentation de Nouvadhibou. TANZANIE: Points d'eau ruraux.
NORD CAMEROUN: Estimation de la profondeur du socle cristallin dans la région des "flats". COTE-D'IVOIRE, MAURITANIE, TCHAD (Ouaddai): Implantation de points d'eau en pays de socle cristallin.

Au DAHOMEY des études ont été effectuées en vue de rechercher des corrélations entre vitesse et perméabilité, pour le repérage de structures profondes.

Parmi les projets "Eaux Souterraines" exécutés par les Nations-Unies et utilisant ces méthodes; il faut citer: en pays cristallin: TOGO, HAUTE-VOLTA, OUGANDA DAHOMEY; en pays sédimentaire: MADAGASCAR (Côte ouest);

En Haute-Volta et en Ouganda les opérations combinées ont montré que la prospection sismique donnait les meilleurs résultats en ce qui concerne l'évaluation de l'épaisseur totale des formations d'altération surmontant le socle cristallin. Cependant, ce n'est pas toujours la zone d'épaisseur maxi. qui fournit les meilleurs débits.

Les méthodes magnétiques et gravimètriques ont été à plusieurs reprises utilisées parfois de manière combinée, en Afrique: par exemple:

MALI: Etude de la fosse du détroit soudanais
AFRIQUE DU SUD: Etude des dolérites de l'Ecca

REGIONS SAHARIENNES: Etude du substratum cristallin et de l'épaisseur de sa couverture.

BASSIN DU TCHAD: Carte gravimètrique au 1/1.000.000
KENYA: (Rift Valley) Etude magnétique des failles de Thomson's Falls; également: OUGANDA.

R.A.U.: Région de la "New Valley" (désert occidental).

4. Forage

Le forage mécanique est le moyen d'investigation le plus direct. On distingue en général trois principaux types de forage: de reconnaissance, d'essai, d'exploitation.

Le forage "de reconnaissance géologique"s'effectue la plupart du temps à petit diamètre en vue de la recherche de certains niveaux déterminés.

Dans les "forages d'essai"le diamètre du tubage permet l'installation d'une pompe mécanique ou électrique en vue de l'exécution d'essais de pompage (diamètre 4 à 10 pouces), pour des débits atteignant 20 à 30 l/s.

Les forages "d'exploitation": sont en fait des puits forés mécaniquement avec des diamètres pouvant atteindre 24 à 40 pouces. Ils atteignent sans la dépasser une profondeur optimale déterminée par une étude technico-économique.

D'une manière générale ce sont les forages d'essai (ou de "pré-exploitation") d'un diamètre de 6 à 8 pouces qui ont été et qui sont les plus fréquemment réalisés en Afrique. On sait qu'il existe deux méthodes principales de forage: 1/ le battage au câble et la rotation (ou "rotary") à la boue ou eau claire.

D'une manière générale le procédé par rotation a été utilisé en Afrique surtout dans les bassins sédimentaires pour la recherche des nappes captives profondes.

Le procédé au battage est très fréquemment employé en terrains d'alluvions, en pays de calcaires durs et fissurés, et dans les régions de socle précambrien, notamment en Afrique orientale

5. Pompages d'Essai

Les pompages d'essai ont pour objectif de déterminer les caractéristiques hydrologiques des terrains aquifères et par voie de conséquence les débits disponibles dans l'immédiat, et dans l'avenir. Leur durée est en général de 24 à 72 heures. En certains cas, lorsqu'il s'agit en particulier de gros débits pour l'alimentation en eau des villes ou l'irrigation, des pompages dits "de longue durée" sont effectuées (aux Haffaya, Sud Marocain:durée 3 mois à 500 l/s 1954; plusieurs mois également au Chott Chergui en Algérie, 1956).

Dans le cas des nappes artésiennes,des mesures de pressions au sol constituent l'equivalent des données des pompages d'essai. Les nappes ascendantes ou faiblement artésiennes sont testées par pompage (RAU: New Valley).

1) Il existe d'autres méthodes: rotation à l'air comprimé, rotation-percussion à l'air comprimé ("down-the-hole hammer", "jet drilling", mais elles sont beaucoup moins utilisées)

En pays karstiques et moins encore en régions cristallines, les pompages d'essai ne donnent guère de résultats concluants en ce qui concerne les caractéristiques hydrologiques des terrains et par conséquent la perennité du débit disponible. Il n'est donc pas surprenant que les pompages d'essai réguliers aient été surtout pratiqués dans les bassins sédimentaires - essentiellement dans le nord du continent où les aquifères sont poreux, homogènes et largement étendus ("Continental intercalaire saharien", Grès de Nubie).

Les calculs d'hydraulique souterraine qui étaient il y a encore quelques années l'apanage d'un petit groupe d'ingénieurs hydrauliciens spécialisés sont de plus en plus souvent effectués par les hydrogéologues, notamment dans les bassins sédimentaires côtiers et les vallées alluviales, (Maghreb, Libye, RAU, Afrique occidentale et orientale).

6. Analyses d'Eau

Un grand nombre d'analyses d'eau ont été effectuées en Afrique surtout au Maghreb et en Afrique occidentale (10,000 analyses). Cependant la difficulté de transporter les échantillons d'eau sur de longues distances jusqu'aux laboratoires - peu nombreux - n'a pas encore permis d'acquérir une connaissance générale de la composition des eaux de l'Afrique. Dans certaines régions étudiées en détail, des cartes hydrochimiques ont pu être dressées, notamment au Maghreb, en Libye, en RAU, en Afrique occidentale, etc...

La connaissance des eaux thermales et thermominérales, abondantes en Afrique, est encore très fragmentaire.

7. Traceurs, Techniques Nucléaires

L'usage de traceurs pour reconnaître le trajet et la vitesse de l'eau souterraine n'a pas connu un grand développement en Afrique - quelques expériences utilisant la fluorescéine ou des sels dissous ont été effectuées en Afrique du Nord, notamment dans les massifs de calcaires karstiques et les zones d'alluvions.

En Afrique les isotopes artificiels n'ont encore été que peu utilisés (quelques études expérimentales en République Arabe Unie).

L'étude des eaux par analyse des isotopes naturels, radioactifs ou non, afin de déterminer leur âge et les zones d'alimentation d'après les teneurs en isotopes deutérium (2H), tritium (3H), oxygène 18 et Carbone 14 tend à se développer, surtout dans les zones arides. L'Agence Atomique Internationale a effectué une première étude de ce genre en 1966 au Niger, dans la partie Est - région de Zinder (entre Air et Lac Tchad).

D'autres études de ce genre sont prévues pour le Sénégal (Dakar), le Maroc, la Tunisie, le Togo et d'autres pays.

8. Organismes de Recherche

En Afrique la prospection des eaux souterraines est effectuée le plus souvent par des organismes gouvernementaux ou des sociétés travaillant par contrat avec ceux-ci. Dans la plupart des cas l'ensemble des opérations sur les eaux souterraines fait intervenir des éléments étrangers à l'Afrique: personnel, technique, matériel, capitaux. Cependant une nette évolution vers l'africanisation est en cours, tendance encouragée par les organismes d'aide bilatérale ou internationale dont la participation à la prospection et l'exploitation des eaux souterraines de l'Afrique est actuellement encore prépondérante.

Si elle est effectuée systématiquement, la prospection des eaux souterraines est en général confiée à un service spécialisé de l'Administration: service "Hydrogéologique" ou "des eaux souterraines".

Quelle que soit l'organisation ministérielle dans laquelle s'insère un service des eaux souterraines, le bon fonctionnement et l'efficacité de ce dernier exige que les conditions suivantes soient réunies:

- Le service doit être individualisé: en d'autres termes, tout ce qui a trait à l'hydrogéologie doit être groupé dans une même unité administrative;
- Il doit être en liaison étroite avec: le service géologique, afin de pouvoir disposer des cartes et données de base; les services chargés de l'étude des eaux superficielles, avec accés aux résultats de jaugeages, et d'observations météorologiques; les services chargés de l'exécution des forages d'eau.

L'organisation peut comprendre un bureau d'études, un bureau de l'inventaire (cartes et fichiers), une section de géophysique, parfois un laboratoire, un bureau de dessin et cartographie, parfois des services régionaux. En certains cas le service est doté de moyens de perforation qui lui sont propres (TUNISIE, AFRIQUE ORIENTALE).

Conclusion: Recommandations

La prospection de l'eau souterraine s'est développée assez récemment en Afrique; elle a connu un grand essor dans les années 50 et au début des années 60.

En Afrique le nombre d'hydrogéologues, géophysiciens, foreurs et autres specialistes des eaux souterraines est encore largement inférieur aux besoins et les matériels qui leur sont nécessaires manquent souvent. Des ingénieurs techniciens et ouvriers spécialisés africains sont formés en nombres croissants dans le pays même ou à l'étranger. Etant donné l'ampleur des besoins d'orienter la prospection des eaux souterraines en Afrique vers les voies les plus économiques les plus efficaces et les plus pratiques. Une esquisse des actions à entreprendre est donnée ci-après.

1. Reconnaissance hydrogéologique - Généralisation de la préparation des cartes de reconnaissance hydrogéologique, selon des méthodes simplifiées. Identification de critères géomorphologiques typiques pour le repérage des reservoirs d'eaux souterraines notamment en pays de socle cristallin; Etablissement de reseaux d'observation piézométrique des nappes.

2. Inventaire des ressources hydrauliques - Elaboration d'un manuel d'instructions pour le levé des points d'eau destiné aux prospecteurs africains; Normalisation à une échelle internationale du système des fiches de points d'eau et fiches du village.

3. Prospection géophysique - Les résultats de toutes les explorations géophysiques d'eaux souterraines devraient être réexaminés dans le cadre d'une étude globale comparée, de manière à déterminer les méthodes, dispositifs et matériels les plus économiques et les plus efficaces.

4. Forage d'eau - Une étude globale de même nature devrait être entreprise pour le forage d'eau, sur une base statistique.

5. Pompages d'essai - Un manuel simple d'exécution et interprétation des pompages d'essai à l'usage de l'Afrique devrait être préparé. Il devrait donner des recommandations spécifiques pour les différents types d'aquifères.

6. Analyses d'eau - Des normes d'organisation de laboratoire de chimie des eaux sont à définir. Une étude préliminaire d'ensemble de la composition chimique des eaux souterraines en Afrique est necessaire.

7. Traceurs, techniques nucléaires - Il convient de déterminer si certaines de ces méthodes modernes peuvent être avantageusement substituées aux méthodes classiques.

8. Organismes de recherche - L'effort d'organisation de Services Nationaux des eaux souterraines et formation du personnel specialisé doit se poursuivre. Il serait intéressant de préparer, pour chaque pays africain, une monographie sur l'état des connaissances hydrogéologiques (avec bibliographie) et de l'exploitation des eaux souterraines.

D'une manière générale, l'Afrique devrait utiliser au mieux les moyens limités - mais croissants - en spécialistes et matériels dont elle dispose pour l'exploration des eaux souterraines. Dans ce but il convient de tirer la meilleure partie des données existantes et des expériences passées. La simplification et la normalisation des méthodes et techniques existantes, et l'adaptation des nouvelles devrait être considérée comme un préalable aux futures investigations, par les pays Africains concernés. Il est souhaitable que les Organismes Internationaux compétents y soient associés.

HYDROMETEOROLOGICAL DATA NEEDED FOR FLOOD-CONTROL STRUCTURES

by Isam Mustafa

ABSTRACT

The paper outlines the types of hydrological data needed for the design of flood control structures.

RESUME

Le document décrit le genre de données hydrologiques requises pour projeter des ouvrages de protection contre les crues.

INTRODUCTION

Water is nature's gift, usually considered as a gentle flowing body which is enjoyable to look at or use. Old civilizations always associated themselves with streams and rivers with a continuous supply of water. Ancient Egyptians almost worshipped the Nile, and offered as a sacrifice a young beautiful virgin every year to the Nile so that the mighty river would flood the banks and their crops would grow. But water in the same stream can be a disaster if it is not well tamed and could wash all civilization from its banks. The records of flood disasters are available in abundance.

Flood control is defined as the prevention of damage from the overflow of natural streams. This definition looks simple and easy to achieve but it is an established fact that in spite of all the measures discussed in this paper, complete prevention with 100 per cent certainty cannot be economically achieved. A certain percentage of probability has to be accepted.

This brings us to the economic aspect of flood control. Is it economical to have flood control structures at a high cost? And how do they compare or compete with development projects yielding quick returns, especially in developing African countries? Apart from the economic aspects, it is essential to undertake flood control projects so as to reduce human suffering which cannot be economically evaluated.

To make these flood control structures certain hydrological data are needed. Hydrological data needs is the main theme of this paper, and it should be emphasized here that such data cannot be collected just prior to the design of the structure like the geological data for the foundation design. Due to many different varying factors and elements, hydrological data have to cover a long period of record. The minimum period of record for reliable analysis is considered to be between 25 to 30 years. This is not a strict rule. It is known that without adequate data, projects will either be under-designed with attendant risk of failure and consequent damage, or over-designed which will render them uneconomic.

TYPES OF FLOOD CONTROL STRUCTURES

Four different controls will be discussedin detail to show what data are needed to design and construct them. These are the structures needed for flood control, but the other measures for flood control such as temporary or permanent evaluation of flood plain, reduction of flood runoff by land management and many others which do not require structures are not discussed here.

(a) Flood control reservoirs. The main function of the flood control reservoirs is to moderate or reduce the high peak of flood that would cause damage if it were allowed to pass downstream. The ideal situation for the flood control reservoirs is just upstream of the lands to be protected. But this is not always possible as there are other influencing factors such as geological and physical suitability of the site for dam construction. The dam may have other purposes beside flood control which also influence its situation. In any case, it has to be upstream of the land to be protected.

The simple operation of the reservoir for flood control is to store the high peak in excess of the downstream channel capacity and when the inflow decreases the stored water to be released at the safe downstream channel capacity (Figure 1) or less, depending on the purpose of the reservoir. There are two types of flood control reservoirs.

Multi-purpose reservoirs: As mentioned above, the reservoir may not be solely a flood control project. It may have other purposes like irrigation, hydropower, recreation or fishing; but, in addition to these purposes, there will be reservoir capacity allocated for flood control. There are two types of such reservoirs.

(i) Annually-filled reservoirs in which a certain capacity of the reservoir is allocated for flood, and has to be left empty at a specific time every year. This is regulated by emptying this portion of the reservoir every year even if that water is wasted.

(ii) Over year storage - Usually they are huge reservoirs, like the Aswan High Dam in Upper Egypt. These reservoirs have certain capacities to store any flood and they need not be emptied each year and can store water over years which can be used when it is needed.

Detention reservoirs: These are usually very small and are only for flood control purposes. Their function and operation regarding flood control are the same as the other type.

(b) Embankments. Flood embankments are the oldest known forms of flood control or flood protection. This type of structure has been and is being used extensively. Embankments include dykes, levees, flood walls and channel bank improvements. These structures could be of a temporary nature in emergencies, or permanent where the danger is expected more often, or combinations of both if necessary. It is usually the first solution one thinks of because it is relatively cheaper and easier to design. This is not always the case but often is, especially where the length of the flood plain to be protected is not long and where local materials are cheaply available. The main function of embankmentsis to confine the stream within its predetermined channel.

The design of such a structure requires consideration of three features: crest level of the embankment; spacing of embankments across the channel; structure of the embankment. It must be noted that these points are very much related to each other and optimum values for each need to be found.

(c) Channel improvement. The objective of channel improvement is to confine the stream in its channel by increasing the stream velocity and accordingly reducing peak levels. This, however, has certain limitations. Increasing the velocity beyond a certain sediment load-carrying capacity will create a scouring effect in the channel and the stable régime of the channel will be very much disturbed. Also the economics of the project is a limiting factor.

There are different ways and means of improving the channel capacity such as:

(i) Reducing the roughness factor (Manning, N) and accordingly increasing the velocity. There are many ways to do this (dredging, lining of the channel, clearing the channel of weeds and debris, straightening of channel bends, bank revetment, blasting stream bed rocks, etc.).

(ii) Increasing the slope of the energy line by shortening the channel path. This can be achieved where the stream is meandering (Figure 2). As the velocity is proportional to the square root of the slope, it will increase with the increase of slope.

(iii) Another method is by narrowing the channel section through sets of dykes in the water course as shown in Figure 3. By narrowing the water section, the velocity will increase. Care must be taken not to raise the water level to flooding range.

(iv) Dredging is another way of channel improvement which physically increases the channel capacity.

(d) Diversions. A long time ago the Egyptians in the Nile and the Babylonians in the Euphrates diverted major floods in these rivers to big lowland depressions. Nowadays, structures may be needed as stand-by in case of a major flood. The principle is the same as that of the ancient Babylonians and Egyptians; that is, to create a temporary flood reservoir (without damming) in available land depressions and to increase the velocity in the channel, thus reducing the stage downstream of the diversion. The channel capacity of both the main stream and the diversion would also be more than the original channel capacity. The ponded water may be allowed to return to the river if the river stage goes below the pond level, or it may be left to evaporate or to be pumped if there is no outlet for it. Diversion work depends very much on the topography of the site. Figure 4 is a schematic drawing of lower Mississippi flood control system. These passes are not used except during major floods.

TYPES OF HYDROMETEOROLOGICAL ANALYSIS NEEDED

(a) Maximum possible flood. This flood by definition is the flood which is expected from the maximized combination of meteorological and hydrological conditions and topographic features, including extremely rare combinations with storm transpositioning. This expected maximum flood is used in the design of flood structures.

Standard project flood is similar to maximum possible flood except that it excludes extremely rare combination and storm transposition. It is the flood from the conditions considered reasonably characteristic of the geographical region involved. Usually it is about 50 per cent of the maximum possible flood. This flood is used to compare project flood estimate and degree of protection provided by the flood control and thus promoting a more consistent policy for the selection of design floods giving comparable degree of protection.

(b) Spillway design flood. In deriving this design flood the economics of the project are considered besides the hydrological data. In general the spillway design flood is the difference between the maximum possible flood and the flood storing capacity of the reservoir. In other words, it is the maximum flood that needs to be spilled downstream, after moderation by the storage capacity of the reservoir.

(c) Flood hydrograph. This is an historical record of the flood of the stream in respect of time. This could either be the water level at a certain site in the stream plotted against time, or it could be the actual flow (in volume/time) versus time.

(d) Flood frequency. This indicates how frequent certain floods can be expected to occur in a given time. This can be expressed in terms of the number of years during which a certain flood will be exceeded, or can be a percentage of probability; in design the former expression is used most.

(e) Storm depth-area-duration. Floods are caused by storms and the analysis of these storms is an essential part in controlling the floods. Storm depth-area-duration is the measure of the intensity and extent of the storm in time, and this reflects what type of storm is expected and accordingly what type of flood control is needed.

(f) Maximum water level. The maximum water level in a stream is an immediate measurement of the extent of the flood expected. This forms the first computed data needed in flood control. It can either be from old historical records or be computed from the design flood.

(g) Mean annual flood. This is the flood which is normally expected each year. Although this is not directly involved in flood control, it is needed for reservoir capacity computation and reservoir regulation for flood control. This is a statistical value computed from the long records of the river. Normally it has a frequency of 50 per cent.

BASIC HYDROMETEOROLOGICAL DATA NEEDED

The basic field hydrometeorological data needed to fulfil the above requirements are considered below.

(a) Precipitation. This is the basic data for all hydrometeorological analysis. It denotes any aqueous deposit, in liquid or solid forms, derived from the atmosphere. The source of all fresh water on the earth is precipitation from rain, snow, hail, frost and dew. The amount, intensity and areal distribution of precipitation are the parameters needed to be measured. To plan accurately the methods and ways for measuring these parameters a knowledge of precipitation is essential. Water vapour is always present in atmosphere in some degree. But to produce precipitation, cooling and condensation of vapour must first take place in the form of clouds and cloud droplets must grow by some means until they are large enough to fall as precipitation. Basically there are two types of precipitation measurement.

(i) Non-recording gauges. This is the simplest form of precipitation gauge. It is essentially a container with certain specified dimensions and exposure. The volume or the amount of precipitation collected is measured at specific time intervals which could be one day, one week, one month or 6 months, depending on its function and on what is expected from it. Obviously this type of gauge measures one parameter of precipitation, that is, the amount. The amount of precipitation is normally expressed in depth.

(ii) Recording gauges. This is a more sophisticated gauge. It has also specific dimensions and sizes. It differs from the non-recording gauge in that a trace of precipitation is made on a chart moving at a constant speed. Clearly, this gauge measures both amount and intensity of precipitation.

(iii) The measurement of the third parameter, distribution, is more complicated than the above two. There are many influencing factors involved: economics, topography, distances, accessibility, method of computation of the means. The subject of network distribution is very wide but the essential requirement is that each gauge should present the precipitation in a certain area of the catchment under study.

As the method of determining average precipitation is very essential, a brief summary is given below. The criterion is how to determine the portion of the catchment a certain gauge can represent.

(iv) Arithmetic mean. This is the simplest method, wherein the precipitation in the catchment is represented uniformly by the number of the precipitation gauges. The mean is calculated by simply adding the results from gauges in the catchment and dividing by the number of gauges. This method is used when the gauges are evenly distributed on a flat land.

(v) Thiessen polygons. This method makes some allowance to the uneven distribution of gauges. The area which each gauge represents is found by constructing a polygon formed by the perpendicular bisectors of the lines joining adjacent gauges. Each gauge represents the polygon that encloses it. Then by weighting, the average precipitation over the total area can be computed.

(vi) Isohyetal method. If used with skill, this method provides the most accurate determination of average precipitation. It is an integration of different factors. It involves the construction of lines that represent equal average precipitation and the area between these lines will have an average precipitation equal to the average of the values of the isohyetal lines enclosing it. Also by weighting, average precipitation of the area can be computed.

(h) Water stage in the stream. This is also one of the basic required data. It is the water level above a certain datum. In Egypt some records go back 1,000 years. This is a direct measurement of the flow of the stream. For flood control purposes the absolute measurement of the extent of flood is required. This type of data does not need a lot of computation before use. It can be used effectively directly from the field. But it is also involved in other computations and analyses. There are two main types of measuring devices.

(i) Non-recording gauges. This is the gauge which is observed at certain fixed intervals of time. There are many different types of such gauges (fixed gauges, portable gauges, chain gauges, straight edge gauges, low datum, upper datum, etc.). But the most common and widely used is the fixed graduated vertical rod with bottom datum. This system, although cheap and simple to maintain, has the disadvantage of missing some readings which cannot often be interpolated correctly.

(ii) Recording gauges. This is a continuous automatic recording of the stage on a chart moving at a constant speed, giving the precise time for any stage. Another type of recording gauge records the crest of the stage at certain time intervals; the latter needs continuous observation. While the former does not need continuous observation, occasional visits are needed for checking, maintenance and collection of data.

(i) The stream flow. The measurement of the flow in the stream gives the volume of the flood. By definition, the flow is the volume of water that passes a certain section of the stream in one unit of time. There are many different direct and indirect methods of measuring flow. Usually this type of data is observed at certain intervals, although new development of techniques may make it possible to have continuously recorded flow. Direct measurement is made in natural streams by directly measuring the volume that passes the section or by measuring the velocity of the flow and the area of the flow and then computing the total flow. The latter is the most practical and widely used method. There are numerous indirect methods. They are usually for specific streams and cases where the velocity-area method is not applicable. (Slope-area, salt or dye method, flow through weirs or culverts with empirical equations, isotope method, step-back methods, pure empirical formulas.)

According to Manning and Chezi equations, the flow is proportional to the hydraulic radius of the section. The stage is a direct measurement of the hydraulic radius. In natural streams, all other factors in the Manning formula are considered to be constant, so the velocity of the stream is directly proportional to the stage. It is found that each stream section has a certain correlation between velocity and stage, depending upon the type of the control section. As the stage is observed more regularly, the corresponding flow can be computed from the stage flow relation established by the less frequent flow measurements. From these data, annual flow or peak of flood or any other flow data can be computed.

(j) Evaporation. By definition, evaporation is the process by which a liquid or a solid is changed into vapour. There are many factors that influence evaporation. It is not intended to go into detail here because evaporation is not a major part of flood control, but in the operation and regulation of the reservoir it is needed. Evaporation can be measured directly from evaporation pans or can be computed from other meteorological data.

(k) Humidity. It is defined as the percentage of vapour pressure of the air to the saturation vapour pressure with respect to water at the same pressure and temperature and is a good indicator for precipitable water in the atmosphere. It can be measured directly with a thermohygrograph or indirectly from wet- and dry-bulb thermometer readings. It is needed to calculate the amount of moisture in the area and to maximize it and give it the most favourable condition, and is a direct method to compute maximum possible flood.

Dewpoint is sometimes used instead of the relative humidity for measuring the moisture content. Dewpoint is defined as the temperature to which air must be cooled in order that it can be saturated at its existing pressure and humidity mixing ratio.

(l) Temperature. Daily maximum, minimum or average temperature is in common everyday use. Air temperature is involved in many of the meteorological computation and analyses mentioned above. It is needed both for design and construction purposes.

(m) Sedimentation. This is the measurement of the amount of annual load of suspended and bed materials, their distribution in time and particle size. The amount which can be transported downstream influences the lifetime of the reservoir and its capacity.

(n) Water quality. The corrosiveness of the water, the P.H. value to determine its acidity, its conductivity and mineral content are estimated. These data are of minor importance but are needed to determine the type of protection that may be needed for the different structures.

CONCLUSIONS

(a) Hydrometeorological data collection is essential, especially for developing countries where more hydraulic structures are expected to be built. Planning for the collection of such data should be started long before the planning of the actual development that involves this data. As a rule, this data should be planned for all potential developments.

(b) The establishment of an ideal network for data collection may encounter some difficulties - lack of personnel, finance and accessibility of sites. Less dense network may have to be undertaken and intensified according to priorities, depending on the development plan, keeping in mind the fact that the longer the record of data the more reliable it is.

(c) Flood control work may need other types of hydrometeorological data for flood forecasting. This was not mentioned above as the discussion was confined to data needed for flood control structures.

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Figure 1

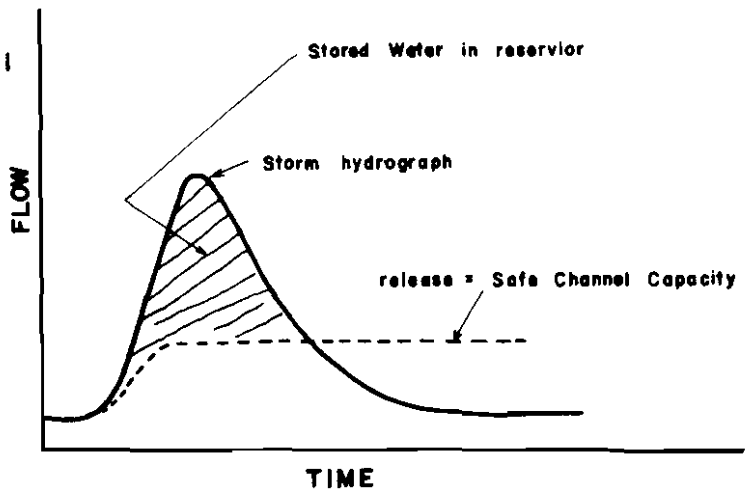
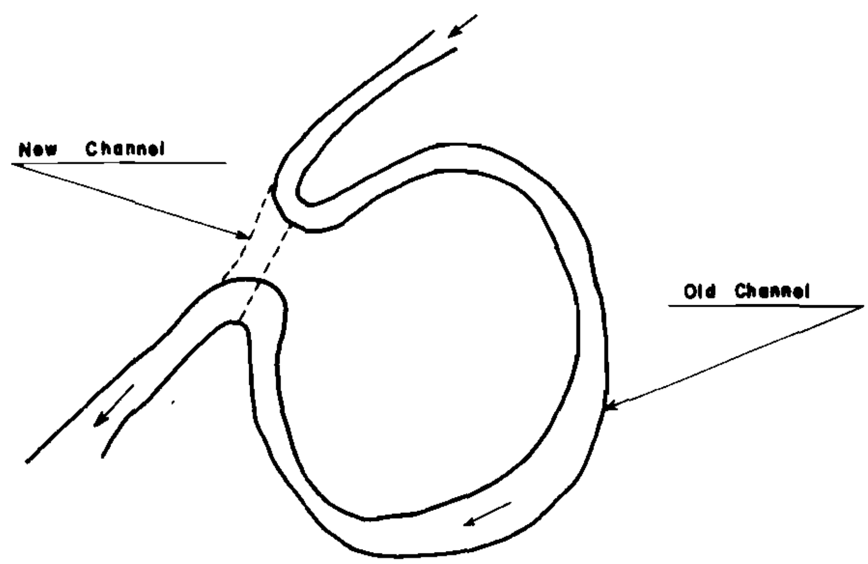


Figure 2



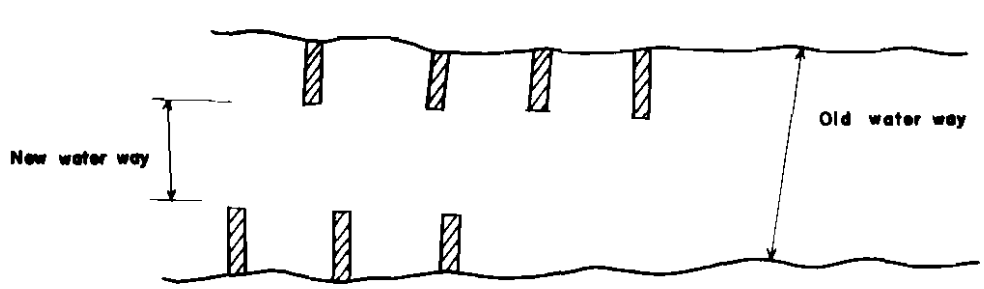


Figure 3

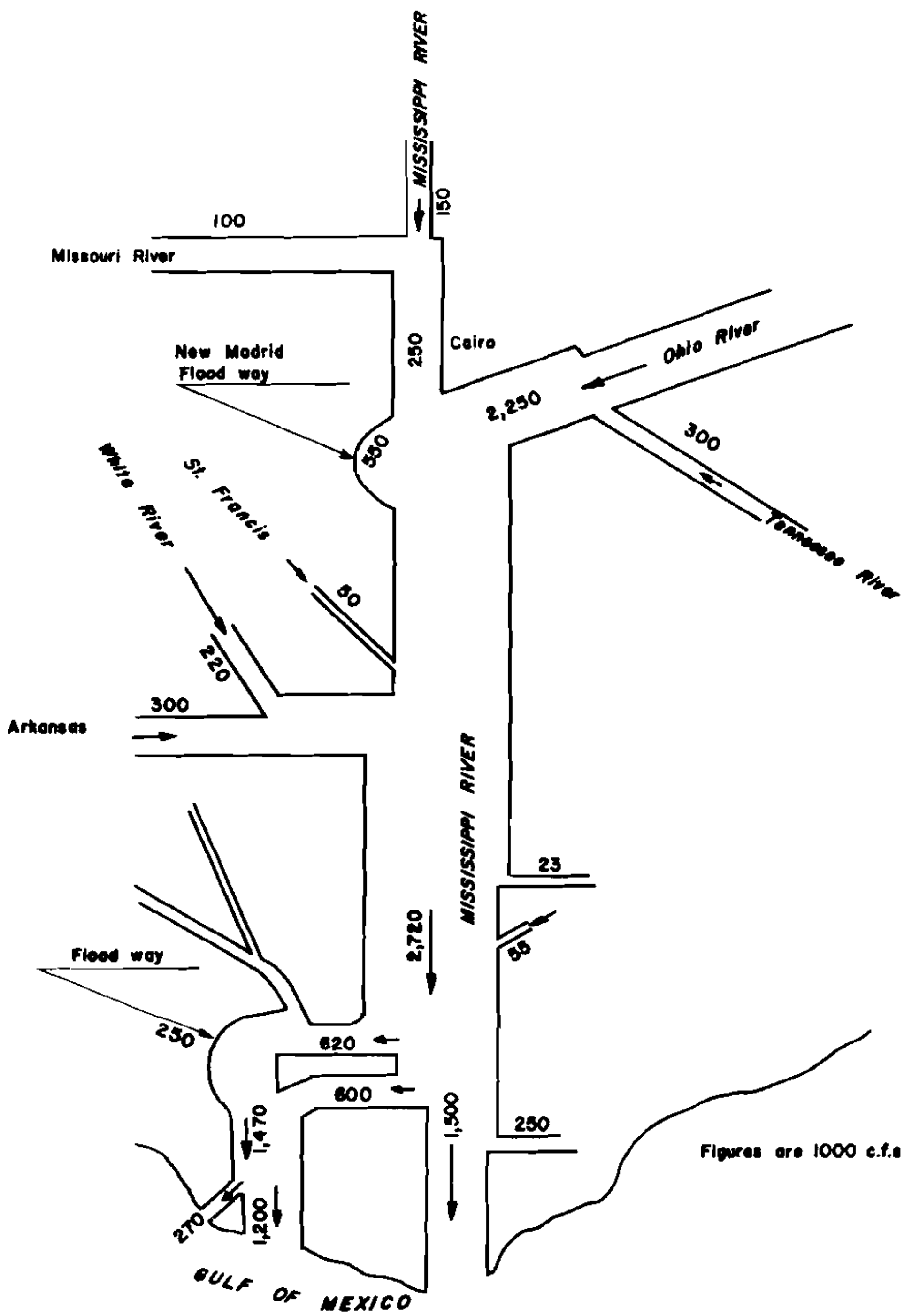


Figure 4

LOWER MISSISSIPPI RIVER DIVERSION

THE USE OF HYDROMETEOROLOGY AND HYDROLOGY IN AGRICULTURAL DEVELOPMENT

THE FAO POSITION

ABSTRACT

Water is one of the primary natural influences on agriculture, and from this stems FAO's interest in hydrology in all its phases. The paper describes the application of hydrology to specific problems in Africa. Examples are selected from a number of FAO Projects involving agricultural planning and development.

RESUME

Pour l'agriculture, l'eau est un élément naturel essentiel, d'où l'intérêt de la FAO pour l'hydrologie sous tous ses aspects. Le présent document décrit les applications de l'hydrologie à la solution de divers problèmes spécifiques qui se posent en Afrique. Des exemples ont été tirés d'un certain nombre de projets de la FAO portant sur la planification et le développement agricoles.

INTRODUCTION

1. Agriculture and food production are basic industries throughout the world, but they are the more significant in Africa where the agricultural sector plays a fundamental role in the national economy of most countries. It is also a sector which in many cases remains near the subsistence level, for development is hindered by socio-economic, physical and technical constraints. It is here that FAO, which is devoted to the world-wide growth and improvement of agriculture and nutrition, has an essential role to play.

2. Water is one of the primary natural influences on agriculture, and from this stems FAO's interest in hydrology in all its phases (including hydrometeorology). This is a practical interest, concerned with the application of hydrology to specific problems of agricultural planning and development. FAO welcomes the opportunity provided by this conference to meet and to discuss with the producers of data, and with other users, the place of hydrology in agricultural development, and the close relationship that should exist between hydrological and agricultural services.

3. To agriculture, and therefore to FAO, hydrology is not an end in itself but is an essential tool, which must be used together with a number of other sciences, to provide the optimum conditions for agricultural production. The place of hydrology in agricultural development is particularly important in Africa, where only about a third of the land area lies in the humid zone, almost half lies under arid and semi-arid climates and about one sixth is desert. This dependence of agriculture on water is reflected in the number of FAO projects in Africa which require hydrological data for water development for agriculture (44 projects completed and a considerable number in progress).

EXAMPLES FROM FAO PROJECTS OF THE USE OF HYDROLOGY IN AGRICULTURE

1. In order to illustrate the place and value of hydrology in agricultural development in Africa, a few examples will be given, together with a table to summarize the purposes for which hydrological data are used. The table and examples are not exhaustive but are offered in summary form to give an indication of the range and type of problems FAO is engaged upon in Africa that involve the use of hydrological data and techniques.

Summary of purposes for which FAO-assisted projects use hydrological data

General	Specific
1. Engineering systems and water control works (irrigation, flood control, drainage, stock watering)	(a) Assessment of availability, variability and quality of water resources, surface and underground
	(b) Design of water development systems for agriculture (reservoirs, spillways, barrages, canals, river control works, drainage systems)
	(c) Calculation of irrigation supply and drainage requirements
2. Environmental management	Dry farming, range management, watershed and forest management, erosion control
3. Fisheries development	Inland fisheries - in rivers, fishponds, lakes and reservoirs
4. Plant production and protection	Hydrometeorological influences on plant selection, growth, cultural practices and pests and diseases

2. The assessment of water availability for engineering development is an integral part of many projects. A good example is the Souss project in Morocco where studies for the agricultural development of the valley are based on analyses of natural rainfall régimes on the plain and water resources available basin-wide for supplemental water supply through irrigation. Although the mean annual rainfall in the valley is 250 mm, as little as 30 mm have been recorded in some years. An inventory has been made of water resources and present water use, and a resistance-capacitor analogue model of groundwater aquifers is being employed as the most convenient way of analysing the groundwater component of a complex water balance, and of estimating the possible groundwater contribution to integrated surface and groundwater development schemes for the whole basin. This study will also include preliminary design of reservoirs and integrated reservoir operation studies based on hydrological data, engineering feasibility and water needs.

3. On the Senegal River a mathematical model of a different type is in use to simulate the flood régime of the river on which present agriculture depends through the recharge of soil moisture by the seasonal floods. This study is a digital simulation similar to the Mekong River study in South-East Asia and will be used to aid the design of hydraulic structures and storage for the progressive flood control of the river.

4. A major problem in most irrigation projects is the determination of the water needs of crops. In the Senegal basin study, for example, all approaches are being used, including evaporation pans, calculation from meteorological data (including complete radiation and energy balance), lysimeters, and changes in soil moisture storage under rainfed and irrigated crops. This question is also being studied through an FAO headquarters programme, through which has been instituted a panel of international specialists to consolidate world experience and to prepare guidance material for field officers on the most suitable ways of estimating crop water needs in different environments.

5. Another project concerned with soil moisture storage and its optimum utilization is a range management project in Kenya. In this case the purpose is to evaluate range land potential for which a mathematical model is being developed which

simulates the rainfall, evaporation, soil moisture and runoff elements of the hydrological cycle; from this simulation can be calculated a running balance of soil moisture conditions, which are correlated with grassland production at experimental stations.

6. Cattle and livestock represent a most important economic resource in Africa, and great efforts are being made for their systematic improvement. In many countries, and projects in Kenya, Uganda and Tanzania may be cited as examples, the development and control of rangeland and fodder resources are being integrated with the development of water resources for stock watering points, for which hydrological data on rainfall, surface and groundwater are essential.

7. The effects of land use on the hydrological cycle are now recognized as an important element in the relationship between man and his environment. Increasing flood peaks, decreasing base flows, soil erosion and sedimentation of reservoirs are some of the results of unwise land use through overgrazing, burning, destruction of forests and shifting cultivation. FAO has assisted several governments in Africa with advice and research on watershed management and soil and water conservation. An example may be found in Mauritius where economic necessity required the cutting of some forest areas for tea planting; to assess the effects of such changes on hydrological régimes the FAO Land and Water Resources Survey aided the Government in selecting three experimental basins, installing the necessary data-collection stations and analysing the results. FAO is also concerned with the relation between man and his environment through its Regular Programme; it provides the Technical Secretariat for the IHD Working Group on The Influence of Man on the Hydrological Cycle, whose interim report ("A guide to policies for the safe development of land and water resources") has had wide circulation, and is at present playing a main part in the preparation, within its own programmes and through the UN Conference on the Human Environment scheduled for 1972, of wider activities in all fields related to conservation of environmental and natural resources.

8. Another interesting project in Africa, an investigation of an internal drainage system, is the Lake Chad project, in which the lake itself is the "sink" for the whole water inflow. A study of the water balance of the lake was a necessary precursor to decisions on the use of its waters. The results show that the probable rate of irrigation development in the basin is small in relation to the magnitude of the natural factors in the water balance of the lake and should therefore cause no anxiety for the next 20 years. However, a macro correlation has been possible between the flow of the Chari River and the long record of Nile flows at Aswan, and the variations shown by Nile river flows can be expected to have occurred also in the Chad Basin. On this time-scale long-term estimates of possible climatic trends may be important in development planning, for in areas where runoff may represent only a very small percentage of rainfall, a small change in rainfall or evaporation results in a much bigger change in available water and so may influence the economics of water development plans.

9. In areas of marked seasonal rains another concern of agriculture in hydrometeorology is the length of the growing season and the most suitable times for farming operations as determined by rainfall; and in marginal areas calculations of risk of crop failure, based on rainfall probability analysis, become of primary importance in agricultural development planning. Short period rainfall intensity is another parameter of interest to the agriculturist, particularly in the design of drainage systems in irrigated areas and in changing land use; for example, when natural forest cover is replaced by plantation farming; it is also used as an aid to identifying areas susceptible to soil erosion and in the design of gully control measures.

10. Agroclimatological studies on a regional basis are most helpful in planning agricultural development. In various regions of Africa such studies have been made by intergovernmental organizations; and FAO has contributed, through the

Interagency (FAO/Unesco/WMO) Coordination Group in Agricultural Biometeorology, to two major studies, one on the Agroclimatology of the Semi-arid Area south of the Sahara in West Africa and the other on the Agroclimatology of the Highlands of East Africa.

11. Fishery development is also a field of FAO activity for which hydrological data are essential inputs. The main hydrological parameters affecting inland fisheries are water quality (physical and chemical), depth and velocity. Pollution, particularly from urban and industrial wastes, affects all uses of water to some extent, but has the most impact on fisheries. Water development schemes such as reservoirs and diversion works may cause adverse effects on downstream fishery through changes in flow régime. Water levels and their range of fluctuation also determine the location and type of facility for boat docks and fish landing stations. At present on Lake Nasser final location of permanent fishing villages is awaiting hydrological data of this kind; similarly in the Niger River delta fish ponds were located, designed and constructed using hydrological information on the rise and fall of the river from tidal effects and from floods.

CONCLUSION — WHAT FAO CAN OFFER

The mandate of FAO, as one of the specialized agencies in the UN family, is to assist the nations of the world to improve their agriculture, food production and nutrition. To this end FAO operates its own Regular Programme of information, collection and dissemination and promotion of research and training; and also, as one of the executive agencies of the UN Development Programme (UNDP) it is an agency for action in the field through the provision of individuals or groups of experts and through the implementation, in cooperation with national governments, of projects for the study and development of resources for agriculture and for agricultural research and training; some aspects of the work of these field projects have been described in Chapter II. Through its Regional Offices, its Senior Agricultural Advisers in member countries and also through the offices of the UNDP representatives, FAO maintains constant contact with national governments, and is always ready to answer calls for assistance within its mandate and within its means.

In this paper the importance of hydrology and hydrometeorology in agricultural development has been stressed. But what is also important is recognition that the value of hydrological data is a function of the type and accuracy of the data and the length of record. It is FAO's experience that in many cases agricultural development schemes have been proposed and discussed for many years before the FAO team arrives on the ground, but no systematic data collection has been made. Particularly in the case of hydrology, which is concerned with time-variable parameters, it is strongly urged that a simple programme of reliable data collection be started as early as possible; it can be expanded as necessary during the project studies for feasibility evaluation, but the length of such a project (usually 3 or 4 years) is not enough to set up a network and obtain sufficient records to support a feasibility evaluation in the absence of some longer records, and as a result many studies have been inadequate in this respect. It is recognized that the activities of national hydrological services are limited by funds and staff, but at the same time the chief justification for expenditure on hydrological services is the socio-economic benefits that should follow, and it is here that producers and users of data have a common interest to ensure that the maximum benefits are obtained within the constraints of available funds and manpower. So far as hydrology concerns the agricultural sector (including land use, forestry and fisheries) FAO is always ready to answer requests for advice through its field representatives and Head Office staff.

AN EXPERIMENT ON THE SITING OF RAINGAUGES IN TROPICAL HIGHLANDS

by I.J. Jackson

ABSTRACT

Differences between the amount of rainfall measured by five gauges under very different exposure conditions are analysed. Whilst there was some indication of the influence of exposure, its magnitude, certainly for monthly totals or falls in excess of 5mm, is fairly small.

RESUME

Une analyse est faite des différences de précipitation enregistrées par 5 différents pluviomètres dont les uns sont différemment situés que les autres. On peut constater des différences dues à l'emplacement mais elles demeurent minimes, surtout si la précipitation mensuelle dépasse 5 millimètres.

INTRODUCTION

General requirements for the exposure or siting of raingauges are discussed in a number of references (e.g. Meteorological Office 1956, Middleton and Spilhaus 1953, WMO 1960). The need for a level site with the avoidance of slopes, concave surfaces or over-exposed locations is stressed. Differences between windward and leeward locations are also emphasised. In highland areas, however, it may well be impossible to satisfy the normal requirements, particularly if forest limits the number of available open sites. Under such conditions, the "representativeness" of gauges in highland areas is open to question. "Representativeness" is in any case a complex issue involving consideration of a wide range of relief scales in relation to the purpose of the study. Relief influence on rainfall varies from major mountain barriers affecting the meteorological processes producing rainfall to minor variations over distances of a few metres which influence wind flow and therefore raingauges catch at a point. It is not possible to draw firm boundaries between the various scales of relief, and rainfall at a point will reflect their combined influence. The lower end of the relief scale encompasses what may be termed local site factors and, except under special circumstances, it is desirable that the gauge catch should not reflect their influence. The influence of relief will vary greatly depending on the type of storm, wind direction and windspeed. For the generally greater rainfall intensities under tropical conditions and often lower windspeeds, it may be true to say that site factors will have less effect on gauge catch than in the case of higher latitudes.

Whilst every situation is unique, case studies may at least give some indication of the possible magnitude of local site influence on gauge catch. In April 1969 an experiment was set up in the West Usambara Mountains, north-east Tanzania, to assess the interception of rainfall by tropical highland forest. Advantage was taken of the presence of observers in the area to mount a small experiment to examine possible local relief influence on gauge catch. Results for the first eighteen months are presented here.

THE EXPERIMENT

The only instruments available were five plastic wedge-shaped gauges (brand name Tru Chek). They were mounted on posts at a height of 90cm along a line running NW - SE as shown in figures 1 and 2. The distance between gauges 1 and 5 is 400m and the difference in altitude some 65m. The aim was to select sites which were very different in character. Because of the need to avoid points which might be restricted by trees, it was not possible to find contrasting sites which were closer together. The distances between gauges 1, 2 and 3 are, however, only 20m, and between 4 and 5 only 80m. Over a distance of 400m it is likely that marked rainfall gradients which are part of more general trends rather than due to local site factors would occur. It was hoped that location of gauges along a line would allow the detection of such trends, particularly in conjunction with other nearby gauges (figure 1). The essential point is that none of the gauges would be considered to have a satisfactory exposure under the normally recognized stipulations. Gauge 1, located at the side of a track, has an upward slope of 16° to the south-east of it and a small valley on the other side (slope of 16° 30') in which is found gauge 2. Gauge 3 has a similar exposure to gauge 1 (i.e. slopes of about 16° on either side) but in the opposite direction. Gauge 4 is located half way up a steep east-facing slope. Below gauge 4 the slope is 25° and above it about 30°. Gauge 5 lies just beyond the crest of this slope.

Readings were normally taken at 9.00 a.m. each day unless it was raining, in which case reading was postponed until later. In addition, during the daytime, extra readings were taken following individual storms. Altogether, 301 individual readings, plus monthly figures, are analysed.

RESULTS AND DISCUSSION

For each reading as well as for months, the gauges were ranked from that with the highest catch (1) to the lowest (5). The number of times each gauge had a certain rank for daily or storm totals is shown in table 1, and the rank for individual months is shown in table 2. A summary of the monthly rankings is presented in table 3.

The most apparent features are: (a) that gauge 2 has the highest catch a considerably greater number of times than the rest. This seems to support previous suggestions (e.g. Hutchinson 1968) that gauges on a concave surface will tend to have higher values; (b) the adjacent gauge 1 has the highest catch on fewer occasions than the others; (c) gauges 4 and 5 have the lowest or second lowest figure on more occasions than the rest. The sums of the rankings in table 4 emphasise the higher values of gauge 2, followed by gauge 3. There does not seem to be any difference between the other three gauges when sums are compared, however.

The above results suggest that there are differences between the gauges, but it is necessary to examine the magnitude of the differences and also to see to what extent they are the result of any general trends rather than local site factors.

For daily, storm and monthly totals, the standard deviation (6) was calculated. Since the gauges were not randomly located, use of this parameter is not strictly correct. The sites were chosen in an attempt to maximise differences, and the estimate of the standard deviation could perhaps be argued to be an over-estimate. For storm and daily totals, a graphical plot of standard deviation against mean values (figure 3) showed that whilst the largest standard deviations occurred under heavy storms and the smallest tended to occur under light storms, there was a very wide scatter of points. Whilst this measure of absolute variation is important, it is perhaps the variation relative to storm size which is of even greater significance. Coefficients of variation ($\frac{\sigma}{\bar{x}} \times 100\%$) were therefore calculated. Part of the variability in gauge catch may be related to a general trend rather than local exposure. Individual readings in about 130 cases suggested that some kind of trend might exist, in most cases the evidence being a difference between gauges 1, 2 and 3 on the one hand and 4 and 5 on the other. Often, however, the differences were small and since gauges 4 and 5, on a marked slope, have a very different site from the others, it cannot be assumed that this is part of a general trend. Data from the interception study and the nearby Mazumbi raingauge suggested that only 33 readings could be considered as almost certainly indicating a trend. Storms are often of very limited extent with considerable variations in intensity over short distances. It is probable, therefore, that in some other cases the variation in rainfall was not the result of local site factors.

The remaining readings (268) were grouped into rainfall classes and the average coefficient of variation calculated for each class. A non-linear decrease in coefficient of variation (V) with increase in rainfall was apparent and the data fitted by a logarithmic expression (figure 4) using the method of least squares.

$$\log V = 1.22 - 0.50 \log \bar{X}$$

$$r = -0.90$$

$$r^2 = 0.81$$

where V = coefficient of variation

$\bar{X}$ = mean rainfall for 5 gauges

The form of the equation is the same as that found by Rigg (1960) who used, however, a slightly different parameter for relative variation. Figure 4 indicates that for a storm of 5mm, the coefficient of variation averages about 7 per cent and is less than 5 per cent on average for storms of more than 11mm. It must be stressed that within an individual rainfall class the coefficients of variation varied quite considerably.

It is perhaps useful to compare these results with those of an experiment in New Zealand indicating random variation in raingauge catch over a small site (Hutchinson 1969). Twelve gauges were randomly located over an exposed site 30' by 50', the object being to establish that there were no variations in rainfall across the site. The results showed that the site was homogeneous but that random variations in gauge catch could be considerable. The analysis was based upon data for only twenty-one storms, and on a plot of standard deviation against mean rainfall, Hutchinson inserted a regression line by eye. From this he read off standard deviations for various storm sizes. These have been converted to millimetres here and the coefficients of variation calculated. Results are shown in table 5. Unfortunately, the heaviest storm was only about 10mm, and therefore it was impossible to compare values for larger falls.

The New Zealand figures show that within the limited range covered, standard deviation varies with storm size, but that coefficients of variation do not, being of the order of 5-6 per cent. For storms of less than 5mm, coefficients of variation are less than in the case of the present study, but for larger storms there are no differences. Bearing in mind that some of the variation in the present study is almost certainly not the result of differences in exposure, this comparison suggests that rainfall differences between sites for falls of more than 5mm are no greater than those which might be expected to occur randomly over a level area.

Much of the rainfall in the area occurred under relatively heavy storms. During the first six months, 59 per cent of the total rainfall was produced by storms of more than 15mm. 40 per cent and 21 per cent of the total were produced by storms of 25mm and 50mm respectively. For such storms, the results suggest that an individual gauge is likely to give a reading which will not be influenced by local site to any marked degree. Table 6 indicates that a single gauge is likely to give a reasonable estimate for monthly totals. The higher coefficients of variation in April and December 1969 and June 1970 appeared to be the results of a general trend across the area.

CONCLUSIONS

Results from a single, small-scale experiment are obviously of only limited value and it is difficult to generalize from them. Ranking of gauges suggested that there were differences between the sites; certainly that gauge 2 tended to have higher totals. Particularly for falls of more than 5 mm and monthly totals, however, the differences are not very great and appear to be of the same magnitude as random variations in gauge catch over a uniform site in temperate latitudes. A raingauge at any of the five sites could therefore be expected to give readings which were not seriously influenced by local site factors (although, of course, a general rainfall gradient could produce very large differences between the sites).

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Table 1

Storms and daily rainfall

Number of times each gauge had a particular rank

GAUGE	RANK				
	1	2	3	4	5
1	112	52	87	28	22
2	190	21	59	24	7
3	134	56	70	18	21
4	135	45	27	77	17
5	138	36	29	83	15

n.b. When all gauges had the same catch they were given the rank 1.

Table 2

Ranking of gauges and monthly totals

Gauge	1969 - Month								
	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	3	3	3	4	3	5	2	2	5
2	2	2	5	5	2	1	2	1	3
3	1	1	4	3	1	1	1	3	[illegible]
4	5	5	2	1	5	3	[illegible]	[illegible]	2
5	4	4	1	1	4	3	[illegible]	4	1

Gauge	1970 - Month								
	Jan	Feb	March	April	May	June	July	Aug	Sept
1	5	3	3	3	3	3	[illegible]	3	5
2	3	1	2	1	1	1	1	[illegible]	1
3	[illegible]	[illegible]	1	2	2	[illegible]	[illegible]	[illegible]	2
4	1	5	4	5	[illegible]	4	[illegible]	[illegible]	[illegible]
5	2	[illegible]	5		[illegible]	5	[illegible]	[illegible]	[illegible]

Table 3

Monthly rainfall - number of times each raingauge had a particular rank

GAUGE	RANK 1	2	3	4	5
1	0	2	10	2	4
2	9	5	2	0	2
3	6	5	2	4	1
4	2	4	2	4	6
5	3	1	2	9	3

Table 4

Sums of rankings

GAUGE	Daily/Storm totals	Monthly totals
1	699	62
2	540	35
3	637	43
4	699	62
5	704	62

Table 5

Mean rainfall, standard deviation and coefficients of variation

Mean rainfall (mm)	2.5	5.1	7.6	10.2	
Standard deviation (mm)	0.13	0.23	0.41	0.64	New Zealand
Coefficient of variation (%)	5.2	4.5	5.3	6.3	New Zealand
Coefficient of variation (%)	10.5	7.3	6.0	5.2	Mazumbai

Table 6

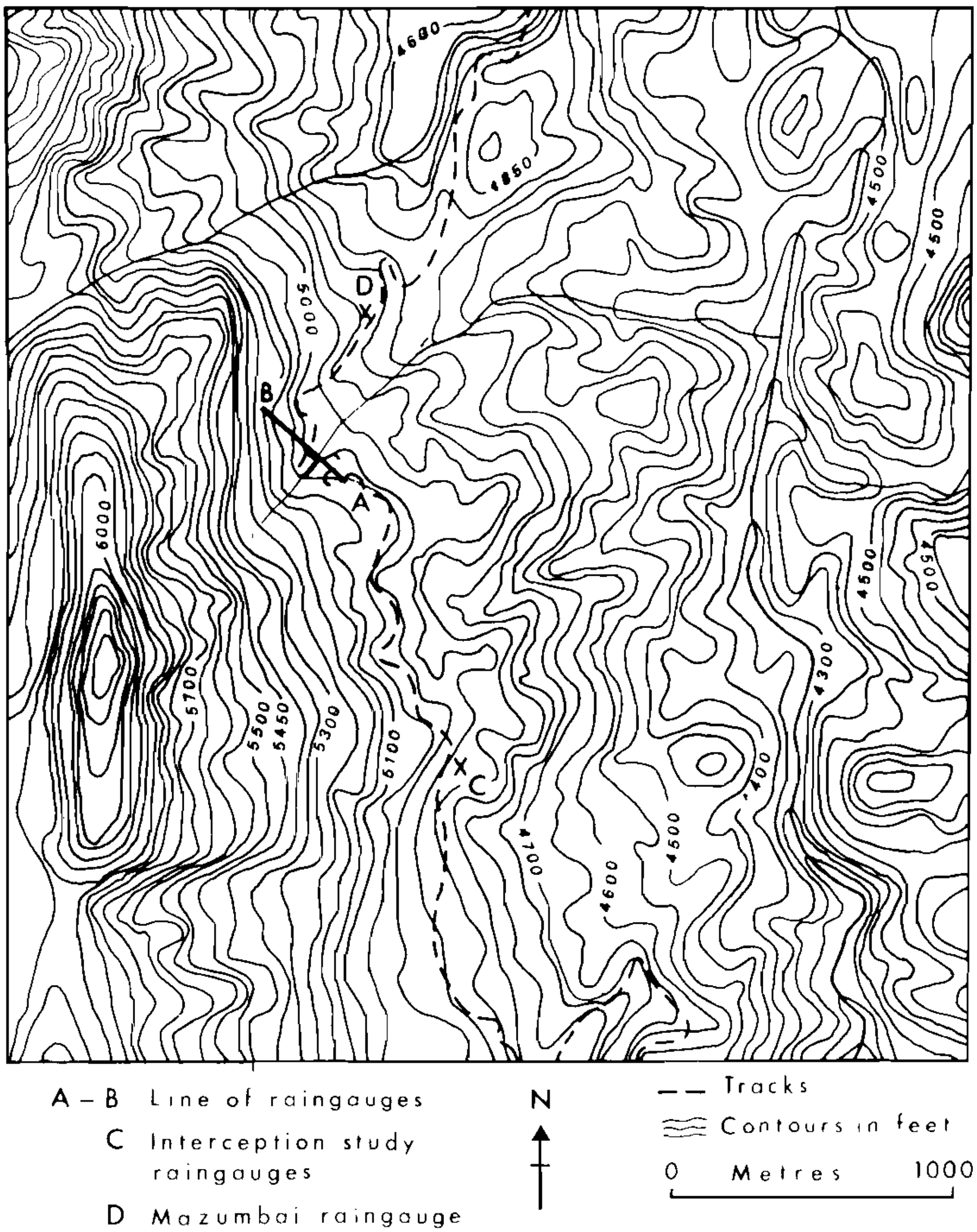
Monthly rainfall (mm) and coefficients of variation (V%)

	1969								
	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	57.9	241.7	86.9	144.4	224.1	45.5	216.9	208.9	26.2
V(%)	7.7	2.4	2.5	2.7	1.1	1.1	2.2	1.1	18.5
	1970								
	Jan	Feb	March	April	May	June	July	Aug	Sept
Rainfall (mm)	92.4	79.7	53.5	236.4	319.8	19.8	56.0	34.9	52.2
V(%)	4.9	4.9	6.0	2.4	4.9	12.3	3.6	6.3	5.6

	April - Sept 1969	Oct 1969 - Sept 1970	April 1969 - Sept 1970
Rainfall (mm)	800.5	1396.7	2197.2
V(%)	1.1	2.4	1.8

FIGURE 1

LOCATION OF RAINGAUGES



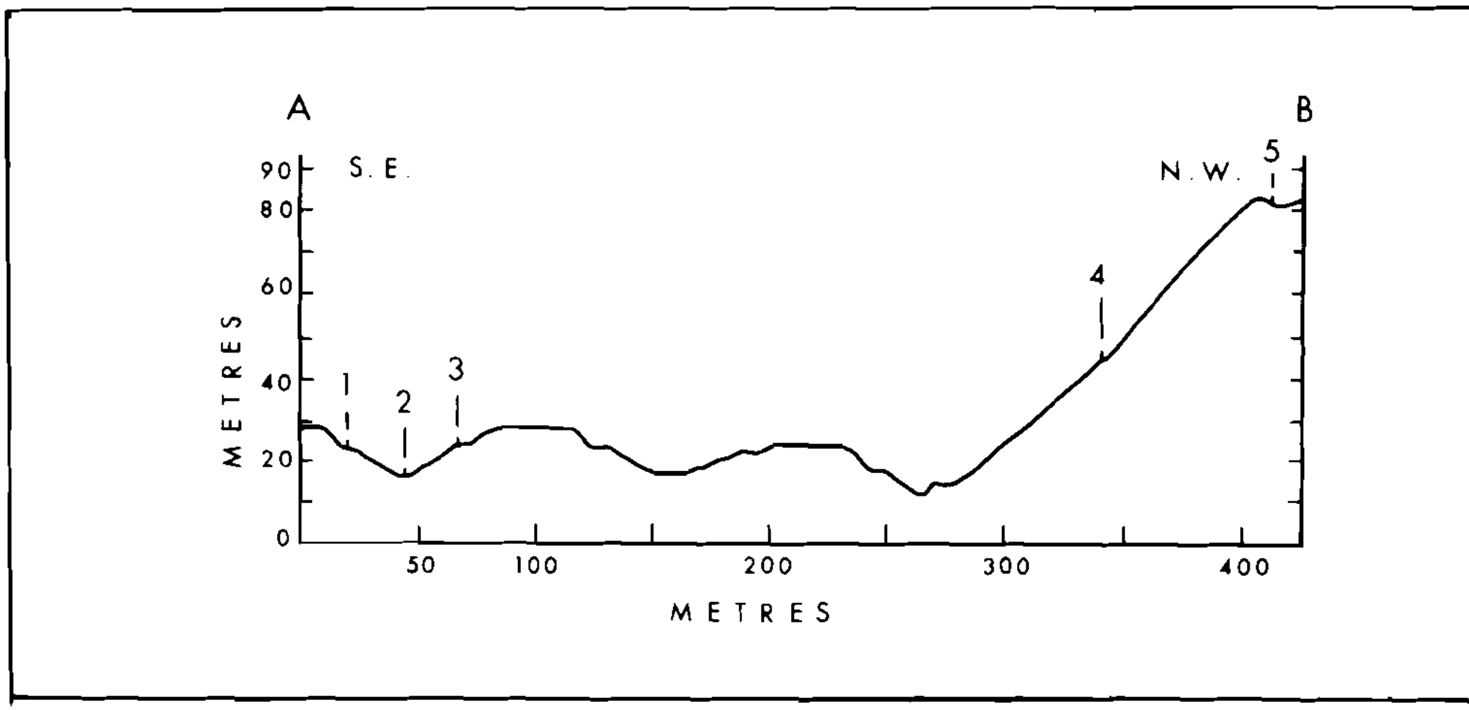
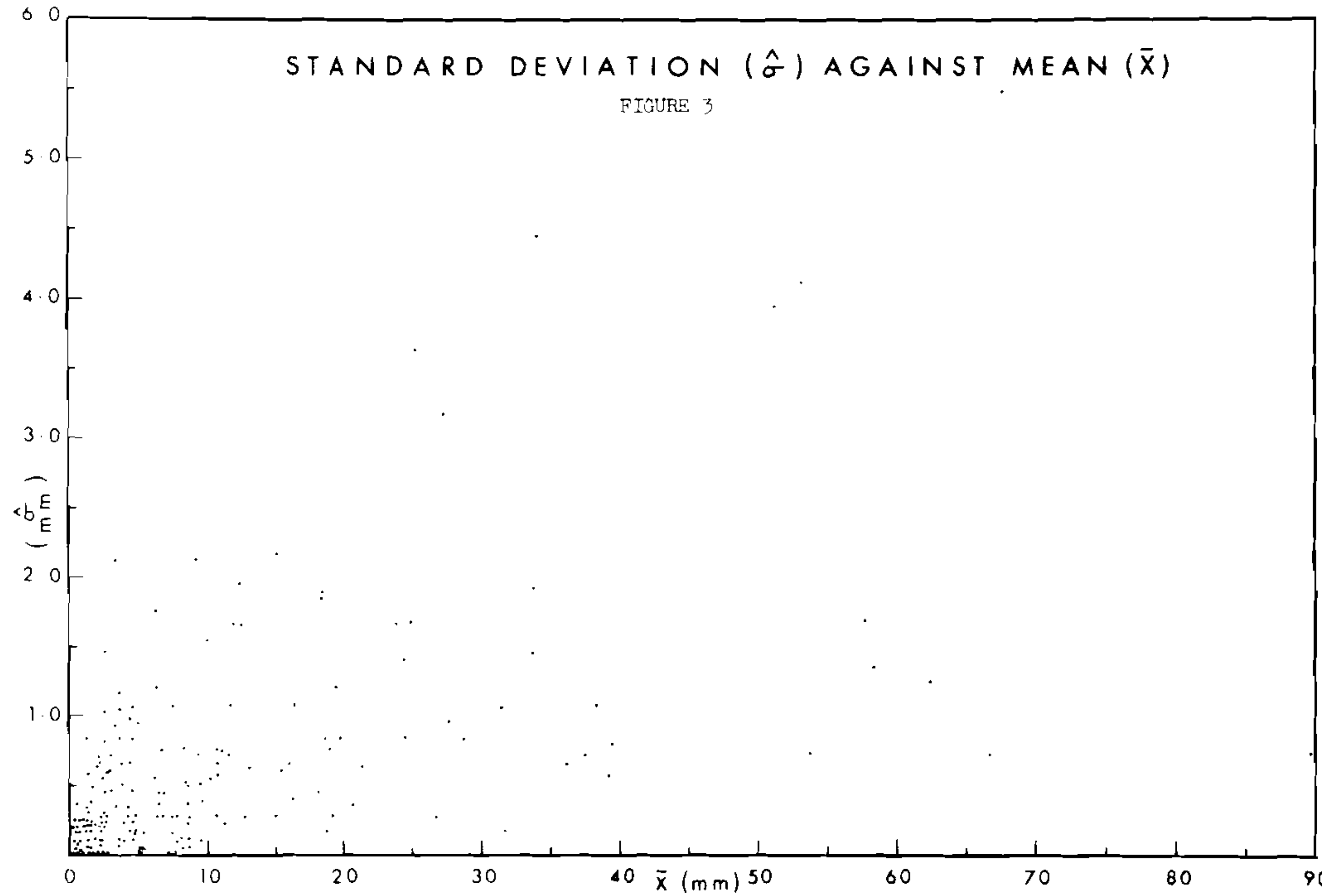


FIGURE 2

CROSS-SECTION SHOWING
LOCATION OF GAUGES


STANDARD DEVIATION ($\hat{\sigma}$) AGAINST MEAN ($\bar{X}$)
FIGURE 3
$\hat{\sigma}$ (mm)
6.0
5.0
4.0
3.0
2.0
1.0
0
10
20
30
40
$\bar{X}$ (mm)
50
60
70
80
90

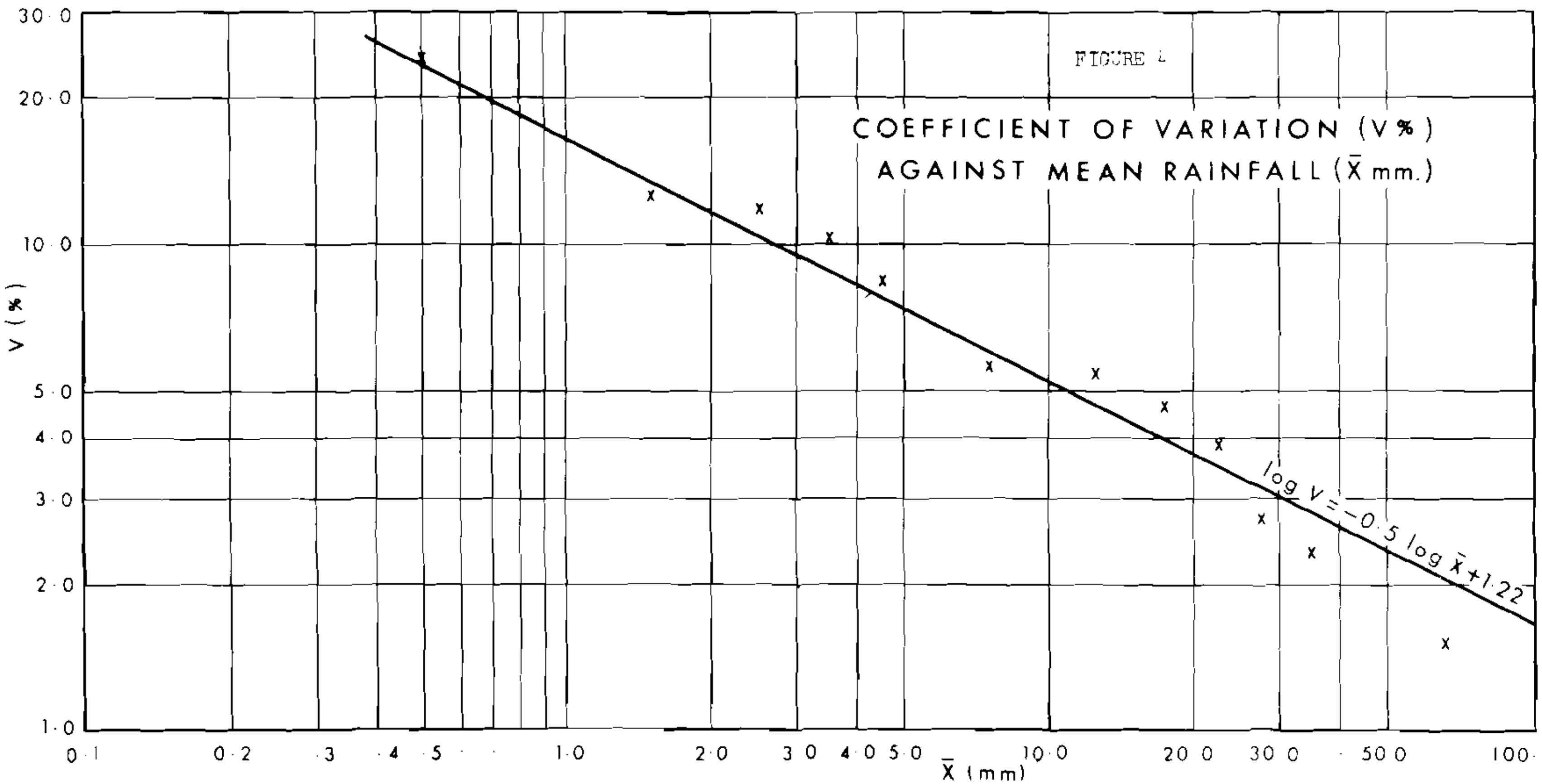


FIGURE 4
COEFFICIENT OF VARIATION (V %)
AGAINST MEAN RAINFALL ($\bar{X}$ mm.)
V (%)
$\bar{X}$ (mm)
log V = −0·5 log $\bar{x}$ + 1·22
30·0
20·0
10·0
5·0
4·0
3·0
2·0
1·0
0·1
0·2
·3
·4
·5
1·0
2·0
3·0
4·0
5·0
10·0
20·0
30·0
50·0
100·0

MEASUREMENT OF RAINFALL AND INTERCEPTION BY TROPICAL HIGHLAND FOREST

by I.J. Jackson

ABSTRACT

An experiment set up in a highland area of northern Tanzania is described. The influence of skewness and great variability of throughfall data is illustrated. For heavy storms, the large standard errors make interception estimates unreliable. The techniques of analysis adopted have a considerable influence on interception estimates.

RESUME

On décrit une expérience faite dans une région de montagnes du nord de la Tanzanie. On souligne les conséquences des irrégularités statistiques et de la grande variabilité dans la quantité de pluie qui n'est pas arrêtée par les obstacles naturels. Pendant les grands orages, à cause de l'accroissement de la marge d'erreur, il est difficile de calculer la quantité de pluie qui n'atteint pas le pluviomètre. Différentes méthodes d'analyse peuvent mener à différentes estimations de la quantité de pluie interceptée.

INTRODUCTION

Most of the detailed studies of rainfall interception have been conducted in temperate latitudes (e.g. Wilm and Niederhof 1941, Law 1957, Reynolds and Leyton 1961, Rutter 1963), although some work has been carried out in the tropics (e.g. Freise 1936, Vaughan and Wiehe 1947, Hopkins 1960, Wimbrush 1947, Pereira 1952). Results of studies have been summarised by Kittredge (1948) and Geiger (1965).

In order to investigate aspects of interception ofrainfall by tropical highland forest, an experiment was set up in the West Usambara Mountains, north eastern Tanzania in March 1969. This paper summarises the problems involved in measuring and processing the data for the first six months. A more detailed analysis together with preliminary results is presented elsewhere (Jackson 1971).

SITUATION AND EXPERIMENTAL SITE

The experiment was set up in a forest reserve belonging to the University of Dar-es-Salaam (lat. 4° 50 S, long. 38° 30 E) which covers an eastern facing slope ranging in altitude from about 1300m in the east to about 1800m in the west. The experimental site is at an altitude of 1,500m. Moreau (1935) describes the vegetation as an Intermediate Evergreen Forest Community, the most luxuriant type of forest existing in East Africa. The mean annual rainfall at the nearby Mazumbai rain gauge is 1338m.

Throughfall was measured using twenty standard five inch rain gauges randomly located on an 80' x 80' grid. The great variability of throughfall distribution necessitates a considerable number of gauges. Discussions of types of gauge, numbers and techniques can be seen in Reynolds and Leyton (1961), Helvey and Patric (1965), Rieley, Machin and Morton (1969).

The use of troughs rather than rain gauges presents problems in terms of construction, shape, bias, reading and comparison with standard rain gauges (Helvey and Patric 1965). Shifting gauges periodically to new random locations has the effect of reducing the standard error if observations under different locations are grouped together. For practical reasons, it was not possible to shift gauges until after six months of observation and the majority of the data analysed here refer to this first period. One of the major purposes of the investigation was an analysis of interception under individual storms and shifting of gauges would play no part in reducing the standard error for these.

Stemflow was measured for twenty trees by means of spiral gutters of a fabric and bitumen compound leading into plastic containers. The gutters projected 4cm from the tree trunks. Helvey and Patric (1965) recommend that stemflow should be measured for plots rather than for individual trees. Five plots consisting of three to five trees were selected whose total crown area could be defined reasonably clearly. Fourteen different tree species were represented.

Incident (gross) rainfall was measured on an adjacent open site. The clearing was about 70m square and within it, an area of 15m square was cleared of vegetation and four standard five inch rain gauges and a Dines tropical recording gauge were mounted. Previous work (e.g. Pereira et al. 1962) suggests that a clearance angle of 45° is adequate for rain gauges. All the gauges were very slightly restricted over a small arc of 1° or 2°. The direction of restriction was different for each gauge and, since it was very slight, it was felt that an average of the four gauges would provide a meaningful estimate of the clearing fall. The close agreement of the four gauges supported this. Reynolds and Leyton (1961) point out that presentation of standard errors for gauges in an adjacent open site is not necessarily sufficient since there may well be differences in falls between the clearing and the canopy site. Measurement of rain incident upon the canopy itself, however, poses considerable problems. In the present study, apart from the problems of turbulence and type of gauge for measurements of rain actually falling on the canopy, the height and variety of trees excluded the possibility of mounting gauges above the canopy. Location of clearing gauges on opposite sides of the canopy gauges would have helped to identify errors due to rainfall gradients over the site. Within the forest reserve, however, only one clearing of sufficient size was available. The distance from the edge of the clearing to the canopy network is 45m and since there is no marked difference in the terrain, it was felt that the clearing gauges would give a reasonable estimate of the fall on the canopy.

Readings were normally begun at 8.00 a.m. every day. If it was raining at the time, or if a shower had occurred a short time before, then reading was postponed. Other studies and personal observation suggested that a delay of at least two hours was advisable between the end of a storm and reading to allow for drip from leaves to end. In addition to the morning reading, measurements were taken after every storm whenever possible. Out of more than 120 readings, some 75 per cent included rain from only one shower.

PROBLEMS OF ANALYSIS

A number of problems emerged. These are outlined below and then their impact illustrated in the following section.

1. Drip points and relation of gauge catch to distance from tree stems. Rutter (1963) discussed the existence of drip points near tree stems and avoided the problem of high gauge totals by keeping them at least 15cm from the trunks. Anderson et al. (1969) omitted high readings which were regarded as drip points, although no specific location was mentioned. Particularly under the varied cover in the present experiment, drip points will occur irregularly and their definition is very subjective. Omission of certain high values was not therefore considered justified. Previous studies have found a relationship between throughfall gauge catch and distance from tree stems (e.g. Reynolds and Leyton 1961). This relationship can be used to help estimate throughfall. No such relationship was apparent here, this being attributable to the variety of trees and interlocking nature of their crowns.

2. Skewness of throughfall gauge catch. The catch distribution forindividual storms indicated a tendency towards skewness and tests indicated that 25 per cent of the distributions differed significantly from normal. It should be noted, however, that while tests indicate skewness, they do not prove that a distribution is normal, merely that it could be normal. The arithmetic mean is normally used as a throughfall parameter but an element of skewness makes it less valid. Both median values and a square root transformation average were therefore also examined. The positive skewness of the data was indicated by the median being less than the average in nearly every case. Transformation tended to reduce the throughfall parameter although not so much as in the case of the median.

3. Errors in throughfall and interception estimation. The standard error of the mean is the most useful parameter to indicate accuracy of the estimates and despite an element of skewness in throughfall data this value was calculated. It is common practice in interception studies to express the standard error as a percentage of mean throughfall. Whilst this is useful, it can be rather misleading, particularly from the point of view of interception estimates. Standard errors of gross rainfall were negligible compared with those of throughfall, being less than 0.1mm in all but fifteen cases. Stemflow amounts were small, amounting to only 1 per cent of gross rainfall over the six-month period. The interception estimate error may therefore be regarded as that involved in throughfall assessment and, in this case, absolute values of the error are most meaningful. To illustrate this, standard errors may be compared with interception estimates using individual storms as examples. Values of two standard errors (i.e. 95 per cent confidence limit) are used.

Whilst the percentage standard error for a small storm of say 1.8mm is large (22.7 per cent), two S.E. (0.17mm) is small compared with interception (1.5mm). A large storm of 30.9mm with a percentage standard error of 7.8 had a large absolute error (2 S.E. = 4.81mm) with an interception value of 1.9mm. For large storms therefore, whilst the throughfall percentage standard error is less than in the case of small storms, in absolute terms, it is large compared with interception values. Interception estimates for large storms therefore are unreliable.

4. The relation between gross rainfall, throughfall and interception. It is general practice to relate throughfall and interception to gross rainfall, Helvey and Patric (1965) pointing out the advantages of using regression techniques for this purpose. Since throughfall is of the same order of magnitude as gross rainfall, the relationship between them appears to be linear (Figures 1, 2). The relationship between gross rainfall and interception is not a linear one (Figures 3, 4), the graphs illustrating also the range in interception for particular storm categories. Assessments of interception for various gross rainfall amounts using these relationships, differ from one another.

THE IMPACT OF THESE PROBLEMS UPON INTERCEPTION ESTIMATES

Analysis of throughfall and interception in relation to gross rainfall was carried out using both arithmetic means and median values (Figures 1-4). For arithmetic means in the case of large storms, throughfall estimates may be as great or greater than gross rainfall. The problems of skewness of data and large standard errors for large storms are relevant here. Even using median values for heavy storms, in a few cases, throughfall was greater than gross rainfall and differences in other cases were small. Regression lines for throughfall against gross rainfall had gradients greater than one (equations 1 and 2), implying that the greatest interception was for low falls.

Equation 1: using the arithmetic mean

$$y = 1.0672x - 0.88$$

Equation 2: using median values

$$y = 1.0067x - 0.99$$

where
y = throughfall
x = gross rainfall

This illustrates the impact of the large standard errors associated with heavy storms, which mean that throughfall estimates may be greater than gross rainfall. In view of this, regression lines for storms of less than 20mm were also calculated (equations 3 and 4).

Equation 3: using the arithmetic mean

$$y = 0.9639x - 0.54$$

Equation 4: using median values

$$y = 0.8802x - 0.56$$

Interception values for various storm sizes were calculated from these equations (table 1). Although not strictly valid, interception estimates for falls of more than 20mm are included.

Plots of interception against gross rainfall (Figures 3, 4) indicate that for moderate falls of up to about 12mm, particularly when median values are used, there is an increase in interception although even within this range the points are scattered. For heavy falls, however, this relationship breaks down and a noticeable feature is that interception figures for falls of over 20mm are often less than for falls of 5-10 mm. For storms of up to 20mm, the data were grouped into gross rainfall classes and the average interception for each class was calculated. The data were fitted by a semi-logarithmic curve (eq. 5, Figure 4b).

Equation 5: using median throughfall values

$$\text{Interception} = y = 0.896 \log(\text{gross rainfall}) + 0.765$$

$$r = 0.823$$

$$r^2 = 0.677$$

Estimates of interception for various storm sizes were calculated from equation 5 and presented in table 1. Comparison of interception estimates from the three equations (table 1) shows that estimates from equation 5 are greater than those from equation 3 but whilst greater than those from equation 4 for falls of up to 7.5mm, they are less for heavier storms. For a storm of 2.5mm, the estimated percentage intercepted varies between 24 per cent and 44 per cent depending upon the technique used. For a fall of 20.0mm, the percentage varies from 6.5 per cent to 15 per cent.

It is apparent therefore that the techniques of analysis considerably influence the results obtained. An important point to be borne in mind is that interception for particular gross rainfall amounts varies considerably from case to case (Figures 3,4). This is to some extent due to the fact that here not all the data relate to individual storms (only 75 per cent). Interception from a single storm is likely to be less than that from two or more storms producing the same total. This is an even greater problem for studies where readings are taken only at daily intervals or even longer ones. This is, however, only one aspect. Intensity and duration of storms, the intervals between storms, their time of occurrence (both the latter influencing the evaporation of intercepted water), and wind conditions are all likely to influence the amount of interception. One purpose of the present study is to attempt an analysis of their influence, together with rates of evaporation of intercepted water.

For longer periods the considerable impact of the techniques of analysis can be seen. During two ten-day periods, 1-10 May, 29 August - 7 September 1969, use of arithmetic mean throughfall gave interception estimates of 2.3 per cent and 7.6 per cent. Use of median values, however, produced interceptions of 12.0 per cent and 21.8 per cent respectively. The fact that interception is not related simply to gross rainfall over a period is demonstrated by the following figures. 103.6mm fell during the period 31 May - 9 June, of which 15.6 per cent was intercepted (using median values). Similar total falls for two other ten-day periods had only about a 6 per cent interception rate. Of 28.1mm occurring between 11-20 April, 40.6 per cent was intercepted, whilst during the 19-28 August, only 11 per cent of 24.6mm was intercepted.

An important point is that interception values over, say, ten-day periods include estimates for heavy falls which have been shown to be of doubtful validity. In view of this, values of interception derived from equation 5 were substituted for storms greater than 20mm. Whilst it is generally inadvisable to extrapolate beyond the range of values used to determine the regression (20mm in this case), it is reasonable to assume that interception is unlikely to show a decrease beyond this point. Since interception estimates from equation 5 show only a slight increase for storms above 20mm, these figures will at least represent minimum values. For periods when heavy storms occurred, use of estimates for storms above 20mm raised the percentage intercepted. Two examples are shown in table 2.

For the six-month period April - September 1969, the percentage intercepted ranges from only 4.2 per cent if arithmetic mean throughfall values are used to 11.9 per cent if median values are used, and 15.6 per cent if an estimate for storms of more than 20mm is used. Use of an estimate from equation 5 for all storms rather than just those over 20mm produced a figure of 16.3 per cent.

CONCLUSIONS

The problems of assessment of throughfall and interception in the present study are considerable both in terms of measurement and analysis. The large standard error of throughfall gauge catch makes interception estimates for heavy storms unreliable. A further problem in terms of data analysis is the tendency for throughfall distributions to be positively skew. This has a bearing on the validity of the standard error. It also results in the particular mean parameter used having a considerable effect upon interception estimates. The techniques of analysis adopted considerably influence the results obtained. The unimportance of stemflow means that this element has little or no impact upon interception estimates.

These problems are particularly noticeable in the tropics where large storms contribute a fairly high proportion of the total rainfall. During the first six months of operation of the present study, 59 per cent, 40 per cent and 21 per cent of the total rainfall was produced by storms of more than 15mm, 25mm and 50mm respectively.

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Table 1

Gross rainfall and interception estimates

Gross rainfall (mm)	1.0	2.5	5.0	7.5	10.0	15.0	20.0	30.0	40.0
Interception (mm)									
Equation 3	0.6	0.6	0.7	0.8	0.9	1.1	1.3	1.6	2.0
Equation 4	0.7	0.9	1.2	1.5	1.8	2.4	3.0	4.2	5.4
Equation 5	0.8	1.1	1.4	1.6	1.7	1.8	1.9	2.1	2.2
% Interception									
Equation 3	60.0	24.0	14.0	10.7	9.0	7.3	6.5	5.3	5.0
Equation 4	70.0	36.0	24.0	20.0	18.0	16.0	15.0	14.0	13.5
Equation 5	80.0	44.0	28.0	21.3	17.0	12.0	9.5	7.0	5.5

Table 2

Interception estimates for two ten-day totals

	20-29 July 1969	9-18 August 1969
Gross rainfall (mm)	101.6	103.5
% Intercepted:		
(a) mean	0.9	-*
(b) median	6.3	6.0
(c) using estimates for storms > 20mm	15.5	10.0

*'negative' interception, i.e. throughfall > gross rainfall.

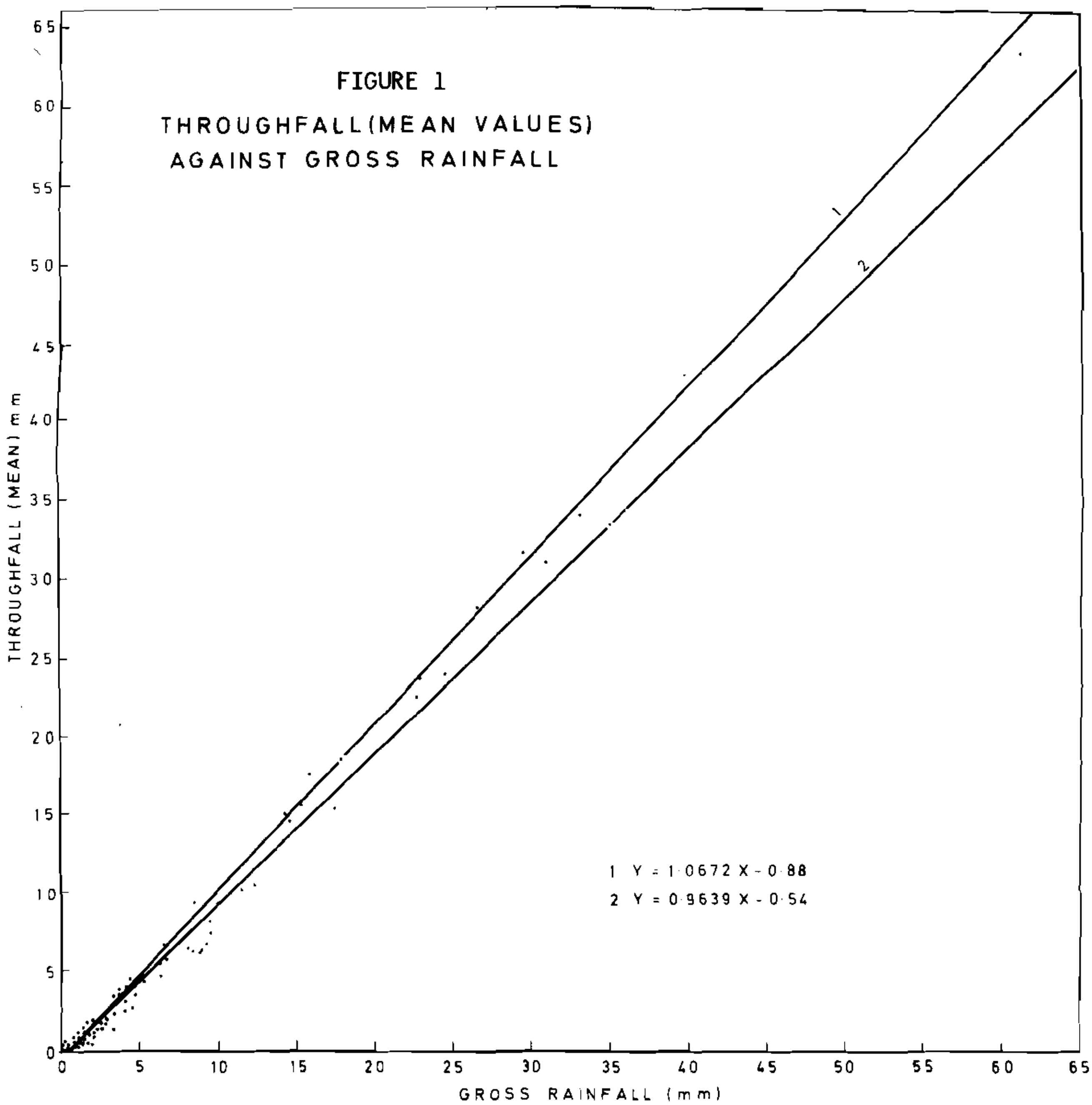
FIGURE 1
THROUGHFALL(MEAN VALUES)
AGAINST GROSS RAINFALL
1 Y = 1·0672 X - 0·88
2 Y = 0·9639 X - 0·54
THROUGHFALL (MEAN) mm
GROSS RAINFALL (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65

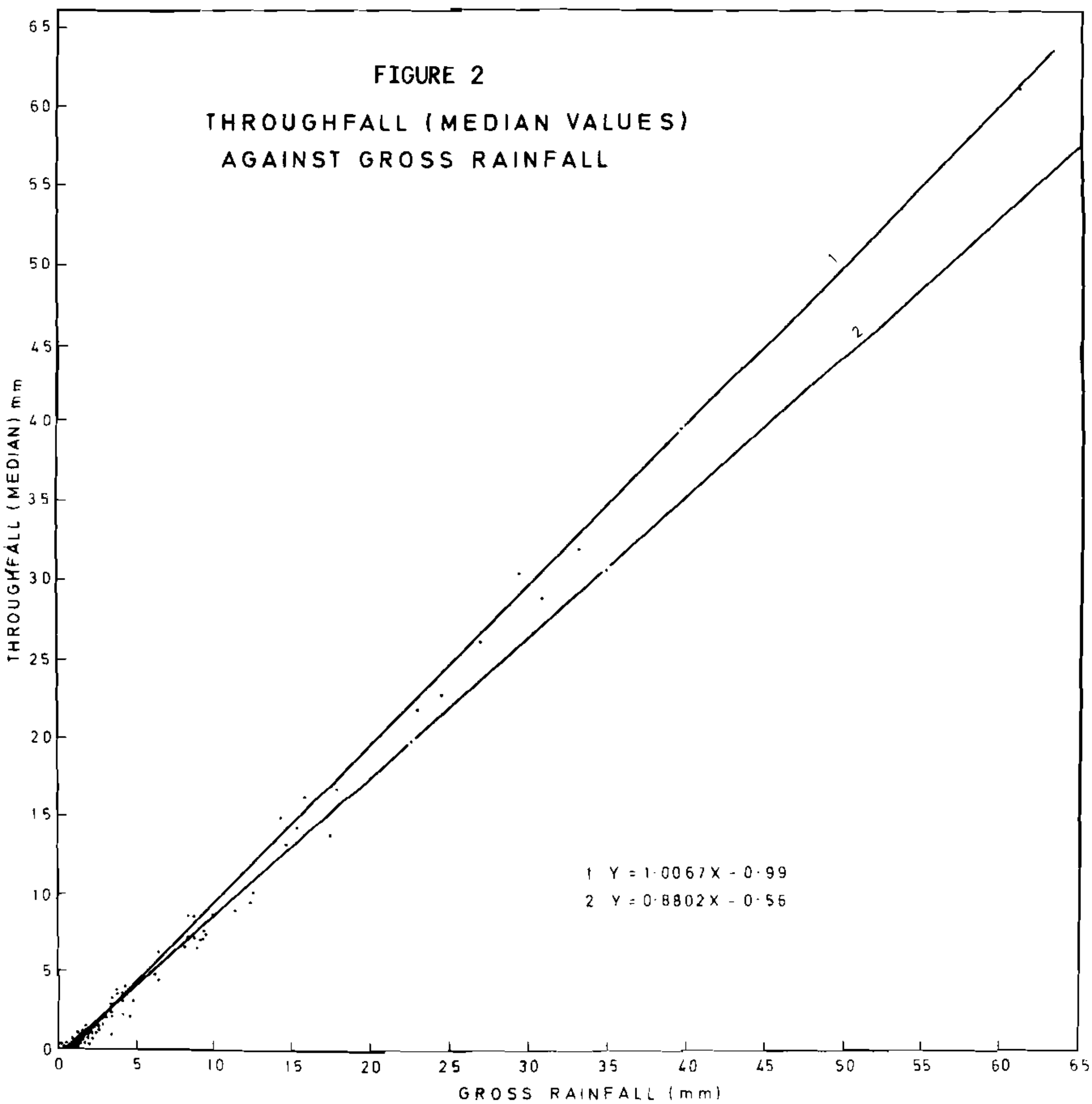
FIGURE 2
THROUGHFALL (MEDIAN VALUES)
AGAINST GROSS RAINFALL
1 Y = 1·0067X - 0·99
2 Y = 0·8802X - 0·56
THROUGHFALL (MEDIAN) mm
GROSS RAINFALL (mm)
0
5
10
15
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55
60
65

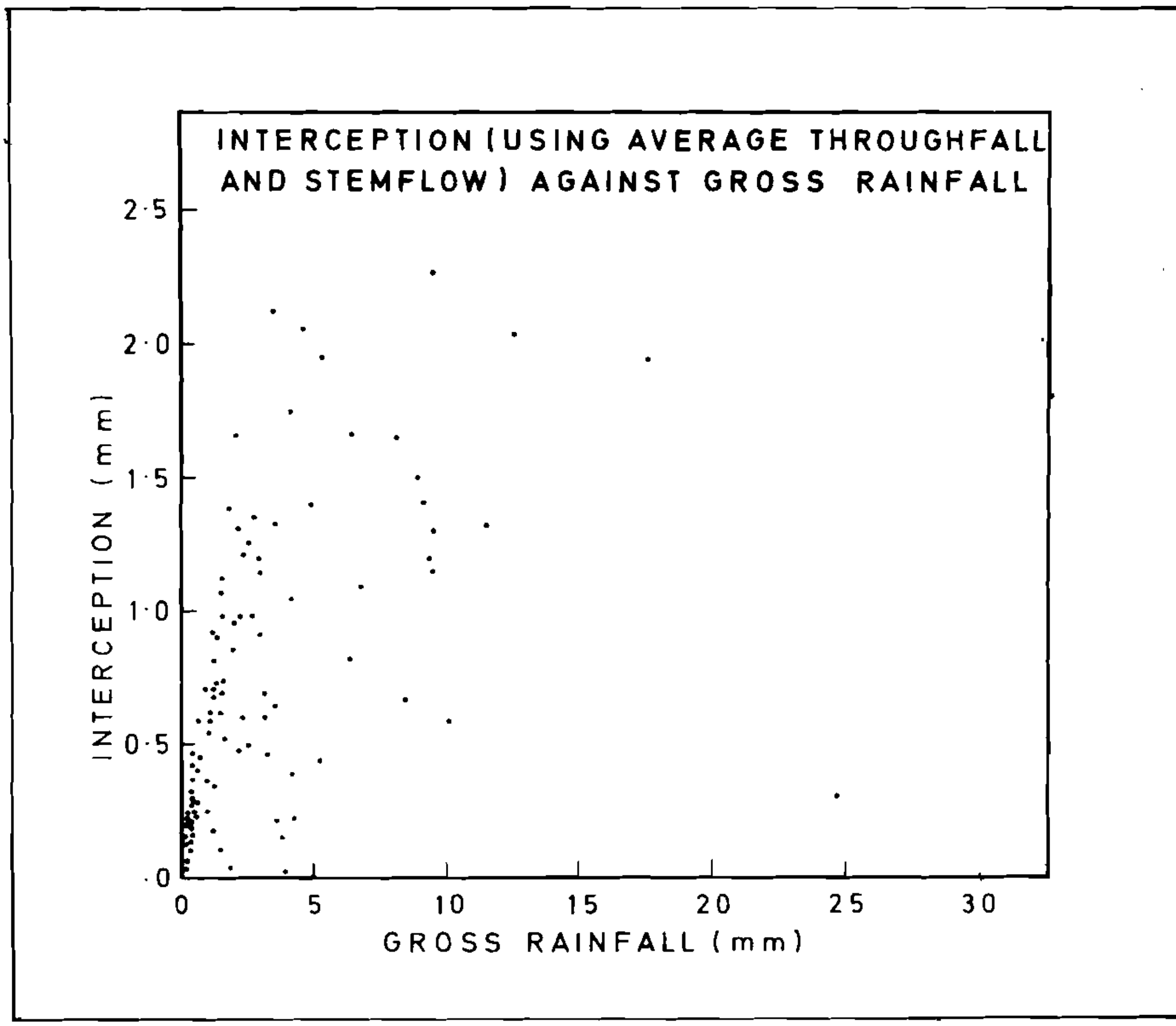
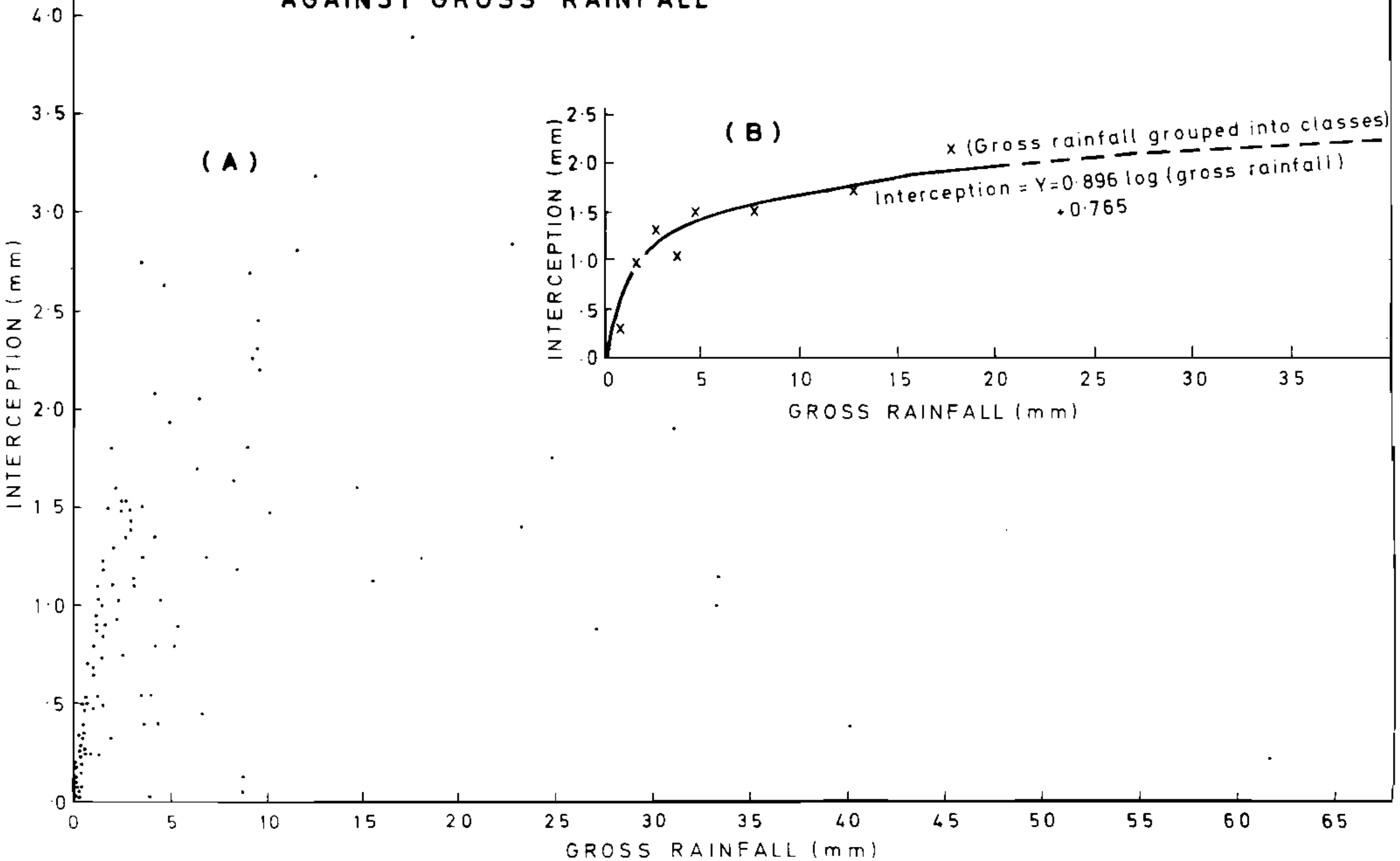


Figure 3: Interception (using average throughfall and stemflow) against gross rainfall.

FIGURE 4 - INTERCEPTION (USING MEDIAN THROUGHFALL AND STEMFLOW) AGAINST GROSS RAINFALL



THE SIGNIFICANCE OF ISOTOPE TECHNIQUES IN THE DEVELOPMENT OF GROUNDWATER RESOURCES IN AFRICA

by T. Dincer, L.O. Asseez

ABSTRACT

The report presents a few of the fundamentals of the principles and practices of the application of isotope techniques to hydrology. A few case histories of such applications to groundwater resources in developing African countries are described. With the present ever-increasing gap between the developed and developing countries it is recommended that the application of isotope techniques to groundwater exploration in African countries is the surest way to the procurement of adequate water resources, which is the most important requirement for a rapid socio-economic advancement.

RESUME

Le présent rapport expose quelques principes et pratiques concernant l'application de techniques isotopiques à l'hydrologie. On y trouvera quelques exemples de l'application de ces techniques aux ressources d'eaux souterraines dans des pays africains en voie de développement. Eu égard au fossé toujours plus grand qui sépare les pays développés des pays en voie de développement, on recommande l'application des techniques isotopiques à la prospection des eaux souterraines dans les pays africains comme étant le moyen le plus sûr de se procurer des ressources en eau suffisantes, première condition d'un développement socio-économique rapide.

INTRODUCTION

The rapid economic development as well as drastic political changes in many developing countries witnessed since the second world war have resulted in unprecedented need for water for world population and stimulated spectacular national and international projects for water resources development. For developed industrial countries the need is as acute as in developing countries. While in the former emphasis is placed on industrial uses and pollution control and scientific research, developing countries have different priorities for water use and control, among which are:

(a) Water for domestic use;

(b) Water for irrigation;

(c) Flood control;

(d) Water for industrial uses and hydro-power development.

Hydrology, which was not even considered as an independent scientific discipline a couple of decades ago and was taught as a part of engineering hydraulics, developed into an earth science and is now included in the curricula of many universities to meet the demand for the development of surface and groundwater resources. New methods have been introduced such as radar measurement of precipitation, infra-red photography, mathematic and electric analog models and the use of nuclear instruments and the use of artificial and natural isotope tracers for studying the occurrence and the movement of water on our planet. All these developments were the result of new discoveries made in physical sciences and precise measurement techniques. The methods based on the use of nuclear techniques are among the more recent and promising ones, although most of the work was done in the past decade.

NUCLEAR TECHNIQUES IN HYDROLOGY

These methods can be classified in the following way:

(a) Instrumental techniques using nuclear radiation for the measurement of soil moisture and density, the water content of the snow cover, sediment concentrations in rivers, aquifer properties (radio-logging).

(b) Tracer techniques using stable and radio-isotope tracers to study the velocity, discharge and in general the movement of water both surface and underground. These techniques can be further classified into two major groups, which are:

Artificial radioactive tracers used in the measurement of stream discharge, hydrodynamic dispersion, bed-material transport and sand movement studies in rivers, estuaries and, in coastal areas, movement of water in the unsaturated zone, velocity and direction of groundwater movement and the determination of aquifer parameters such as effective porosity.

Environmental isotopic tracers which occur in nature or are produced by cosmic rays and by thermonuclear devices. Tritium, a radio-isotope of hydrogen, radio-carbon, and the stable isotopes deuterium and oxygen-18 are in this important group. Recent advances in analytical techniques have made it possible to determine precisely the concentration of these isotopes in surface and groundwaters.

Tritium is mostly used in infiltration and groundwater recharge studies and in shallow groundwater bodies with relatively short turnover times (of the order of decades). Tritium pulses added to the atmosphere by thermonuclear testing devices have found a peaceful use by raising the tritium content of the precipitation by several orders of magnitude compared to the cosmic ray production of natural tritium, and by giving to the hydrologist the opportunity of monitoring these pulses in groundwater for several decades to come.

For groundwaters moving very slowly, carbon-14 can be used to determine transit or residence time of water in aquifers. When the piezometric conditions are known, the information on the transit time of water between two points in the aquifer can yield valuable data concerning the permeability of an aquifer over large areas. Although radio-carbon dating of water is not as simple and straightforward as dating solid carbon or carbonate species, owing to the interaction of water with carbonate rocks, adjustment techniques have been developed to overcome these difficulties.

Deuterium and oxygen-18 are incorporated in the water molecule like tritium. Depending on the seasons, distance from oceans and altitude, the stable isotope content of the precipitation varies and labels water infiltrating to the soil. Evaporation causes the isotopic enrichment of water in lakes and reservoirs. The study of these natural variations of stable isotopes is useful to determine the altitude of recharge of groundwater bodies, the relations between surface and groundwaters, and the water balance of evaporating water bodies.

Although all nuclear methods require the use of precision instruments and techniques to be applicable and successful, the use of these modern techniques offers tremendous advantages over the conventional techniques in the rapid evaluation and development of water resources, especially those related to groundwater. The detection of measurable tritium in a groundwater body, for example, is an indisputable sign of relatively rapid turnover - hence of active recharge - in the aquifer. Such a measurement can be made by collecting a water sample from a well or from a spring and sending it to tritium laboratories, which are becoming more and more numerous every year. The stable isotope content of groundwater can give valuable information concerning its relation with surfacewater bodies and the neighbouring aquifers. The vertical tritium profile in the unsaturated zone is useful for calculating annual infiltration and recharge, which would be difficult to estimate with conventional techniques.

Depending on the case studied, the complexity of the problem and the hypotheses to be tested, environmental isotope investigations can be simple or extensive. The isotopic composition of a single groundwater sample can sometimes give a definite answer. A well-planned areal and time sampling programme would be necessary to cover more complicated situations.

EXAMPLES OF ISOTOPE APPLICATIONS IN AFRICA

In recent years, a number of environmental and artificial isotope applications have been made in Africa within the framework of the United Nations Development Programme Special Fund Projects and of the bilateral agreements between European universities and African countries. Many of these projects are still in operation and can be considered as prioneering work in the field of isotope applications in hydrology. Results of such isotope investigations have already provided large amounts of hydrological information, a few of which are cited hereunder:

(a) Investigations of groundwater resources in northern Sahara (Environmental isotope investigations by the International Atomic Energy Agency, project executed by UNESCO within the framework of UNDP): The purpose of this project is to investigate the huge groundwater body underlying northern Sahara in the Nubian Sandstone (Continental Intercalaire and Continental Terminal). The early stable isotope data show a wide range of variations which can be very useful in understanding the relation between different aquifers and their respective recharge conditions.

The carbon-14 measurements made by the University of Bonn, Federal Republic of Germany, in a bilateral agreement with the State Hydraulic Services of Tunisia have also given extremely interesting results, and have shown that the water, even in the deepest aquifers, contains measurable amounts of carbon-14. Some shallow aquifers even contain recent water which has infiltrated into them during the last decades. These results are encouraging for the development of groundwater resources in the northern Sahara, especially in the region of Gabes, where most of the samples were collected. The environmental isotope studies undertaken by IAEA covering the northern Sahara as a whole are still in progress and will undoubtedly answer many problems related to the recharge, movement and interrelation of groundwater in the northern Sahara.

(b) Water resources of the Hodna Basin, Algeria (UNDP Special Fund Project executed by FAO, environmental isotope studies by IAEA): The groundwater investigations made within the framework of this study include a thorough isotopic survey of the shallow and deep groundwater in the Hodna Basin, and the limestone aquifers in the eastern parts of the basin. Problems such as the areas of recharge of these aquifers, rates of recharge, possible interrelation between the deep and shallow aquifers are to be solved. The stable isotope content of the groundwater, together with its tritium and carbon-14 content, provides a unique tool for the solution of these problems. First results have been very satisfactory and helpful for the understanding of the groundwater recharge and movement, and their interrelation.

(c) The water supply project of Dakar, Senegal (UNDP Special Fund Project executed by WHO, environmental isotope investigations by IAEA): The project includes the study of groundwater resources in the peninsula of Cap-Vert. Considerable work has been done using conventional methods by the BRGM (Bureaux de Recherches Géologiques et Minières) of Senegal (1). The WHO project supersedes this work and includes a major component of environmental isotope studies. The most important aquifers in the region are: the sub-basaltic sandy aquifer; the sandy aquifers of the dune region north of Dakar; the deep and shallow Maestrichtian aquifers; the limestone aquifers bordering the outcrops of the Maestrichtian formation.

Early results of tritium and stable isotopes content of groundwater in these aquifers have given most valuable indications on their rate of recharge and the inter-relations between different aquifers. The isotopic study is still in progress. Final results of this study will show whether the hydrogeological hypotheses based on conventional techniques are valid or not.

Due to the importance of the deep Maestrichtian aquifer which underlies the whole country, IAEA also initiated an extensive environmental isotope study of this aquifer. The study is conducted by the BRGM of Senegal and financially assisted by IAEA within the framework of a research contract.

(d) Study of the Chad Basin (First UNDP project executed by UNESCO, isotope measurements by the University of Groningen and IAEA; second UNDP project executed by FAO, isotope studies by IAEA): The hydrological study undertaken by UNESCO was of a reconnaissance type involving collection and synthesis of available hydrologic data (2). The basic work on the hydrology of Chad Basin has been done by ORSTOM (Organisation de Recherches Scientifiques et Techniques d'Outre-Mer) (3, 4).

These studies include the isotopic survey of Lake Chad and the bordering regions done by ORSTOM in co-operation with the University of Paris (5, 6). The environmental isotope survey of the Chad Basin by UNESCO, which also introduced the infra-red technique to the project, is remarkable by its size and variety of the isotopic analyses (deuterium, oxygen-18, tritium and carbon-14 and carbon-13) (2) Figure 1). However, the effort spent on the interpretation has not been proportional to the impressive amount of isotope data collected.

One of the main problems in the Chad basin is the explanation of the water and salt balance of Lake Chad, which has no surface outflow. It is surprising therefore that Lake Chad, being situated at the middle of a large closed basin and seemingly its ultimate outlet, is not saline. Studies made by ORSTOM (3) attempted to explain this fact by the seepage of lake waters to the bordering permeable formations, without saying, however, what happened next; i.e., their ultimate outlet. Such a hydrological problem can best be studied by the stable isotopes of hydrogen and oxygen, as most lake water is enriched with respect to these isotopes. The oxygen-18 content of Lake Chad is in fact enriched considerably and is isotopically heavier than the precipitation and groundwater in the Chad Basin. The hypothesis of seepage therefore can easily be verified by collecting groundwater samples from the suspected regions of seepage and compare their isotopic composition to that of the lake. In fact, oxygen-18 data collected by UNESCO (2) indicate that lake waters can be present along the Bahr-el-Gazal and in the Bodele depression where the water tables are lower than the surface of the lake. The isotope data so far obtained favour the hypothesis of seepage from the lake and Bodele depression being the ultimate of outlet of lake and groundwaters in the Chad Basin. This point is also confirmed by infra-red photography, which indicates that Bodele depression is a large transpiration and evaporation area, although the precipitation over the Bodele depression is almost negligible.

The problems related to the rate of recharge and movement of groundwaters in the Chad Basin have also been solved with the use of tritium and carbon-14. In many wells, tapping the shallow aquifers, measurable quantities of tritium have been found. In some wells the tritium and carbon-14 content of the water indicates the presence of water recharged since 1952, when the thermonuclear testing started.

The deep groundwater body west of the lake does not contain measurable quantities of carbon-14, indicating that this aquifer was recharged at least 40,000 years ago.

The environmental isotope study which is at present being conducted by IAEA has the purpose of complementing the data collected by UNESCO, correct the inconsistencies found between tritium and carbon-14 data in some wells and to interpret thoroughly all isotope data collected.

(e) Study of the groundwater in Zinder Area in Niger (Isotope investigations by IAEA within the framework of a UNDP project executed by FAO): This area, which is situated on the west of the Chad Basin, has been investigated using stable isotopes. Tritium and carbon-14 have been useful in understanding the recharge conditions, as measurable tritium has been found in many locations. Stable isotopes have given the opportunity of differentiating several aquifers, as there are marked stable isotope variations in the area studied.

(f) Water balance of Lake Chala and its relation to groundwater: In one of the most spectacular and interesting applications of artificial tritium and natural stable isotope content of the waters, the difficult problem of the water balance of a lake, situated on the slopes of Kilimanjaro, has been nicely solved (7). The lake, with a volume of about 300×10^6 m^3 and a surface area of 4.2 km^2, has no surface inflow and outflow. In February 1964, 1900 Ci of tritium were used to label the entire lake, raising its tritium concentration to 1600 tritium units (a tritium unit is 10^{18} times the isotope ratio $\frac{T}{H}$). Regular sampling of the lake later showed an exponential decrease of tritium in the lake due to the molecular exchange of the lake waters with the atmospheric moisture, the radioactive decay of tritium and the dilution of lake waters with groundwater inflow (figure 2). It has been estimated (reference 7) that the annual groundwater inflow to the lake amounts to about 8×10^6 m^3. Such information is almost impossible to obtain with conventional hydrologic methods. Considering the relatively humid conditions prevailing in the region, the author (7) believes that the stable isotope content of the lake waters indicates that its water balance is close to that of a saline lake with an evaporation-inflow ratio of about unity, which again shows that the groundwater inflow to the lake should be of the same order of magnitude as the evaporation from the lake.

The interrelation of some springs which were believed to be fed by lake Chala has also been solved using the stable isotope content of lake and spring waters (figure 3). It is evident that the springs have an isotopic composition similar to precipitation and there is no significant contribution of lake waters, which are isotopically enriched.

(g) Single-well technique for tracing groundwater movement: Hazzaa (1970) described a radiographic method of measuring the velocity and direction of groundwater movement through the use of ^{32}P injected at a desired level in a well (8). The injected isotope is carried with the normal flow of water and is detected by means of a pair of screens. Radiographs of the screens indicate the direction of movement which is indicated by the darker areas, and the velocity is determined by displacement method or through the use of calibration curves. Although there are areas for improvement in the technique, it is applicable in the location of groundwater in the crystalline rocks using hand-dug wells.

The importance of water in the socio-economic development of a nation cannot be over-emphasized. The location and assessment of potential groundwater supplies can be made only when dependable data, often covering a considerable period, are available. Data aquisition is expensive, tedious and time-consuming. Many developed countries in Europe and America have accumulated such data over extended periods sometimes exceeding two centuries, through the co-operation of diversified disciplines such as hydrology, engineering, physics, geology and chemistry.

The gap between the developed and developing countries continues to widen, and so it is not realistic to expect developing African countries to go through all phases of exploratory programmes to produce adequate groundwater resources for their needs. Such a programme is bound to be hindered by several factors:

(i) Conventional techniques of groundwater exploration and assessment (geological, hydrological, hydrochemical and others) demand the availability of highly competent technical personnel which, though present in some cases, are not uniformly distributed.

(ii) The political division of Africa into a conglomeration of countries is a serious handicap for the dissemination of scientific and technical information, especially when a language barrier exists between these countries.

(iii) Africa is a continent of climatic and vegetational extremes. Conventional field studies are hindered by thick vegetation, inaccessible terrain (e.g. Sahara) as well as highly restricting climatic conditions.

With the above factors, it is obvious that any extensive programme of hydrogeological exploration is bound to be attended by success which cannot be commensurate with the expenditure committed to it.

It is therefore obvious that Africa cannot follow the path of Europe and America in discovering and utilizing her huge groundwater resources. It is necessary to start rather high on the ladder. The use of radio-isotopes satisfies this requirement. Although a big disadvantage is the cost per unit sample analysed, very reliable inference on the groundwater potential of a large area can be based on a few well-selected samples. Such studies have several advantages:

(i) The information is very easily disseminated through the International Atomic Energy Agency;

(ii) Results are obtained much faster; and

(iii) The total cost is only a fraction of that using conventional techniques.

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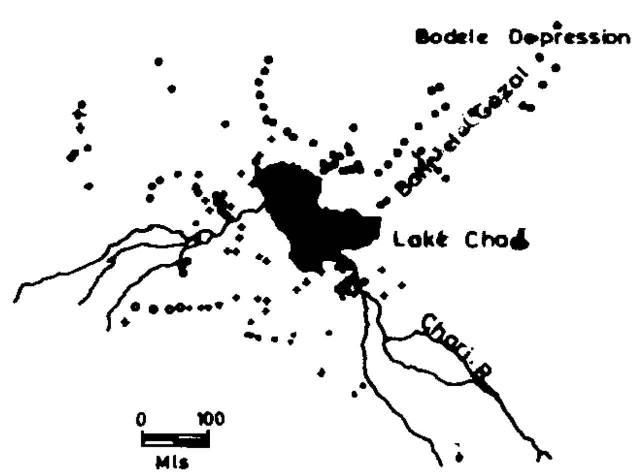

FIG.1 Sampling sites for enviromental isotopes, Lake Chad (UNESCO, 1969)

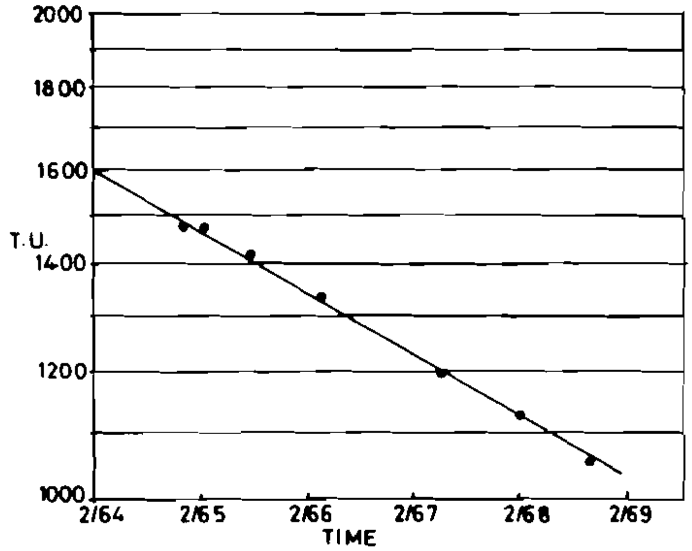

FIG.2 Tritium variation in Lake Chala, corrected for radioactive decay (Payne,1970)

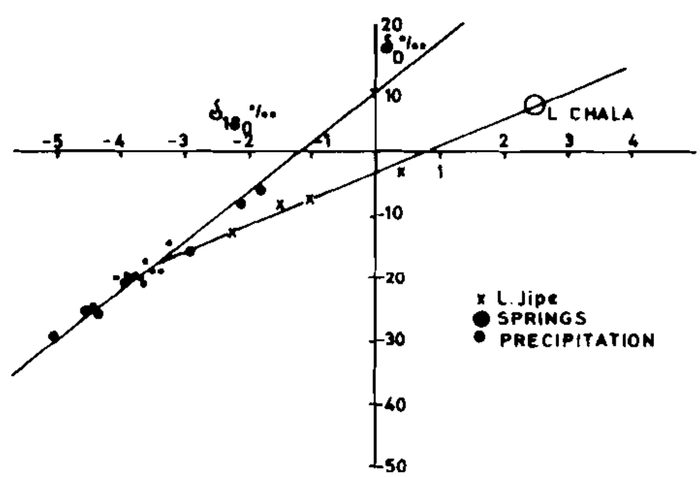

FIG.3 Stable isotope composition of waters in Lake Chala Region (Payne,1970)

SOME ASPECTS OF PRECIPITATION OCCURRING IN GHANA

by J.B. Dankwa and A.N. De-Heer Amissah

ABSTRACT

The surface circulation over Ghana is briefly described, together with the associated weather zones. These weather zones are greatly influenced by the surface position of the Inter-Tropical Boundary (ITB) which migrates north and south over Ghana, drawing along with it these associated weather zones. This is clearly shown by the distribution of the average monthly rainfall totals and the annual march of rainfall throughout the year.

The type, régime and distribution of rainfall are described and also the trend, and finally the probabilities of various stations receiving annual rainfall amounts of certain stated magnitudes are indicated.

RESUME

La présente communication décrit brièvement la circulation qui règne en surface au-dessus du Ghana ainsi que les diverses zones de temps qui en résultent. Ces zones de temps sont fortement influencées par la position en surface de la Limite Inter-Tropicale (L.I.T.) qui se déplace alternativement vers le nord et vers le sud au-dessus du Ghana en les entraînant avec elle. Cela apparaît très nettement lorsqu'on examine la répartition de la hauteur moyenne des précipitations tombées au cours de chaque mois et la courbe annuelle des précipitations.

La communication contient un exposé sur le type, le régime et la distribution des précipitations ainsi que sur les tendances relevées et indique quelle est, pour diverses stations, la probabilité de voir la hauteur annuelle des précipitations atteindre certaines valeurs déterminées.

*

* *

GENERAL

Ghana lies between latitudes $5^{o}N$ and $10^{o}N$ and the climate is tropical. Ghana also experiences some monsoon effect, especially along the coast. This effect is due to the uneven distribution of land and water masses in West Africa. Neglecting diurnal variations of sea and air temperatures, the land surface is warmer than the sea surface throughout the year. Consequently, in the mean, the doldrums never move south of the Equator but oscillate between the coast and about $15^{o}N - 20^{o}N$. The doldrums reach the southernmost position in January and the northernmost position in July/August.

The prevailing surface winds south of the Equator are the S.E. trades. As the winds cross the Equator, they veer, becoming south-westerlies along the Guinea Coast. To the north (about $10^{o}N$), the prevailing surface winds are the N.E. trades.

The zone of convergence of the north-easterlies and the south-westerlies forms a quasi-frontal boundary called the Inter-Tropical Boundary (ITB). Unlike a true frontal boundary, such as that encountered in temperate climates, rainfall is not associated with the frontal zone. However, further south of this quasi boundary (about 200 miles) there is a region, about four hundred miles in width, where well-organized storms (line squalls) oriented in a north-south direction move from east to west. Walker (1957) has given a description of the various weather zones which are associated with the Inter-Tropical Boundary (ITB).

North of the "line-squall zone", i.e. within the first 200 miles south of the Inter-Tropical Boundary, is a region of intense convective activity. In this region, late-afternoon or evening thunderstorms, especially over hilly areas, are very frequent. The storms are very localized and the duration of rainfall is short.

During the night, the sea is warmer than the land surface; convective activity is therefore more intense over the sea than over the land. When the warm air from the ocean reaches the cooler land surface, it condenses and may produce light rain, especially over the coastal belt. This rainfall, which is triggered by oceanic influence, normally starts late at night or in the early hours of the day. The rainfall is light to moderate and may continue for several hours.

Thus it may be summarized that three types of rainfall occur in Ghana. These are:

1. Heavy thundery showers during late afternoon and evening, caused by convective activity over land;

2. Heavy rainfall characterized by squally winds, and associated with disturbance lines; and

3. Light to moderate continuous rainfall which occurs late at night and in the morning.

PRECIPITATION PATTERN - GENERAL (Figures 1(a), (b) and (c))

The Inter-Tropical Boundary oscillates between the coast and latitude 20°N. As it moves up and down, it draws with it the associated weather zones. Thus in January or February, for instance, the region of localized thundery activity (Zone B) and the disturbance-line region (Zone C) are south of the Guinea coast, and the whole of Ghana lies in the cool, dry north-easterly trades (Zone A) (Walker, 1957). In July/August, on the other hand, the north-east trades retreat north of latitude 20°N; most of northern Ghana would lie in Zone C, and southern Ghana in Zone D.

The movement of the Inter-Tropical Boundary therefore controls to a measurable extent the distribution of rainfall, both in time and in space, over West Africa. In general, stations north of about latitude 9°N show one annual maximum which occurs around September/October. Between the 9th and the 6th parallels, two annual maxima are observed. South of about 6°N the annual maxima are more pronounced, being separated by a relatively drier period. North of latitude 6°N but south of 9°N the drier period which separates the two maxima is not so pronounced. In both cases, the principal maximum occurs in June and the minor in October.

Monthly isohyetal pattern

December, January and February

The isohyetal maps for these three months are identical except in rainfall amounts. Maximum rainfall amounts are observed in the south-western corner of Ghana, centred around Axim and Half Assini, whilst the lowest amounts occur in the extreme north. During this period the Inter-Tropical Boundary is around the Guinea coast, and in general rainfall amounts are very small all over Ghana. This is so because of the dry north-easterly trades reaching up to the coast. In the northern and upper regions monthly rainfall totals are less than 0.5 inches per month; the south-western corner of Ghana receives between two and four inches of rain per month.

In general, a north-south cross-section shows a trend of increasing rainfall amounts from north to south, as far as the Akwapim Range, and then decreasing down to the coast.

March and April

During this period, the Inter-Tropical Boundary moves northwards, drawing up with it the isohyets. By now, almost all regions in Ghana get more than 1.0 inch of rain a month.

South-western Ghana still remains the wettest part and the areal distribution once more shows an increase from north to south up to the Akwapim Range, followed by a decrease down to the coast.

May and June

June is the wettest month in Ghana. By now, the Inter-Tropical Boundary lies between 15°N and 18°N. The upper region lies in Zone B; the northern region, Ashanti, Brong Ahafo and the northern parts of the coastal regions lie in Zone C; whilst the coastal belt lies in Zone D. The minimum monthly precipitation for all stations in Ghana is greater than four inches, and the average monthly rainfall at Axim is some 23 inches.

July and August

In August, the Inter-Tropical Boundary reaches its northern most parallel and the upper and northern regions lie in Zone C. During the same month, there is a complete reversal of the isohyetal pattern. The north has now become the wettest region and the isohyets decrease from north to south, unlike the months already described.

One interesting feature worth noting on the July map is the tongue-like shape of the five-inch and six-inch isohyets which follow a southerly course, cutting through the Volta region to about $6\frac{1}{2}^{\circ}$N. It is not clear whether, during July, certain atmospheric or surface conditions combine to steer the storms along the trajectory indicated by the five- and six-inch isohyets. Perhaps the reason is that July is a transitional period during which reversal of the isohyetal pattern occurs.

September

The isohyetal pattern still shows decreasing rainfall amounts from north to south. However, during this period, a secondary maximum forms around the Volta region. As the Inter-Tropical Boundary moves southward, the upper region is freed of Zone C, which would at this time be around the northern region and Volta region.

October/November

The above months show an appreciable reduction in rainfall amounts after September, especially in the northern regions. The Inter-Tropical Boundary during this period lies around latitude 10^{o}N, and the general trend is to increasing rainfall amounts from north to south up to the Akwapim Range and then decreasing again down to the coast.

Annual isohyetal pattern

In general, southern Ghana, apart from a narrow coastal belt to the east, receives more rain in a year than northern Ghana. The wettest part is the south-western corner, west of about 2^{o}W longitude. East of this meridian, rainfall amounts decrease very rapidly along the coast.

Various reasons have been given for the decrease in rainfall amounts from west to east. Perhaps the most cogent reason is that east of longitude 2^{o}W, the coastline is orientated in such a way that the prevailing moisture-laden winds (south-westerly trades) blow parallel to the shore-line. Consequently, the full influence of the onshore winds is not felt inland. On the other hand, west of longitude 2^{o}W, the same prevailing winds blow perpendicularly across the coast-line.

It has also been suggested that the counter-equatorial current along the Guinea coast causes an upwelling of cooler water. As a result there is a reduction of water surface temperature along the Guinea coast. This reduction in water temperature reduces the moisture uptake of the prevailing winds.

Rainfall amounts increase northwards from the coast up to the mountainous regions in Ashanti, from where the amounts decrease from south to north.

North of latitude 8^{o}N rainfall is fairly evenly distributed. The pattern shows a tendency to larger rainfall amounts in the east than in the west. Otherwise the whole region gets an annual rainfall amount of between 55 inches and 40 inches.

ANNUAL MARCH OF PRECIPITATION TREND

Figures II (a), (b), (c), (d), (e) and (f) are shown as representative rainfall stations for Ghana. Lawra and Navrongo are both north of latitude 10^{o}N. The two stations show one annual rainfall maximum in August and are typical of all stations north of latitude 10^{o}N.

Kintampo and Worawora show two annual maxima in June and September/October. The maxima are separated by a dry period which is not very pronounced. At Ho, which is further south, the two maxima and the drier spell are more pronounced.

The above monthly rainfall distribution pattern is controlled by the movement of the Inter-Tropical Boundary. There is yet another type where the June peak is higher than the September peak.

In general, therefore, the rainfall régime in Ghana can be divided into three broad groups, namely the southern portion of the country, where there are two distinct peaks; the transitional zone in the middle of the country, where the two peaks gradually merge into one; and the upper part of the country, where there is only one peak. All these follow the apparent movement of the sun, which crosses the southern half of Ghana twice during the year; once on its journey northwards and the other time on its journey southwards.

A more detailed rainfall analysis in Ghana reveals that there are six different rainfall régimes.

PRECIPITATION TREND

Figures III (a), (b) and (c) show histograms of annual precipitation amounts for a few selected stations in Ghana: Tamale, Kumasi, Accra. The horizontal line is the mean annual precipitation for the total observation period. Superimposed on the average line is the "5-year running average" which shows the trend in precipitation from year to year. The "running average" was obtained as follows: The mean of the first five annual precipitation amounts was calculated, and the mean plotted on the third year. To get the next point on the diagram, the first year's data were dropped and the mean from the second year to the sixth year was calculated and plotted on the fourth year. The next step was to take the third to the seventh year, and so on.

The "running averages" reveal one striking feature, namely that all the coastal stations (Takoradi, Saltpond, Ada, Accra) show a trend in increasing annual precipitation amounts. No statistical analysis has been made yet but it appears at a glance that the "running averages" curve is superimposed on an exponential curve. On the other hand, at the northern stations (Yendi, Tamale, Kumasi, Wenchi) the running average seems to be superimposed on the mean annual line. This indicates that, at the northern stations, there is no evidence that the stations are getting wetter or drier.

FREQUENCY CURVES

The annual precipitation amounts for the total period of observation and for selected stations were tabulated in order of decreasing magnitudes and plotted in the form of a histogram (see Figures IV(a), (b) and (c)). The total period of observation was taken as 100 per cent, and a graph of percentage of occurrence was plotted against annual total precipitation in inches. The graph therefore gives the percentage of total number of years for which precipitation was equal to or greater than the amount indicated. The graph also shows the maximum and minimum annual rainfall amounts and the median for the period of observation.

SUMMARY

An attempt has been made to explain the types, distribution trend and régime of rainfall commonly affecting Ghana. These are closely related to the wind circulations and their movements over West Africa.

The annual march of monthly rainfall totals is portrayed in map form and finally frequency curves for certain representative stations in Ghana are drawn. From these curves, the probabilities of occurrence of annual rainfall totals of various magnitudes and the extreme values can be obtained.

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MEAN JANUARY RAINFALL (1931-1960)
VALUES IN INCHES

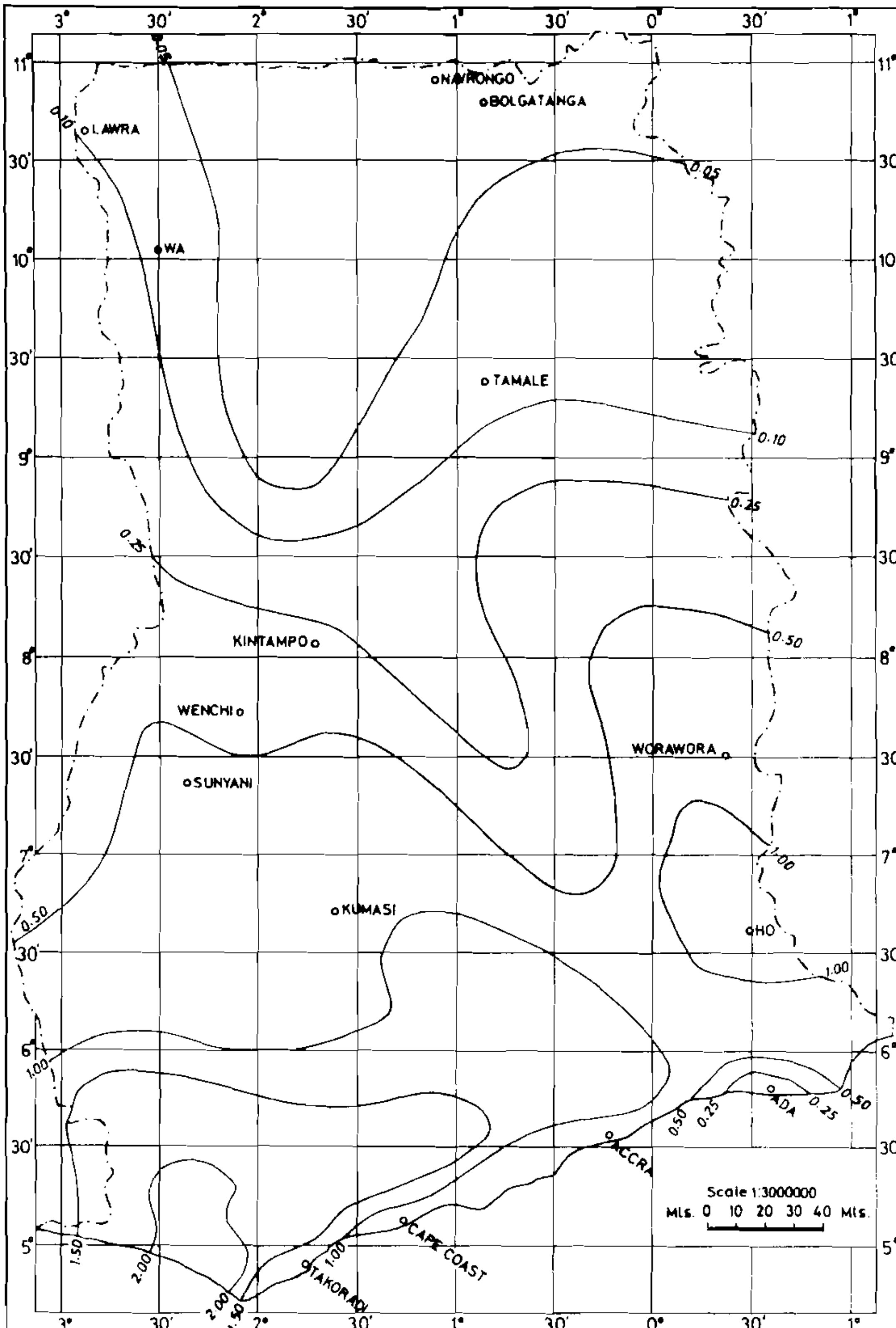

FIG.1 (a)

MEAN JUNE RAINFALL (1931-1960)

VALUES IN INCHES

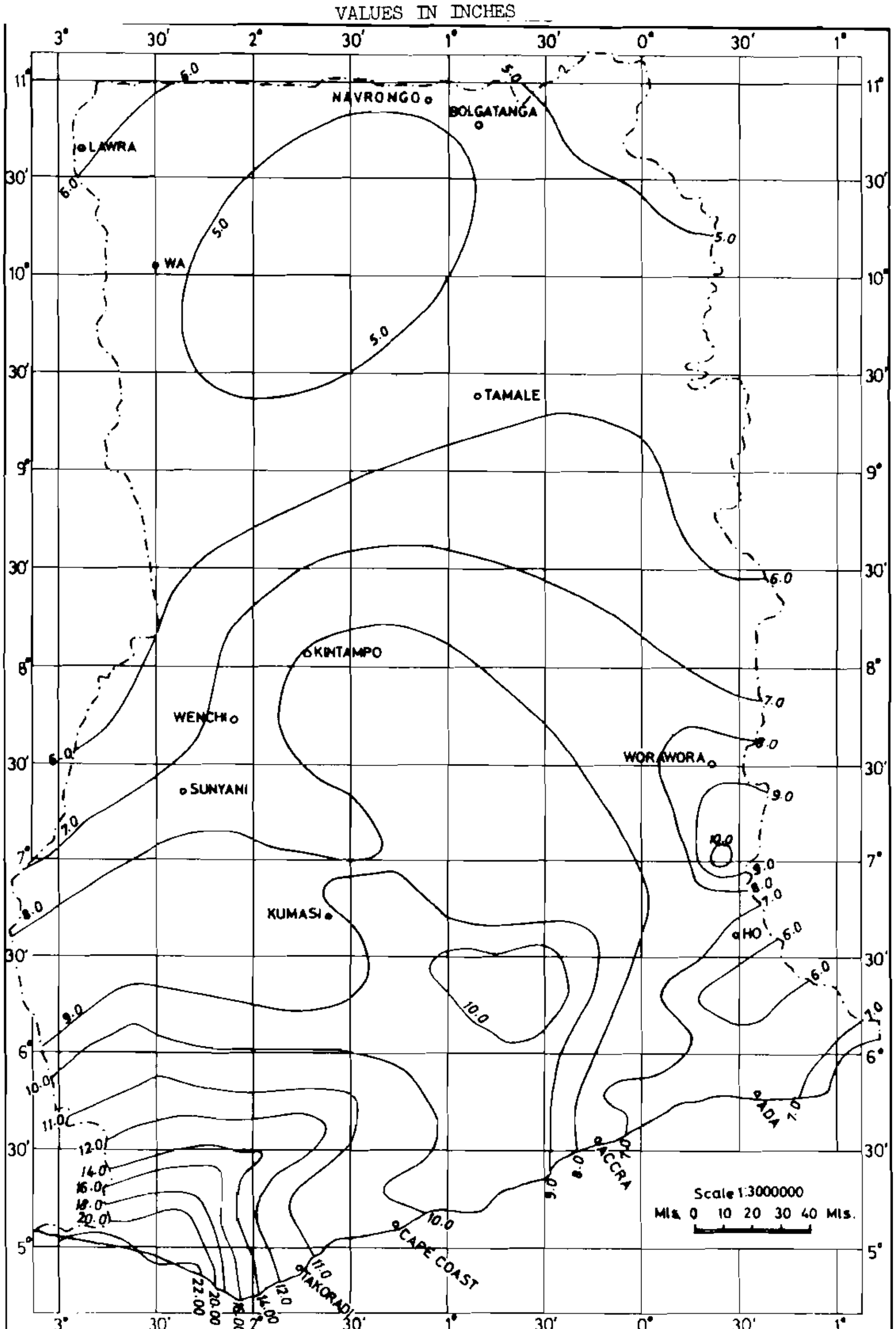

FIG. 1 (b)

MEAN ANNUAL RAINFALL (1931-1960)
VALUES IN INCHES

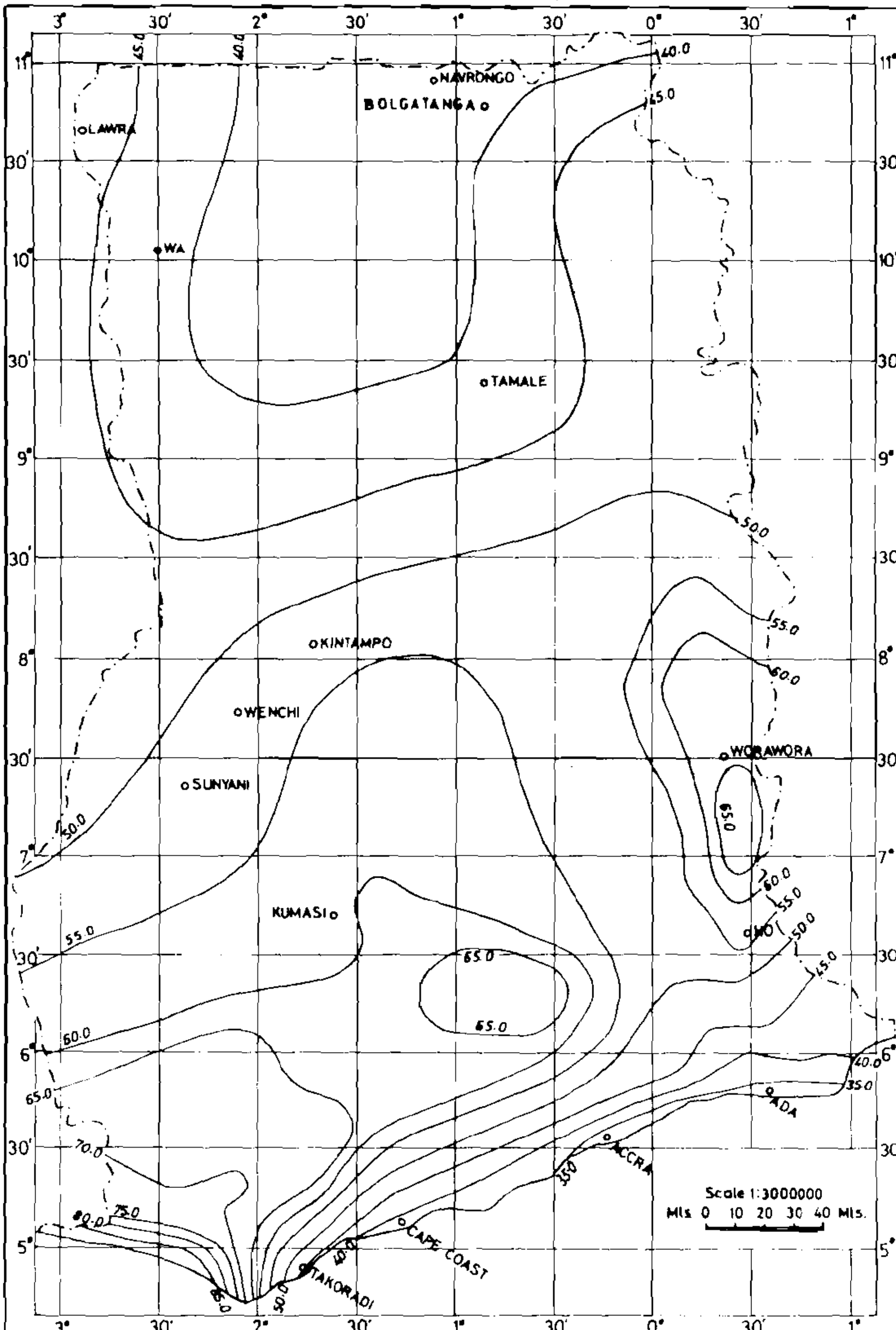

FIG. 1 (c)

REPRESENTATIVE RAINFALL STATIONS FOR GHANA SHOWING THE ANNUAL MARCH RAINFALL

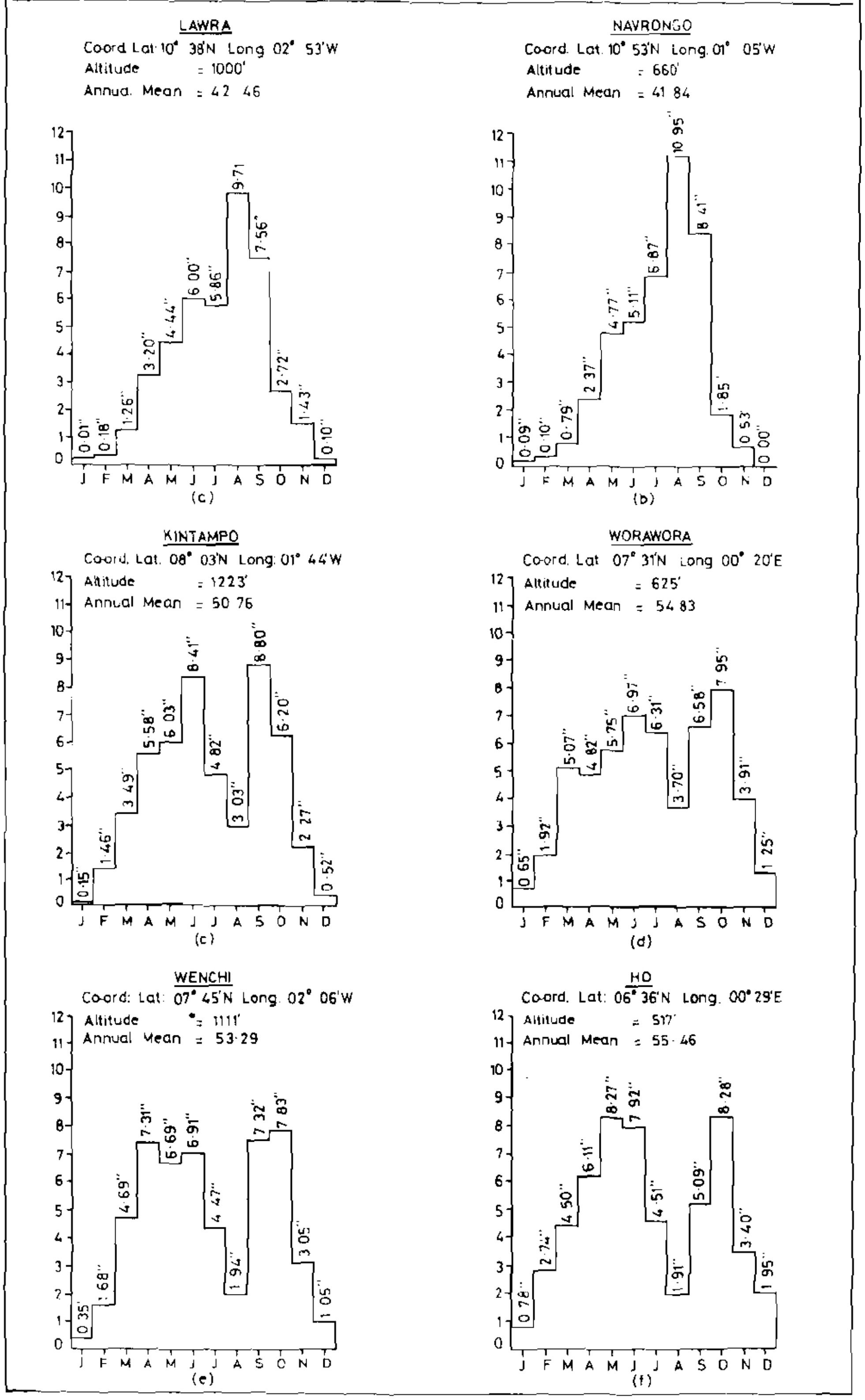

FIG 11

ANNUAL TOTAL PRECIPITATION PLOTTED IN BAR DIAGRAM
WITH "5YR. RUNNING AVERAGE" SUPERIMPOSED
(RUNNING AVERAGES PLOTTED AT THE MID-POINT OF PERIOD)

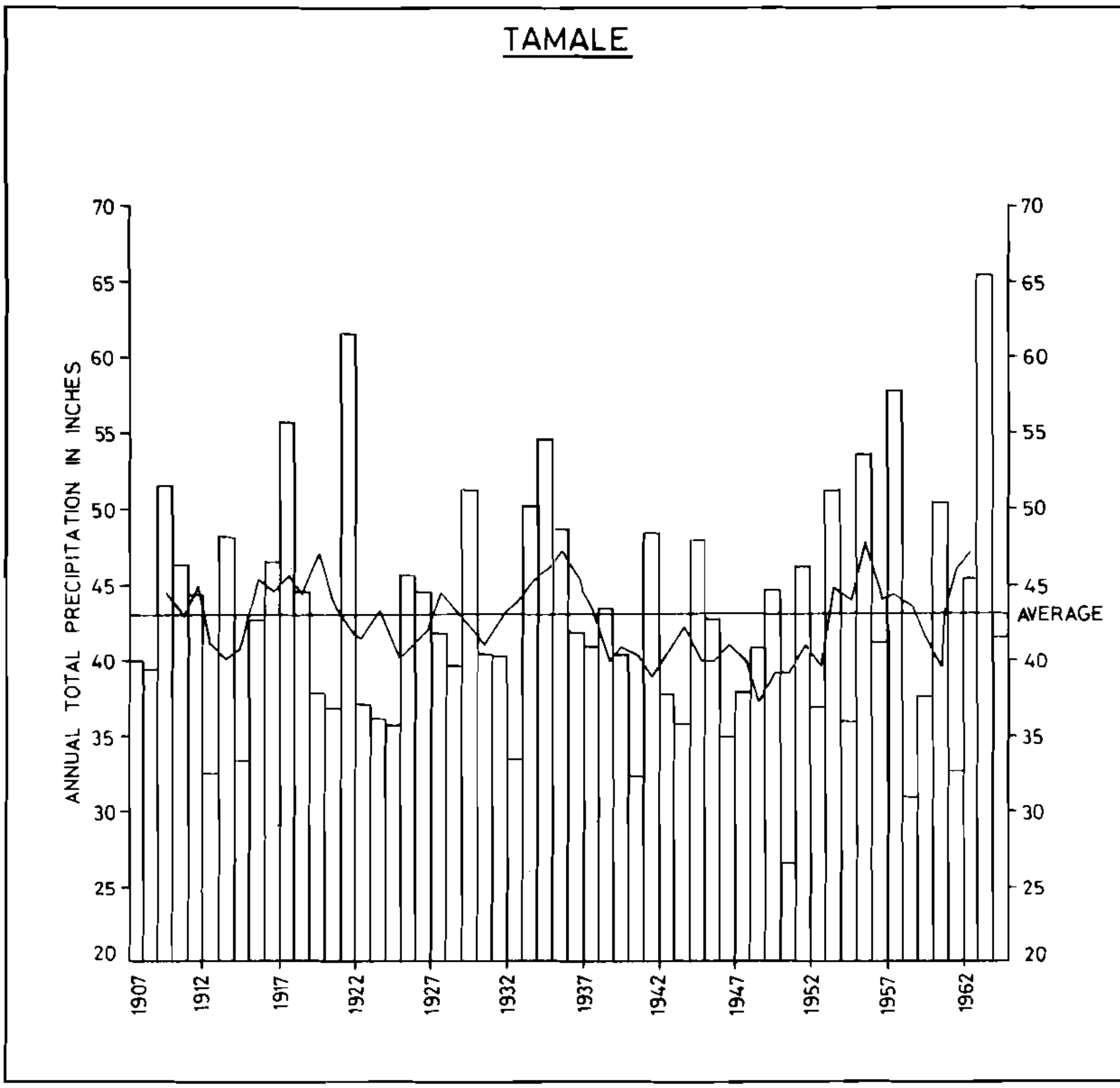

FIG. III (a)

ANNUAL TOTAL PRECIPITATION PLOTTED IN BAR DIAGRAM
WITH "5YR RUNNING AVERAGE" SUPERIMPOSED
(RUNNING AVERAGES PLOTTED AT THE MID-POINT OF PERIOD)

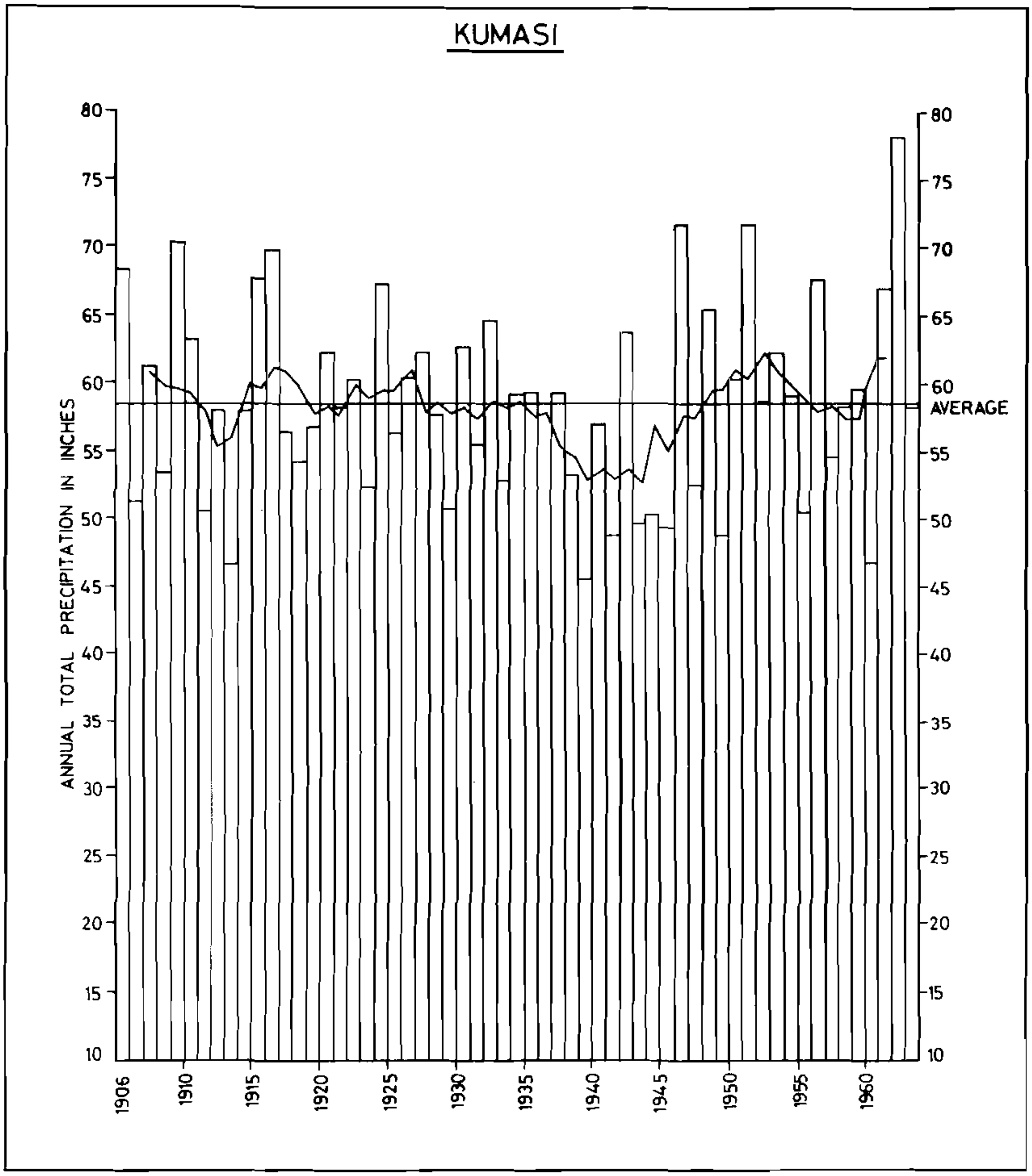

FIG. III (b)

ANNUAL TOTAL PRECIPITATION PLOTTED IN BAR DIAGRAM
WITH "5YR. RUNNING AVERAGE" SUPERIMPOSED
(RUNNING AVERAGES PLOTTED AT THE MID-POINT OF PERIOD)

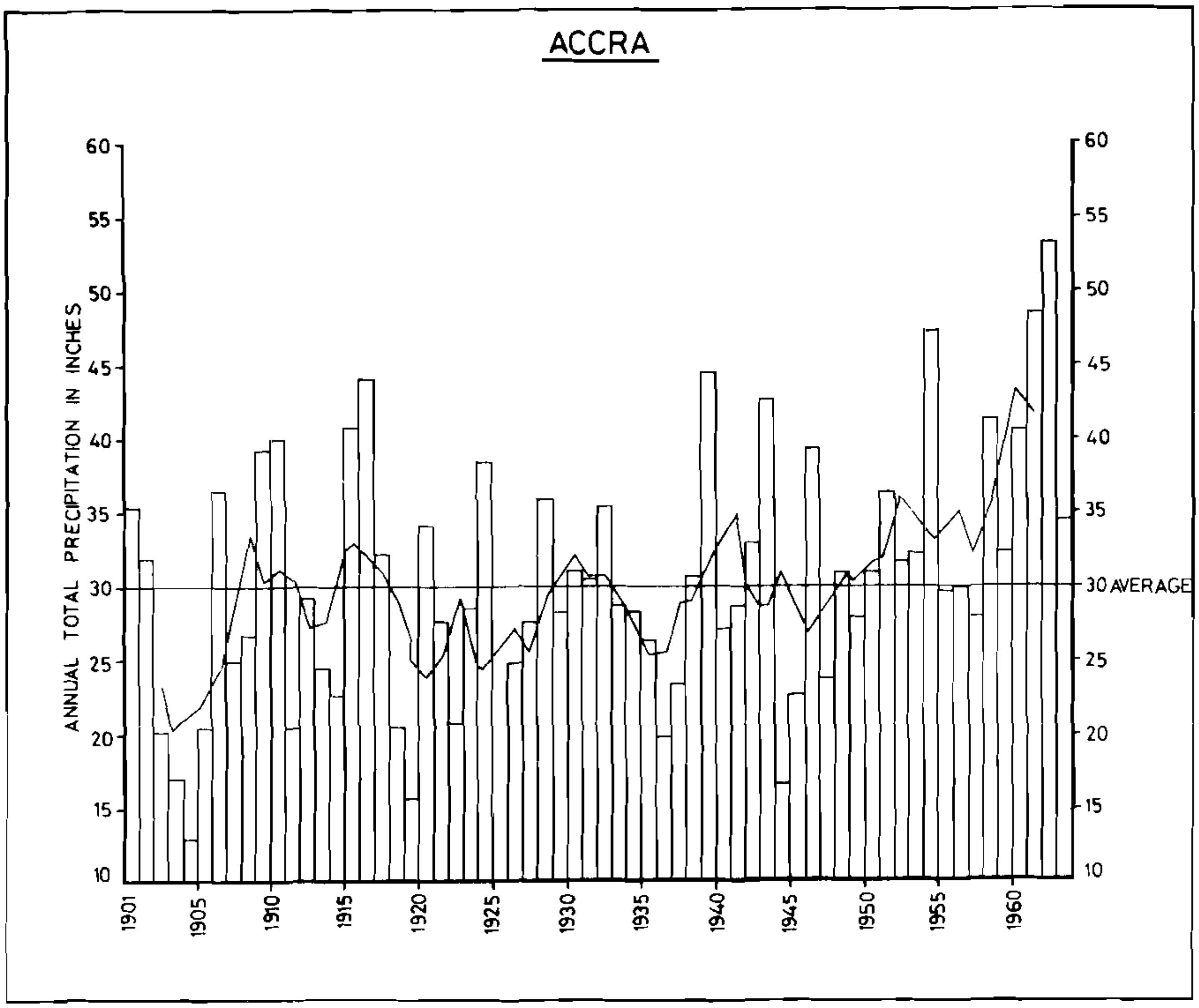

FIG. III (c)

ANNUAL TOTAL PRECIPITATION WITH YEARS ARRANGED IN DECREASING ORDER OF PRECIPITATION AMOUNTS

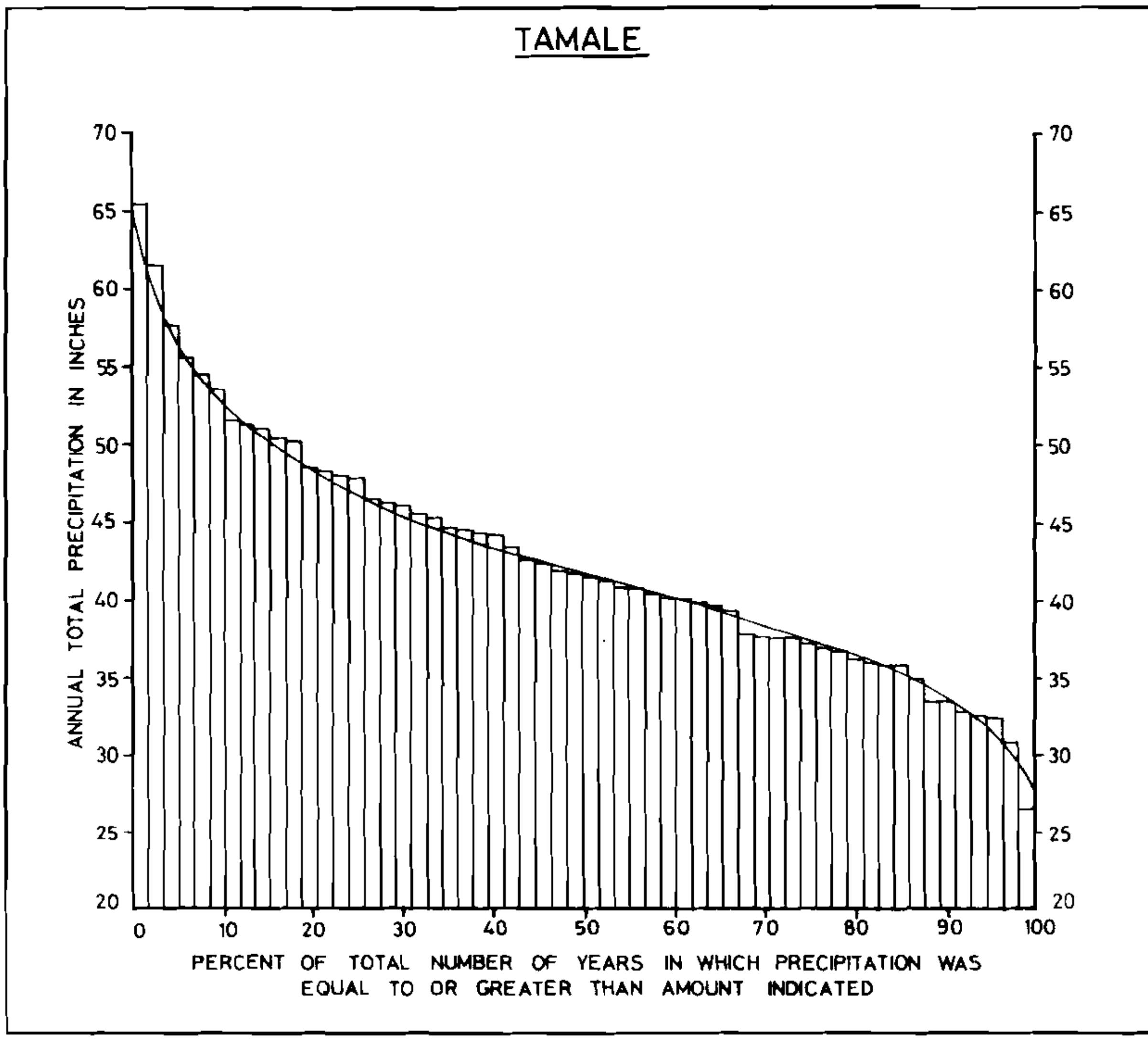

FIG. IV (a)

ANNUAL TOTAL PRECIPITATION WITH YEARS ARRANGED IN DECREASING ORDER OF PRECIPITATION AMOUNTS

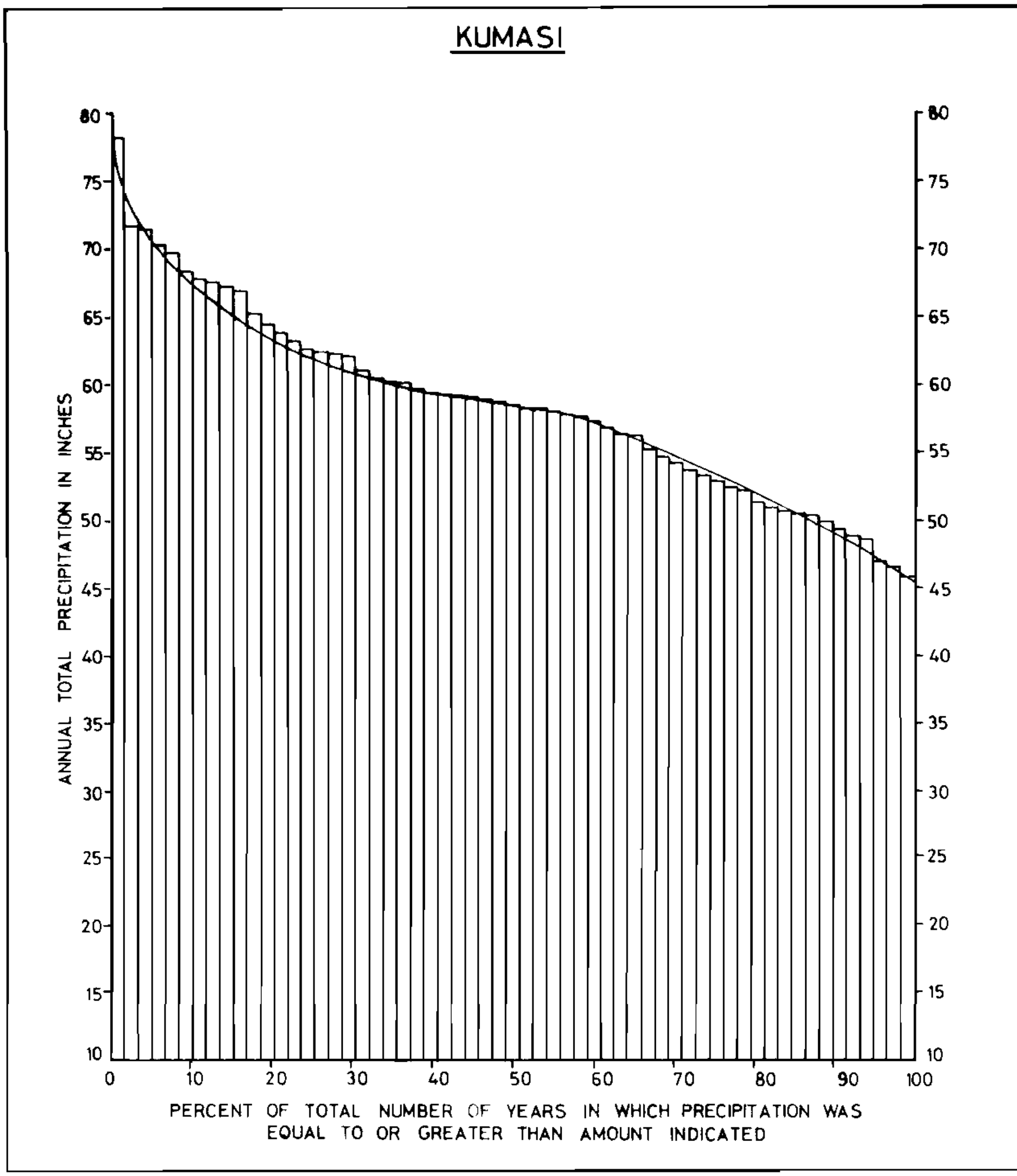

FIG. IV (b)

ANNUAL TOTAL PRECIPITATION WITH YEARS ARRANGED IN DECREASING ORDER OF PRECIPITATION AMOUNTS

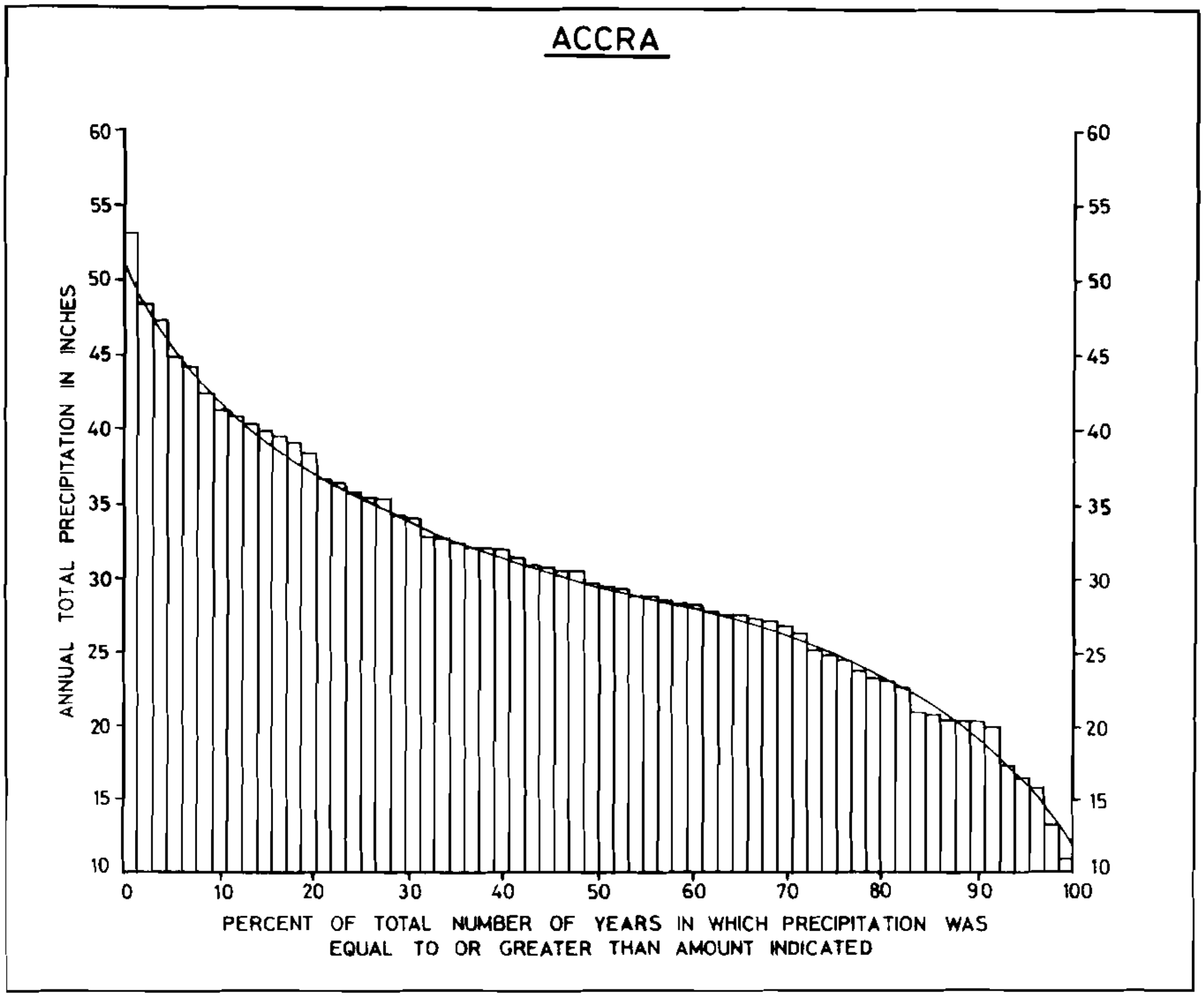

FIG. IV (c)

RAINFALL SYNTHESIS OVER LAKE VICTORIA FOR PREDICTION OF LAKE LEVELS

by H.L. de Baulny and David Baker

ABSTRACT

Prediction of lake levels calls first for an accurate knowledge of the water balance elements. This paper describes the method used for acquiring monthly rainfall data on Lake Victoria, and its statistical parameters, for the period 1925-1969.

Outflow and lake levels are measured regularly, surface water inflow estimated globally, and evaporation calculated by difference. A mean monthly balance of Lake Victoria is presented, and multilinear correlations derived to predict lake levels month by month. It will be shown that good agreement between the predicted and actual change in storage was obtained, thereby validating the method of approach. It is intended to undertake a time series analysis of the monthly rainfall data, and hence generate a long pseudotime series of lake levels so as to investigate the occurrence of extreme levels and their reduction.

RESUME

La prévision des niveaux des lacs nécessite, avant tout, une connaissance précise des facteurs du bilan hydraulique. Cette communication décrit la méthode employée pour acquérir les données relatives aux précipitations mensuelles et leurs paramètres statistiques pour la période 1925-1969.

Les niveaux du lac, et les débits qui s'en écoulent sont mesurés régulièrement, les apports des eaux superficielles sont estimés globalement et l'évaporation calculée par différence. Un bilan hydraulique moyen mensuel est présenté, et des correllations multilinéaires en ont été tirées afin de prévoir les niveaux du lac Victoria à l'échelle du mois. Il sera montré que l'accord entre les variations de niveaux prévues et mesurées est très satisfaisant, justifiant par là même la méthode employée. Une analyse sérielle des précipitations mensuelles est projetée en vue d'engendrer une longue pseudo-série de niveaux du lac, afin d'étudier l'incidence de niveaux extrêmes et de leur chute.

1. In 1961 a spectacular increase in the levels of the principal East African lakes occurred and, contrary to all expectations, high levels were sustained all through the decade; even now in the case of the largest, Lake Victoria, the level remains at more than 0.50 metres above the highest recorded peaks prior to 1961. Although this has had relatively minor economic consequences — partial disruption of transport facilities through submersion of roads and ferry wharfs, and limited flooding of agricultural land — considerable concern was shown by the riperian countries. An investigation has therefore been undertaken into the causes that led to the present conditions, succeeding an earlier study by Dr. H.T. Mörth (1) which provided a satisfactory model of the lake behaviour.

2. Lake Victoria is a 69,000 Km^2 oval, shallow depression of geologically recent origin (2). Its catchment, 190,000 Km^2, covers large areas in Uganda, Kenya, Tanzania, Rwanda and Burundi.

Through recent works (3) and (4), hydrometeorological parameters are fairly well known over the land part of the catchment, however, over the lake conflicting estimates have been published. These have been revised in the light of the present hydrometeorological network (5).

3. The water balance of Lake Victoria can be written as:

$$\text{INPUT} = \text{OUTPUT} \pm \text{CHANGE IN STORAGE}$$

where INPUT is essentially rainfall and inflow from streams
OUTPUT is evaporation and outflow into the Nile at its outlet at Jinja.

The ground water component of the water balance cannot at present be estimated; it is in all likelihood negligible and balances from year to year.

Lake levels and lake discharge have been analysed from 1900 to 1969 and rainfall records only between 1925 and 1969, as prior to 1925 very few stations were available. The mean monthly water balance has been investigated for the period 1925 to 1959 so as to exclude the exceptional 1960 to 1969 decade.

4. Lake levels are regularly measured at a number of stations around the lake. The Jinja gauge was chosen for reference, although records are only available since 1913 and prior records must be determined from the Entebbe gauge (Jinja = Entebbe + 0.53 ± 0.01 metres), because it controls the Lake Victoria outlet.

For the period 1925-1959 the monthly mean change in storage is given below expressed in mm followed by the cumulated change in storage so as to show geographically the actual movement of the lake.

J	F	M	A	M	J	J	A	S	O	N	D
-19.9	- 2.7	+51.8	+139.3	+107.1	- 60.1	- 90.3	-62.7	-50.3	-36.7	+ 5.7	+29.9
-19.9	-22.6	+29.1	+168.4	+275.5	+215.4	+125.1	+62.4	-12.1	-24.6	-18.9	+11.0

5. Prior to construction of the Owen Falls dam at Jinja, outflow of the lake was controlled by the Ripon Falls and an agreed relationship of lake level and outflow was determined. Releases at the dam have consistently corresponded to "natural" flow according to daily readings of lake level.

Nile flows have been analysed since 1900 and reproduced below are the means for the period 1925-1959, expressed in $m^3 \times 10^9$.

J	F	M	A	M	J	J	A	S	O	N	D
1.69	1.53	1.71	1.76	2.00	1.95	1.91	1.82	1.70	1.70	1.63	1.71

The mean yearly flow of $21 \times 10^9 m^3$ very nearly doubled between 1960 and 1969 to a mean of $40 \times 10^9 m^3$.

6. Stream flow into Lake Victoria is very difficult to estimate accurately, stream flow records being for the most part few and of short duration.

Forty per cent of the inflow is attributable to the Kagera River where records are available since 1940; 50 per cent to smaller streams with short records, and 10 per cent to ungauged catchments. The contribution from the Kenyan Highland catchments is particularly important.

Mean monthly inflow volumes have been determined and are given below in $m^3 \times 10^9$.

J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1.65	1.45	1.76	2.42	2.52	1.59	0.76	0.62	0.79	1.03	1.48	1.83	17.90

7. This investigation is not limited to a lake water balance study but aims to achieve a relationship between the factors of the water balance and change in lake storage, and ultimately to generate a long pseudotime series of lake levels from rainfall data. For this the mean monthly (or yearly) precipitation is only part of the information needed. Actual monthly and yearly rainfall values must also be made available as well as their statistical parameters. It is then necessary to design a spatial distribution of rainfall over the lake, and by some method derive monthly values over as long a period of time as possible.

As rainfall stations exist only on the shores (Figure 1) and on some of the larger islands, estimates of mean precipitation have been achieved in the past by extending land isohyets and drawing a steady gradient between the eastern and western shores.

The model is unsatisfactory as there is no reason why there should be an evenly distributed East-West gradient. Apart from general climatic conditions being nearly the same over the 67,000 km^2 of open water, which can be expected to give a constant rainfall "background", rain is caused essentially by turbulence, either orographic or convectional; the latter induced by the differential heating and cooling of land and water masses. The model adopted is such that over 75 per cent to 80 per cent of the lake the rainfall is constant, sharp gradients occurring in the immediate vicinity of the shores and islands (Figure 2).

The isohyets at 200 and 25 mm intervals for mean yearly and monthly rainfalls respectively were based on the data from 17 meteorological stations which are closest to the lake and where records exceed 20 years. Most of them are sited along the Northern and Western shores. The areas between the isohyets and the lake shore have been planimetered and mean yearly and monthly rainfall computed. The means expressed in mm are given below.

TOTAL	J	F	M	A	M	J	J	A	S	O	N	D
1650	130	135	190	250	205	85	65	65	85	110	165	170

The reconstitution of rainfall records from 1925 to 1969 over the lake could have been carried out in a number of ways.

(a) The isohyets could have been drawn month by month and planimetered. Although this certainly is the best method it had to be rejected, firstly because this would have involved a very long exercise of the drawing and planimetering of 540 rainfall maps, and secondly because only eight stations were available for analysis in 1925.

(b) Thiessen's polygon method was investigated; however, considering the position of the eight stations, far too much weight would have been given to some stations which are not really representative of the mean rainfall. A striking example is that of Kalangala.

Moreover, the relative weight of each station's rainfall to the total rainfall varies within the year from season to season. For instance, the ratios of the mean January rainfall at Entebbe (70 mm) and at Mwanza (98 mm) to the actual mean lake rainfall are 0.55 and 0.75 respectively; for July, Entebbe (75 mm) and Mwanza (12 mm), the ratios become 1.15 and 0.18. A need for a more flexible method is therefore evident.

Of the 17 rainfall stations used for drawing the isohyets, only 8 were subsequently selected on the basis of their length of record and proximity to the lake.

Uganda: (JINJA, (ENTEBBE, (KALANGALA

Kenya: KISUMU

Tanzania: (MUSOMA, (MWANZA, (KAGONDO, (BUKOBA

By referring to the mean monthly rainfall maps, each station has been allocated a coefficient between zero and unity, varying within the year from month to month so that:

- if summed for a particular month for each station the result is unity;
- in the same way as for Thiessen's method by multiplying the rainfall at each station by this coefficient and summing the values for any month the result is equal (or very close) to the mean monthly rainfall over the lake as determined from the isohyetal maps.

The coefficients used are:

	J	F	M	A	M	J	J	A	S	O	N	D
JINJA	.00	.00	.05	.10	.15	.20	.20	.15	.25	.20	.10	.05
ENTEBBE	.05	.05	.30	.30	.25	.20	.35	.20	.15	.15	.10	.05
KALANGALA	.20	.30	.10	.05	.05	.05	.05	.05	.10	.15	.20	.25
BUKOBA	.45	.25	.10	.05	.05	.30	.15	.20	.10	.15	.20	.25
KAGONDO	.25	.25	.25	.20	.25	.05	.05	.15	.25	.25	.30	.25
MWANZA	.05	.05	.10	.10	.05	.00	.00	.05	.05	.05	.10	.15
MUSOMA	.00	.05	.05	.10	.05	.00	.05	.05	.00	.00	.00	.00
KISUMU	.00	.05	.05	.10	.15	.20	.20	.15	.10	.05	.00	.00

After interpolating the missing data, monthly rainfall at each station and the coefficients were treated by computer to give a synthetized record of rainfall over the lake, and its mean and standard deviation, for the period 1925 to 1969. Although the actual rainfall pattern will not always conform to the mean pattern, the means thus obtained agree very well with those obtained from the rainfall maps.

J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
132	128	184	248	213	87	68	70	82	100	152	166	1630

Evaporation calculated from the water balance equation is given in the following table:

J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
151.4	129.5	133.0	118.2	113.4	141.8	141.6	115.3	119.2	127.1	144.2	137.8	1583

The difference between the mean yearly rainfall and evaporation is about 3 per cent, a figure often quoted by previous authors.

Over most of the year evaporation exceeds rainfall and the system is balanced by a decrease in lake storage, which builds up significantly only during March, April and May. The less wet season of November and December approximately balances evaporation and only a little storage occurs (Figure 3).

From an analysis of the water balance and of the rainfall during the last decade it seems probable that the exceptional rise in the lake level was due not only to the amount of rain, but also its distribution. In fact the November-December rains were often far above the average and their effect of increasing the lake level could not be cancelled by the less dry season of January-February before the April-May rains started to raise the level.

8. A month by month prediction of lake level on the basis of hydrometeorological parameters has been attempted. A linear relationship between rainfall and change in lake storage explains only 72 per cent of the variations. A number of multilinear regressions were attempted by computer.

The first multilinear regression compared the factors of the water balance to change in storage, for the period 1925-1969. Monthly rainfall was taken from the synthesized records. Monthly outflows were those measured at Jinja. Mean monthly inflow and evaporation were introduced as continuous record of these two factors could not be determined. The change in storage was compared to the current and five preceding months' hydrometeorological parameters. The multilinear correlation coefficient was 0.9116 and the standard error only 41 mm on the prediction of change of storage. The error was greatest for the exceptional rises and falls in the lake which could not be accounted for entirely (Figure 4). This suggests that the use of the mean values for evaporation and inflow is justified.

Reducing the period of reference by excluding the 1960-1969 decade has improved the correlation coefficient and standard error of the estimate only very marginally to 0.9128 and 36 mm. The same exercise using only the current and antecedent month's factors reduced the multiple correlation coefficient to 0.885 and increased the standard error of estimate to 45 mm. Retaining only factors for which continuous data is available (rainfall and outflow) the multiple correlation coefficient drops slightly to 0.892 whereas the standard error of estimate increases to 44 mm showing that the use of mean values of inflow and evaporation does improve the correlation, although the importance of these two factors is not very great.

9. The ultimate aim of this investigation being the generation of a long pseudo-time series of lake levels, it is preferable to use only one variable, i.e. rainfall, and either to include the other factors with it or to express them as a function of lake levels or rainfall. A multiple correlation using rainfall only gave a correlation of 0.864 and a standard error of 45 mm. It is then evident that outflow must be retained. This can be achieved by expressing outflow as a function of lake level through the rating curve. An initial level is known and as each subsequent change in storage is obtained

from the multilinear correlation it will be added (or subtracted) to (or from) the original level to give the outflow which will then be used for the next month and so on. In order to eliminate the terms of evaporation and inflow it is suggested that a further variable exponential of rainfall be added. The value of the exponential should be determined by computer. This is expected to improve the prediction of the sharp rises in lake level.

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3. Proposal for a Comprehensive Hydrometeorological Survey of the Lake Victoria Catchment, WMO/FAO (1963).

4. Potential Evaporation in Uganda, by D.A. Rijks, W.G. Owen and L.W. Hanna: Water Development Department of Uganda (1970).

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FIG 2

MEAN YEARLY RAINFALL OVER LAKE VICTORIA

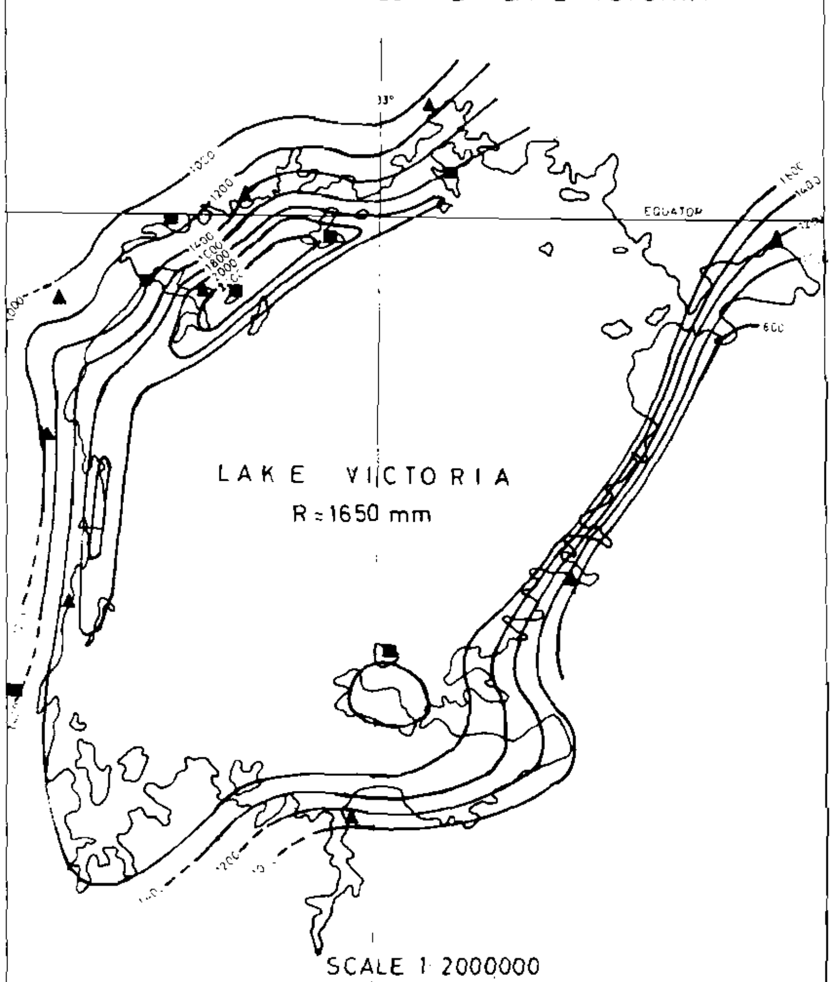
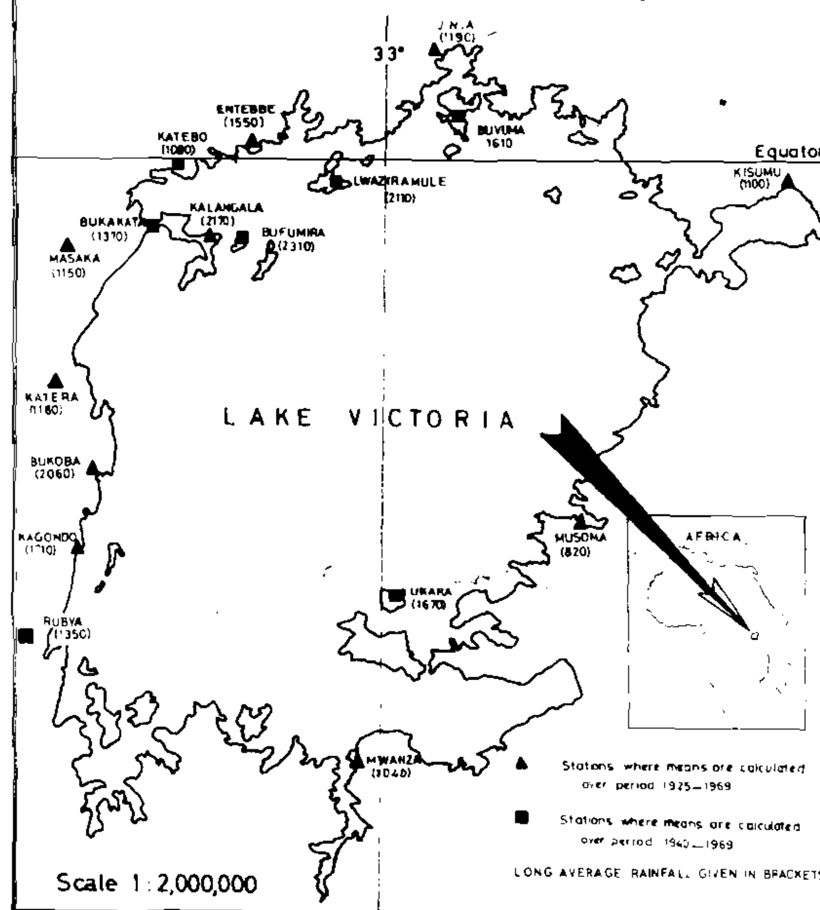
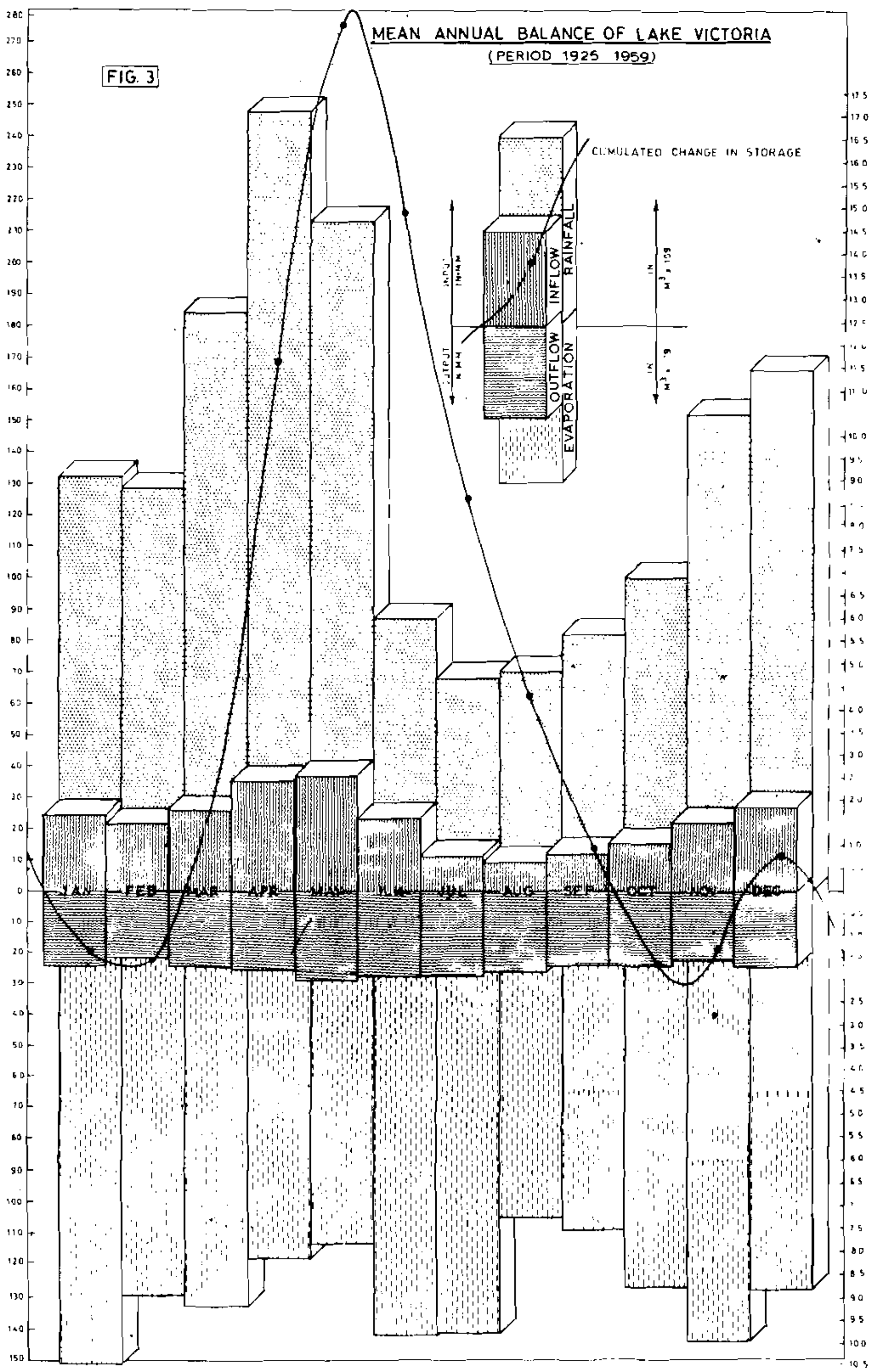


FIG 1

MAP SHOWING LOCATIONS OF RAINFALL STATIONS




MEAN ANNUAL BALANCE OF LAKE VICTORIA
(PERIOD 1925 1959)
FIG. 3
CUMULATED CHANGE IN STORAGE
INFLOW
RAINFALL
OUTFLOW
EVAPORATION
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

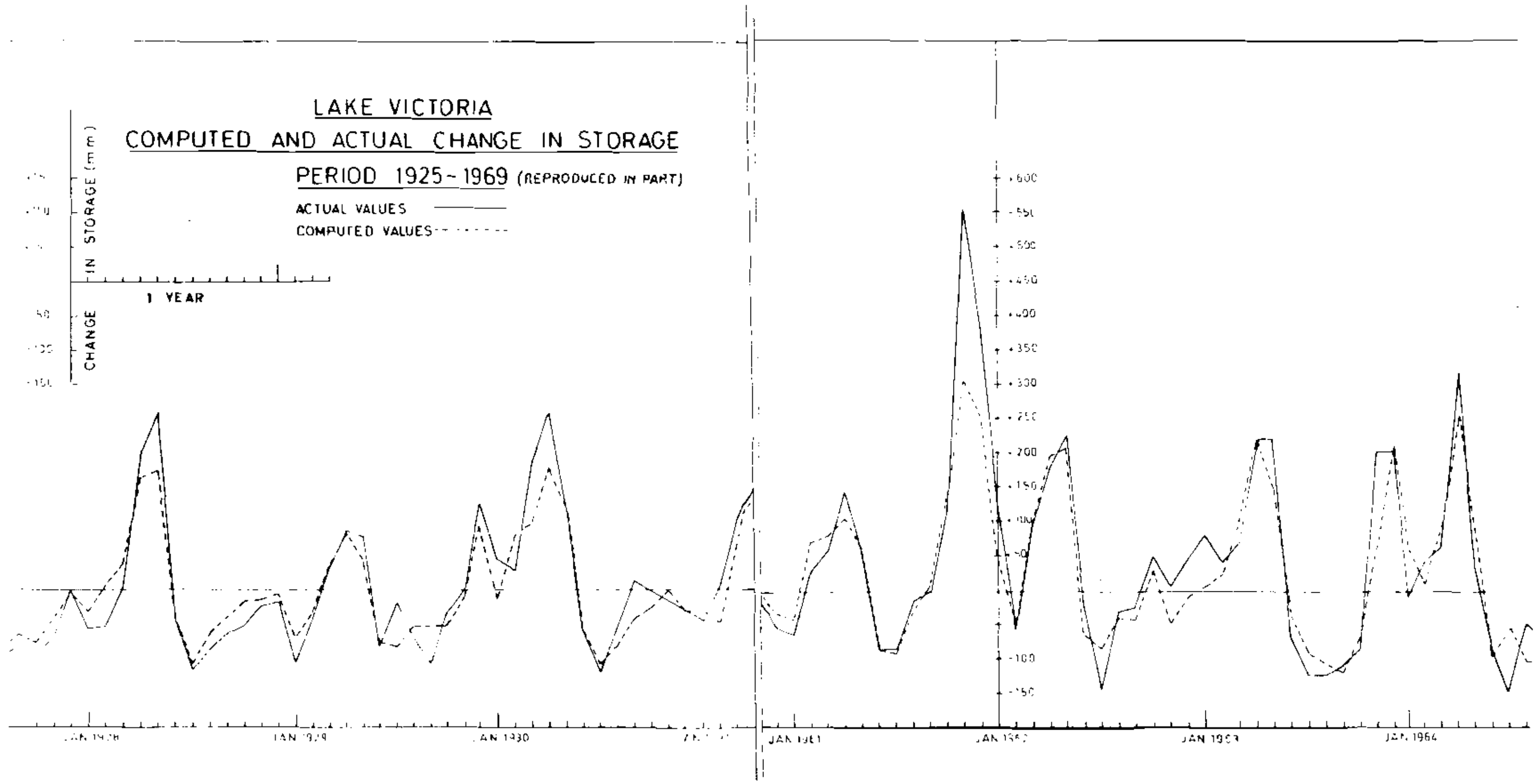

LAKE VICTORIA
COMPUTED AND ACTUAL CHANGE IN STORAGE
PERIOD 1925-1969 (REPRODUCED IN PART)
ACTUAL VALUES
COMPUTED VALUES
CHANGE IN STORAGE (mm)
1 YEAR
JAN 1930
JAN 1963
JAN 1964

FIGURE 4

SURVEY OF HIGH-LEVEL AND MIDDLE-LEVEL MANPOWER IN WATER RESOURCES DEVELOPMENT AND RELATED FIELDS IN GHANA

by Nii Boi Ayibotele

ABSTRACT

This paper reports the results of a survey carried out in Ghana to determine the position of high level and middle level manpower in water resources development and related fields as at the end of June, 1968.

The report considers the proposed establishment for engineers, scientists and technicians by water resources agencies as at the end of June, 1968, and the number that had been filled. It also considers the projected rise in establishment over a 5-year period 1969-73. Ways and means of meeting the shortages and the projected rises are examined and the financial costs to Government in meeting them also considered.

RESUME

Le présent document indique les résultats d'une enquête effectuée au Ghana pour déterminer la situation concernant le personnel de conception et d'exécution, dans le domaine de la mise en valeur des ressources hydrauliques et les domaines connexes, à la fin de juin 1968.

Le rapport compare les effectifs d'ingénieurs, de scientifiques et de techniciens prévus pour la fin de juin 1968 dans les différents organismes qui s'occupent des ressources hydrauliques, et le nombre des postes pourvus. Il examine aussi les accroissements d'effectifs projetés pour la période quinquennale 1969-1973. Il étudie les moyens de pourvoir les postes vacants et de réaliser les accroissements projetés, ainsi que les charges financières qui en résulteront pour l'Etat.

INTRODUCTION

One of the critical factors in water resources development is the availability of manpower trained in the various specialisations and in sufficient numbers to undertake the tasks of planning, investigation, design, construction and operation. It has been known for a long time that Ghana is short of qualified and experienced manpower, especially in the scientific and technological fields. In this regard, the field of water resource development is no exception. This paper reports the results of a survey carried out for the first time to determine quantitatively the manpower position in water resources development and related fields in Ghana as at the end of June, 1968.

METHOD OF SURVEY

The survey was conducted by means of 2 kinds of questionnaires sent to appropriate organisations and to individuals. The first type dealt with questions which individuals in the field were required to answer. It requested among other things educational and professional qualifications, field of specialisation and field of work since qualifying. Establishments which directly or indirectly operate in the water resources field were sent these forms for distribution to their individual employees. These individuals were meant to have trained up to university level.

The second set of questionnaires requested the organisations themselves to provide the answers. It requested information regarding the numbers at post and vacancies for various specialisations and projected requirements for the next five years.

ANALYSIS

The returns were analysed to find the number of posts that were required to be filled by the end of June 1968, by engineers and technicians in the agencies, and also the proportion of this number which had actually been filled. The number of Ghanaians and expatriates holding the filled positions was determined.

From the answers to the questionnaires the numbers of engineers and technicians required over the 5-year period (1969-73) were determined. An identification was made of the specialised fields in civil engineering and science required for water resources development and the numbers that had been trained in them. An estimation was made of the number of such specialists required for the efficient operation of the agencies as they existed at the end of June, 1968, and the shortages at that time correspondingly worked out. A similar analysis was made in the case of technicians. The possibilities of meeting the shortages were analysed, and the costs involved also estimated.

DISTRIBUTION OF CIVIL, MECHANICAL AND ELECTRICAL ENGINEERS IN AGENCIES

Civil engineers. Table 1 shows the distribution of civil engineers in water resources development agencies as at 30 June 1968. Of the total number of 95 civil engineers (Ghanaian and expatriate), 27 were expatriates. The majority of the engineers - 59 per cent - were employed by the Ghana Water and Sewerage Corporation. It is estimated from the table that over the next 5 years, 104 more civil engineers would be required. This would be a rise of 110 per cent over the 1968 total of 95.

Mechanical engineers. It was found in the case of mechanical engineers that there were 49 posts on 30 June, 1968, of which 36 were filled and 13 vacant. Of the posts filled 89 per cent were held by Ghanaians and 11 per cent by expatriates.

Electrical engineers. In the case of electrical engineers it was found that there were 49 posts, 44 of which were filled and 5 vacant. Of the filled posts 91 per cent were held by Ghanaians and 9 per cent by expatriates.

DISTRIBUTION OF TECHNICIANS OVER AGENCIES

In Table 2, the distribution of technicians including civil, mechanical and electrical technicians in the agencies is shown. The word technician here refers to those with 2-3 years post secondary training in the civil, mechanical or electrical engineering and related fields and receiving a salary of $790 and above. It is seen from the table that of 685 posts available at the end of June, 1968, 239 or 35 per cent were vacant. Over the 5-year period 1969-73, a projected establishment of 1,010 for all grades and kinds of technicians in the agencies was expected. This would represent an increase of 564 or 126 per cent over the 1968 filled posts.

It was found out that among the agencies the Ghana Water and Sewerage Corporation is the largest employer of both civil and mechanical engineering technicians while the Volta River Authority is the largest for electrical engineering technicians. Reported vacancies at 30 June, 1968 were highest in the civil engineering field - 136, followed by 24 and 9 vacancies in the mechanical and electrical fields respectively.

By 1973, the demand for civil engineering technicians was expected to increase to 397, a rise of 145 per cent above the 1968 filled posts. At the same time, the demand for mechanical and electrical engineering technicians was expected to rise by 105 per cent and 42 per cent respectively above the 1968 figures.

SPECIALISED FIELDS IN CIVIL ENGINEERING

Because of the importance of civil engineering in water resources development, it was decided to do a more detailed analysis of this field to find out the availability and distribution of manpower in the field of hydraulics and hydrology, sanitary and irrigation engineering, coastal and tidal engineering, water resources economics and planning. It was found that the sanitary engineering field had the largest percentage of engineers with 30 per cent. This was followed by irrigation engineering with 12.8 per cent and coastal and tidal engineering with 7.7 per cent. These percentages indicate the relative importance and level of activity in various aspects of water resources development in the country. Specialists in hydrology, hydraulics and water resources economics were few.

ESTIMATION OF SHORTAGE OF SPECIALISTS

In this section an estimation is made of the manpower shortages existing at the end of June 1968 in the specialised areas. The procedure adopted was to take each field and estimate the number of specialists considered necessary for the efficient running of the organisations as they existed at the end of June 1968. With the number at post known the shortage was then computed as the difference between the estimated number and the number at post. The summary is shown in Table 3 which also shows the number of specialists that are required to be trained in each field to meet the shortage over a 5-year period.

PRODUCTION OF ENGINEERS AND SCIENTISTS FROM LOCAL INSTITUTIONS COMPARED WITH SHORTAGES TO BE MET

The procurement of engineers to meet the demand in the public and private sectors of the economy will be determined largely by the output of the Faculty of Engineering of the University of Science and Technology. An examination of the intake of students and the output of engineers from the faculty will therefore give an indication of its capability to meet current and projected demand.

This was done for the three main branches - civil, electrical and mechanical. Over the period 1960-68, the annual intake of students rose from a minimum of 36 in 1960 to a maximum of 107 in 1965. In civil engineering the output increased from 7 in 1960 to 16 in 1967; for mechanical engineering from 2 in 1960 to 14 in 1967 and for electrical engineering from 3 in 1960 to 12 in 1967.

It is seen from Table 3 that to meet the shortage of civil engineering specialists there must be an additional output of 17 civil engineers per annum for 5 years. In the case of electrical and mechanical engineers it was estimated from the returns that there were shortages of 9 and 17 engineers respectively. These could be met at the rate of 2 and 4 per year over a 5-year period.

In the case of engineers, when the requirements over the 5-year period are compared with the output of the University of Science and Technology, it is found that while the output may be sufficient to cater for the shortages in the electrical and mechanical engineering fields it is inadequate for that of civil engineering. It is therefore in this field that more engineers will have to be produced.

In the case of geologists, physicists and lawyers the output of the universities at Legon and Kumasi is adequate to meet the demand.

MEETING THE SHORTAGE OF ENGINEERS

It was concluded above that the shortage of engineers cannot be met in civil engineering with the current rate of output of the University of Science and Technology. The shortage to be met is 17 civil engineers per year for 5 years. To determine the intake of students to produce 17 engineers an output/input ratio of 60 per cent is used. This is based on the performance of the faculty over 1960-68. Applying this ratio the intake is calculated to be 30. For a 4-year course, the first intake will complete their course at the end of the fourth year of the scheme, and the fifth intake will complete theirs at the end of the eighth year.

Three alternatives for meeting the shortage are now considered.

(a) Solution based on expatriate recruitment: This solution will save the country from making any investment to expand her own facilities for training the additional numbers required. This saving is, however, defeated because of the high cost of expatriate employment. Based upon current figures it is estimated that a single expatriate engineer with a family of a wife and 3 children costs Ghana an average of $9,500 per annum. Of this amount, $3,600 is paid in foreign currency. The total amount of $9,500 can employ between 2 and 3 Ghanaian engineers. It is further estimated that if the present projected numbers are programmed to be built up in 5 years, the country will invest $161,000 in the first year rising to $807,000 in the fifth year. Foreign exchange components will be $61,000 and $306,000 respectively.

(b) Solution based on training Ghanaians in overseas institutions: With this solution scholarship awards will be made to 30 students a year for 5 years to study abroad. It is currently estimated on conservative basis that it costs the Government £1,000 (sterling) per annum to keep one student overseas. As such the education budget will be increased by $73,000 in the first year rising to a maximum of $227,000 in the fourth and fifth years and falling to $41,000 in the eighth year when the programme comes to an end. All the investment to be made will be in foreign exchange.

(c) Solution based on expanding training facilities at the University of Science and Technology: To cope with the estimated increase in student population the training facilities at the University will have to be expanded. This will involve investments in staff and student accommodation, lecture rooms and laboratories, direct student bursaries and indirect student subsidy to the University, recurrent expenditure arising from capital expenditures and staff remuneration for additional lecturers.

The estimates of investment show that the education bill will rise by $365,000 in the first year, reach a maximum of $440,000 in the third year, falling to $87,000 in the eighth year when the project ends.

(d) Comparison of the 3 alternatives: It is seen from the above that reliance on expatriates to man our water resources development projects is the least attractive financially. Also such reliance is not considered to be in the best interest of a nation like Ghana. A choice therefore lies between overseas training and local training.

On the face of it, overseas training appears attractive since it involves less capital investment and generates no recurrent expenditure after the objective is achieved. The first disadvantage of this solution is that all the investment will be in foreign exchange, a total of about $1,140,000 over the 8-year period. The second disadvantage is that while courses at home can be adapted to take the country's development problems into consideration this may not be possible in overseas institutions. Also this solution will be affected by the number of places that foreign institutions will make available to Ghana each year. This is a factor over which the country will have no control.

Regarding the training of engineers at home, it should be noted that the investment in student accommodation will serve not only the faculty of engineering but other faculties in future. The investment in employing more lecturers has to be made in any case, since the staff/student ratio has been low for many years, and this needs correcting.

DEMAND AND OUTPUT OF TECHNICIANS

The type of technicians needed are in the fields of civil, mechanical and electrical engineering. Local institutions train people in these fields, but the specific needs of water resources development are not catered for. Water resources agencies like the Ghana Water and Sewerage Corporation, the Volta River Authority and the Meteorological Department have established their own departmental schools to cater for their special needs.

Technicians required by the Public Works Department - Hydrological Branch, the Irrigation and Drainage Division of the Ministry of Agriculture, the Water Resources Research Unit and the University of Science and Technology are not trained in any such departmental training schools. These are field and office assistants required in the observation, measurement, and analysis of hydrological and hydrogeological data. These agencies take on Middle School Certificate as well as West African School Certificate holders and give them in-service training.

The situation has not been quite satisfactory and it has been difficult to retain such trained personnel, for reasons such as lack of proper establishment, low salary, inadequate or non-existent prospects for promotion. For this situation to be rectified it would be necessary for these agencies to pool their resources and to set up a training school, and introduce service conditions which will help retain those trained.

It was calculated from a breakdown of Table 2 that for a 5-year programme aimed at meeting the deficiencies and increases, there would be need to produce 48, 16 and 10 civil, mechanical and electrical technicians respectively each year for 5 years. After the end of the programme additional numbers will be dictated by the growth of the economy.

Assuming that 10 per cent of these numbers will be engineering diploma technicians from the University of Science and Technology, then there would be a demand of 5, 2 and 1 civil, mechanical and electrical diplomates each year for 5 years in the water resources sector. A comparison of these numbers with the output of diplomates shows that there are adequate facilities at the University to turn out the required numbers provided the bias in recent years to produce more mechanical and electrical engineering technicians is corrected and the needs of civil engineering catered for. It is therefore not considered necessary to make further investments for the training of diplomates except that the course structure should take into consideration the needs of those going into the water resources development sector.

The non-diploma technicians to be turned out each year works out at 68. Taking the same output/intake ratio used for engineers, the intake per year comes to about 115. The basic qualifications for training for this grade is West African School Certificate or General Certificate of Education Ordinary Level. Under the present system they are given 3 years technical training leading to appointment as Technical Officers on completion of the course. To train this number, investment will have to be made in training allowances, employment of more teachers and provision of lecture space. It is believed that the investment in lecture space will not be required because present courses of some technical schools need to be discontinued as their products cannot be placed in the economy. This discontinuation should make room for the required lecture space.

For this training the education bill will be increased by $77,000 in the first year of the programme rising to $193,000 in the third, fourth and fifth years and falling to $81,000 in the seventh year.

CONCLUSIONS

As at the end of June 1968, there was a total of 169 engineers in the water resources development agencies; 35 of this number were expatriates. Of the 169 filled posts 95 were held by civil engineers, 36 by mechanical engineers and the remainder by electrical engineers. There was an estimated shortage of 82 civil engineering specialists, 7 hydrogeologists and 6 hydrometeorologists. There were no water resources economists and no water resources planners with engineering background. There was a shortage of 17 mechanical engineers and 9 electrical engineers.

The shortages of manpower in mechanical and electrical engineering, and in hydrogeology and hydrometeorology can be met with the existing output of graduates from the Universities in Kumasi and Legon, and no additional investment beyond the existing levels is required to meet the shortage, as far as the needs of the water resources sector are concerned.

In the case of the shortage of civil engineering specialists the present facilities at the Civil Engineering Department of the Faculty of Engineering of the University of Science and Technology are inadequate to meet it. An amount of about $1,900,000 will be required to expand facilities to take on additional students.

At the end of June 1968 were were 446 technicians in the water resources and related agencies. No expatriate held a technician's post. There was, however, a shortage of 239 technicians of all grades, and it was anticipated that 5 years later this number would be met and an additional 131 also employed. It is estimated that the cost of meeting the shortage will be $1,600,000.

While some agencies, notably the Meteorological Services Department, the Ghana Water and Sewerage Corporation, and the Volta River Authority, are in a position to programme their training to meet their demand for technicians, the other agencies like the Hydrological Branch of the Public Works Department and the Water Resources Research Unit are not yet in a position to train their own technicians. A training school for the latter agencies is imperative.

Table 1

Distribution of civil engineers in agencies

Agency	Establishment 1968			Projected establishment				
	Ghanaian	Expatriate	Vacancies	1969	1970	1971	1972	1973
Ghana Water & Sewerage Corp.	40	7	13	58	58	64	70	77
Irrigation & Drainage Division	7	10	18	35	35	35	37	40
P.W.D. Hydro. Branch	5	7	6	18	22	26	28	30
Volta River Authority	5	-	-	5	5	6	7	8
Min. of Lands & Mineral Resources	1	-	-	1	1	1	1	1
University of Science & Technology, Kumasi	9	3	2	19	22	27	30	32
Water Resources Research Unit	1	-	2	4	8	8	9	11
Meteorological Services Dept.	-	-	-	-	-	-	-	-
Totals	68	27	41	140	151	167	182	199

Table 2

Distribution of all technicians in agencies

Agency	Establishment 1968			Projected establishment				
	Ghanaian	Expatriate	Vacancies	1969	1970	1971	1972	1973
Ghana Water & Sewerage Corp.	163	-	124	287	301*	316	328	341
Irrigation & Drainage Division	8	-	35	53	53	53	58	58
P.W.D. Hydro. Branch	18	-	24	42	50	56	60	62
Volta River Authority	80	-	-	80	84	88	92	97
Ministry of Lands & Mineral Resources	-	-	-	-	-	-	-	-
University of Science & Technology, Kumasi	49	-	6	52	79	91	103	114
Water Resources Research Unit	2	-	4	6	10	11	15	20
Meteorological Services Dept.	126	-	46	246	266	283	303	318
Totals	446	-	239	756	843	898	959	1,010

* Figures underlined are projections of the author.

Table 3

Estimated shortage of specialists in agencies

Agency	Hydrology/ hydraulics	Sanitary	Irrigation	Water power	Coastal and tidal	Economics/ planning	Hydraulic structures	Hydrogeology	Hydrometeorology	Water law	Total
Ghana Water & Severage Corp.	2	27	-	-	-	4	2	4	-	-	39
Irrigation Division of Ministry of Agriculture	2	-	18	-	-	-	1	-	-	-	21
Public Works Department	16	-	-	-	3	-	1	-	-	-	20
Volta River Authority	1	-	-	5	-	2	-	-	-	-	8
University of Science & Technology, Kumasi	4	2	1	-	1	1	1	1	1	-	12
Water Resources Research Unit	4	-	-	-	2	2	1	4	1	-	14
Meteorological Services Department	-	-	-	-	-	-	-	-	10	-	10
Ministry of Finance & Economic Planning	-	-	-	-	-	2	-	-	-	-	2
Attorney General's Department	-	-	-	-	-	-	-	-	-	1	1
Ghana Railways & Harbours Authority	-	-	-	-	2	-	-	-	-	-	2
Estimated total requirement	29	29	19	5	8	11	6	9	12	1	129
No. at post	3	12	5	1	3	0	1	2	6	0	33
Estimated shortage	26	17	14	4	5	11	5	7	6	1	96
Rates per year	5	4	3	1	1	2	1	1	1	1	20

MANPOWER REQUIREMENTS AND TRAINING IN HYDROLOGY AT PROFESSIONAL AND SUB-PROFESSIONAL LEVEL IN AFRICA

by UNESCO

ABSTRACT

The paper introduces the complex nature of hydrology as a pure and as an integrating science and from this complexity derives definitions of the profession of a hydrologist at various levels. It shows the relation between the profession and the needs for hydrologists as parameters of national policy and development. Attempts to arrive at an exact indication of the manpower need in East Africa are described.

The paper defines training requirements at different levels and briefly refers to current Unesco activities in the field of hydrological teaching at the post-graduate and sub-graduate levels.

RESUME

Cette note montre la nature complexe de l'hydrologie en tant que science pure et intégrée et, à partir de cette complexité, définit les caractéristiques de la profession d'hydrologue à des niveaux divers. Elle fait apparaître les relations entre la profession et les besoins en hydrologues comme facteurs du développement et d'une politique nationale. Elle contient également un compte rendu sur les essais effectués en vue de préciser les besoins exacts en main d'oeuvre en Afrique de l'Est.

La note définit les besoins de formation à différents niveaux et rend compte brièvement des activités entreprises par l'Unesco dans le domaine de l'enseignement de l'hydrologie aux niveaux post-universitaire, universitaire et technicien.

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INTRODUCTION

The rapidly increasing application of more comprehensive procedures in the planning of water resources development and the use of modern scientific and technical methods imply that a civil engineer, geologist or agricultural engineer and even the hydraulic engineer is generally no longer in a position to master the problem alone. For the solution of problems the collaboration of a wide range of engineers, scientists and technologists is generally needed. The design engineer finds himself to be more and more a part of a team which also contains physicists, meteorologists, biologists and economists.

The design may in certain cases be split up into various sub-sections which are dealt with by experts in that branch. For the planning phase, however, it is indispensable to have the collaboration of a team which, besides the above-mentioned engineers and scientists may also contain sociologists, social geographers, political scientists and the representatives of rural and urban planning authorities.

Although in general the engineer will maintain the leading role and have a position of co-ordinator, he must be aware that he is also one member of a multidisciplinary team.

Through their education, today's engineers and scientists must be acquainted with the present level of knowledge and, in addition, trained to seek the collaboration and advice of their colleagues and scientists of other branches with a willingness to learn to understand their problems. The idol of past times was the all-round man with a justified pride of his knowledge. Nowadays this pride would isolate him. He has to be convinced that pride of workmanship can best be developed through concerted action.

THE HYDROLOGIST

No mining company would dare to carry out the exploitation of an ore deposit without the exhaustive preparatory work of a mining engineer and an economic geologist. However, in the field of water resources development and river training, including the construction of irrigation schemes and dams, very often projects are executed without consulting a hydrologist.

Hydrology, as the science of the hydrological cycle and the behaviour of water within this cycle as well as its relation to the environment, should be regarded as an indispensable prerequisite for planning in the field of water resources development.

Apart from pure research activities, hydrologists are generally associated with other specialists in the preparation and execution of projects. In this context, the long-term collection of data on precipitation, evapotranspiration, discharge, etc. does not only serve research hydrologists but is also of immense practical use. There is no one more qualified than the hydrologist to interpret these data.

In spite of its essential role the choice of hydrology as a profession or career is an exception. The reasons are based on the nature of this science as well as on the historical development of administrative and university systems. Hydrology has developed principally from civil engineering, meteorology and geology. These points of origin are, however, so different that it required a long time for hydrology to emerge as a separate discipline independent but closely related to its subjects of origin without which it cannot exist. This complex origin is believed to be the main reason why hydrology, integrated with elements of basic natural sciences, civil engineering, meteorology, soil sciences and geology, has only become a separate branch of science in a few highly developed countries. The splendid idea of integration, however, is extremely difficult to materialize since no one is capable of acquiring a deep knowledge of all these subjects within a reasonably short time. Therefore, the usual approach is to regard hydrology as a supplement to the traditional branches of science.

Modern teaching programmes in hydrology generally require prior and complete study of one of the important basic sciences, e.g. civil engineering, geology, geography, meteorology or agricultural engineering. This practice makes the hydrologist a valuable expert because of his knowledge of related fields; it also gives him the possibility of choosing from a variety of job opportunities.

The diversity of basic training of hydrologists must be kept in mind when considering their fields of interest and operation. The "ideal" hydrologist does not exist, but a hydrologist can distinguish himself from other scientists by his flexibility and by his capabilities of adapting himself to various types of problems within a short period.

On the other hand, the flexibility which is the advantage of the hydrologist may also be his weak point. The structure of competition in a given social and economic system may lead conventional specialists (e.g. a chemist) to more profitable jobs in industry instead of in hydrological services and therefore the hydrologist may be forced to try to substitute him (e.g. by conducting water quality surveys himself) instead of calling upon the specialised knowledge of the chemist.

THE MANPOWER PROBLEM

It is not the purpose of this paper to develop a complete philosophy of the profession of a hydrologist. This chapter therefore will only highlight some of the important viewpoints on the manpower problem.

The foregoing sections have shown the difficulties in trying to define the profession of a hydrologist. The same difficulties are encountered in trying to estimate the number and qualifications of hydrologists required for the future. Every consideration must therefore take into account:

- national plans for water resources development;
- national structure of administration;
- national plans for research and education;
- attractiveness of jobs and competition in the industry.

The synthesis of these items may lead to an assessment of the need for hydrologists or the number of jobs requiring profound knowledge of hydrology. In analysing any training programmes in hydrology, the key question must be: what is the balance between the need for hydrologists and the possibilities of training a sufficient number?

This is no static problem. The balance which satisfies present needs will not necessarily allow for future development. Since gaps in personnel requirements cannot be filled easily and since overproduction in a certain profession cannot be deviated to other fields without hard disadvantages for the persons concerned, the question of balancing need and training must always be the centre of attention of the planners at all levels.

THE NEED FOR HYDROLOGISTS

There are abundant examples to prove that the manpower market is not self-regulating. Overproduction in some branches and wide gaps in others occur again and again. The young student in most cases is not in a position to predict the needs of his profession sufficiently in advance. Changing requirements due to administration and economy, changing relations of income and salaries, and changing modes and trends add confusion to the problem of early decisions on a career. However, this is much more than an individual problem. The fluctuations in certain disciplines, such as the problem of overcrowding or lack of personnel for the employing agencies, have implications on the capacity of universities and colleges and thus influence national economies.

In restricting our consideration to hydrology the problem becomes much more difficult. The problems of defining the need for medical doctors, teachers, etc. are well known. Nevertheless a rough estimate is possible due to the relatively permanent need for these professions. On the other hand, projects connected with water may have a boom period and then disappear. Classical examples are the canalization of big rivers, land reclamation in bays and certain projects for irrigation and drainage. Furthermore, during various phases, from the initial planning period and hydrological investigation, through detailed planning, design, execution and the final exploitation, a variety of skills is required. If a country only undertakes a few projects, or if intervals between massive projects are too long, it might find it extremely difficult to keep experienced personnel. Where national plans for the development of certain aspects of the water resources cannot assure more or less permanent occupation of the personnel, it may be more economical to use external consulting firms and engineering agencies.

Foreign firms should not, however, be employed to carry on fundamental work of the hydrologist, i.e. the collection of data. Since full assessment of existing water resources depends on sufficient and reliable data, each country should regard hydrological data collection and processing as a primary interest essential to national planning and development. Governments should realize that this need exists and should make every effort to ensure a permanent collection of information. The need for continuity in the employment of hydrologists would also favour the establishment of multinational or regional agencies or institutes. These agencies could function more economically and be better equipped than relatively inactive ones in smaller countries.

The number of hydrologists needed by a country is likely to depend on its overall area and climate, the quantity and stage of development of its water resources, and on potential plans for water resources development.

In 1965 Unesco circulated to its Member States questionnaires on: needs for hydrologists, needs for teaching personnel, and on training facilities within the country. The replies revealed the difficulties of this type of survey and the problem of finding a suitable method for comparing the data. Projects for water resources development are generally entrusted to a great variety of agencies, institutions, authorities and firms, some of them being occasionally engaged in water resources development. Under these circumstances it is obvious that it is nearly impossible to obtain reliable figures or to distinguish full-time hydrologists from those who are also engaged in other tasks.

In spite of the not very encouraging results of the 1965 survey, Unesco has continued to collect information and to participate in surveys carried out by other organisations. The Unesco regional hydrologists report on experiences gained during their missions and try to obtain significant data from national authorities. Thus, a certain amount of information has been collected, mainly from Asian countries.

In the autumn of 1968 Unesco participated in the ECA's inter-agency survey which visited fifteen West African countries - Mauritania, Mali, Niger, Nigeria, Dahomey, Togo, Ghana, Upper Volta, Ivory Coast, Liberia, Sierra Leone, Gambia, Senegal, Chad and Cameroon.

An additional survey of the manpower situation in hydrology in East Africa was conducted by a Unesco consultant in 1969.

The report of the survey (Horst, 1969) concerns six countries of the Eastern African Region: Ethiopia, Kenya, Malawi, Tanzania, Uganda and Zambia.(1) The general situation in the countries surveyed can be summarized as follows:

(1) These conclusions are drawn from the report Manpower and Training in Hydrology in Eastern Africa by Unesco consultant L. Horst, 1969.

In the field of hydrology, national services were in existence in most countries for quite some time but were generally geared to specific projects, rather than to the assessment of overall hydrological characteristics in the countries. Due to the repatriation of expatriate personnel after independence and the lack of national technicians and professionals they are at present understaffed. The present day requirements of water resources development on a planned basis, combined with the acute shortage of staff, difficulties in recruitment and low technical ability of technicians, results in hydrological services being hardly able to collect and process basic data, let alone take care of its analysis and rationalization, the optimization of networks, research, etc.

Technicians working in hydrology are, for the large part, secondary school leavers with in-service training. Due to the shortage of professional staff, this in service training consists, in most cases, of the bare minimum. The technical level is low; consequently an increasing amount of sub-professional technical work is carried out by professionals.

The present number of river-gauging stations in the six countries is in the region of 1200. Many rivers are still rarely gauged or not gauged at all. It is generally felt that in order to obtain a satisfactory basic network the total number of stations should be increased slightly, but their location should be rearranged in a more rational manner.

In Eastern Africa the situation prevails that very few, if any, technically inclined school leavers or University students choose hydrology as a profession mainly due to several factors:

- the number of secondary school and University leavers is limited and the demand is large;
- the private sector pays better. In the framework of africanization many private firms are attracting technical personnel for relatively high salaries;
- within the government, there often exists a discrepancy in salary and promotion possibilities between one department and another. The hydrology sections are often lowest on the scale. (e.g. public works department increasing their salary scales in order to compete with private contractors; water supply is often a municipality concern, and offers higher salaries, etc.);
- hydrology often is only a small but specialized section. The ceiling is quickly reached and promotion possibilities limited.

Exact information could not be obtained in all cases for all countries concerned. Therefore the figures mentioned in the annex should be considered only as orders of magnitudes. The figure on manpower includes the WMO Hydrometeorological Project on Lake Victoria. At present, the largest part of the work-load of professionals consists in sub-professional work as a result of the technical shortcomings of the sub-professional staff. On increasing the ability of the hydrological technician, the output of professional work could easily be doubled. The conclusions that can be drawn from the report are:

- This serious manpower deficiency in the field of hydrology is twofold: firstly, the number of professionals, of which only a few are nationals, and secondly the number and the technical standard of the technicians.
- Training facilities for professionals are only adequate in a few countries for professionals but there is a good potentiality for technicians.

- The deficiency in training of manpower in hydrology will remain as such for many years to come, as long as there is an uneven ratio between supply and demand and the governments do not effectively promote the sector of water resources development and do not make it as attractive as other branches of government services.

The report recommends that the governments recognize the importance of hydrology as a basis for water resources development by promoting salary and career possibilities in the water development departments in general, and the hydrological services in particular.

It further recommends that the countries explore the possibilities of strengthening the existing water resources and training institutes, in order to develop adequate training facilities for hydrological technicians in this region.

Similar evaluations are planned for the future. The IHD Working Group on Education in Hydrology will discuss ways of analysing the situation in selected areas at its next session.

The above considerations are valid for hydrologists at all levels. Nevertheless, when undertaking special surveys the levels have to be distinguished. In the terminology of the IHD Working Group on Education:

- Research hydrologists are required to develop new techniques and to study deeply special problems particularly on the theoretical background. They usually have a higher academic rank and are generally employed in institutes, universities, research stations, etc.

- Professional hydrologists are needed to study hydrological phenomena relevant to the design, construction and operation of water resources schemes. In most cases, they have an academic grade.

- Technicians are expected to be able to apply accepted methods and techniques. Normally they have attended a technical school.

- Observers are employed for reading instruments and for maintaining instruments and field stations.

TRAINING OF HYDROLOGISTS

Measures and methods for training hydrologists differ according to the level, purpose and depth of training. This section will give the main concepts of the different personnel in hydrology. It will not present a collection of syllabi and curricula or a compilation of training possibilities.

1. Research Hydrologists

Hydrological research is undertaken by scientists with varying backgrounds. The trend is for more and more scientists, other than civil engineers and, in particular, mathematicians, statisticians and physicists, to be involved in hydrological research. As a rule, research workers cannot be educated in formal courses of study. Their initiation to hydrology used to take place at a scientific institute of higher learning under the guidance of a professor or senior scientist after their university education or even at post-doctorate level. In order to attract promising young scientists to this field, it is important to try to interest university professors of earth sciences, meteorology and natural sciences and their respective departments, in problems relating to hydrology.

2. Professional Hydrologists

For professional hydrologists a formal, specialized education is necessary. In most countries this training is connected with studies on water resources in civil engineering. Study programmes, at graduate or at post-graduate level, for agricultural engineers, geologists, meteorologists or physical geographers also normally include some hydrology courses. Sufficient facilities for undergraduate education in professions related to water resources exist in many countries. In several cases courses can be supplemented by additional subjects on water resources with special emphasis on hydrology.

On-the-job training is rather widespread. It requires very good national hydrological services with sufficient senior hydrologists who regard training young hydrologists as part of their daily task. Experiences show that this method generally suffers because the senior hydrologists are overloaded with other work, give the fellows too much manual work, and are often neither willing nor able to teach. On-the-job training has been well developed in some countries and is very effective when carefully planned and organized especially when the trainee can be accustomed to tolerate the relatively long duration of the period of formation.

The advantage of post-graduate studies is that applicants with a degree in civil engineering, geology, agricultural engineering or even in physical geography can be accepted, provided their basic study programme included some training in water resources or groundwater. Post-graduate courses are generally organized in universities and special institutes, often in connection with courses in other branches. Unesco initiated a programme for the promotion of post-graduate courses in various disciplines of natural sciences, in 1962. As a result, some national courses received support from Unesco and a number of new courses were organized through the initiative and support of Unesco. Post-graduate courses in the field of hydrology are at present being conducted in Budapest, Delft, Graz, Jerusalem, Madrid, Padova and Prague. As a whole, these courses cover practically all aspects of hydrology and water resources management.

All the courses have proved to be successful; their world-wide appreciation underlines the necessity of continuing this programme. The courses have been organized with all possible efforts to ensure an adequate participation of post-graduates from developing countries and a good geographical distribution.

In this regard it should be mentioned that Unesco sponsors summer schools for hydrology professors in the USA and the USSR.

3. Technicians

Whereas the professional hydrologist must be able to choose and develop the methods of investigation and design that best fit the problems encountered, hydrological technicians and other auxiliary personnel are expected to follow fixed methods and procedures which are already in use in the organization to which they belong. Training of such technicians in a philosophy and region different from that of their service will lead to confusion. The training of technicians can, therefore, best be undertaken within the countries. The way in which the service is organized and the procedures used for data collection, handling, storage and retrieval, determine the type of personnel required and the content and scope of their training.

In countries with very large hydrological services, it is possible to organize formal courses of teaching for hydrological technicians at technical colleges or secondary technical schools. In most cases, however, technician training will take place in "post-college courses" for candidates who already hold a certificate as a technician in building or engineering.

Unesco regularly organizes training courses for technicians with a view to the establishment of model courses for technician training. The first course for technicians was held in Bamako, Mali, in 1965, with participants from the Central African Republic, Gabon, Ivory Coast, Mali, Niger and Senegal. A second regional training course for technicians was held in Tunis in 1967, with participants from Algeria, Morocco and Tunisia. A third training course for technicians in hydrology was organized in Lower Kabete, Kenya, in 1969, for participants from Ethiopia, Kenya Malawi, Sudan, Tanzania, Uganda and Zambia. A similar course to be held in the Arab States in 1972 is under preparation.

The above-mentioned type of courses for technicians is intended for hydrologists who are not at an academic level. The participants are expected to have considerable experience in operational hydrology and to be engaged in national hydrological services. The courses therefore have the function of a refresher course as well as of familiarizing the participants with some scientific background for their daily work.

The experience gained from these courses has also shown the need for a regional approach to training hydrologists at a more advanced level than technician; for example, for persons with some academic training who require special training in selected subjects.

With this in mind, Unesco is preparing special regional courses such as one on the use and application of computers in hydrology to be held most probably in Japan in 1972. Another course is planned to be held on snow and glaciers in Latin America, and a similar one is to be held in Asia in 1972.

The courses will also serve as a source of experience regarding the feasibility of future similar programmes. Special consideration will be given to the syllabus and to the duration of the courses in order to plan improved courses for the biennium 1973/74. A course on general hydrology is foreseen to be held in the English-speaking countries of West Africa in 1973 or 1974.

AN APPROACH TO THE PROBLEMS OF SYNTHESISING HYDROGRAPHS FROM RAINFALL DATA CASE STUDY: KILOMBERO RIVER, TANZANIA

By Bo Wingard and Ulf Riise

ABSTRACT

The paper describes a case study of synthesising runoff from rainfall data. The results of the study are examined.

RESUME

La présente communication étudie un cas particulier de calcul de l'écoulement à partir des données pluviométriques et examine les résultats obtenus.

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BACKGROUND

A general problem in many developing countries is the lack of river runoff records of sufficient length. Many projects will have to be delayed or built on inadequate data if this problem is not solved.

There are many approaches to the problem of synthesising hydrographs. Due to the fact that rainfall stations have often been operating for a longer period than the hydrometric stations, we found it interesting to try to find a simple method by which rainfall data can be used to extend the runoff data. This study shows the construction of a long-term hydrograph based on experience from simultaneous rainfall/runoff observations for a four-year period only.

THE RESULTS

Figure 2 shows the result of a synthesised period of seven years, 1962-1968. The construction is based on a relationship obtained between rainfall and runoff during the four years, 1963-1966. As can be seen from the figure the synthesised hydrograph in many cases is different from the observed one. The result is by no means a success because in some cases both the flood-peak values and the flood volumes differs much from the actual ones. We have, however, decided to present the results obtained for further investigation and discussion.

THE STUDY

We have been working on data collected from the Kilombero River Basin. The basin is a part of the Rufiji River Basin, potentially one of the most important water resources in Tanzania. A map of the catchment is shown in Figure 1. The river has been gauged at Swero (1 KB 17) since November 1957. The area of the catchment above the gauging station is 33,400 km^2. The maximum recorded discharge at the station is 3,100 m^3/s, and the minimum is 80 m^3/s. This wide range reflects the marked seasonal difference in rainfall.

There are six rainfall stations in the area with observation periods of 20 years or more at Malangali, Ifinga, Ifakara, Njombe, Mahenge and Mufindi.

The records from Njombe and Malangali were left out at an early stage. Njombe is situated very far upstream from the river gauge, and Malangali, outside the catchment basin. We found that whether or not these stations are included, it made little difference to the average of all stations. Two other stations, Kwiro and Kibwele, were introduced in order to fill the gaps in the Mahenge and Mufindi records.

THE METHOD

The study is, to some extent, based on an investigation made on Tana River in Kenya*. One of the more important differences is the introduction of an antecedent precipitation index.

The basic equation used in the study is:

$$\Delta Q = \Phi(P) - c\,Q \qquad (1)$$

where ΔQ is the variation of the discharge during one unit of time

$\Phi(P)$ is a function of rainfall at the rainfall stations within time units of the same length

Q is the discharge at the beginning of the time unit

c is a constant

This means that the hydrograph is composed of one positive and one negative part. By excluding the rainfall part the equation is reduced to a well-known equation for recession curves. The time unit was fixed at one pentade (5 days).

Generally P can be written as $P_t = f(P_{1_t}, P_{2_t}, \text{----}\ P_{n_t})$ (2)

where P_{n_t} can be written: $P_{n_t} = g\,(P_{n_t}, P_{n_{t-1}}, P_{n_{t-2}}\ \text{----})$ (3)

where P_t is the precipitation function for runoff construction in pentade t

P_{n_t} is a precipitation function for rainfall-station n

$P_{n_{t-1}}$ is the mean rainfall at station n for pentade t-1

By introducing the $P_{n_t} = g\ (\ )$ function we aim to include both the delay due to different travel times from the rain gauges to the river gauge and also the precipitation index for the antecedent pentades.

An antecedent precipitation index of a maximum of 6 pentades is introduced. It is obviously not right to give the earlier pentades as much weight as the last ones. Thus the P_{n_t} function was defined as:

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* G. Kovacs, H.J. Mörth: The use of rainfall data in estimating actual and maximum probable river discharge (Tana/Kenya).

$$P_{n_t} = xp_{n_t} + yp_{n_{t-1}} + zp_{n_{t-2}} + qp_{n_{t-3}} + rp_{n_{t-4}} + sp_{n_{t-5}} \tag{4}$$

where $x+y+z+q+r+s = 1$

The four selected rainfall stations were numbered:

Station 1 - Ifakara Station 3 - Ifinga

Station 2 - Mahenge Station 4 - Mufindi

For the four stations the P_{n_t} functions were defined as:

$$P_{1_t} = xp_{1_t} + yp_{1_{t-1}} + zp_{1_{t-2}} + qp_{1_{t-3}} + rp_{1_{t-4}} + sp_{1_{t-5}}$$

$$P_{2_t} = xp_{2_{t-1}} + yp_{2_{t-2}} + zp_{2_{t-3}} + qp_{2_{t-4}} + rp_{2_{t-5}} + sp_{2_{t-6}}$$

$$P_{3_t} = xp_{3_{t-2}} + yp_{3_{t-3}} + zp_{3_{t-4}} + qp_{3_{t-5}} + rp_{3_{t-6}} + sp_{3_{t-7}} \tag{5}$$

$$P_{4_t} = xp_{4_{t-2}} + yp_{4_{t-3}} + zp_{4_{t-4}} + qp_{4_{t-5}} + rp_{4_{t-6}} + sp_{4_{t-7}}$$

i.e. the rainfall from the area represented by stations 3 and 4 is lagged two pentades and from station 2, one pentade. No time lag was assumed for station 1.

The function (2) was defined as:

$$P_t = P_{1_t} + P_{2_t} + P_{3_t} + P_{4_t} \tag{6}$$

From the recession curves of the four-year runoff records the envelope curve for the recession curves was constructed and the constant c in equation (1) was calculated assuming $\Phi(P)$ equals zero when the rainfall is below some negligible value. As will be seen later, no direct runoff was assumed when P_t was below a certain limit. Thus the discharge variation due to recession only is known and equation (1) can be reduced to:

$$\Delta pQ = \Phi(P) \tag{7}$$

where ΔpQ is the variation in discharge due to direct runoff only.

Some rough analysis showed that one possible form of the unknown function in (7) could be the hyperbolic

$$\Delta pQ = aP_t^b \tag{8}$$

This was chosen in the subsequent correlation and regression analysis in order to select the best of a number of combinations of x, y, z, q, r, s in equation (5). It was, however, necessary to divide this analysis in two parts (one for $P_t \geq P_{t+1}$, the other for $P_t < P_{t+1}$) in order to increase the correlation coefficient to an acceptable level.

The non-linear runoff condition of the catchment made it also necessary to use different values of the x,y,z,q,r,s in the different parts, and also for higher and smaller amounts of rainfall expressed by equation (6) (see Figure 3). The discontinuity thus introduced was assumed to be of only minor significance.

Small amounts of rain given by equation (6) were assumed either to evaporate or to produce no increase in the ground water yield. For values of P_t less than 1.0 mm., equation (7), was put equal to zero. As can be seen from Figure 2 this value of 1.0 mm. is probably too low for the dry parts of the year.

No seasonal distinction of the influence of rain on the hydrological conditions was introduced. However, it is expected that different hydrological reactions of the rainfall in different seasons (or the state of dryness in the catchment expressed by the function (5)) should improve the results.

The values shown on Figure 2 were computed by the equation:

$$Q_t = Q_{t-1} + \Delta Q$$

For t = 1, Q_{t-1} was estimated from the constructed recession curve.

CONCLUSION

The results of this attempt to synthesise runoff from rainfall data are not satisfactory. It should, however, be possible to improve the method, but whether a more sophisticated method is likely to produce considerably better results may be doubtful. It is probable that improvements can be obtained in the selection of x,y,z,q,r,s and in the estimation of travel times. From equation (5) it will be seen that the same x,y,z,q,r,s combination is used for all four stations. This is obviously a very crude simplification.

It would be fairly easy to improve the recession part of the constructed curve. The curve is too flat; this is probably due to the limit for rain, which does not contribute to the direct runoff, being set too low.

It must be pointed out that the huge area of 33,400 km^2 is covered only by four rainfall stations. Due to the scattered pattern of tropical rainstorms this is obviously not an adequate network. This is probably the most serious disadvantage with this study. It is felt, however, that the results are of such a quality that the method should not be left untested on more favourable catchments.

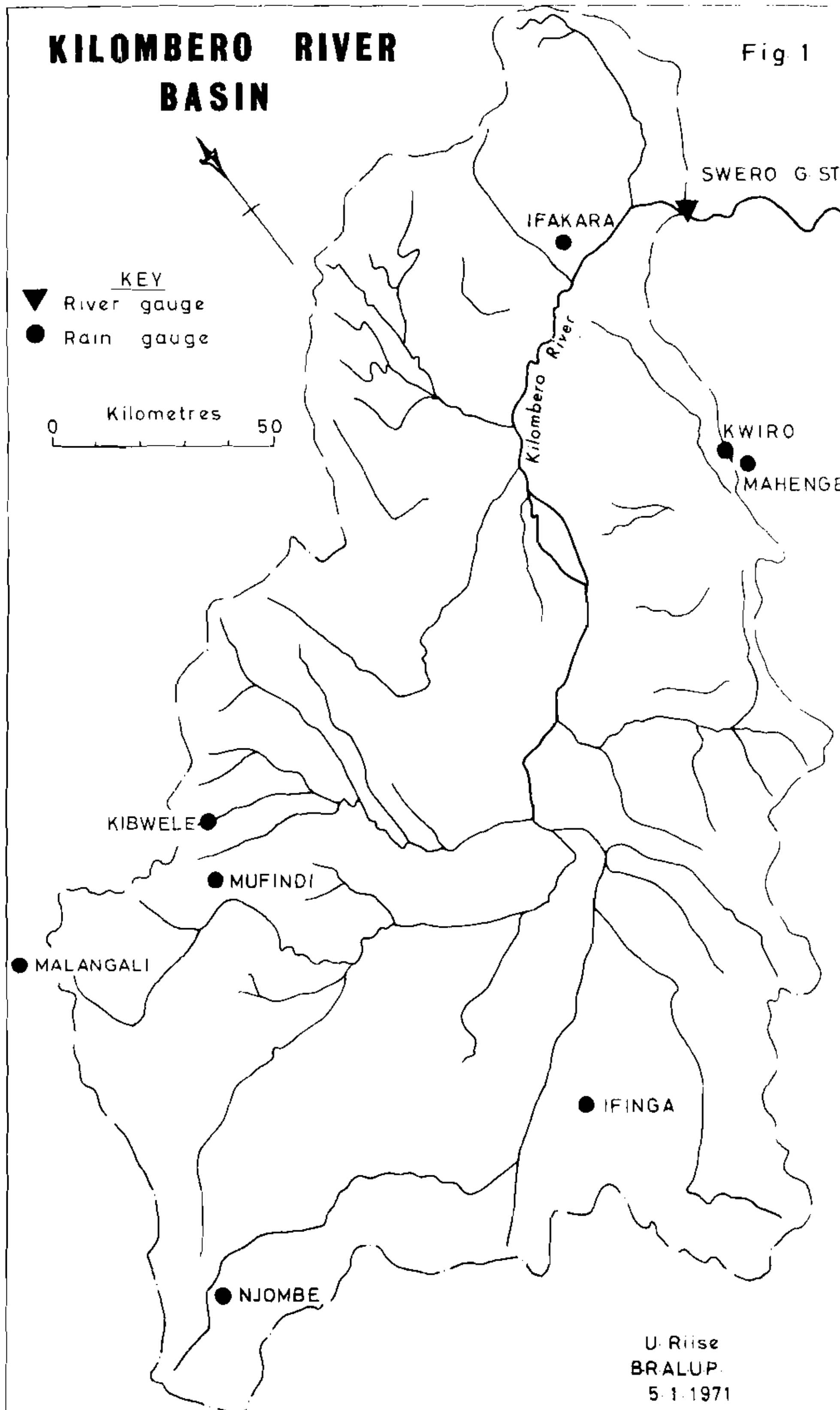
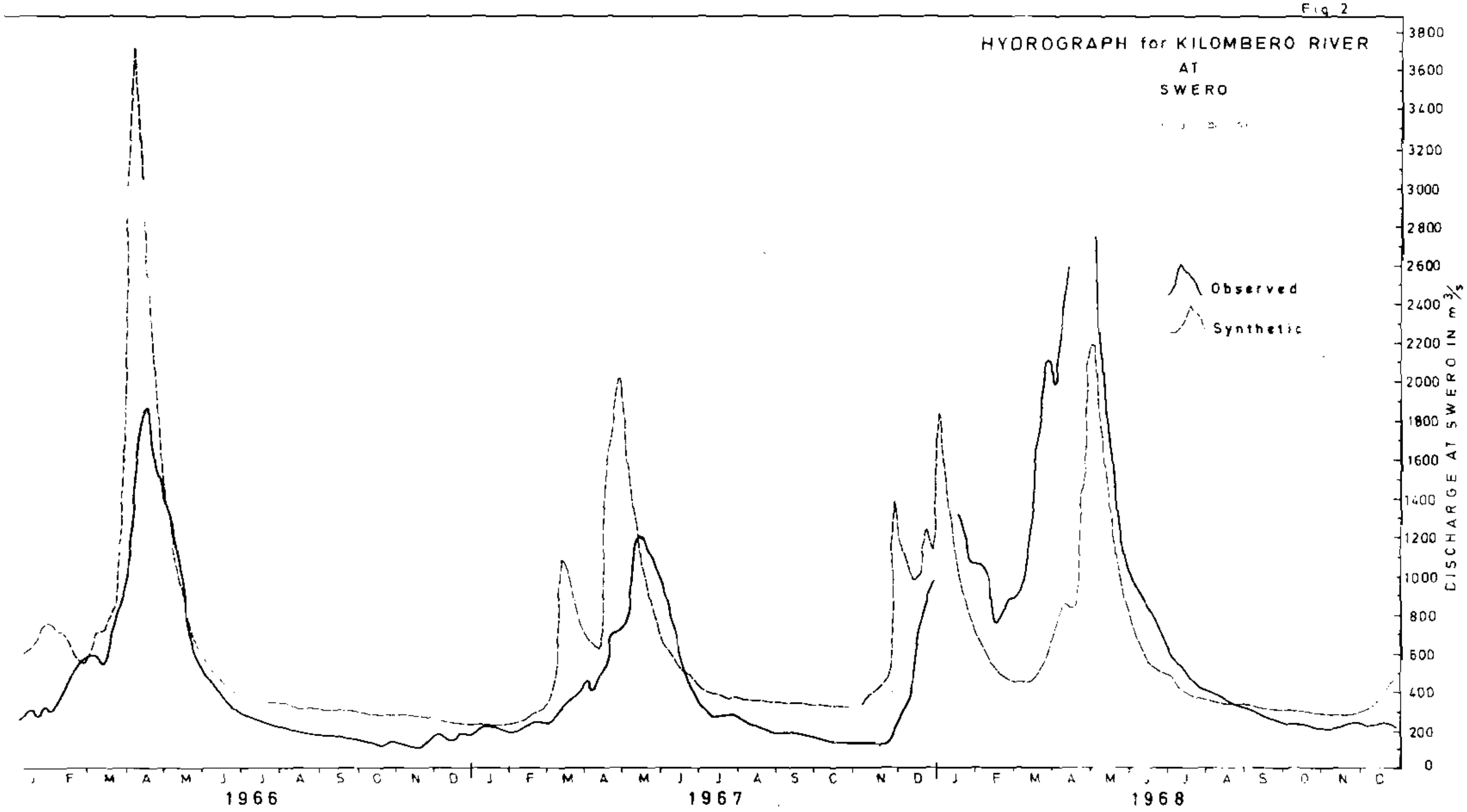
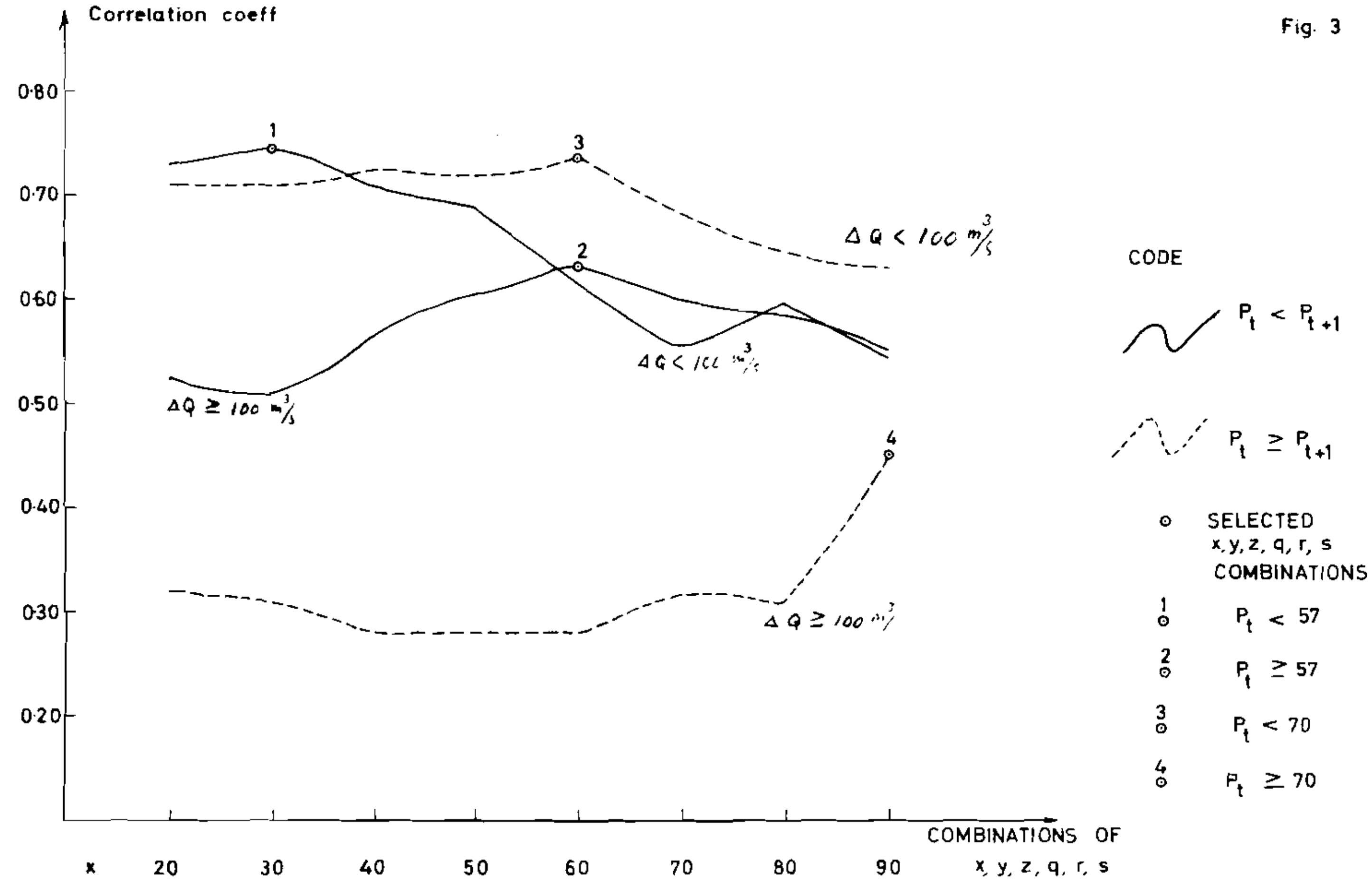

KILOMBERO RIVER BASIN
Fig 1
SWERO G ST
IFAKARA
KEY
River gauge
Rain gauge
Kilometres
0
50
Kilombero River
KWIRO
MAHENGE
KIBWELE
MUFINDI
MALANGALI
IFINGA
NJOMBE
U. Riise
BRALUP.
5.1.1971

Fig. 2



HYDROGRAPH for KILOMBERO RIVER
AT
SWERO
Observed
Synthetic
DISCHARGE AT SWERO IN m³/s
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
J F M A M J J A S O N D
1966
J F M A M J J A S O N D
1967
J F M A M J J A S O N D
1968

Fig. 3



x	20	30	40	50	60	70	80	90
y	20	20	20	20	15	15	10	5
z	20	20	15	15	10	10	5	5
q	15	15	10	5	5	5	5	0
r	10	10	10	5	5	0	0	0
s	5	5	5	5	5	0	0	0

A STUDY OF SOME ETHIOPIAN AND OTHER NATURAL WATERS

By Laurence R. Pittwell

ABSTRACT

The chemistry of many Ethiopian rivers has been examined at least qualitatively and the results and conclusions to date are given. The main emphasis has been on the metal content, and the ligands responsible for keeping metals in solution. It is suggested that one way of classifying natural waters is by the ligands responsible for keeping the various metals in solution. In Ethiopia, this is mainly carbonate ion, but also water, chloride, fluoride, and in a few rivers organic acids. As rivers are dynamic systems not in true equilibrium with their surroundings, these ligands may change along the course, and with season. One of the reasons for the large amount of colloidal silt in Ethiopian rivers is a ligand exchange reaction, which results ultimately in a negative charged colloidal gel which is easily peptized - the unstable alkaline soils of the Sudan. For completeness, some not readily accessible analyses of waters from other parts of the world are included, some of which illustrate that carbonate ion co-ordination is a world-wide phenomenon.*

RESUME

La chimie de nombreux cours d'eau éthiopiens a été étudiée, du moins sur le plan qualitatif, et les résultats et conclusions auxquels on est parvenu jusqu'ici figurent dans le présent mémoire. On a mis l'accent en particulier sur la teneur en métal et sur les ions, groupes ou molécules grâce auxquels les métaux restent en solution. Il est proposé de classer les eaux naturelles selon ces ions, groupes ou molécules qui maintiennent en solution les divers métaux et qui, en Ethiopie, sont principalement des ions carbonates, mais également des molécules d'eau, des chlorures, des fluorures et, dans quelques cours d'eau, des acides organiques. Comme les cours d'eau sont des systèmes dynamiques qui ne sont pas vraiment en équilibres avec le milieu qui les entoure, ces ions, groupes ou molécules peuvent se modifier selon la partie du cours d'eau et la saison. Si l'on trouve de grandes quantités de limon colloïdal dans les cours d'eau éthiopiens, c'est notamment par suite d'une réaction d'échange chez ces ions, groupes ou molécules, qui aboutit en définitive à la formation d'un gel colloïdal à charge négative, lequel est facilement peptonisé, d'où les sols alcalins instables du Soudan. Certaines analyses difficiles à obtenir concernant les eaux d'autres parties du monde complètent le mémoire en question; il ressort de certaines d'entre elles que la coordination des ions carbonate est un phénomène à l'échelle du globe.

*

* *

INTRODUCTION AND ANALYSIS

A large number of Ethiopian natural waters have been analysed for various reasons by Italian scientists, the Awash Valley Authority, Wood, Baxter, and Prosser (Ethiopian Lakes), and the present author. For references to this work, see Pittwell, 1967. The majority of the author's own analyses are given in Table 1 of the appendix.

* For brevity, the bulk of the analyses are deposited (see Table 1).

Seasonal variations are illustrated by Table 2. Most of these analyses were made by conventional methods, which in general are described in the author's aforementioned monograph. It was noticed that in some instances results varied by as much as a power of ten in extreme cases, depending on the method used; nor was it reassuring when circulation of both genuine and synthetic samples to outside laboratories showed similar variation. This was traced to the ignoring of interference effects from elements such as iron, aluminium silicon, boron and manganese, which are occasionally quite high. It was also found that some laboratories ignored known interference effects such as that of calcium with sodium in flame photometry. With flame photometry, it was found that this interference obeyed the already known emission spectrographic equations (Pittwell, 1962 and 1966), and corrections were made. The fluoride values originally reported by the author have been revised to take account of interference effects. Recent work on synthetic doped samples has shown that accurate results can be obtained by extracting a known volume of sample with 8-quinolinol and chloroform prior to the normal alizarin red S, zirconium colorimetric method.

It will be noted that with a few exceptions, the trace element spectrographic analyses in Table 1 are only order figures. Synthetic studies showed that the solvent extraction technique devised by Pohl (1953) could be simplified by using only a mixture of dithizone and 8-quinolinol in chloroform, provided that the sample was extracted to completion sequentially at pH 1, 4, 7 and 9 approximately, and any precipitate added. This extract was carefully evaporated to dryness and charred at 450°. The char was then weighed and excited in the spectrograph without any additional graphite, the carbon line at 2478.6 A° being used as reference line. Work is still proceeding to put figures to these range analyses. This work with synthetic samples has confirmed Belyaev (1965), who estimated the accuracy of Pohl's method as 50 per cent.

CO-ORDINATING LIGANDS

From Table 1 it is evident that in Ethiopia the only ligands present in sufficient concentration to be significant in co-ordination are carbonate (including bicarbonate) and water. It just might be possible that in some places fluoride, chloride, nitrite, ammonia and organic acids also co-ordinate to metals, and in rare instances sulphide, but these are the only probable ligands. A search of literature revealed that in some parts of the world sulphate and nitrate might be important as well, so a considerable amount of synthetic work was done to determine the relative importance of these various ligands for transporting metals in solution. This work will not be given in detail here. The absorption spectra of metal solutions was measured as solutions of various ligands were added one at a time, or mixed in competition with each other at different pH. The ability to leach metal carbonates, oxides and aerated sulphides was also measured. In some instances, especially carbonates and nitrites, solid compounds were also isolated and studied. In almost every case, it was found that ligands co-ordinated metals only when present in more than theoretical excess, though with metals such as cobalt and copper, partial co-ordination might occur at saturation or high temperature. The results of this work are summarized in the author's aforementioned monograph. For Ethiopian waters, this means that carbonate is the only major probable ligand, except water, and must therefore be responsible for keeping most of the metals in solution that are normally precipitated by alkali. Synthetic work confirmed that this was possible, and many stability constants and hydrolysis constants have been measured. The former are given in the monograph; the hydrolysis constants will be published shortly.

It is well known that complex formations are governed by the Mass Law so that, in a complex mixture of metals and ligands, the relative bond strengths determine which is bonded to which. An interesting case of this found during this work was in the co-ordination by fluoride ion. Under natural surface conditions, fluoride might be expected to co-ordinate to aluminium, scandium, yttrium, iron III, tin and beryllium, but not other metals. However, the fuoride-beryllium bond is far stronger than the iron-fluoride bond, and when iron is determined by a thiocyanate colorimetric method in the absence of beryllium, and re-determined after the addition of excess beryllium, the apparent increase in iron content is the concentration of fluoroferrate present. In a few Ethiopian rivers, this can be as high as two thirds or even all the iron.

The actual metal content carried by a river in solution will be dependent not only on the concentration of suitable ligands and the pH, but also on the availability of metals from the soil and bedrock. Hence, rivers will rarely be saturated in metals. However, if the concentration of "heavy metal" concentrate obtained from a sample be plotted against pH for rivers high in carbonate alone, or chloride alone, it is obvious that the efficiency of carbonate as a ligand rises rapidly above pH 5. Below this there are probably only simple bicarbonates of aquated ions; whilst that of chloride falls almost to nil above pH 9. This results in a minimum "heavy metal" content at pH 7-8. The results are summarized in Table 3. A similar curve is obtained if calcium content is plotted against pH, presumably due to the formation of soluble carbonatocalcium anions. If a sample of optically clear (no Tyndal's cone) Awash River water is acidified from pH 8.3 to 6.3 using an acid such as perchloric whose anion is poor at co-ordination, the "heavy metal" content drops from about 140 mg/l. to 40 mg/l. presumably due to destruction of carbonate ion. Further evidence for the existence of carbonateferrate II and III, and carbonatomanganate II has been obtained from some chalybeate springs in the cliffs of an upper tributary of the Kassem. The only other complex ions definitely detected in Ethiopian waters other than by probability are chloroferrates II and III identified by absorption spectra in samples from Dallol. Additional evidence for carbonato complexes is given when exceptionally alkaline water, such as L. Shalla, is shaken with azurite, the copper content rises to 2 g/l., and bisaquobiscarbonatocuprate II ions can be detected in the water. Other points of interest are: copper carbonato complexes are among the most stable, and as the sea is alkaline, this may explain the high copper content of the sea remarked on by Goldschmidt (1937); calcium carbonato complex is among the least stable; hence, although limestones will precipitate most heavy metals from acidic waters in which water or chloride is the dominant ligand, they have no action on alkaline carbonate waters. Differences of stability with valence can cause springs to lose large amounts of iron and manganese as their waters meet the air, as happens at the chalybeate springs in the cliffs above the Kassem gorge. There are also ligands such as sulphide, sulphate and phosphate which, although not forming soluble complexes with metals, may precipitate some of them. Thus, passage over gypsum in the Ogaden almost completely strips lead from the Wabi Shabbelli. In the laboratory, gypsum rapidly decomposes carbonatoplumbates to lead sulphate. An unfortunate side effect of carbonato complexes is that alkaline carbonate waters when aerated will dissolve metal plumbing, including copper; whilst boiling the least stable gives slimy precipitates.

PRACTICAL OBSERVATIONS

Several people have shown (see the author's earlier monograph) that the pH of groundwater is controlled by the leaching of alkali and alkaline earth metals from the rocks and soils by carbonic acid; by the action plants which by metabolizing bicarbonate may raise the pH to over II, or lower it well below seven when they die and decompose. Dilution by rain is another potent effect, whilst hot springs and sun heat may be locally important. Tests on synthetic complexes and real rivers show that if the pH of an alkaline river falls, carbonato complexes decompose; first to polymeric colloids, and then to gels which have residual negative charge on the surface. These negatively charged colloids should be coagulatable by highly charged positive ions, and this is the case. If such colloids are allowed to polymerize slowly, the resultant gel particles are bonded together by absorbed alkali metal ions neutralizing the repelling charges. If these ions are removed by washing, the gel is peptized. The muddiness of alkaline rivers after rain is well known, and might be attributed to simple erosion, but prolonged observation has revealed that the Sebeelu river from the Sululta plain just occasionally turns acid at the end of the dry season, before the rains start, due to rotting weeds. When this happens, the river becomes exceptionally turbid. Likewise, samples of river water dialyzed to remove colloids, and then diluted with distilled water, give easily peptized colloidal gels on prolonged standing. This is reminiscent of certain Sudan-type alkaline soils which, when an attempt is made to wash out the alkali, peptize and wash away. It is suggested that these soils have been produced by polymerization of such colloids, and that the alkali metal ions are the bonding agents holding the particles together. If it is necessary to remove this alkali, it would be advisable to replace it by ammonium ion, by washing the soil with an ammonium salt. When the plants subsequently metabolize these ammonium ions, the residual hydrogen ion will still neutralize the charge.

Other observations are that: Ethiopian waters appear to contain plenty of copper and fluoride, occasionally too much of the latter; but there is often a scarcity of cobalt. A comparison of analyses of lakes at one time or another reported to be terminal sinks, shows that whilst Shalla and Baasaka are undoubtedly sinks, Chamo definitely is not. Careful enquiry confirms that there is a connexion between L. Chamo and the Sagan R.L. Awassa is more of a problem. It is not alkaline enough or brackish enough to be a sink, yet it definitely has no visible outlet; but on the south shore of the lake there is a very low col leading to the headwaters of streams flowing to L. Abaya, and the rocks of this col are quite porous. It is suggested that L. Awassa drains through this col by underground seepage. Hence, L. Chew Bahr is the ultimate sink for the whole region south of Hosanna and Shashamane. There are quite considerable variations in the published analyses for Lakes Abayatta and Baasaka. This has been traced to rafting of fresh water from the tributary streams over the top of the denser brackish lake water. Intermittent dilution and hence lowering of the stabilizing carbonate ion concentration may account for the large banks of silt that form where streams enter L. Abayatta. There appears to be an intermittent cross connexion between L. Abayatta and L. Shalla, the water of which is highly alkaline.

The island of Dahlak Kebir has relatively fresh water despite its very low rainfall. The presence of a large amount of carbonate in this water suggests that an underground syphon exists under the sea, connecting a mainland aquifer with the island. The big problem in this area is the origin of the high chloride concentration, and in some instances the acidity of the Danakil Rift waters. It is not due to desert conditions, as comparison with Yemeni waters, especially those of the Tihama coastal desert, which are normal carbonate, low-chloride waters like those of the adjacent plateau. The chloride content of the Danakali waters must therefore come from the underlying salt beds of marine evaporite origin. The very high acidity of some Danakil springs lies in the tectonics of the area. When exceedingly hot rocks from the mantle come into contact with sedimentary rocks which will include carbonates, sulphates, sulphides, halides, and hydroxyl groups, in addition to minor things like borates, etc., carbonates decompose, hydroxyl groups condense to form water (as steam) and a series of chemical reactions, well known to cement and ceramics makers, take place with silica to form sulphur dioxide, and trioxide, volatile metal halides, and so on. These latter are then hydrolysed by steam to metal oxides and hydrogen chloride, etc. These highly corrosive gases will be under high pressure, and once having broken through to the surface will form a volcanic region until that area has drifted far enough from the deep-seated thermal zone. The Danakil rift is thought to be a point of crustal separation where magma is coming into contact with, among other things, halite. This is evident for the trace element content of a red halite located south of Dallol at a place nick-named "Skating Rink" which contains not only traces of typical volcanic minerals, but also lithium, aluminium, manganese, iron, beryllium, silicon, titanium, germanium, chromium, lanthanum, boron, molybdenum, zirconium, hafnium, niobium and tantallum, much of which are precipitated as oxides when the salt is re-crystallized from water. It is concluded that this salt deposit has been metamorphasized by molten lava reacting with it. The Dallol hot brine springs which are unusually high in hydrochloric and sulphuric acids as well as iron and copper chloro complexes are located just north of this structure. These springs are interesting because they contain large quantities of copper in the presence of hydrogen sulphide. Some years ago the author found that whilst the water molecule could react with halocuprates, the negative hydrosulphide ion was repelled without reaction. Hence, at very high halide concentrations when virtually all the copper is present as halocomplex, copper is not precipitated by hydrogen sulphide at any acidic pH (Pittwell, 1964). This happens here.

CLASSIFICATION OF NATURAL WATERS BY LIGAND

Currently, natural waters are classified by the predominant anion present. For some purposes this is very useful, but when determining the metals likely to be in solution, this can be somewhat misleading, and sometimes it might be more useful to classify waters by the main co-ordinating ligands present. This for many of the waters of western Europe, and eastern north America would give us water type waters, where the anions present are merely simple anions, in contrast to the carbonate, fluoride, and chloride waters of Ethiopia. It is sometimes difficult to draw a definite line. Thus, although sulphate is usually merely an anion, without co-ordination, its presence in Ogaden waters does account for the virtual absence of lead and barium.

A common misconception is that high carbonate content implies alkalinity. This depends on the cation. Thus, in the south of Britain high concentrations buffer the rivers to a maximum pH of 7.2, that of saturated calcium bicarbonate. Increase in carbonate results in loss of carbon dioxide and precipitation of calcium carbonate onto the river bed. On the other hand, the river will not get more acid than this unless all this precipitated calcium carbonate has dissolved. A pH above 7.2 indicates alkali metals (usually sodium, sometimes potassium). The calcium content must be mineral between pH 7.2 and about 8.3, at which pH the solution is saturated in alkali bicarbonates. However, the concentration of carbonate is usually measurable before this, and as it increases, unstable carbonato-calcium complexes form. Barium does not form such complexes, and this may be used as the basis for determining true carbonate in the presence of bicarbonate (Pittwell, 1969).

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Table 1. Typical Analyses of Ethiopian and Related Natural Waters.

No.	Sample	pH	HCO_3^-	$CO_3^=$	$SO_4^=$	$S^=$	F^-	Cl^-	Br^-	I^-
29	Dallol, hot spring	0.2	-	-	1807	-	t	36350	t	-
101	Awash R., Melka Konture	8.3	305	t	9	-	2	249	-	-
104	" " "	7.6	90	-	-	-	3	-	-	-
106	" " "	7.2	76	-	-	-	1.1	-	-	-
161*	L. Baasaka, Metahara	10.0	-	23200	2120	t	4	3320		
328*	Tekoor Waha R., Awassa	7.3	124	-	-	-	28	t		
548	Sebeelu (dry season)	8.5	128	t	-	-	0.6	-	-	-
551	" (big rains)	8.3	40	t	-	-	-	-	-	-
556	"	6.9	90	-	-	-	8	-	-	-
746	Well 30 km E of Hodeida	8.3	250	-	190		4	-	-	-
769	Niger, Baro	7.6	54	-	-	-	t	-	-	-
790	Indus, W of Attock	7.55	146	t	-	-	h	-	-	-
837	L. Myvatn, Iceland	9.7	88	t	-	-	4	vft		

No.	Organic acids	NO_2^-	NO_3^-	NH_3	SiO_2	$PO_4^{\equiv}$	$BO_3^{\equiv}$	Li	Na	K	Ca	Mg	Fe
29	-	-	-	34	t	t	-	80	6960	1100	6200	2800	5620
101	-	-	-	-	76	-		-	370	20	34	t	t
104	t				0.02	0.02		1	25	9	50	30	15
106	-	-	-	-	2300	-		t	h	t	t	m	2.2
161	t	-	-	30	t	-		2	22500	t	70	60	t
328	vh	-	-	-									5
548					171						2	0.5	1
551											4	1	
556	t	t	t	t	140	t					2	4	10
746		6		4				1.5	285	7	17	t	t
769				ft				-	2	-	19	-	t
790								0.9	13.8	7.8	84	34	t
837	-	-	-	-	t	t		t	22.7	0.6	6.7	3.2	t

No.	Heavy Metal Concentrate	Trace Element Concentrations				
29	10950	Al 1000 mg/l	Bi 40 ng/l	Ge 90 ng/l	Ni 200 ng/l	Sr 21 mg/l
		Ag 70 ng/l	Cd 10 ng/l	Hf 530 ng/l	Pb 360 ng/l	Te 130 ng/l
		As 400 ng/l	Co 70 ng/l	La 200 ng/l	Pt 120 ng/l	Ti 16 ng/l
		B 900 ng/l	Cr 1 mg/l	Mn 94 mg/l	Sc 20 ng/l	V 130 ng/l
		Ba 2 mg/l	Cu 1.3 mg/l	Mo 6 ng/l	Si 1 mg/l	Zn 600 ng/l
		Be 60 ng/l	Ga 100 ng/l		Sn 90 ng/l	Zr 30 ng/l
101	140	h Si Al Mg Fe Ca. m B Mn. t Ag Cu. ft Ni Ba Sn Pb. vft Sr Te				
104	116	Ag 3ng/l	Be 5ng/l	Cu 8ng/l	Pb 8ng/l	Si 20ng/l	Ti 1ng/l
		Al 600	Cd 0.3	Mn 100	Pt 0.5	Sn 5	V 8
		B 20	Co 1	Mo 5	Sb 0.5	Sr 10	Zn 3
		Ba 2	Cr 2	Ni 0.5	Sc 1	Te 2	

Note vh, h, m, t, ft, vft, eft, are in decreasing order of magnitude for range, if known, see deposited full table.

* This lake has trona in its bed acting as a buffer.
* A very variable river with respect to Fe, F, and organics see full table.

Table 1 contd.

No.	Heavy Metal Concentrate	Trace Element Concentrations
106	239	h Fe. m B Si mg Mn Al. t Li Pb Ca Ti Cu Zr. vft Y Be As Hf Ag Cr Ba Ge Ce Sn Sr Ni. eft Co Ta Th Sc Zn. (Al 1.5 mg/l, Mn 160 ng/l, Cu 84 ng/l, Ni 7.5 ng/l)
161	1550	h Si B Al Mg Fe. m Ca. t Mn Cu Sn. ft Ag Co Sr Pb.
328	80	vh mg. h Ca Si Fe. m Li Al Mn. t Cr Ti. ft Ba Ge La Ni Mo Cu Zn Co V Be Hf Zr Pb.
548	14	h Mg Si. m B Fe Al Mn Cu. t Zn Ca Cr. ft Ag Ba Be Cd Zr Ce.
551*	37	h Mg. m Fe Ca Si B Mn. t Al Cu. ft Zn Li Ba Ag Cr. vft V Mo La. eft Ni Be Ta Co Sb Zr K Sn Cd.
556	62	h Si Mn. m Fe Al Zn. t Sn Ag Yb Li. ft Y K Cu Co La Cr Ni Mo Ca Ti Ta Be. vft Mg Ba Cd Zr Sb. eft V Nb Ta As Hf Te.
746	only a	composite Yemen sample analysed and similar to Ethiopian
769	65	h Si Al Mn. m Zn. t Fe Be Li Mg Sn Ca Cu Ag. ft Ta Sc K Sr. vft La Ba Hf Zr As B Cr Ga. eft Co Ti Mo.
790	32	h Si B Ca Fe Mg. m Al Cu. t Ag Be Ti Co Ni Mn Pb Sr Sb Ba. ft Zn Zr Cr Ge Mo V Cd Ce.
837	63	m Ca Al Zn Cu Mn. t Ni Si Mg. ft Sr V Mo Ti Be. vft La Sc Nb Bi Ag Zr B In Pb. eft Dy Ta Cr La Cd.(Ni 300, Cu 190 ng/l)

Table 2 Seasonal Variations in Typical Rivers

River	Location	pH	$CO_3^=$	HCO_3^-	$SO_4^=$	Cl^-
Awash	Melka Kontura	7.1 - 8.3	0 - 2	76 - 305	0 - 190	0 - 249
	Koka Dam	7.5 - 8.6	0 - 15	162 - 522	0 - 12	10 - 32
	Awash	7.6 - 8.7	0 - 30	121 - 228	0 - 78	2 - 20
Borkenna	Kombolchia	7.5 - 8.6	0 -200	210 - 540	0	2 - 350
	below swamp	7.2 - 7.6	0 -100	330 - 452	0 - 120	1 - 70
Sebeelu	at road	6.8 - 8.7	0 - 10	40 - 150	0	0

Other ions etc vary just as widely.

Table 3 Variations in Metal Content with pH

pH range of group	Mean weight of "heavy metal" concentrate in mg/l. All types	High CO_3	High Cl	Max wgt concentrate mg/l	No. samples in group	Mean Ca mg/l.
0 - 1	8601	-	8601	10950	2	)
4 - 5	92	-		92	1	)1850
5 - 6	7	7		92	4	)
6 - 7	284	136	5446	5624(high Cl)	37	)
7 - 8	180	153	3044	3610(and CO_3)	215	50
8 - 9	266	268	230	3310	270	20
9 - 10	559	559	-	4200	22	12
10 - 11	819	819	-	1630	4	) 38
11 - 12	1140	1140	-	1630	2	)

Note, rivers rarely achieve saturation in trace elements

Only a selection of table 1 has been given. The full table is deposited at Haile Sellassie I University Library, Addis Ababa, The Geological Society in London, England, and the National Museum of France, Paris etc.

DESIGN OF RAINGAUGE NETWORK IN THE PROJECT
AREA OF LAKES VICTORIA, KYOGA AND ALBERT

by P. K. Raman

ABSTRACT

The optimum number of raingauges in a catchment required to estimate the mean catchment rainfall, correct to a predetermined relative error, is given by the statistical relationship:

$$n = t^2 . C_v{}^2 / p^2 \text{ or } n = (2\, C_v / P)^2$$

where n is the optimum stations required, C_v is the coefficient of variation with existing network, P is per cent relative error of estimation assumed, and t is Student's t value from tables for confidence level and degree of freedom used.

The paper examines on the basis of the above relation the optimum network required for the Hydromet Project catchments to estimate mean catchment rainfalls correct to 8 per cent or 10 per cent of the true mean using the 1967 network.

The deficiencies in the network were made up by addition of about 150 new land stations and 16 manned and 13 automatic raingauge stations on the Lake Victoria islands. The accuracy of estimation over the project land area improved from 14 per cent to 9 per cent and over the Lake from 24 per cent to 13 per cent. Suggestions for locating additional stations in areas still found deficient are indicated.

RESUME

Le nombre optimal de pluviomètres nécessaires pour évaluer la pluie moyenne tombant sur un bassin versant, avec une marge d'erreur relative fixée d'avance, est donné par la relation statistique

$$n = t^2 . C_v{}^2 / p^2 \text{ or } n = (2\, C_v / P)^2$$

où n = nombre optimal de stations requises, C_v = coefficient de variation par rapport au réseau existant, P = pourcentage supposé d'erreur d'estimation relative, t = variable de Student d'après tables relatives aux seuils de confiance et aux degrés de liberté utilisés.

L'auteur examine, en se fondant sur la relation susmentionnée, le réseau optimal qui est requis dans les bassins versants du projet hydrométéorologique pour pouvoir estimer les pluies moyennes au-dessus de ces bassins avec une marge d'erreur de 8% ou 10% par rapport à la moyenne vraie et en utilisant le réseau 1967.

Pour pallier les insuffisances du réseau, on a ajouté environ 150 nouvelles stations continentales, ainsi que 16 stations pluviométriques habitées et 13 stations automatiques sur les îles du lac Victoria. La précision des estimations s'est accrue de 14% à 9% sur la partie continentale du projet et de 24% à 13% sur la partie lacustre. L'auteur formule des suggestions pour l'emplacement de stations supplémentaires dans des zones encore jugées insuffisamment équipées.

INTRODUCTION

The objective of the Hydromet Survey of Lakes Victoria, Kyoga and Albert is the collection and analysis of hydrological and meteorological data of the river catchments that drain into the above lakes, with a view to studying the water balance of the Upper Nile Basin.

The important aspect of data collection planned in this project has been summarized in the Biennial Review (1967-1969) (4). The present note discusses the results of a statistical investigation undertaken for the design of an optimum raingauge network required for assessment of areal mean rainfall, in the sub-catchments and the project area as a whole, with a specified degree of accuracy for water-balance studies.

RAINGAUGE NETWORK IN EAST AFRICA

The East African Meteorological Department, with its headquarters at Nairobi established in 1929, functions as a Common Services Organization of the East African Community of the three States and is responsible for the systematic collection, scrutiny, processing and publication of reliable rainfall and other climatological statistics for East Africa. Though rainfall records have been collected since the beginning of the century, the first rainfall summary for the International Standard 30-year period, 1931-1960, was published in 1966 (3). The publication of daily, monthly and annual rainfall data published by EAMD every year forms a valuable source of data for all studies to be undertaken in the project.

Based on the directory of raingauge stations listed in the rainfall volumes of Kenya, Uganda and Tanzania for 1967 (3), a preliminary study of the existing network of stations, inside and in the neighbourhood of the project boundary and located in position on a map (scale 1 : 1 000 000) in the 38-degree squares (approximate area 408 000 km^2) revealed that about 945 stations would be available. Inside the project boundary (area 336 750 km^2) there were about 690 raingauge stations (Figure 2). In Kenya, it was found that each 10-min. square had more than 10 stations, whereas about 50 per cent of the 10-min. squares of the project area were without any station. Recognizing this deficiency, the Plan of Operation for the Hydromet Survey (11) envisaged setting up of an additional network of about 150 more stations in a planned and objective manner to overcome the gaps found.

PROBLEM OF DESIGN OF RAINGAUGE NETWORK

The purpose of rainfall data-collection in hydrological studies is the evaluation of the volume of water falling over a catchment area, in the form of rain contributing to eventual runoff through the rivers. An absolute value of the "true areal average rainfall" over an area will remain an unknown quantity, and the true value has always been estimated, as the mean given by a large network of stations, evenly distributed in the area. The areal density of gauges required to determine the mean areal rainfall depth within a specified relative error of estimation has been studied by methods of statistical theory of design of sample surveys, the raingauge station being regarded as a space-time sample. The duration of time has considerable smoothing effect on areal variation of precipitation. The areal variability is substantially reduced with the length of period over which observations are averaged and also the intensity of the storm. In practice, the percentage coefficient of variation over an area for daily rainfall is 80 per cent, for monthly rainfall 15 per cent to 17 per cent, and for seasonal or annual rainfall 7 per cent (Makay, (8)). McGuiness (9) gives the average error as 8 per cent for one-inch storms and 5 per cent for 5-inch storms. A level of accuracy of 8 per cent for annual areal rainfall was considered acceptable for purposes of water balance studies from hydrological considerations on the basis of a preliminary study of "water balance of Lake Kyoga" (5). Keeping in mind the errors of observation by voluntary observers and the instrumental errors due to exposure, etc., for a country-wide survey like the present project, an error of 8 per cent to 10 per cent appears reasonable, and a lesser error of estimation does not appear practical.

STATISTICAL APPROACH TO NETWORK DESIGN

The WMO/IASH Symposium at Quebec (1965) (12), on the "Design of Hydrological Networks", considered in its papers the different techniques and practices adopted in various countries. In a recent WMO/IHD Report by Rodda (1969) (10), the present state of knowledge on the subject of network design was summarized, indicating the nature and scope of the problem, but no standard method of design has been recommended.

The number of sampling points (n) required for estimating the true areal mean of a population, based on a random sample taken from the population, for a desired level of statistical accuracy, can be derived by methods of random sample survey. Several authors (12) have applied this method, to plan and design the optimum number of raingauges, using the general equation

$$n = \frac{k^2 \, v^2}{D^2} \qquad (1)$$

where n = number of samples (gauges) required;
v = variation of the mean of n observations;
D = desired relative difference between estimated sample mean and the true mean;
k = determines the probability that the sample mean will have a relative error not greater than $\pm D$.

Stein (12) (1945) and Kozlik (12) modified the above equation by substituting Student's probability distribution for k and gave an equation

$$n = \frac{t^2 \, v^2}{D^2} \qquad (2)$$

where n, v and D have the same meaning as in equation (1), and the t value is taken from the standard tables of Student's t, for chosen confidence levels and degrees of freedom used. Equation (2) is the same as:

$$n = t^2 \, . \, c_v{}^2 \, / \, p^2 \qquad (3)$$

where C_v = coefficient of variation in per cent;
p = desired percentage error of estimation assumed.

For the generally accepted confidence level of 95 per cent and for sample size 6 to 60 observations or more, the value of Student's t varies from 2.00 to 2.25. In a paper on Development and Design of Raingauge Network in the UK, Bleasdale (12) assumed that:

$$n = (2 \, c_v \, / \, P)^2 \qquad (4)$$

which gives the optimum network required in a simplified form.

The optimum network for each catchment was calculated using equation (3) where c_v and p are known; the value of t was chosen by trial so that it corresponds to the degrees of freedom given by the sample size n, finally chosen as the optimum number (6). Simplified equation 4 was also used to calculate the optimum number n for comparison of results.

METHOD OF ANALYSIS AND RESULTS

Annual rainfall data averaged up to 1967 for all the available number of years of record, for all the stations, have been published by EAMD (2). The mean annual rainfall for all the available stations in each of the sub-catchments of the project area was tabulated. From the tabulated annual rainfall data, the arithmetic mean ($\bar{x}$), standard deviation (σ) and percentage coefficient of variation ($c_v = 100\,\sigma/\bar{x}$) of rainfall for each sub-catchment was computed.

Using these statistical parameters, the optimum number of raingauges n required for each of the sub-catchments was calculated by trial for estimation error of 8 per cent and 10 per cent using the method mentioned earlier. These results are given in Table 1. It will be seen from Table 1 that the optimum number of gauges obtained from equation 3, using Student's adjusted $t_{.975}$ values and those obtained using simplified equation 4, using a constant value of 2 for t, give remarkably similar results. A higher confidence level of 99 per cent (or $t_{.995}$) increased the optimum number of samples to almost double the number for 95 per cent confidence level. Table 2 summarizes the analysis for the three lake basins, giving the d density of gauges (km^2 per station) for 1967, the optimum number of gauges required for an assumed estimation error of 8 per cent, the additional gauges required for each catchment, the number of raingauges installed by the project in different catchments up to 1970 and the density of network (km^2 per station) that will be attained. The last three columns of the tables give the percentage coefficient of variation for the 1967 network, the relative error p per cent of estimation with the 1967 network and the expected relative error with the 1970 network.

DISCUSSION OF RESULTS

It will be seen from Table 2 that the majority of sub-catchments in the project show an expected percentage error of less than the pre-determined 8 per cent error of mean areal rainfall, using the data of the network. It is evident that the 1970 network will yield an areal mean rainfall with a relative error of less than 10 per cent of the true mean for most of the catchments in the project.

The sub-catchments where the network was deficient in 1967 and 1970 ($p > 10$ per cent) are given in Table 3.

The optimum number of raingauges required for the above catchments have to be objectively located to avoid clustering, taking into consideration the diversity of the terrain. The annual isohyetal pattern generally adjusts itself parallel to the topographical features and climatological influences of the country.

The distribution of the decided optimum number of gauges is made in the proportion of the ratio of area enclosed by standard isohyetal intervals drawn in the catchment to the total area of the catchment.

Figure 1 gives the mean annual isohyetal map of the project area (the base map used is of a scale 1 : 1 000 000). Figure 2 gives the 1969 network and raingauge stations recently added up to 1970.

The Kagera sub-catchment is taken to illustrate the method of objective distribution of the optimum network (see Figure 1). The isohyetal lines crowd near the Lake

Victoria coast, and the area to the west shows a low gradient of rainfall distribution. The number of gauges in each of the areas bounded by the isohyets drawn is to be distributed in proportion to the ratio of area bounded by the isohyetal lines to the total area of the catchment (26 000 km^2). The central portion, which is marshy, undeveloped and sparsely populated, does not have any representative raingauge. Region 5, between 1 000 mm isohyetal, requires 6 stations.

All the catchments requiring improvement have similarly been considered separately, and the areas found wanting in networks should be provided with additional storage gauges as far as practicable in the near future, as shown in Table 4.

There are, however, two areas in the project considered as deficient in network density. These are the difficult, undeveloped, sparsely populated Masai regions (the Serengeti National Park and Game Sanctuary of Tanzania). However, the Serengeti Game Research Institute at Seronera maintains additional monthly rainfall records from a network of about 27 storage raingauges distributed over the reserve area. These data when collected and used for studies in the project, will give an estimated mean areal rainfall over this region also with a relative error of less than 10 per cent.

With this network, a reasonably correct isohyetal map of the project including Lake Victoria can be prepared for calculation of mean areal catchment rainfall on a monthly and yearly basis.

LAKE VICTORIA

The inaccuracy in the estimation of average rainfall over Lake Victoria (area 69 300 sq. km.) is one of the major deficiencies in the present network. Measurements of rainfall by radar methods have been considered and found not to be justifiable because of cost. Radar techniques give only qualitative results, and it is not possible to dispense with the maintenance of the network of manned and automatic island raingauges, since these are required for calibrating the radar echo intensities.

Areal estimation of rainfall over Lake Victoria will have to be worked out from the data of stations situated on the islands and along the coast. Thirty-three stations in 1967 gave an annual mean rainfall of 1 304 mm, a C_v of 27 per cent and a relative error of 24 per cent. The 29 stations added in 1970, giving a total network of 62 stations, will improve the relative error to 13 per cent. Further improvement can be effected by increasing this network after re-appraisal of the data collected for a number of years.

SUMMARY

The percentage error of areal estimates of mean annual rainfall in the different sub-catchments of the three lake basins and the project as a whole and Lake Victoria separately have been estimated using the 1967 and 1970 networks of raingauge stations.

A comparison of the percentage error with the network of raingauge stations in 1967 and the increased network in 1970 shows that estimates of mean areal rainfall over a few sub-catchments having a large error will be reduced to an estimated accuracy of 8 per cent to 10 per cent (assumed appropriate for the purpose of water-balance studies to be undertaken in the project), with the increased 1970 network. The present increase in networks thus appears satisfactory for the project as a whole.

Table 1.1

S. No.	Catchment	Area (km^2)	No. of RG used	Mean RF (mm)	Standard deviation σ	c_v%	t = 2 8%	t = 2 10%	t.975* 8%	t.975* 10%	t.995* 8%	t.995* 10%	Mean volume of RF (milliard m^3)
	I. LAKE VICTORIA BASIN												
1	Sio, Nzoia	13 850	56	1 256	253 4	20.2	25	16	27	18	46	31	17.39
2	Yala	3 500	18	1 789	106 4	6.0	3	2	6	4	3	6	6.26
3	Nyando	3 600	38	1 420	234 4	16.5	17	11	19	13	32	22	5.11
4	Sondu	3 600	12	1 566	383.0	24.5	37	24	38	25	66	42	5.64
5	Gucha-Migori	6 600	14	1 585	330.0	20.8	27	17	28	19	49	32	10.46
6	Mara, Mori	15 900	11	1 309	180.4	13.8	12	8	14	10	24	17	20.81
7	Ruwana Gurumeti and Suguti	12 250	6	871	268.1	30.8	59	38	59	38	101	67	10.67
8	Simiyu Mbalagati	14 150	8	964	260.5	27.0	46	29	46	30	80	52	13.64
9	Magogo Isanga	8 000	11	921	172.4	18	22	14	23	15	40	27	7.37
10	Kagera	26 000	25	1 234	286.2	31.3	61	39	61	39	105	69	32.08
11	Ruizi Kibale	8 400	14	1 013	176.0	17.4	19	12	21	14	35	24	8.51
12	Katonga	14 700	23	1 037	173.6	16.7	17	11	19	13	33	22	15.24
13	South shore area	21 500	23	1 040	254.0	24.4	37	23	38	24	66	42	22.36
14	North shore area	5 300	26	1 141	139.2	9.9	6	4	9	6	14	10	7.48
15	Kavirondo area	5 500	28	1 469	283.7	19.3	23	15	25	17	42	28	8.08
	Lake plus islands	-	-	-	-	-	-	-					-
	(a) North-west	24 500	17	1 552	323.8	20.9	27	17	29	19	49	33	-
	(b) South-west	17 500	6	1 278	234.7	18.4	21	13	23	16	38	26	-
	(c) South-east	17 300	6	1 034	317.5	30.7	58	38	59	38	102	66	-
	(d) East	10 000	4	1 209	201.9	16.7	18	11	19	13	33	22	-
	Whole lake	69 300	33	1 304	-	26.7	124	79	-	-	-	-	90.37
	Land area only	162 850	451	1 173	-	-	-	-	-	-	-	-	191.11
	Lake area only	69 300	33	1 304	-	-	-	-	-	-	-	-	90.37
	Victoria Basin as a whole	232 150	484	1 212	-	26.2	-	-	-	-	-	-	281.48

* Adjusted by trial (6).

Table 1.2

S. No.	Catchment	Area (km^2)	No. of RG used	Mean RF (mm)	Standard deviation σ	c_v%	t = 2 8%	t = 2 10%	t.975* 8%	t.975* 10%	t.995* 8%	t.995* 10%	Mean volume of RF (milliard m^3)
	II. LAKE KYOGA												
1	Kafu	16 700	23	1 198	112.4	9.4	6	4	8	6	13	10	20.1
2	North shore plus lake	12 000	16	1 271	136.4	10.7	7	5	10	7	16	12	15.25
3	Salisbury region	24 000	23	1 312	373 6	28.5	51	32	51	33	88	58	31.49
4	Mpologoma	14 100	33	1 375	191.6	13.9	12	8	14	10	23	17	19.39
5	Victoria Nile	3 500	9	1 301	94.6	7.3	4	2	6	5	9	7	4.55
6	South shore plus lake	5 200	15	1 353	137.7	10.2	7	4					7.04
7	Kyoga Basin as a whole	75 500	119	1 294	222.7	17.1	87	-	-	-	-	-	97.72

Table 1.3

	III. LAKE ALBERT												
1	Albert Shore plus lake	18 000	27	1 306	187.7	14.4	13	8	15	11	25	18	23.51
2	Albert Nile	11 100	15	1 388	130.9	9.4	6	4	8	6	13	9	15.41
	Albert Basin as a whole	29 100	42	1 337	178.5	13.6	19						38.91

Table 1.4

	Victoria Basin	232 150	484	1 212	341.3	26.2							281.48
	Kyoga Basin	75 500	119	1 294	222.7	17.1							97.72
	Albert Basin	29 100	42	1 337	178.5	13.6							38.91
	Project as a whole	336 750	645	1 241	305.9	23.5							418.11
	Lake Victoria only	69 300	33	1 304	365.6	26.7							90.37

* Adjusted by trial (6).

Table 2.1

S. No.	Catchment	No. in 1967	Density (km^2/ stn.)	Optimum No. of gauges for 8% error	Additional required	New stn. in 1970	Total	Density (km^2/ stn.) 1970	c_v% 1967	P %	P% 1970 expected
	I. LAKE VICTORIA CATCHMENT										
1	Sio, Nzoia	102	136	27	-	1	103	135	20.2	5.5	4.0
2	Yala	26	135	6	-	1	27	130	6.0	3.0	2.4
3	Nyando	47	77	19	-	-	47	77	16.5	5.5	4.8
4	Sondu	23	156	38	15	-	23	156	24.5	15.6	10.6*
5	Gucha Migori	18	367	28	10	3	21	134	20.8	12.0	9.5
6	Mara, Mori	14	1 136	14	-	8	22	723	13.8	9.3	6.1
7	Ruwana Gurumeti plus Suguti	6	2 042	59	53	6	12	1 021	30.8	32.3	19.5*
8	Simiyu, Mbalagati	8	1 768	46	38	3	11	1 286	27.0	22.6	18.1*
9	Magogo, Isanga	11	727	23	12	8	19	421	18.7	12.6	9.0
10	Kagera	47	553	61	14	15	62	419	31.3	12.9	8.0
11	Ruizi Kibale	19	442	21	2	3	22	382	17.4	10.1	7.7
12	Katonga	30	490	19	-	6	36	408	16.7	7.2	5.6
13	South shore area	31	693	38	7	11	42	512	24.4	10.6	7.6
14	North shore areas	29	183	9	-	2	31	171	9.9	4.0	4.0
15	Kavirondo area	40	137	25	-	2	42	131	19.3	7.5	6.1
16	Lake plus islands										
	(a) North-west	17	1 441	29	12	11	28	875	20.9	10.8	8.0
	(b) South-west	6	2 917	28	17	8	14	1 250	18.4	19.3	10.0
	(c) South-east	6	2 883	59	53	7	13	1 330	30.7	32.3	18.6*
	(d) East	4	2 500	19	15	3	7	1 428	16.7	26.6	13.0
	Whole lake only	33	2 100	130	97	29	62	1 118	26.7	23.6	13.0
	Land areas only	451	361	433	-	69	520	313		13.6	9.4
	Victoria Basin	484	480	563	79	98	582	399	26.2	16.4	10.3

* Coefficient of variability is still large with 1970 network.

Table 2.2

S. No.	Catchment	No. in 1970	Density (km^2/stn.)	Optimum No. of gauges for 8% error	Additional required	New stn. in 1970	Total 1970	Density (km^2/stn.) 1970	c_v% 1967	Relative error: P % expected 1967	Relative error: P % expected 1970
	II. LAKE KYOGA										
1	Kafu	29	576	8	-	9	38	439	9.4	4.1	3.1
2	North shore plus lake	23	522	10	-	2	25	480	10.7	5.7	4.4
3	Salisbury	32	750	51	19	10	42	471	28.5	12.3	8.9
4	Mpologoma	38	371	14	-	1	44	320	13.9	5.0	4.2
5	Victoria Nile	14	250	6	-	-	14	250	7.3	5.6	4.2
6	South shore plus lake	20	260	9	-	2	22	236	10.2	5.6	4.5
	Kyoga Basin	156	484	98	-	24	180	419	17.1	7.0	5.3

Table 2.3

	III. LAKE ALBERT										
1	Albert shore plus lake	30	600	15	-	13	43	418	14.4	5.7	4.4
2	Albert Nile	21	528	8	-	4	25	444	9.4	5.2	4.0
	Albert Basin	51	570	23	-	17	68	404	13.6	5.5	4.2

Table 2.4

	PROJECT AS A WHOLE										
	Victoria Basin	484	480			98	582	399	26.2	16.4	10.3
	Kyoga Basin	156	484			24	180	419	17.1	7.0	5.3
	Albert Basin	51	570			17	68	404	13.6	5.5	4.2
	Lake Victoria only	53	2 100			29	62	1 118	26.7	24.0	13.2
	Project as a whole	691	487			139	830	406	23.5	10.8	7.1

NOTE: Network in index catchments not included.

Table 3

S. No.	Sub-catchment	1967 c_v%	1970 network	1967 P%	1970 P%
1	Sondu	24.5	23	15.6	10.6)
2	Gucha Migori	20.8	21	12.0	9.5)
3	Rwana, Gurumeti and Suguti	30.8	12	32.3	19.5)
4	Mbalageti, Simiyu	27.0	11	22.6	18.1)
5	Magogo, Isanga	18.7	19	12.6	9.0
6	Kagera	31.3	62	12.9	8.0
7	Lake Victoria	26.7	66	24.0	13.2
8	Project as a whole	23.5	830	10.8	7.1

Table 4

Distribution of raingauges in areas of deficient network

S. No.	Sub-catchment	Region	% area	Optimum No. of raingauges	1970 existing network	Required
1	Kagera	1	1.6	1	5	-
		2	9.2	6	10	-
		3	10.6	7	16	-
		4	2.6	2	2	-
		5	76.0	46	40	6
	Total		100.0	62	73	6
2	Sondu	1	18	7	1	6
		2	78	30	21	9
		3	4	2	1	1
	Total		100	39	23	16
3	Gucha Migori	1	54	15	18	-
		2	16	4.5	4	1
		3	30	8.4	8	1
	Total		100	28	30	2
4	Rwana-Gurumeti	1	50	30	3	27
		2	36	21	4	17
		3	14	8	3	5
	Total		100	59	10	49
5	Simiyu Mbalagati	1	53	24	16	8
		2	36	17	5	12
		3	11	5	-	5
	Total		100	46	21	25
6	Magogo Isange	1	18	4	2	2
		2	61	14	19	-
		3	21	5	3	2
	Total		100	23	24	4

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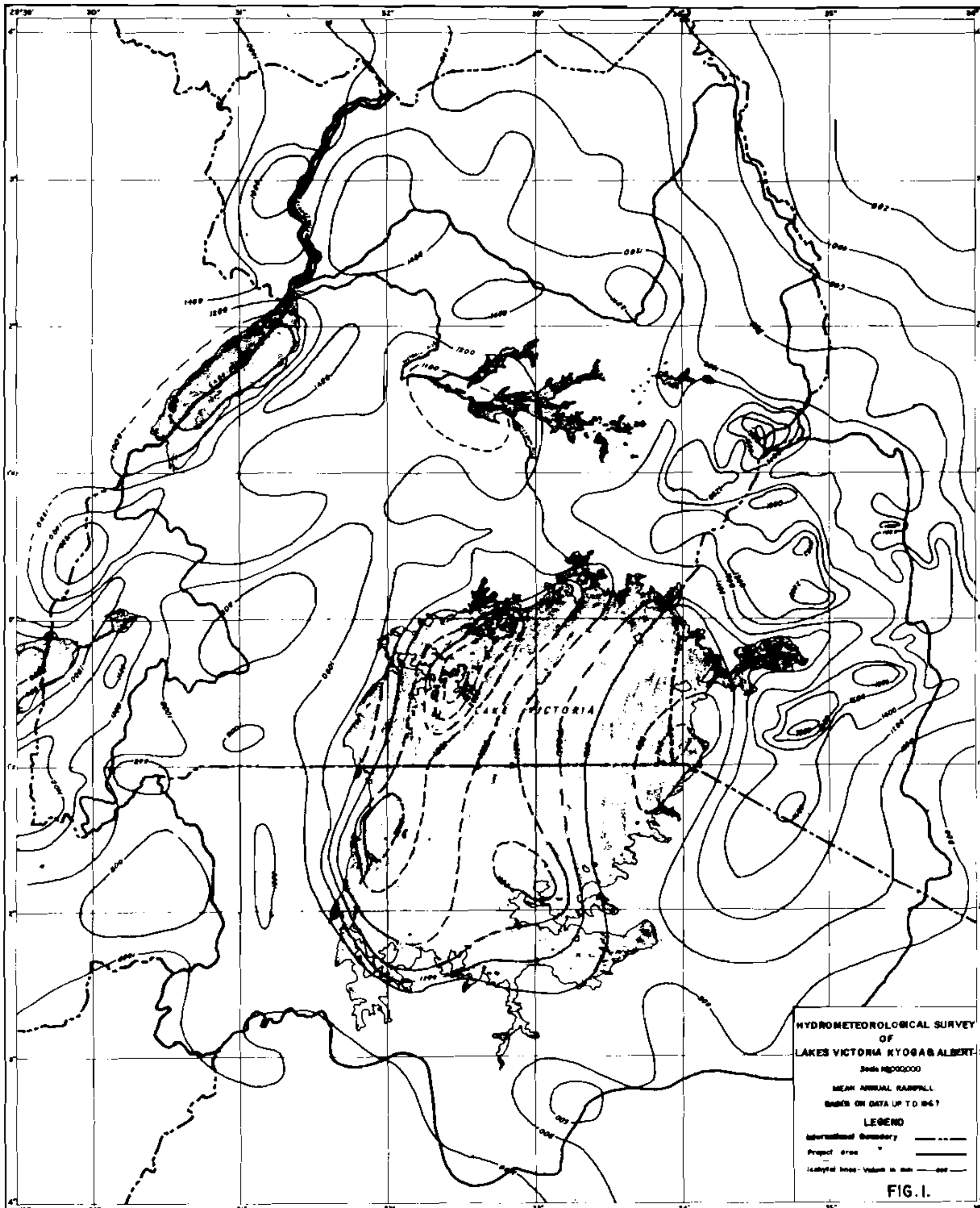

FIG. I.

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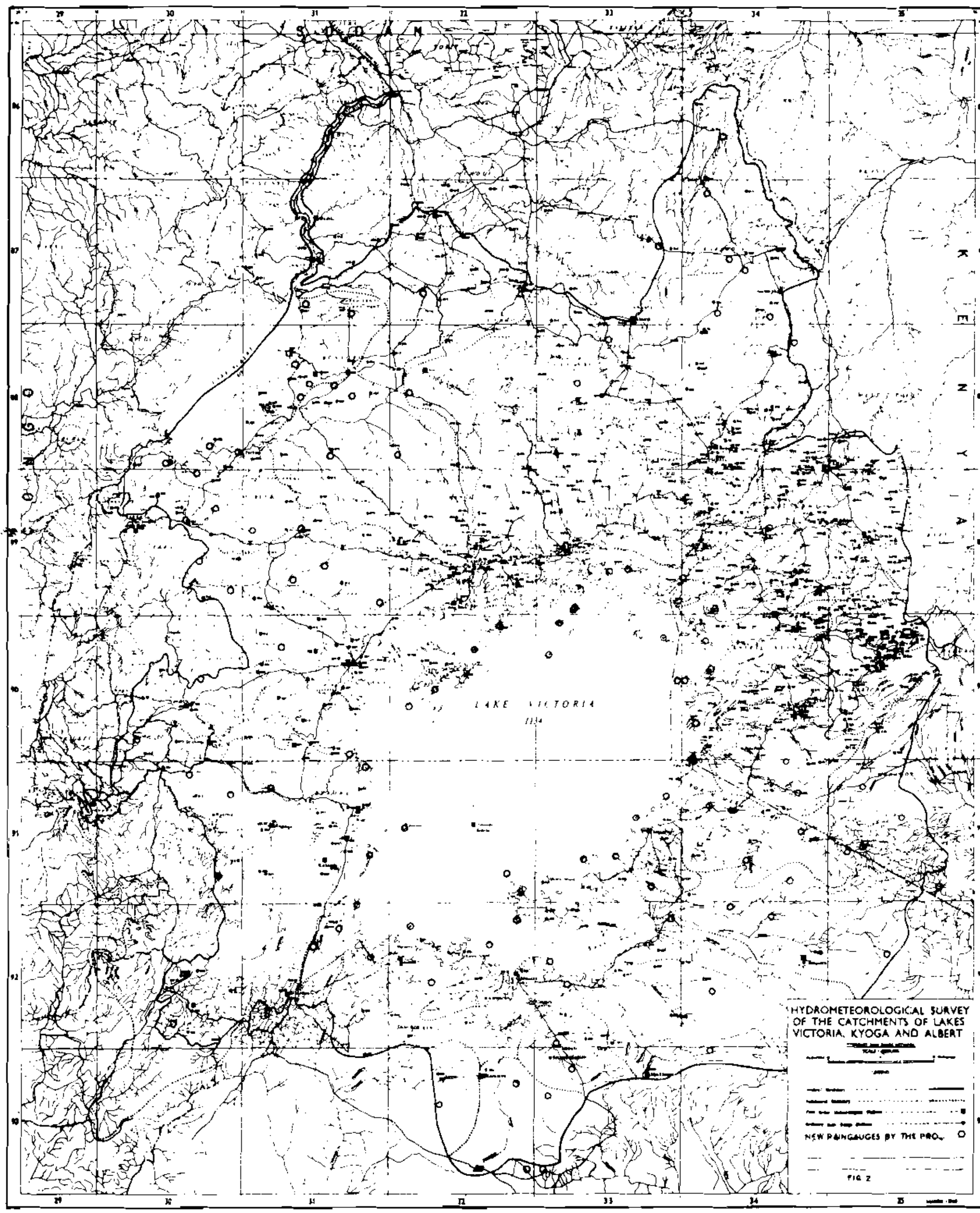
HYDROMETEOROLOGICAL SURVEY
OF THE CATCHMENTS OF LAKES
VICTORIA, KYOGA AND ALBERT
NEW RAINGAUGES BY THE PRO.
SUDAN
KENYA
LAKE VICTORIA
FIG 2

THE ROLE OF GROUNDWATER IN SOCIAL AND ECONOMIC DEVELOPMENT: AN EXAMPLE BASED ON FAO'S NEAR EAST REGIONAL ACTIVITIES ON GROUNDWATER DEVELOPMENT AND USE

by D.J. Burdon, D.A. Caponera and J.P. Hrabovszky

ABSTRACT

Groundwater is a component of the water resources of a country, a region or a continent, whose scientific investigation, proper development and prudent management can contribute much to social development and economic progress. Based on the work carried out by FAO in the 17 Member States of its Near East Region, some facts, policy considerations and conclusions are presented to the Conference on Hydrology and Hydrometeorology in the Economic Development of Africa since there are many similarities between the two overlapping regions, and one can benefit from the experience of the other.

The importance and value of groundwater to the agricultural development of the Near East Region is described, with emphasis on the integrated approach, not only to irrigation with surface water, to rainfed agriculture and to pastoral development, but in conjunction with soil surveys, fertilizer use and other agricultural inputs which enable maximum returns to be obtained from the use of water. The groundwater resources of the Region are outlined, as well as their state of development. The three main categories of groundwater development considered are: (i) tubewell irrigation, (ii) supplementary irrigation in rainfed areas, and (iii) stock water for the steppe and savannah pastures. Other development objectives are noted, as to provide water supplies to rural communities and to facilitate movement of animals and rural communications. The technical methods of investigating, appraising and developing groundwater are outlined, as well as brief descriptions on some new scientific methods and techniques which reduce costs and speed up the development process.

The costs and economics of groundwater investigation, development and use for irrigation purposes are outlined. Figures are given for the cost of groundwater prospection and development and for the returns to be obtained from the use of groundwater in irrigation projects. A comparison is made between the relative advantages and disadvantages of groundwater and surface water development projects. The problem of financing groundwater development is also considered, and rates and amount of return which can be expected.

The need for national groundwater policies is stressed, and a possible ten-point statement of policy is given as a guideline. The lack of a clear policy on groundwater (alone or in conjunction with an overall water policy) can lead to many and increasing difficulties and to waste, deterioration and abuse of a country's natural resources of water. Water legislation is treated, first on a general basis, with notes on eighteen points which are of basic importance, and then with specific reference to groundwater and the control of prospection, development and extraction. The problem of the government organization for groundwater is considered and presented under organization at the national level, at the regional, basin or sub-basin level, at the lower level and at the international level. The functions and powers of a possible Water Organization for a state are outlined, and considered with respect to eleven distinct functions.

The paper ends with a discussion of the problem of training and employing the technical staff required to enable governments to formulate a wise groundwater policy, to plan logically for development, to oversee and control development schemes, and to ensure that the natural resources of groundwater are used to the best advantage of the people and of the state.

RESUME

Les eaux souterraines constituent une des ressources d'un pays, d'une région ou d'un continent qui, si elles font l'objet de recherches scientifiquement conduites, d'une mise en valeur appropriée et d'une gestion prudente, peuvent contribuer, dans une grande mesure, au développement social et au progrès économique. Certaines données, considérations politiques et conclusions, fondées sur les activités de la FAO dans les dix-sept Etats Membres du Moyen-Orient, sont ici présentées à la Conférence sur l'hydrologie et l'hydrométéorologie dans le développement économique de l'Afrique, en raison de ce qu'il existe de nombreuses analogies entre les deux régions considérées, l'une pouvant profiter de l'expérience de l'autre.

Ce document décrit l'importance et la valeur des eaux souterraines au regard du développement agricole des pays de la région du Moyen-Orient, en insistant sur une approche intégrée, non seulement par rapport à l'irrigation au moyen des eaux de surface, au développement de l'agriculture irriguée par l'eau de pluie et de l'élevage, mais également par référence à l'étude des sols, à l'utilisation des engrais et des autres éléments de production susceptibles de contribuer à un rendement maximum à partir de l'utilisation des eaux. Il fournit un schéma des ressources en eaux souterraines de la région ainsi que de leur stade d'exploitation. Les trois principaux modes de mise en valeur des eaux souterraines considérées étant i) l'irrigation au moyen de puits, ii) l'irrigation complémentaire des aires normalement irriguées par la pluie et iii) la mise en réserve des eaux destinées aux pâturages en zones de steppe et de savane. Il indique également les autres objectifs qui consistent à fournir de l'eau aux communautés rurales et à faciliter la transhumance des troupeaux et les communications rurales. Il met en relief les méthodes techniques de recherche, d'évaluation et d'exploitation des eaux souterraines et fournit une brève description des méthodes scientifiques et des techniques récentes en vue de réduire les frais et d'accélérer le processus de mise en valeur.

Il indique le coût et les incidences économiques de la recherche des eaux souterraines, de leur mise en valeur et de leur utilisation pour l'irrigation. Il donne des chiffres relatifs aux frais de prospection et d'exploitation ainsi qu'aux profits résultant de l'utilisation desdites eaux dans les programmes d'irrigation. Il établit une comparaison entre les avantages et les inconvénients relatifs aux programmes d'exploitation des eaux souterraines et des eaux de surface. Il étudie les problèmes de financement liés à la mise en valeur des eaux souterraines ainsi que le taux et le montant du profit que l'on peut en attendre.

Il met l'accent sur la nécessité d'élaborer une politique nationale des eaux souterraines et fournit, à titre d'exemple, une déclaration de politique en dix points. L'absence d'une politique bien délimitée, en matière d'eaux souterraines, (prise isolément ou bien dans le cadre d'une politique d'ensemble des eaux) peut engendrer des difficultés multiples et croissantes ainsi qu'un gaspillage, une détérioration et une utilisation abusive des ressources naturelles en eaux d'un pays. La législation des eaux est traitée en premier lieu sous un angle général avec des commentaires sur les dix-huit points d'importance fondamentale et avec, en outre, des références spécifiques aux eaux souterraines, au contrôle de la prospection, de l'exploitation et de l'extraction. Le problème des structures administratives au regard des eaux souterraines est étudié et présenté par rapport aux structures nationales et régionales, au niveau des bassins ou des sous-bassins, aux échelons inférieurs ainsi qu'au niveau international. Les fonctions et les pouvoirs d'une éventuelle organisation des eaux dans un état, sont schématisés et traités par rapport à onze fonctions distinctes.

Le document se termine par une étude des problèmes relatifs à la formation et à l'utilisation du personnel technique nécessaire pour permettre au gouvernement d'élaborer une sage politique des eaux, d'en planifier d'une manière logique la mise en valeur, de superviser et de contrôler les programmes d'exploitation et de veiller à ce que les ressources naturelles en eaux souterraines soient utilisées pour le meilleur profit de la population et de l'état.

INTRODUCTION

This paper, presented to the Conference on "Hydrology and Hydrometeorology in the Economic Development of Africa", sets out the particular role of groundwater in such operations, drawing on FAO's experience in its Near East Region, which includes many African countries, such as Libya, Egypt, Sudan and Somalia.

The importance of groundwater in the Near East Region is due to the need of the Region to develop all its potential water resources to increase agricultural production and raise standards of living, and the fact that groundwater is the sole remaining source of natural water whose amount is still unknown, which appears to exist under most or even all of the Region, and whose full use and development is not already planned and committed. Hence, groundwater is a potential resource of the Region, whose proper development and wise use poses problems and possibilities which are of deep concern and immediate interest to the Governments and people of the Region.

It is hoped that by drawing attention to planning and policy considerations on groundwater investigation, development, use and management for hydroagricultural purposes, this paper will assist the governments taking part in the Hydrology and Hydrometeorology Conference in the wise utilization of a natural resource which is no longer neglected, but on which less precise data are available than on most other waters.

IMPORTANCE OF GROUNDWATER IN THE NEAR EAST

Although the density of population (177 million) in the nineteen countries and states which comprise FAO's Near East Region* averages only 13 per square kilometre over the total area of 13.6 million square kilometres, in fact, the general aridity of the region forces the population to concentrate in the limited areas of high rainfall and even more densely into the valleys of the main rivers of the Region.

As distinct from the surface waters, the groundwater resources of the Near East Region are not fully known or exploited. Groundwater is considered to be present beneath the surface of most of the Region, and recent exploration has shown that there are valuable reserves of good-quality groundwater under even its most arid portions. The amount of groundwater which can be extracted varies from place to place, but since small amounts of potable water suffice to supply the needs of man and beast on the steppe and savannah, though high production is necessary for any extensive irrigation scheme, the groundwater development potential is high. The chemical quality of groundwater is also variable, and too high mineralization may prohibit or limit the use of the water.

Groundwater is flexible both in the ways it can be developed and can be used. Within certain limits, the aquifer system through which groundwater moves in any area can be considered as a buried distribution system, and under some hydrogeological conditions the water can be tapped by a borehole located where the water is required. Where groundwater is abundant, as in the alluvial deposits of the river basins and depressions of the Region, and where annual recharge is large, groundwater can be the basis of extensive tubewell irrigation systems, or can be used to supplement surface irrigation and utilize hydro-electric power supplies, both by pumping groundwater and by operating the aquifers as underground

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* Afghanistan, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Pakistan, Saudi Arabia, Somalia, Sudan, Syria, South Yemen, United Arab Republic, and Yemen, plus Bahrain and Qatar as Associate Members.

storage reservoirs. In areas of rain-fed farming, groundwater may be used for supplementary irrigation. On the steppe and savannah, groundwater plus cisterns and haffirs is the way which will allow full utilisation of the rangelands by pasturing herds and flocks; the control of watering points can be a valuable component in proper range management and the prevention of over-grazing and erosion.

Groundwater can be developed quickly and close to the place of use; development can proceed step by step, and indeed pilot development and use should follow the investigation progress. Thus, initial capital for groundwater development can be small, and a quick return may be obtained on such investment. If returns prove satisfactory, the groundwater development scheme can be enlarged as required and profits increased. However, there is always a danger of over-development, which will lead to falling water levels, deteriorating chemical composition, increased pumping costs and possible collapse of the scheme.

Much of what has been found important regarding groundwater in the Near East Region is also relevant to Africa. In addition, groundwater development for irrigation has an important path-breaking rôle in creating and using all the year round sources of irrigation water, thus permitting the development of meaningful pilot efforts leading later to large-scale surface or groundwater developments. There is a need in most of Africa, South of the Sahara, to start, on a relatively small scale, schemes which would provide the training and proving grounds for later larger-scale developments; groundwater is eminently suitable for this purpose. These relatively small-scale schemes are also an excellent training ground for technical personnel and are an important first step towards successful development of large-scale irrigation schemes based on surface water storage.

GROUNDWATER RESOURCES OF THE NEAR EAST REGION

The resources of groundwater of a vast region stretching over 45° of latitude and 80° of longitude can be considered here only in a very general way. In so doing, however, it is possible to see them within their framework of regional geology and climate; this overall picture is sometimes lost when working within an individual river basin or specific area.

Geologically, the region falls into three major structural units. First, there is the platform on the south, composed of Pre-Cambrian crystallines of the Afro-Arabian and Peninsular India shields, overlain by continental and epicontinental deposits as in Libya, Egypt, Sudan, Jordan, Saudi Arabia, Yemen and the south of Pakistan. Secondly, there is the mobile geosynclinal belt, where Mesozoic and Cainozoic marine and lagoonal sediments have been deformed and folded, often in complex structures, and which extends from the folded coastal belt of Libya and Egypt, across through Lebanon, Syria, Iraq and eastern Saudi Arabia into southern Iran and most of West Pakistan. Thirdly, there is the foreland of intensive Alpine folding, extremely complex, with great thrusts and nappes, and plutonic activity; this structural unit extends from northern Syria and northern Iraq through Iran and Afghanistan and into northern Pakistan.

The general pattern of precipitation is simple. In the south, it is monsoonal, with summer rainfall. In the north, it is Mediterranean, with winter precipitation and abundant snow. In the centre, there is the desertic zone, where high atmospheric pressures and subsiding cyclonic air prevent the inflow of moisture-bearing winds. Southwards from the deserts, there are the savannah and related zones, where summer rainfall becomes increasingly large. Northward from the deserts, there are the steppe zones, with winter rainfall increasing northwards. These general zones are interrupted and modified by local factors, such as proximity to sea and gulfs, and to the local topography.

The groundwaters of the Region originated, and are replenished, by the infiltration of a portion of the precipitation. The amount is very variable, but is generally small; evapotranspiration may account for up to 80%, while the balance may be divided in varying proportions between surface runoff and infiltration. It is a task of a groundwater survey to determine the annual recharge or replenishment of the groundwater in the area under study, and to establish a "water-balance" for that area. A most important task is to determine how much of the groundwater now found underground is due to infiltration in the past, when precipitation during the Pluvial periods of the Quaternary was much higher throughout much of the Region than it is today; such old groundwater is known as "fossil groundwater", though it may be of good chemical composition.

It is possible only to mention the main aquifers and aquicludes of the Near East Region. The great aquifers of the platform areas are the epi-continental sandstones of Nubian facies, which accordingly underlie the deserts, and are under study and development in Libya, Egypt, Sudan, Saudi Arabia and Jordan; much of their stored water must be fossil, yet flowing boreholes are not uncommon. In the geosynclinal belts, the principal aquifers are the Secondary and Tertiary carbonate rocks, where karstification of varying forms has turned them into major aquifers in Libya (Jebel Akhdar), Lebanon, parts of Syria and Jordan, in the Zagros ranges of Iran and Iraq, in certain areas of the Arabian Peninsula, and in the fold mountains of Pakistan and Afghanistan; in these regions there are also some sandstone aquifers, as well as evaporites whose waters are rich in sodium chloride and calcium or magnesium sulphate and which are often unsuitable for use. A third major group of aquifers are the alluvial deposits of the major river basins, coastal plains and inland basins; where gravel and sands predominate or are important, and where river flow or seasonal floods bring annual recharge, then these alluvial aquifers offer major possibilities of large-scale groundwater development for irrigation. But a word of warning — the surface and underground waters of such a system have a common origin and interflow, so that when pumped out as groundwater they can no longer contribute to the flow of the river. There are several other types of aquifer within the region, of varying importance; these include plateau basalts, good aquifers in the Hauran and Djebel Druze of Syria; decomposed crystalline rocks, as in parts of Sudan, Saudi Arabia and Yemen; and other rocks and soils, such as volcanic ash, loess and fractured cherts, which are only of local interest as aquifers.

The chemical composition of groundwater often limits severely the uses to which it can be put. These limits are the same as for surface and other waters; but since groundwater is more subjected to mineralization, its chemical composition calls for closer investigation and consideration.

GROUNDWATER DEVELOPMENT IN THE NEAR EAST

The traditional methods of groundwater development in the Near East Region have been by wells of varying forms and lifting devices, and by the ingenious system of infiltration galleries known as foggaras, kharaz and other names. Open wells, mainly hand-dug and often lined, are still of importance, especially on the steppe and savannah where animal or human power raises water for drinking often from great depths. The foggaras still furnish groundwater for irrigation schemes, but their importance is decreasing, as engines take over the task of pumping up the groundwater.

Groundwater development must be seen as an integral component of overall water resources development; hence groundwater development can be considered in relation with surface water development, with the most effective utilization of direct precipitation, and on its own only in the more arid areas of the Region. So considered, groundwater development falls under three main headings: (i) Tubewell irrigation; (ii) Supplementary irrigation in rain-fed areas; (iii) Stock water on the pastures of steppe and savannah.

Tubewell development involves bringing large areas under irrigation with groundwater, pumped in large amounts from standard tubewells sunk to limited depths. Such development is possible mainly in the alluvium aquifers of the large river basins where there is strong recharge to balance high extraction. Exceptionally, it can be of major importance in certain desertic areas, as the New Valley of Egypt, in Harradh and other oases of Saudi Arabia and in Kufra and the Fezzan of Libya, though the water may be drawn from storage, not current recharge. Within the Near East Region, groundwater development for tubewell irrigation is best exemplified in the Indus basin of Pakistan. There, the groundwater reserves are estimated at between $2,345 \times 10^9$ and $1,123 \times 10^9$ cubic metres (from six to ten times the annual flow of the Indus river itself), and it is planned to pump from tubewells some 62×10^9 cubic metres per annum, of which only 40% will be obtained from current infiltration and 60% will be "mined" from capital reserves of groundwater.

Supplementary irrigation with groundwater, or development of small irrigation schemes, is the form of groundwater development suitable to areas where there is some useful precipitation, but more water is required to ensure good harvests, while groundwater is present but not in large amounts. Such development may be considered as an insurance against crop losses and famine in dry years, and as a means of agricultural diversification, including fruit trees and vegetable production in areas of present mono-culture. Such development of groundwater is to be found in the higher rainfall areas along the coastal zones of Libya and Egypt, in parts of Jordan, Lebanon and in northern Syria and Iraq and also in Iran, Afghanistan and Pakistan. South of the deserts, it is also found in Sudan, Somali, the Asir and Tihama of Saudi Arabia and the Yemens, though on a smaller scale in this tropical savannah zone than in the northern parts of the Region.

Proper development and control of groundwater, together with construction of haffirs and cisterns in suitable areas, can lead to full and continuing utilization of the grazing potential of the vast expanses of steppe and savannah country which form such a high percentage of the lands of the Near East Region. Lack of water for man and beast has in the past made it difficult to graze wide areas of good pasture, but this lack of water has also prevented over-grazing; new water development can destroy the existing ecological balance. Unwise development of water, particularly groundwater, may lead to over-grazing around watering points, to deterioration of pastures, to destruction of the more palatable vegetation and to initiation or acceleration of erosion, mainly aeolian erosion. Hence, strict control of stock watering points must be established from the beginning; watering points must be constructed in sufficient number to allow flocks to move to alternative water when one or many have to be shut-down to control local over-grazing. In addition to problems of control, this type of groundwater development presents problems of maintenance of the wells, boreholes, haffirs and cisterns and of the pumping installations. Many countries have found that the open-well and animal-powered extraction are in the long run the easiest to maintain. But rate of extraction is low, and control difficult or impossible.

INVESTIGATION AND DEVELOPMENT OF GROUNDWATER RESOURCES

Only governments can undertake large-scale groundwater resource surveys, but whether such groundwater investigations should be undertaken directly by a government, or by agreements with consultants and contracts with drilling firms, is a difficult decision. A judicious blending of policy, planning and direct work by a government department, plus consultants for specific problems and the execution of major operations by contractors (drilling, geophysical surveys, groundwater development by tubewells) would seem the best solution.

When considering groundwater development for agriculture, it is desirable to stress once more the integrated approach. This does not apply solely to integration with other water resources, such as rivers, streams and direct rainfall, but also to integration with all the other inputs required for a successful use of water. In particular, soil survey and land classification work is required to determine where irrigation water may best be used. Where groundwater is being developed for stock, well location must take into consideration as many relevant factors of pasture, animals and proposed operation-control as possible, though on the steppe and savannah hydrogeological conditions will often restrict severely the points where successful boreholes or wells may be constructed.

In considering large-scale groundwater development for irrigation, standard design, construction and equipment of tubewells offer major economies in capital cost as well as in operation (including maintenance and replacement costs). Sources of power must be considered, and where electrical power is available, its potential use for pumping may in turn justify the installation of a multi-purpose dam, so that there is integrated use not only of the water but also of the hydro-power. Standardization of equipment will also influence supply of spares and the development of an efficient maintenance system; it should integrate with the import and local manufacture policy of the country.

It should be emphasized that the development of groundwater, in particular for irrigation, is only one step in many to enable the farmer to produce more and to lead a better life. Hence, there is need of ancillary and supporting services at all levels, including credit facilities, extension, marketing research and organization, if full (or any) benefit is to be derived from such groundwater development.

COSTS AND ECONOMICS OF GROUNDWATER DEVELOPMENT AND USE

Costs and returns for investments in groundwater development must be known with reasonable accuracy before governments or private investors can make valid decisions in the allocation of their resources. The economic considerations given here relate only to irrigation. The aims of this analysis are: (1) to discuss the conditions of costs and returns under which an investment in groundwater is profitable; and (2) to compare the costs and returns of groundwater with those of surface water development and use.

Costs of Groundwater Prospection and Development

The components for the total cost for groundwater development and use may be put into five groups and these are discussed below:

(i) General Background Costs: These cover the supply of basic information, such as topographical mapping, geological survey and hydrological observations.

(ii) Prospection Costs: include expenses incurred for hydrogeological mapping, collection of data on existing wells and boreholes as well as spring regimes, hydro-chemistry, the drilling and test-pumping of some exploratory boreholes and possibly special investigations. At present, \$25 - \$50/km^2 for extensive groundwater pre-investment surveys and \$150 - \$350/km^2 for intensive investigations including research-training may be taken as general indications of magnitude.

(iii) Development Costs: Development costs are comprised of drilling, testing and equipment (casing, pump, motor, screens, gravel-packing, etc.) and the cost of the water distribution system and land preparation for irrigation. The range of costs for each of these component items is wide.

Cost of the pump and motor will vary with both depth and yield of water. The cost of pump and motor ranges from $38 - 75/ha. Cost of drilling may be as low as $4/m for shallow tubewells and up to $100 for deep wells. Cost of casing and screens will vary with diameter and depth.

The cost of water distribution systems needs to be accounted for, unless groundwater development is used to supplement the water in existing canal systems. Lining of canals is advised for costly pumped water. The cost of such distribution systems will vary widely, but without lining may be estimated as $30 to $50/ha yet could reach $100/ha for systems using reinforced concrete underground conduits.

To prepare the land carefully by levelling and grading can cost as much as $250/ha if fields are of a reasonable size and the terrain uneven, but as an average they may be estimated at around $100/ha.

(iv) Use Costs: need to be separated into fixed costs and variable costs.

Fixed Costs do not change with the quantity of water pumped per year; they include depreciation and interest on investment, and the pump operator's wages if he is engaged on an annual basis. Depreciation costs may lie between $55 and $230/ha. Depreciation rates will be different for various components of the investment and a rate of 8% is assumed as an average giving "useful life" of 12½ years, though part of the equipment may last longer.

Variable Costs or operational costs are the sum of fuel or power costs, lubrication and maintenance, repairs and labour costs if the attendant is not engaged on an annual basis. These costs are shown in Table 1 below as they relate to two important situations. Part A shows cost per ha and per m^3 of water for a 12" deep well and part B shows the same information for a 6" shallow tubewell.

(v) Control and Management Costs: arise from the need to set up an organization for collection of data to determine extraction rates and also for the enforcement of the law. However, at present little information is available on the magnitude of such costs.

Returns to Groundwater Use in Irrigation

The identification of returns to groundwater use is generally more difficult as compared with cost estimates. Returns will vary according to crops grown, efficiency of water use, general level of management and use of production technology, including inputs other than water and finally the price for the products. Because of the wide variations, only a few comparative examples can be given in terms of additional net yield increases (by net yield increases is meant the increase in yields on irrigated lands as compared with non-irrigated lands after deduction of all the costs other than water from the returns) per ha required for paying the cost of water. They are shown in Table 2:

TABLE 1

Examples of Annual Use Costs for Groundwater in US $

Type of Cost	A. Deep 12" tubewell	B. Shallow 6" tubewell
Irrigated Area:	240 ha	40 ha
	$/ha	$/ha
Fixed costs 1/		
Depreciation at 8%	18.40	4.40
Interest at 6%	13.80	3.30
Variable costs		
Fuel (power)	71.17	22.10
Lubrication + maintenance	2.80	7.89
Repairs 2/	7.64	1.83
Labour 3/	1.72	6.72
For distribution drainage & land preparation 4/	(included)	9.00
Total costs $/ha	$ 115.53	$ 55.24
Total costs cents/m3	¢ 2.31	¢ 0.90

1/ Based on $55,000 for A and $2,200 for B and an annual use of 6,600 and 4,300 hours.
2/ Based on 10% value of pump and motor, valued at 1/3 of total installation costs for tubewells.
3/ At US$0.50 per day.
4/ For B, $100/ha and depreciation, maintenance and interest at 9%.

TABLE 2

Quantities of specified products required in net additions to yields/ha to pay for the cost of irrigation water from groundwater sources

	Price of product $/m.t.	Situation A	Situation B
Per ha cost or water	-	115.53	55.24
Wheat	70	1.66 m.t.	0.79
Barley	50	2.33	1.11
Sugar Beets	15	7.77	3.68
Vegetables	50	2.33	1.11
Seed Cotton	200	0.58	0.28

Comparison of the costs of groundwater and surface water development and use

Recent decades have seen many changes in the comparative costs of groundwater and surface water development. Thus, interest charges have risen sharply and this favours groundwater development, which usually has lower investment costs per ha than surface water schemes. Again, the cost of labour has increased versus equipment and power, yet technological developments have lowered the relative cost of drilling and pumping.

The information collected in the Near East for the Indicative World Plan of FAO has shown that within the Region surface water development costs ranged from $250/ha of equipped area to $1,500/ha. The average cost for these schemes was estimated as approximately $1,000/ha equipped, and given the average cropping intensity of 86%, this is equivalent to $1,162/ha for irrigated cropped land. Using the annual cost factor of 9.5%, the average annual cost is estimated to equal $110.04/ha of cropped area; this is only slightly below the high-cost groundwater development shown under Situation A of Table 1 and just about double the costs for Situation B.

Comparative data from the Asian Study of the IWP show that per hectare the annual cost of surface water schemes comes to about $66.50/ha, still higher than the costs shown for Situation B.

The IWP study for the Region of Africa, South of the Sahara, has shown considerably higher costs at about $105. The evidence thus points to groundwater development being strongly competitive with surface water development, and given many other advantages groundwater development may often present a more attractive proposal in comparison with large-scale schemes based on surface water.

These apparent cost advantages need to be qualified by the different foreign exchange components of groundwater and surface water development. In general, a higher percentage of groundwater development costs will require foreign exchange as compared to surface water development; the use of "shadow prices" for foreign exchange may change the relative advantages. A further consideration is the relatively high unskilled human labour component in surface water schemes and this may be a desirable feature in those countries where rural unemployment is high.

From the productivity point of view, groundwater schemes have many advantages. Their flexibility in operation, the security of the availability and timing of water deliveries and low conveyance losses are all in their favour. In addition, the favourable seasonal water availability gives to those schemes served by groundwater sources a much wider choice in selection of high profit crops than exists for most surface water based schemes which rely on the run of the river.

FINANCING OF GROUNDWATER DEVELOPMENT

Two major considerations are discussed here with respect to groundwater development for irrigation. First, from what sources could capital resources come, and secondly, if servicing and repayment are involved, what form could they take?

Direct government financing through budget allocations is nearly always the source of funds for background information collection, for prospecting for groundwater and for the management and control of groundwater exploitation.

Groundwater development may be planned under government or private financing.

If government is investing directly in groundwater development and will retain the management of the scheme as well, sufficient development funds and an operational budget need to be provided. These should be revolving funds; the water rates charged should allow for the replenishment of the development fund and for the annual cost of operation, unless government intends to subsidize the scheme for social or political reasons. Groundwater schemes lend themselves ideally for using volumetric sales of water as the base for water payments. It appears, however, that often a combined form of a fixed "betterment levy", combined with water rates based on the quantity of water consumed offers attractive advantages.

If the government itself is borrowing to finance either the total or the foreign exchange part of the investment, then loan repayment schedules should harmonize with receipt of those portions of the scheme's revenues which are meant for capital services.

It is a different situation when groundwater development is through private individuals or groups. Here government support for development and use costs may take the form of loans or subsidies. Direct subsidies, though at a lower level, may serve as well as subsidized loans in increasing the tempo of private investment, and their administration is much simpler and cheaper than loan systems. Considerable financial incentives can be given by the Government through subsidies on fuel and power.

With respect to financing, groundwater schemes have some distinct advantages over large-scale surface-water schemes in that they take only a short period to construct, can be constructed piecemeal, well by well, and thus are not burdened with heavy interest payments on capital invested before the schemes become productive and can provide the basis for repayments.

Through its relatively high foreign exchange cost component, groundwater development often provides good opportunities for aid financing which becomes attractive both to recipient and donor country.

NATIONAL GROUNDWATER POLICIES

Unless there is a definite national policy regarding groundwater (and the same applies to surface water) the investigation, utilization and conservation of this important natural resource will be retarded, misdirected and wasteful. The water policy may vary according to the existing situation and factors prevailing in any one country or region. The purpose of a water policy, is to ensure the most beneficial and optimum use and conservation of available waters, taking as a base the hydrologic cycle, present water demands and future needs indicated by population growth. A declaration on water policy may take place either in the preamble of a groundwater legal enactment or in any consolidated Water Act or Code, and could be based on the following principles:

(i) Definition of groundwater to include all kinds of waters located below the surface.

(ii) Groundwater being a natural resource, should either be declared as state, crown or public property or subject to state control.

(iii) Individuals and corporations may establish only a legal right to use waters, as distinct from an ownership right.

(iv) Existing rights may be recognized, consistently with availability of water, beneficial use, competing claims, Government water policy.

(v) Rights to use shall be controlled and administered by the state.

(vi) Priorities to use groundwater should be flexible so as to satisfy present and future requirements, changing circumstances, provided that first priority be given to household consumption.

(vii) Legal protection of existing and future users and rights to use.

(viii) Government right to control extraction in areas endangered by depletion of aquifers through reduction, suspension or modification of existing rights to use.

(ix) Government right to control and prevent waste, misuse and over-exploitation of groundwater.

(x) Government does not guarantee groundwater to users, and cannot be responsible for damage or injury caused by a lawful user to another lawful user.

The theoretical principles outlined above are meant only as an illustration of the basic considerations involved, and each country, on the basis of its particular circumstances, must determine its own groundwater policy. In a state where only groundwater is or might be available a groundwater policy may be defined; in other countries where surface waters also exist, a global water resources policy, including both surface and groundwater, is more desirable. In all cases, the need of agriculture must be defended, as agricultural uses are the greatest consumer of water. The price of water must be flexible so that the incomes deriving to the state from water resources are assessed not only on purely economic and financial factors, but also on social factors.

The lack of a groundwater policy, uncontrolled pumping and/or overpumping may cause depletion of aquifers, intrusion of sea waters in coastal areas, salinization and destruction of otherwise good lands, degradation of water quality, pollution, and spreading of water-borne diseases.

GROUNDWATER LEGISLATION

Water legislation in general, and groundwater legislation in particular, are the means through which it is possible to effectively implement and enforce any desired water policy. Legislation by itself, does not constitute the panacea for solving problems and, in turn, is strongly influenced by the legal systems followed and must take into consideration the sociological, religious and philosophical character of the people of any particular country or region.

The purpose of water legislation is to ensure, on the basis of water availability, the rational use of such resource, its conservation, in order to satisfy present and future water demands. This may be achieved by bringing under unified, coordinated or centralized administrative control past, existing and future uses of water. Special provisions are necessary for the control of ground waters either in a separate underground water act or as a chapter of a consolidated water code.

A basic water code or act could include provisions with respect to the following items:

(i) Ownership of water: to be clearly defined with respect to both surface and groundwater. If public ownership of water is not feasible, the right of the state to at least control and regulate such ownership is indispensable. Public ownership should include the river bed, the embankments and any other required appurtenances.

(ii) Right to use water: must be distinct from ownership right. A water legal enactment should frame rules with respect to the origins of this right, various purposes of utilization, recognizance, reallocation, re-adjustment of existing rights of use, and granting of new rights of use consistently with availability of water, conflicting water demands on the same waters and government water policy.

(iii) Water Conservation: These provisions relate to public health aspects, to conservation of land and water resources, improved water supplies, drainage, waterlogging and salinization, abatement and prevention of pollution.

(iv) Water rights administration and water authorities: Allocation of water to users as to their amount, purpose and timing should be centralized in a water administration, according to circumstances, at the state, basin or as a minimum at sub-basin levels in the case of large basins. An institutionalized, coordinated and obligatory cooperation is indispensable among all existing water controlling authorities. Such a water administration will be empowered to recognize existing rights, grant new rights, and issue licences, permits, authorizations or concessions.

(v) Water Rates and charges: The water legislation shall empower the water administration to establish procedures for the assessment, levying and collection of water rates, charges and fees; such provisions to be flexible in order to consider not only different types of water uses, but, together with economic and financial factors, also social factors.

(vi) Government financial contribution: including credit facilities, fiscal facilitations or exemptions, flexibility in water charges and fees etc., to be based on Government policy in these matters.

(vii) Criteria for rating of priorities and approval of projects: Based on financial, economic, social and technical factors.

(viii) Beneficial uses of water: Domestic, agricultural, hydropower, watering of animals, industrial, fishing, transportation, etc.

(ix) The protection and control of hydraulic structures and waterworks: Including minimum standards specifications, approval and inspection procedures.

(x) Control of harmful effects of water: Floods, salinization, soil erosion, overflow, poor drainage, etc.

(xi) Water quality, pollution control, health preservation: In close collaboration and coordination with other responsible authorities (Health, Industry, etc.).

(xii) Promotion of water users' associations: As a means to combine many users into one legal entity, which would participate locally in water administration.

(xiii) Powers to declare protected zones or areas: In the case of emergency circumstances: droughts, floods, depletion of aquifers, water rights conflicts, pollution, spreading of waterborne diseases, intrusion of sea-water etc.

(xiv) Coordination and interconnection with other enactments affecting water, such as: forestry, fishing, housing, land settlement, land reform, mining, municipal and town planning, etc.

(xv) Implementation and enforcement: to include judicial and administrative protection of water rights and claims against such determination, inspection and sanctions.

(xvi) Sequence of entry into force and of implementation: By areas, basins, quantity of water utilized, etc.

(xvii) Repealing of pre-existing water legislation.

(xviii) Power to issue regulations.

With respect to groundwater legislation, most of the provisions outlined above also apply. However, specific legal measures are required which may include:

(a) Licensing of drillers, who have to be qualified; through their licences it is easier to control groundwater development.

(b) Exploration or prospecting licence, as different from a water utilization licence, of a short-term duration, since water availability, quantity and quality may not yet be known.

(c) Utilization or abstraction licence, permits: These could follow the same procedure as for surface water, after an aquifer has been struck, to succeed the exploration licence.

(d) Metering of abstraction, whenever feasible, to be established on economic, technical and social grounds.

(e) Modification of existing legislation which may affect groundwater control, such as the civil code, land laws, according to the necessities dictated by a new constitution or a Government water policy.

GOVERNMENT ORGANIZATION FOR GROUNDWATER

Institutions and organizations for groundwater cannot be separated from institutions and organizations for water resources in general, since they are a part of the same resource.

Generally many Ministries and other more or less autonomous authorities are responsible for sectorial aspects of water resources without adequate coordination. Water users' associations, either recognized by legislation or by custom, also exercise authority.

Planning the development and conservation of groundwater resources requires a comprehensive and unified approach, which calls for the need of bringing water under centralized administrative management through the issuing of water utilization permits, licences, authorizations and concessions, as well as for the coordination of various projects, through adequate institutions and organizations.

Institutions and organizations may be envisaged either at different levels - national, regional, basinwide, local, international - or according to the different functions they are called to perform - political, technical, executive, coordinating, advisory, administrative, legal.

Organization at the National Level

The political and technical coordination as well as the administrative control over water resources may be achieved by setting up at least a National Water Council composed of those Ministers having sectorial responsibility for water. Such a body would ensure coordination at the highest political level, and would have the functions of (i) framing the overall water policy of the nation, (ii) deciding on the allocation of funds and water for different purposes, and (iii) deciding on reimbursement policies, payment of water charges and related financial policy matters.

In addition a technical and economic Water Board or Commission could be set up, composed of the senior technicians and economists responsible in the various Ministries and authorities, including representatives of the water users' associations. This body would ensure an institutionalized and obligatory inter-Ministerial coordination at the technical and economic levels at the national level; its functions could be either advisory or executive.

Still at the national level, a Central Water Administration is necessary in order to: (i) execute the political and technical decisions taken by the National Council and the Commission, (ii) administer the rights to use water through the issuing of water permits, authorizations and concessions, (iii) evaluate, coordinate different projects before their execution, (iv) standardize and pool all information and data relating to water resources, (v) prepare a master water plan and regional plans; and (vi) control, authorize or execute individual projects.

Organization at the Regional, Basin or Sub-basin Levels

Regional institutions may be envisaged either as Branches or Departments of a unified Water Administration or as more or less autonomous bodies at the basin, sub-basin or local levels responsible for a particular water utilization, project or area.

Organization at the Lower Level

Local, departmental, district or municipal water authorities which exist at the lower level, should be either integrated or at least coordinated at the basin or sub-basin level in order to avoid segmenting watersheds or aquifers by artificial administrative divisions. Water users' associations exist in many countries. They are generally efficient, but slow in adapting to increased Government control. Their creation often provides a solution to conflicting customary and traditional water rights, and should be encouraged.

Organization at the International Level

Whenever international aquifers or basins are present, proper international institutions are required in the form of International River or Basin Boards or Commissions in order to: (i) exchange hydrologic and other data, (ii) submit proposed projects affecting another co-basin state, (iii) establish joint technical cooperation for integrated development, (iv) prevent and settle water disputes with reference to the equitable apportionment of water resources, and (v) pool and combine efforts to facilitate international financing and assistance.

Functions and Powers of a Water Organization

With respect to the different functions - and necessary powers - which water institutions and organizations could perform, they may vary from case to case, depending on Government policy, availability of personnel and other local conditions.

Such institutions may be either (i) a development institution, i.e. an organization set up to plan, construct and/or operate one or more specific projects; in this case, the area under its jurisdiction (a whole river basin, a part thereof, a project area) will have to be defined, as well as its relationship with the central Government water organization, or (ii) a regulatory institution, in which case it will coordinate activities, allocate funds and water, but should not undertake works which might cause interagency rivalry with other developing institutions. In general, a regulatory authority should be fully Governmental and may constitute the Government Central Water Administration.

The type of water organization, its nature, powers and functions, may vary from country to country, according to circumstances, and there is no clear cut formula valid for all cases. Finally, the need for training in water administration and legislation cannot be underestimated.

TRAINING OF STAFF FOR GROUNDWATER DEVELOPMENT AND USE

If the investigation, development and use of a country's resources of groundwater are to be carried out successfully, then Government will have to take a lead in this work, and will need trained personnel to staff the various organizations to direct and control the implementation of development projects and to ensure that the legal and administrative operations required for harmonious use and conservation of groundwater are fully effective. This paper does not deal with the related extension and training of farmers and labourers to utilize groundwater, though the importance of such services cannot be over-estimated; the paper concentrates on training of staff for Governmental posts.

First, it is necessary to estimate the number of trained men required in the various disciplines. The number trained should be related to the number required, allowing for wastage and probable expansion of the groundwater operations.

Second, staff for training should be selected with care. For groundwater operations, entailing much fieldwork, at least at the beginning of a career, it is most desirable that trainees should be those who really wish to work in the field.

Third, the institute or university for training should be selected with care. It is desirable that primary training at technical college or school, or at a university, should be within the country. Thereafter, the graduate should work for some two to four years in his own country, under good direction. After practical experience, fellowships abroad for a second degree or specialisation through course and seminars are desirable, but not necessary.

Fourth, it is necessary that Government use to the full the staff they have trained. Too often, graduates slip into the most senior post available, and not into the work for which they have been trained. If at all possible, the graduate or technician should be employed under supervision of someone with good experience; otherwise the knowledge gained at school or college may be used incorrectly. Staff should be encouraged and helped to attend seminars and meetings, and to present papers on their work and the results of their investigations.

Finally, refresher courses should not be omitted. The rate of change in the technology of water and groundwater is very great, and it is easy for staff to fall behind. There should also be continuous training on-the-job.

The basis of a Government's effective direction and participation in the investigation, development, use and conservation of its groundwater resources will be its staff. If the staff is good, the work will be good; if the staff is bad, the work will be bad. Training and development of staff are basic to success.

ON ESTIMATION OF AREAL AVERAGE PRECIPITATION BY A WEIGHTED MEAN METHOD

by P. K. Raman and H. Virji

ABSTRACT

A climatic factor based on the extent of the influence of normal precipitation at a point to over an area, is computed for each raingauge inside a given square grid fitted over the area of interest. The result is a set of weights which, when multiplied by the observed rainfall at each gauge, give the total volume of rainfall over the area. Once the weights have been determined for a given gauge network in the area, the method is suitable for computation of mean areal rainfall over any given catchment area.

RESUME

En se fondant sur la mesure dans laquelle les précipitations normales relevées en un point déterminent les précipitations de l'ensemble d'une zone, on calcule un coefficient climatique pour chacun des pluviomètres d'un réseau quadrillant la zone considérée. On obtient ainsi une série de valeurs pondérées qui, multipliées par la hauteur de pluie relevée à chaque pluviomètre, donnent le volume total de pluie tombée sur la zone. Une fois que les valeurs pondérées ont été déterminées pour un réseau pluviometrique donné de la zone, la méthode convient pour calculer la lame d'eau moyenne tombée sur un bassin versant quelconque.

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INTRODUCTION

Estimates of volume of water precipitated over an area depend on the reports of point rainfall measurements. Reliable estimates of average precipitation over a catchment for different durations is a prerequisite for all hydrometeorological investigations.

Methods of estimating areal average precipitation have been described in the literature (3, 4, 6). However, most methods require detailed study of rainfall data, which is a time-consuming process. Increasing use of catchment models in hydrology and water resources studies requires an efficient and rapid method of computing areal estimates of rainfall from point raingauge data.

Recent work on the subject includes a paper by Diskin (1), who suggests a Monte-Carlo method for evaluating Thiessen weights. Kwan et al. (2) have used an interpolation process to construct contours, the areas between the contours being subsequently integrated to give the volume of rainfall. Rockwood (5) used a modified polygon weighting method to estimate areal rainfall from weighted point precipitation values. While the Thiessen method has the advantage of simplicity, the interpolation technique suggested by Kwan et al. permits a better representation of rainfall distribution. However, the technique suggested by Rockwood has the advantage of both of the above methods. This paper describes this method and its applicability in relation to other methods.

THE PROPOSED METHOD

Consider a basin of total area A and mean areal rainfall $\bar{P}_A$. If there are n precipitation recording stations within the basin and the Thiessen Polygon method of estimating average areal rainfall is used, we have:

$$\bar{P}_A = \sum_{i=1}^{n} p_i w_i$$

Thiessen

Where p_i = precipitation recorded at the station i, and the weighting factors $w_i = \frac{ai}{A}$, a_i being the area of the Thiessen Polygon represented by the station p_i. It is evident that

$$\sum_{i=1}^{n} a_i = A \quad \text{and that} \quad \sum_{i=1}^{n} w_1 = 1$$

$$\text{Therefore } \bar{P}_A = \sum_{i=1}^{n} p_i \frac{ai}{A} \qquad (1)$$

Thiessen

The Thiessen Polygon method uses a weighting factor which depends only upon the ratio of the area of the polygon (representative area) indexed by the precipitation recording station to the total basin area. When point precipitation records are extended to areal precipitation estimates, one should consider the influence of the long-term climatic effects attributable to topography and other physical factors besides the weighting due to area representativeness. Thus, it is necessary to re-define the equation of areal precipitation as:

$$\bar{P}_A = \sum_{i=1}^{n} p_i \frac{ai}{A} f_i \qquad (2)$$

Where f_i is the climatic factor defined as

$$f_i = \frac{(NAP_{ai})}{(NAP_i)} \qquad (3)$$

such that (NAP_{ai}) = normal (long term) annual areal precipitation over the representative area indexed or represented by the station i;

and (NAP_i) = normal annual point precipitation at the station i.

The climatic factor then represents the ratio of long-term areal precipitation to the long-term point station precipitation, thereby taking into account the long-term topographic and climatic influences over the area.

The new weighting factors can now be written as

$$w_i = \frac{a_i}{A} \cdot \frac{(NAP_{ai})}{(NAP_i)} \qquad (4)$$

It can be readily seen from (4) that when the value of the climatic factor is unity, then the weighting factors are reduced to those of the Thiessen type; i.e., in the ideal case where the actual precipitation at the station is perfectly representative of the rainfall over the indexed area, then the climatic factor is equal to one. This suggests that the regular Thiessen type analysis gives accurate estimates for idealized situations only, whereas equation (2) is applicable to all non-idealized cases.

If the area ratios $\frac{ai}{A} = A_i$ are considered as percentages, then we may write (2) as

$$\bar{P}_A = 10^{-2} \sum_{i=1}^{n} p_i A_i \frac{(NAP_{ai})}{(NAP_i)} \qquad (5)$$

Also, if a representative area encloses several (say x) precipitation recording stations, then the value of (NAP_i) may be estimated as the arithmetic mean of the spot normal annual values at these stations. In such a case the spatial location of p_i within the representative area a_i may be taken as its centre. The final equation for areal precipitation may now be written as:

$$\bar{P}_A = 10^{-2} \sum_{i=1}^{n} p_i A_i \frac{(NAP_{ai})}{(\sum_{x} NAP_i)} \cdot x \qquad (6)$$

APPLICATION OF THE METHOD

The method requires a grid which would divide the area of the catchment into representative small areas or zones of influence that may be attributed to a number of rain-measuring stations inside or in the vicinity of the catchment. Index precipitation stations (one for each representative area) are chosen as representative of the rainfall in these areas.

The normal mean annual isohyetal map is also required to check unreliable data and to evaluate the factor NAP_a. It is necessary to planimeter the area enclosed by isohyets within the representative area to arrive at an estimate of NAP. This has to be done only once for each small area and the weighting factors, once established for an index station (actual or hypothetical) can be used against all spot values, actual or interpolated (daily, monthly or annual) at these stations.

For practical analytical purposes, a square 20-minute grid (for map scale 1 : 1,000,000) was adopted. Actually, this grid can be as small as practicable, but the 20-minute grid appeared to be sufficient for manual evaluation purposes. A smaller grid can be used when the method is programmed for computer.

The method was applied to all the catchments in the project area of the Hydromet Survey of Lakes Victoria, Kyoga and Albert. Appropriate weighting factors were evaluated, and these in turn were applied to the spot 1967 annual rainfall values at the index stations. Resulting estimates of 1967 annual rainfall over these catchments are summarized in Table 1. For comparison purposes, the corresponding rainfall estimates obtained by the regular isohyetal method and the arithmetic mean method are also tabulated. Assuming the estimates obtained by isohyetal method as the most reliable ones, then those obtained by the present grid method lie within 1 per cent of the former estimates for all catchments.

For elaboration of the actual processing involved in the present method, a worked out example is attached for Nyando, Sondu, Gucha-Migori, Mara and Mori Catchments (Figure 1, Tables 2 (a) and (b)).

For this project area, since weighting factors for all index stations are now available, estimates of areal mean precipitation for any duration can be determined by applying the appropriate weights to the corresponding spot rainfall values at the index stations. Several points of interest need further elaboration. These are: Is there a necessity to introduce the climatic factor:

$$\frac{(NAP_a)}{(\sum_x NAP_i)}.X$$

From the attached illustrative examples, it is apparent that the corresponding values of An (per cent) and W_n (which include the climatic factor) are very close. This implies that either the index stations chosen to correspond to representative areas are very nearly ideal or, more probably, the grid is small enough to allow the station precipitations to be representative of the respective areas. Of course, as the grid is made progressively smaller, one obtains the station precipitation representing progressively smaller areas around it and hence the areal representation would be closer to ideal.

The variation about the ideal (unity) in the case of the above chosen grid is about ±5 per cent. It therefore appears that a slightly larger grid also could have been utilized to demonstrate the correction of inherent non-representativeness of stations by the climatic factor.

The weighted factors are time independent; i.e., they apply equally well for evaluation of monthly or annual precipitation estimates. This is borne out by application of the weighting factors to the northern shores of Lake Victoria and Sio Catchments for evaluating monthly rainfall estimates (Table 3). The corresponding rainfall estimates obtained by the isohyetal method and the arithmetic mean method are also given. It is encouraging that the results obtained by the present method are in close agreement with those obtained by the isohyetal method.

CONCLUSION

The results obtained by the method are indicative of its validity. The method is as easy to use as the Thiessen polygon method, but takes into account the effect of other parameters such as altitude exposure and long-term variations in climatological elements. The method is suitable for manual evaluation and adaptable for computer programming.

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Table 1

Comparison of estimates of 1967 annual areal average precipitation obtained by 3 methods

Catchment (project area of hydromet survey of Lakes Victoria, Kyoga and Albert)	Value of precipitation obtained by		
	Planimetry mm	Weighted normal mean mm	Arithmetic mean mm
1. Nzoia, Yala, Northern Kavirondo Gulf	1,538	1,513	1,630
2. Ruizi, Kabale, Katonga	913	907	998
3. Lake Victoria (plus islands)	1,436	1,445	1,340
4. Nyando, Sondu, Mara, Gucha-Migori	1,251	1,222	1,611
5. Kagera	993	970	1,154
6. Northern shores of Lake Victoria plus Sio	1,454	1,462	1,416
7. Rwana, Gurumuti, Mbalagati, Duma, Bariati, Simiyu	1,048	1,056	1,186
8. Magogo, Isanga, Nyakerenei and Southern shores of Lake Victoria	967	947	1,136
9. Lake Albert land area	1,176	1,129	1,160
10. Lake Kyoga Basin	1,269	1,262	1,577

Table 2(a)

Gucha-Migori, Mara and Mori Catchments - Computation of weighting factors

$$W_n = \frac{A_n.(NAP_a).X}{(NAP_i)}, \quad x = 1$$

No.	A_n(%)	NAP_a mm	NAP_i mm	$\frac{NAP_a}{NAP_i}$	W_n
1	3.91	1,412	1,350	1.05	4.09
2	4.03	1,286	1,175	1.09	4.41
3	0.27	1,100	1,190	0.92	0.25
4	0.76	838	820	1.02	0.78
5	2.33	1,200	1,325	0.91	2.11
6	3.79	1,438	1,375	1.05	3.96
7	4.42	1,754	1,760	0.99	4.40
8	4.42	1,518	1,600	0.95	4.19
9	0.97	1,190	1,180	1.01	0.98
10	2.09	781	750	1.04	2.17
11	4.42	1,263	1,300	0.97	4.29
12	4.42	1,734	2,025	0.86	3.78
13	4.42	1,394	1,360	1.02	4.53
14	3.76	1,184	1,120	1.06	3.97
15	3.42	948	900	1.05	3.60
16	4.42	1,342	1,350	0.99	4.39
17	4.42	1,481	1,500	0.99	4.36
18	4.42	1,203	1,200	1.00	4.43
19	2.88	962	975	0.99	2.84
20	0.61	900	850	1.06	0.65
21	1.51	900	875	1.03	1.55
22	4.33	1,109	1,150	0.96	4.17
23	4.42	1,487	1,500	0.99	4.38
24	4.42	1,399	1,380	1.01	4.48
25	4.42	1,132	1,125	1.01	4.44
26	4.39	938	950	0.99	4.33
27	1.51	910	910	1.00	1.51
28	1.67	1,202	1,200	1.00	1.67
29	2.36	1,387	1,400	0.99	2.34
30	1.64	1,241	1,250	0.99	1.63
31	2.36	1,100	1,120	0.98	2.32
32	1.97	958	950	1.01	1.99
33	0.82	900	850	1.06	0.87

Table 2(b)

Gucha-Migori, Mara and Mori Catchments
Computation of areal rainfall using the weighting factors

$$W_n = A_n \cdot \frac{(NAP_a) \cdot X}{(NAP_i)} \quad , \; x = 1$$

No.	W_n	P_n 1967 Annual	$P_n W_n$
1	4.09	1,550	6,339.50
2	4.41	1,400	6,174.00
3	0.25	1,190	297.50
4	0.78	1,000	780.00
5	2.11	1,360	2,869.60
6	3.96	1,375	5,445.00
7	4.40	1,600	7,040.00
8	4.19	1,480	6,201.20
9	0.98	1,475	1,445.50
10	2.17	800	1,736.00
11	4.29	1,560	6,692.40
12	3.78	1,500	5,670.00
13	4.53	1,300	5,889.00
14	3.97	1,000	3,970.00
15	3.60	1,200	4,320.00
16	4.39	1,200	5,268.00
17	4.36	1,160	5,057.60
18	4.43	1,130	5,005.90
19	2.84	925	2,627.00
20	0.65	810	526.50
21	1.55	900	1,395.00
22	4.17	1,300	5,421.00
23	4.38	1,400	6,132.00
24	4.48	1,050	4,704.00
25	4.44	975	4,329.00
26	4.33	820	3,550.60
27	1.51	1,075	1,623.25
28	1.67	1,300	2,171.00
29	2.34	1,175	2,749.50
30	1.63	1,100	1,793.00
31	2.32	1,050	2,436.00
32	1.99	950	1,890.50
33	0.87	800	696.00

$$\sum_{n=1}^{33} P_n W_n = 122245.55,$$

which gives estimated 1967 annual rainfall for the catchment as 1,222 mm

Table 3

Comparison of 1967 monthly precipitation estimates obtained by various methods

Northern shores of Lake Victoria and SIO catchments

1967	Planimetry mm	Weighted normal mean mm	Arithmetic mean mm
January	24	20	28
February	37	35	36
March	130	130	118
April	190	189	144
May	251	249	260
June	108	112	121
July	84	85	70
August	95	90	93
September	101	106	92
October	160	159	158
November	224	240	217
December	68	62	74

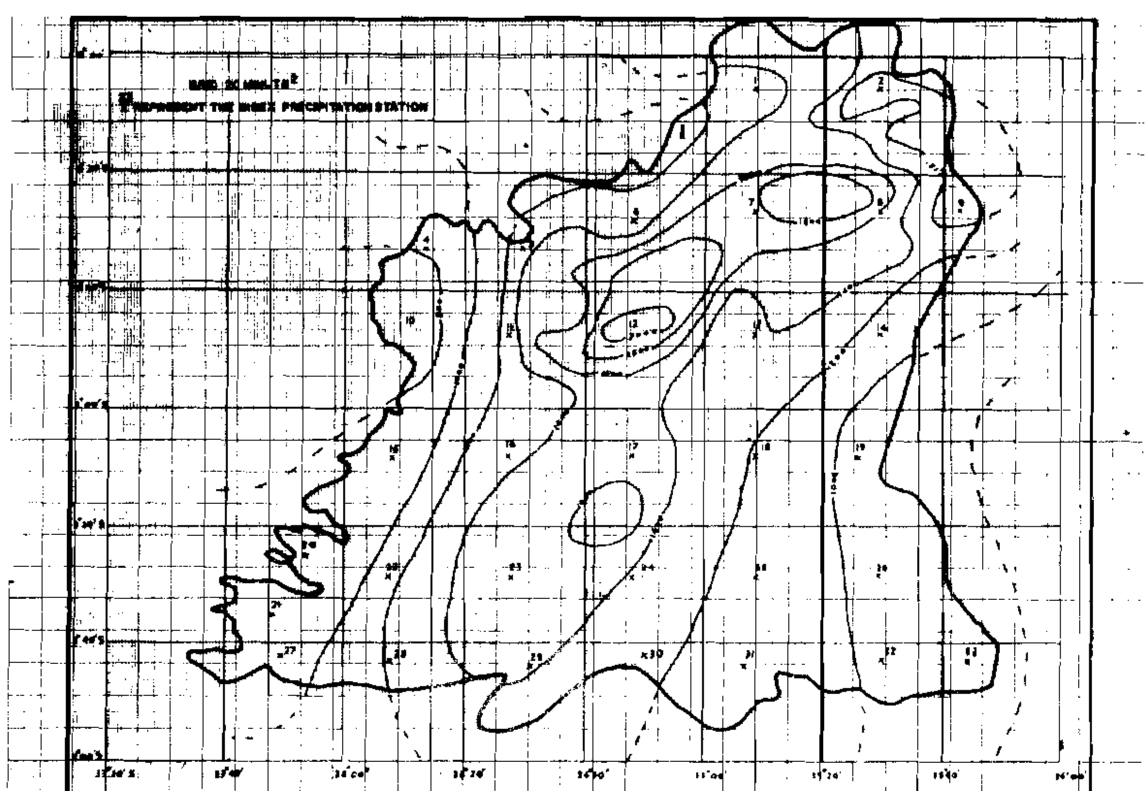

Figure 1 - Gucha-Migori, Mara and Mori catchments. Normal annual rainfall.

PRELIMINARY ESTIMATION OF EVAPORATION FROM LAKE VICTORIA, BY THE WATER-BUDGET METHOD

by A. K. Afifi

ABSTRACT

The problem of determining evaporation from large surfaces of open water has not yet been solved. The approach has always been to use different methods and computations, compare and evaluate the results to serve as the basis for the final estimates in the water-balance studies. The determination of evaporation from Lake Victoria by balancing the other factors was necessitated due to the lack of evaporation-measuring instruments around the lake during the period of discussion (1959-1967).

This paper briefly describes the procedures used in estimation of the average annual evaporation from the lake by the water-budget method.

RESUME

Le problème de la détermination de l'évaporation de grandes surfaces d'eau libre n'a pas encore été résolu. Jusqu'à présent, on a utilisé différentes méthodes et divers calculs; on a comparé et évalué les résultats devant servir de base aux estimations finales dans les études du bilan hydrique. Si l'on a déterminé l'évaporation du lac Victoria en se fondant sur les autres facteurs du bilan, c'est en raison de l'absence d'instruments évaporométriques autour du lac durant la période considérée (1959-1967).

L'auteur expose brièvement les procédés utilisés pour évaluer l'évaporation moyenne annuelle du lac à l'aide de la méthode du bilan hydrique.

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INTRODUCTION

The lakes of the world are basically a natural resource available for use by man. Throughout the history of civilization, lakes have supplied such basic needs as food, primary water supply and transportation routes.

From the point of view of the hydrologist, the yield of the lake and the actual loss of water by evaporation from the lake's surface are of considerable interest.

There are some methods for estimating evaporation such as water budget, energy budget, direct method (evaporation pans) and empirical equations. Each of these methods has certain advantages and disadvantages in its use.

This very short note is an abridgement of a more or less detailed study for estimating evaporation from Lake Victoria by the water-budget method. This study can give a somewhat clear picture of the order of evaporation from the lake and, by so doing, it will bring to light several issues which have to be studied in the future.

The period used in study is from 1959-1967 where some provisional data of inflows of some feeding streams and rainfall are available in concurrence with the somewhat long terms of outflow.

SHORT DESCRIPTION OF LAKE VICTORIA

Main characteristics of the lake. Lake Victoria lies between 3° 00' south, 0° 30' north of the equator and longitude 32° 35' and 34° 30' east. Its drainage basin extends from 3° 00' south to 0° 30' north of the equator and longitude 30° 00' and 36° 00' east. The surface area of the lake is 69 000 km^2, including the islands, while the area of its drainage basin, excluding the lake itself, is about 195 000 km^2. Lake Victoria as a whole has a rather regular form, being almost semi-circular. Its maximum length is 315 km, while the maximum width is 275 km. The shore line is about 3 400 km. The mean depth is about 40 m, while the maximum known depth is 82 m. The volume of the lake is 2 700 km^3. The lake draws its supplies from a group of streams which flow into the lake, of which the major tributary is the Kagera River. The Victoria Nile is the only outlet of Lake Victoria. It leaves the lake at Jinja at the head of Napoleon Gulf by the Ripon Falls.

General hydrological characteristics. The extreme range between the maximum and the minimum lake levels is 3.15 m during the period 1896-1967. The average annual total outflow from the lake is 23 milliard m^3 for the period (1912-1967), which makes the average of 63 million m^3/day. The maximum ten-day means of the discharge exit is 168 million m^3/day (11-20 May 1964), while the minimum ten-day means is 28 million m^3/day (1-10 February 1923).

Climate and rainfall. The average rainfall of the lake is about 1 400 mm. The rainfall has a well-marked maxima in April and an ill-defined one in November-December. Fairly well-defined minima occur in January and July, but there is rain in every month of the year. The driest parts lie along the southern shores in Tanzania, the wettest are localized along the west shores and also in the north-east, which are on the mountainous parts. The temperature is moderate where the annual mean around the lake is of the order of 24°C. There is, of course, little variation in the normal temperatures from month to month throughout the year. The winds on Lake Victoria are variable and generally not very strong.

Salinity of the lake. Lake Victoria is the second largest freshwater lake in the world (next to Lake Superior). The water of the lake contains very little dissolved matter owing to the fact that its principal water supply is the rain which falls upon its own surface. Analysis showed only 65 parts per million of dissolved solids, and it is worth noting that the water of the lake is always perfectly sweet.

ESTIMATION OF EVAPORATION BY USING THE WATER-BUDGET METHOD

The water budget method is a simple and direct technique using measurable parameters like inflow, outflow, rainfall, change of storage and evaporation. The writer herein tried to estimate evaporation from Lake Victoria by using the water-balance technique. Using the data available for the period in hand, the water-balance parameters were approached in the following manner:

The known water-balance equation could be formulated in the following manner:

$$E = I + P - O \pm U \pm \Delta S$$

Where I = inflow
P = rainfall
O = outflow
U = underground seepage (outflow or inflow)
ΔS = change in storage
L = evaporation

A. Inflow "I". There are several streams flowing into Lake Victoria, of which the Kagera is the largest (see Plate 1). Some of these streams are gauged such as Kagera, Gucha, Sondu, Nyando, Nzoia and Sio, and the annual water yield of these rivers has been computed. Their average total contribution to the lake is estimated to be of the order of 67 per cent of the total estimated surface inflow.

The inflow of the ungauged streams has to be catered for by applying different runoff coefficients to the rainfall of the different feeding watersheds. The annual rainfall for each river has been determined and used to obtain a first approximation of the annual runoff as mentioned above. The assumption of the runoff coefficient was based on the nature of the river and also on the comparison of these rivers to the gauged rivers.

For the west swampy rivers such as Katonga and Ruizi, the runoff coefficient has been assumed to be 0.7 per cent. For the southern tributaries such as Magogo, Simiyu and Mbalagati it was assumed to be 6-8 per cent while for the eastern streams, the runoff coefficient was assumed to be between 10-15 per cent.

Table 1 shows the summary of the total annual inflow from all the gauged and ungauged streams flowing into Lake Victoria in millions of m^3.

B. Rainfall "P". It is rather difficult to estimate the accurate annual rainfall over Lake Victoria, due to the fact that there were not enough raingauge stations inside the lake during the period 1959-1967. There are only about 10 raingauges at the islands, and about 40 along the lake shores (see Plate 1). The arithmetic mean is applied for its simplicity for the determination of the average rainfall over Lake Victoria. Table 2 shows the average annual rainfall over the lake in milliards.

C. Outflow "O". The outflow from Lake Victoria is controlled by the sluices of the Owen Falls Dam (constructed in 1954) which is located immediately downstream of the Ripon Falls. The outflow from the lake is by far the best known parameter in the water balance, and is certainly measured with a margin of error of ± 2 per cent and probably even less. Table 3 shows the total monthly and annual exit flow in millions of cubic metres.

D. Underground seepage (outflow or inflow) "U". There is no direct information about seepage, but as the lake is surrounded by high lands, serious outward seepage is unlikely, and there is not likely to be any considerable inward seepage other than that entering the streams, and so included in the runoff from the basin.

E. Change in storage "ΔS". The lake being very large, its storage capacity is enormous, even for very small variations of level. Every centimetre of increase in the level corresponds to the storage of 0-69 milliards in the average. If the observations are made over a sufficiently long time, the significance of ΔS, which is not cumulative, will decrease and may be ignored. But for a short period, DS has to be calculated. Table 4 shows the change in storage for the years under discussion and all the values of flows or volumes of water in millions of cubic metres.

Col. (1): Entebbe gauge on January first in any year is taken as the mean of the last 10 days' mean gauge reading in December and the last 10 days' mean gauge readings in January.

Col. (2): Gives the difference in gauge readings.

Col. (3): Equal the values in Col. (2) x 69 000 km^2 being the surface area of Lake Victoria.

Having computed all the above-mentioned parameters, evaporation could be mathematically estimated from the water-balance equation as previously stated (see Table 5).

SUMMARY AND CONCLUSIONS

From the above preliminary study for the period 1959-1967, the following conclusions are arrived at:

A. Inflow. On the basis of the estimated runoff coefficient, the ungauged portion of inflow into Lake Victoria only amounts to 33 per cent of the total inflow, and the gauged portion of inflow of Kagera, Sondu, Nyando, Nzoia and Sio river accounts for 67 per cent of the inflow. However, the ungauged portion of 33 per cent may be considerably in error due to the use of incorrect runoff coefficients.

B. Rainfall. The determination of rainfall over the lake is not very accurate due to the lack of an adequate number of raingauges.

C. Outflow. The determination of outflow is very accurate, especially in comparison to the accuracy with which the other water-balance parameters are being measured.

D. Groundwater. This paper has assumed that groundwater inflow or outflow is non-existent or negligible.

E. Evaporation. The evaporation estimates for the period 1959-1967 range from 650 mm for the wettest year, 1961 to 1 375 mm for the relatively dry year, 1959. The mean annual evaporation over the lake is of the order of 1 075 mm. The average value may be an under-estimate of the long-term value since the period considered, 1959-1967, was generally a wet period.

FUTURE STUDIES

The results obtained in the foregoing study have been based on all available data, 1967. Improvements in these results can be achieved if:

(i) The network of raingauges in the lake area and river gauging stations are extended in density and areal coverage;

(ii) Small index catchments are set up for detailed studies of variation of runoff coefficients to be applied to streams contributing to the inflow, but difficult to gauge properly;

(iii) Evaporation estimates are obtained by the other methods such as mass transfer and energy budget, and a comparison made with the estimate obtained by the water-budget method.

One of the objectives of the Hydromet Project is to undertake extension and improvement of hydrometeorological networks with the ultimate view to determining reliable estimates of evaporation of the lake. In accordance with this, it is stipulated to set up additional data-collecting stations (about 25 hydrometeorological, 160 rainfall, 50 hydrological and 11 lake-level recorders, besides a network of radiation and lake-surface-temperature measuring instruments. Seven index catchments are also to be studied in detail).

This will increase the accuracy of the final estimates, since the relative accuracy in all parameters such as inflow as the gauged portion will increase from 67 per cent to 90 per cent of the area of interest.

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Table 1

Summary of the total annual inflow from all the streams flowing into Lake Victoria in million m^3

No.	Name of river	1959	1960	1961	1962	1963	1964	1965	1966	1967
	Gauged streams									
1	Kagera	5 030	6 450	5 200	9 410	11 790	11 360	8 060	8 250	6 730
2	Gucha	630	730	1 230	1 195	975	845	675	975	825
3	Sondu	830	1 250	2 100	1 975	1 960	1 900	745	1 190	1 845
4	Nyando	540	620	980	830	835	685	470	625	770
5	Nzoia	2 010	2 060	4 720	3 670	4 450	3 740	1 450	2 125	3 360
6	Sio	250	360	510	630	480	450	240	350	520
	Total	9 290	11 470	14 740	17 710	20 490	18 980	11 640	13 515	14 050
	Ungauged streams									
1	Isanga	174	180	290	174	250	174	189	180	184
2	Magogo	162	166	288	260	202	209	166	137	212
3	Simiyu	550	560	890	590	890	600	940	790	735
4	Mbalagati	200	200	200	200	200	200	200	200	200
5	Rwana	760	780	985	800	840	625	687	625	750
6	Suguti	92	100	119	110	99	93	92	103	115
7	Mori	127	145	242	218	208	165	131	156	188
8	Mara	1 325	1 295	2 025	1 960	2 125	1 565	1 255	1 280	1 750
9	Yala	700	875	1 225	1 030	1 160	910	770	860	940
10	Ruizi	57	50	72	68	76	58	49	78	37
11	Katonga	98	104	120	99	120	102	89	104	55
12	North Shore	44	45	59	46	53	49	38	42	44
13	South Shore	756	875	1 490	1 110	1 147	1 100	944	1 040	1 140
14	Kavirondo gulf streams	846	895	1 385	1 175	1 040	1 020	890	1 030	910
	Total	5 890	6 270	9 390	7 840	8 410	6 870	6 440	6 625	7 260
	Grand Total	15 180	17 740	24 130	25 550	28 900	25 850	18 080	20 140	21 310

Table 2

Average rainfall along the shores, islands and over the lake

Year	Shores	Islands	Over the Lake	
	millimetres	millimetres	millimetres	milliards
1959	1150	1704	1320	91.080
1960	1226	1768	1374	94.806
1961	1595	2038	1680	115.920
1962	1331	2186	1506	103.914
1963	1358	2107	1549	106.881
1964	1287	1840	1398	96.462
1965	1160	1596	1245	85.905
1966	1310	1621	1383	95.427
1967	1242	1687	1356	93.564

Table 3

Total monthly and annual exit flow in million cubic metres

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1959	1559	1410	1587	1567	1724	1638	1609	1499	1404	1441	1443	1553	18430
1960	1537	1461	1687	1885	2062	1939	1832	1672	1585	1614	1570	1578	20420
1961	1523	1365	1517	1617	1804	1709	1653	1590	1547	1616	1946	1690	20580
1962	3014	2686	2994	3065	3525	3455	3459	3350	3217	3365	3204	3382	38720
1963	3479	3157	3626	3563	3895	4102	4155	4013	3670	3633	3536	3989	44820
1964	4253	3787	4145	4230	4549	4400	4613	4285	4118	4205	3882	4009	50480
1965	4470	4124	4596	4285	4403	4313	3701	3549	3294	3312	3311	3520	46880
1966	3523	3175	3623	3657	4233	4252	3647	3461	3332	3367	3301	3380	42950
1967	3301	2886	3103	3042	3417	3285	3298	3156	2923	3007	2993	3348	37760

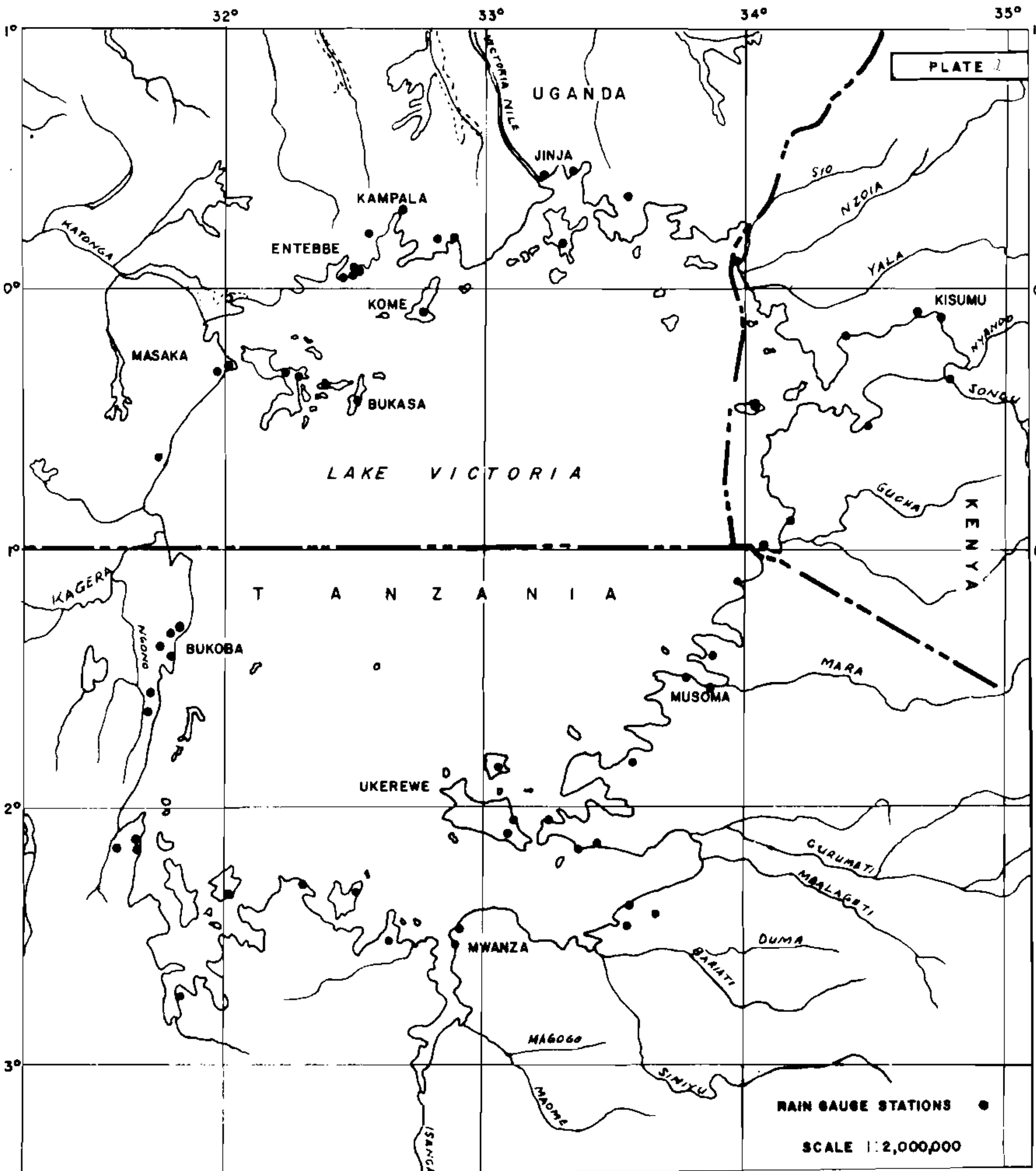
Table 4

Year	G_E (1)	Rise + Fall - (2)	Δ Vs (millions m^3) (3)
1959	10.435		
1960	10.335	- 0.100	- 6900
1961	10.350	+ 0.015	1035
1962	11.430	+ 1.080	74520
1963	11.880	+ 0.450	31050
1964	12.390	+ 0.510	35190
1965	12.385	- 0.005	- 345
1966	11.975	- 0.410	- 28290
1967	11.845	- 0.130	- 8970
1968	11.780	- 0.065	- 4485

Table 5

Summary of all the items of the water budget to estimate the annual evaporation

Year	Inflow I	Rainfall P		Outflow O	Δ S	Evaporation E	
	milliards	mm	milliards	milliards	milliards	mm	milliards
1959	15.180	1320	91.080	18.430	- 6.900	1375	94.730
1960	17.740	1374	94.806	20.420	1.035	1320	91.090
1961	24.130	1680	115.920	20.580	74.520	650	44.950
1962	25.550	1506	103.914	38.720	31.050	865	59.695
1963	28.900	1549	106.881	44.820	35.190	810	55.770
1964	25.850	1398	96.462	50.480	- 0.345	1045	72.177
1965	18.080	1245	85.905	46.880	- 28.290	1238	85.395
1966	20.140	1383	95.427	42.950	- 3.970	1182	81.585
1967	21.310	1356	93.546	37.760	- 4.485	1185	81.581



PLATE
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33°
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3°
UGANDA
VICTORIA NILE
JINJA
KAMPALA
ENTEBBE
KOME
MASAKA
BUKASA
KATONGA
SIO
NZOIA
YALA
KISUMU
NYANDO
SONGU
GUCHA
KENYA
LAKE VICTORIA
TANZANIA
KAGERA
NGONO
BUKOBA
MARA
MUSOMA
UKEREWE
DUMA
MWANZA
MAGOGO
SIMIYU
ISANGA
RAIN GAUGE STATIONS
SCALE 1:2,000,000

PRACTICAL ASPECTS OF RAINFALL NETWORK OPERATION

by H. T. Mörth

ABSTRACT

Recognizing the gap between network design and implementation in some developing countries, the need for a more practical approach and for personal contact with station operators is stressed. Relative merits of various types of equipment and important points regarding site selection and raingauge installations are discussed. Practical hints are given on the routine of observation, recording and data return. The procedure of rainfall station inspection is described in detail.

RESUME

Etant donné l'écart entre la conception et la réalisation des réseaux hydrométéorologiques dans certains pays en voie de développement, il y a lieu d'insiter sur la nécessité d'examiner avec plus d'attention les méthodes pratiques et de se mettre davantage en contact avec les opérateurs de chaque station. Les mérites relatifs des différents types d'équipement, les critères concernant la sélection du site et l'installation des appareils pluviométriques font l'objet de discussions. On donne des conseils pratiques au sujet de l'observation, de l'enregistrement et des données chiffrées. Les procédés d'observation des stations pluviométriques sont décrits de façon détaillée.

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INTRODUCTION

Network design is discussed in a number of papers of this conference, and a wealth of literature and guidance material has been published over the recent past. WMO gives an impressive account of its contribution to this subject in one paper under this agenda item.

Yet, the advances on the scientific and strategic work on networks are not matched by a corresponding progress in the actual development of networks in Africa. This discrepancy between planning and execution is a much encountered feature of developing countries. It might be appropriately called the "implementation gap" and appears to be widening.

Obviously, serious problems are encountered in operating hydro-meteorological networks, and agencies offering technical assistance should think about ways to provide more practically orientated help.

Shortage of skilled manpower is one principal cause given by a number of authors. While this is true, the reasons may be more subtle than appear at first sight. Apart from special networks that are installed and operated by professional services, many **hydrometeorological** stations are run by non-professional staff. Observers at rainfall stations may range from scientifically trained agricultural assistants to office messengers, factory clerks, or policemen, with little or no technical education. Also of consequence is the permanency (or the lack of it) of individual observers and operating agencies, which may range from many years at mission stations to a few months at administrative centres. With such large ranges in the educational background and continuity of operators, a formal training is not possible. The alternative must therefore be sought it the provision of <u>suitable</u> operational guidance to such stations. There appear to be serious shortcomings in that guidance material is often not supplied, or supplied so infrequently that it cannot be found at the station, written in a style and language that is not understood by the observer, or not thorough and detailed enough, thus leaving room for individual erroneous interpretation.

The latter two points are likely to arise when such material is compiled by someone who never left his desk at service headquarters. The author of a successful practical guide to hydrometeorological station operation must have extensive field experience in the operation of such stations. A large amount of notes on deficiencies detected during station inspections is a good basis for drafting of practical guidance material aimed at avoidance of such shortcomings.

There is a great need for a continuous and thorough personal contact between station operators and hydrometeorological services.

The following notes summarize practical experience gained during installation, inspection and field work over five years. They limit themselves to the aspect of ordinary (not recording) raingauge operation.

EQUIPMENT

There is a wide range of commercially produced raingauges on the market. Most of them are good value for money. They can be divided in three types:

Type P: Cheap gauges, often wedge-shaped, made from plastics, measuring scale engraved on gauge.

Type I: Inexpensive metal gauge made from galvanised iron sheeting, with soldered joints.

Type C: Same kind of gauge as Type I, but made from copper sheeting with soldered joints.

The choice between the three types listed depends primarily on the availability of funds.

Type P should not be used in permament rainfall stations. Type C involves a high initial investment, but low replacement costs. The reverse is true for type I. Type C entails a lesser risk of inaccuracies through leakage when inspections are not, or infrequently, carried out. Theft and damage inflict much greater financial losses with type C than with type I, thus security is a major point of consideration. Type C's potential attraction to thieves can be considerably reduced by painting the outer surface of the gauge. A Type C gauge is more liable to be dented and deformed but less easily perforated than a type I gauge.

Rainfall measuring devices comprise engraved scale on plastic wedges, metal cyclinders with dipsticks, plastic and glass measuring cyclinders.

The glass cyclinder is expensive but allows permanently accurate measurement. The longer and narrower the more accurate, but the greater the risk of breakage. There is the additional danger that observers, instead of reporting breakage, substitute ordinary measuring glasses as used in hospitals and laboratories, without regard to the volume/section/height relation.

Graduated cyclinders made from clear hard plastic would be a good compromise between accuracy and fragility, but are not generally available.

Metal cyclinders and dipsticks are very durable, but the measurements become difficult and inaccurate when dipsticks become grimy and hydrophobe with age. Again, there is a risk that lost dipsticks are replaced by ordinary graduated rulers.

INSTALLATION

Selection of site: The criteria of site selection are well treated in text books and guidance literature. However, it is often not possible to satisfy them. Observation points are by necessity linked to availability of personnel and communications and must therefore be situated within reasonable distance of observer's place of work or residence. What is the use of an ideally exposed gauge if its reading entails so much hardship for the observer that he will dodge this chore whenever possible? One major problem is the abundant and fast growth of vegetation in parts of the tropics. In many places along the coast it is simply impossible to find a site free of palm trees. If it is not possible to fell palms and control future growth, the risk of some rain-shadowing must be accepted.

Trees with thin foliage may be tolerated up to 60 degrees from the horizontal if they cover less than 10% of the sky ring between 30 and 60 degrees elevation. Complete tree shadowing up to 60 degrees from the horizontal can be accepted for a gauge standing in the centre of a dense forest clearing. It is sometimes necessary to accept horizon elevations up to 45 degrees near high mountains. Rooftop sites are frowned upon by network designers, but are unavoidable in some urban areas.

Providing that there is no actual rain shadow effect, any natural protection and shelter from high winds improves the exposure of the gauge. Sites exposed to high winds should be avoided. Where this is not possible, as on mountain tops and ridges, an artificial wind break should be fitted around the gauge.

When choosing a site, much consideration should be given to potential vegetation growth and construction activity in the future. Rainfall records attain their full climatic value only after 30 years of coninuous recording, and changes in the gauge environment are undesirable. Even worse is a forced movement of the gauge to another site, however small the distance.

Mounting the gauge: Two items are of great importance. Firstly, the gauge rim, and thus the rain catching circle, must be, and remain, level (horizontal). This can be achieved by burying the lower part of the gauge in the ground. A hole with vertical walls, only just larger than the gauge bottom, should be dug. The bottom of the hole is then lined with small gravel which is adjusted until the gauge rests level on it. Then the space between gauge and hole wall is packed with excavated soil. Watering around the gauge and tamping the ground with a wooden ram will produce a good compaction. Setting the gauge into a concrete foundation improves the security of the equipment and reduces corrosion. It does not necessarily prevent a gauge from being tilted out of plumb by earth movements.

Secondly, rain splash on the ground must not enter the gauge. This can normally be achieved by keeping the distance between the ground and the rim of the gauge 30 cm or more.

Sometimes, a gauge must be kept well above the ground for reasons of security. In such a case, a sturdy concrete or iron pillar with solid foundations should be constructed. Gauges which stand free, or fixed by wire, on top of wooden posts are frequently out of plumb as the post surfaces weather, or the whole pole leans over.

OBSERVATIONS, RECORDING AND RETURNS

Observers should have absolutely clear and non-ambiguous instructions on procedures of rainfall observation, recording and data returns. They should be frequently reminded of the most important points, such as time of observation, importance of "Nil" records, and dates for data returns by telephone, telegram or mail.

This can be achieved by printing such instructions in large letters at the top of the record forms. Print at the bottom of the forms is soon rendered illegible by creases and fingermarks. Better still, is the annual issue of specially printed calendars for rainfall observers. Instructions on the most important points should be repeated on each calendar leaf, and dates requiring transmission of returns marked by boxing, encircling, or different colour print. Voluntary observers are often very busy with their main occupation and need this kind of reminder. Instructions and reminders by letter prove to be rather ineffective.

Only one reading is generally made every 24 hours, at a fixed hour during daytime. This means that a 24-hour rainfall period spreads over two calendar days. Whatever decision is made as to which date the observed rainfall refers, it is essential that the observer is not required to figure it out. He should always record his measurement against the date on which he makes it. Any adjustment, such as to the previous date when observations are made in the morning, should be effected at the data-processing centre.

It is imperative to enter a "Nil" record whenever no measureable rainfall is observed. A blank should be reserved for the occasions when the observation was missed altogether. If "Nil" is not recorded, and dry days are simply shown by a blank, it will later be impossible to decide whether "no rain" or "no observation" applies. This has a great bearing on the analysis of 24-hour rainfall maxima. If the maximum recorded on a certain date is preceded by one or more blanks, it is impossible to be sure that this maximum is a true 24-hour rainfall. If, however, the maximum recorded is preceded by "Nil", there can be no doubt.

It is important to keep duplicate records for each station as returns may get lost in the mail. This can be achieved by issuing the station annually with one large record card for 365 (366) entries, in addition to twelve smaller mailing cards for monthly returns. Pre-punching of annual record cards, and issue of a protective file cover, encourage orderly retention of station records. Pre-franking and addressing on the reverse side of the monthly return cards encourages timely posting. All cards should be of durable paper or card-board to withstand daily handling.

The following hints on actual reading and recording procedure help the observer:

Read the gauge daily at the prescribed time, although you may be sure that no rain has fallen. Even during long dry spells the routine of daily rain-gauge inspection should not be broken. During prolonged inattention the gauge may become infested with insects or blocked by airborne debris and may fail to function at the first rain thereafter.

When measuring rain, make sure to have the measuring cylinder standing truly upright, and the eye at the level of the water surface. Always take pencil and paper to the gauge. An amount mentally noted may soon be forgotten over a sudden distraction before it has been recorded. When the measuring cylinder has to be filled many times, due to large rainfall amounts, mark each fill on the paper. An unexpected distraction may soon make you wonder how many times you had already filled the cyclinder.

After the measurement is completed, check whether the funnel stem is clear by looking through it. Obstructions, early detected, are easily removed by blowing through it. If this does not help, fill the funnel with water and shake it in the direction of the stem until the blockage is cleared. Do not push a wire or rod through the stem as this may compact and worsen the obstruction in the case of sand or termite blockage. Check funnel, inner can and outer can for leaks, and report such immediately to the data collecting agency. Enter the readings <u>daily</u> in the records sheet (book). Check when the next return is due to be made. Store the measuring cylinder safely with its opening downwards.

The agency operating a rainfall station should be advised to have a second person instructed and familiarized with the routine of observation, recording and returns. Otherwise the quality of data will suffer, or observations will stop altogether, when the first observer is absent on leave or sickness.

INSPECTION AND SURVEY

Regular inspection of all stations in the network serves a number of specific purposes, such as:

Updating of particulars of station,
check on gauge exposure,
check on state of equipment,
maintenance,
check on observation and recording procedures,
survey of prospective sites for new stations,

but above all it provides the personal contact between the **hydrometeorological** service and the individual operator which is so necessary for a good functioning of the network.

Therefore, it is very important to have network inspectors with a flare for good public relations in addition to technical knowledge. When selecting personnel for this job, one should bear in mind the hardships and physical strains associated with prolonged travel in remote areas, which may prove too much for an older person. Because of very long absences from home, the family status must be considered. Sobriety and personal integrity are essential in the person of inspector, as he is in charge of a driver, vehicle and equipment. Having to make decisions on the opening and closure of stations requires objective judgement and readiness to accept responsibility.

The frequency of rainfall station inspections depends on the permanency of observers at the stations and on the quality of the gauges. Once in four years is considered an absolute minimum, once in two years may be indicated in many cases.

Experience has shown that up to 5 gauges can be inspected on one day in densely gauged rural areas, 2 to 1 gauges in sparsely gauged areas. The inspection routine takes, on average, one hour at a station, more when a gauge has to be replaced a moved, or a new observer instructed.

Inspection schedules can be arranged in such a way that the inspector works three weeks in the field and then returns to base for the remainder of the month. This ensures adequate time for service and repair to the inspection vehicle and allows the inspector to write his report, plan for the next trip, and replenish his equipment.

The inspector should be given clear written instructions on his task, the inspection procedure, and the authorities vested in him. An example is attached in Appendix A. Detailed notes on all relevant observation during inspections are entered in an inspection book or inspection form. **On return to base the inspector is required to write an inspection report, containing a summary of all station particulars requiring amendment action, and statistics on the quality of exposure, equipment and observation routine.**

When planning the next trip, the inspector should consult the network planner on requirements for opening of new station in data-sparse areas. Each trip should include an element of survey of potential gauges sites. Whenever possible, the inspector should himself supervise the installation of new gauges and assist in the commencement of operations.

CONCLUSION

The above notes do not claim to be applicable universally, nor to be exhaustive. To the professional they may appear unnecessarily elaborate but field experience has shown that attention to detail is badly required. To the observer in the field and to the network inspector they should be of practical use and may thus help to improve the standard of operation.

APPENDIX A

.STRUCTIONS FOR INSPECTION OF RAINFALL STATIONS

Preparation of Inspection Trip:

Rainfall stations should be inspected at least once in four years. When selecting an area in which the raingauge network is to be inspected, due consideration must be given to the seasonal weather in relation to road conditions and type of available vehicle.

Select a number of stations which can be inspected in three weeks, working on a daily average of four stations where the network is dense, and appropriately less where travelling distances are great. The inspector should thereafter return to base for follow-up action on the inspection results and to allow the vehicle to be checked and serviced before proceeding on the next inspection.

Make a list of all stations to be visited, showing their name, registration number, geographical coordinates, altitude and operating agency. Put a transparent paper overlay on a road map (preferably 1:1,000,000) and mark the station position given by the geographic coordinates with a dot. Put an identification letter against the dot and against the station in the list. Study the road network to determine the most economical route for visiting all stations, keeping in mind a possible return to a base at the end of each day. Then put consecutive numbers in order of all visits against the station identification. Trace from the map the routes to be taken. This paper is a travel guide for the inspector during the safari.

Obtain a supply of rainfall station inspection forms and enter only the registration number of the stations to be visited. In consultation with the officer in charge of the regional climate section, and on hand of the rainfall station files, enter on the back of the report sheets all information relevant to the performance of each station. This should include correctness of filling returns, time of dispatch, accuracy of sums, recording of NIL rainfall, etc. Put all station report sheets and some blank ones, on a file with a strong protective cover (Leitz file with cardboard cover box was found useful). Also, put a set of all valid circulars and instructions to rainfall observers on this file.

Obtain equipment, budgeting for 70% raingauge replacement, 80% measuring cylinder replacement, 100% bottle supply.

Make sure that the empty bottles, which can be bought cheaply secondhand, are of a good size and fit the inner cans in width and length.

Make sure that the inspection vehicle is licensed, in good mechanical order, equipped with essential spares, and serviced. Sufficient cash for purchase of petrol, oil and to cover breakdown service must be carried.

The first-aid kit must be complete and contain some medicine (eg. Mexaform) against intestinal disorder. It is wise to commence taking anti-malarial drugs before starting a safari.

Attempt to arrive at a station during normal working hours (08.00-12.30, 14.00 - 17.30). Ask for the person in charge of the operating agency, not for the rainfall observer. Do not enter the grounds and proceed to the raingauge (which you may have spotted on looking around) until you have met the owner or the manager of the property. Introduce yourself properly and explain the purpose of your visit. Ask for permission to move on the premises for the purpose of inspecting the raingauge.

In consultation with the operator, check the correct station name, map location, mailing address, telephone number (if any) and road access. If the place is difficult to find make appropriate notes on how to get there. Always enter altimeter readings for QNH 1013 and time, unless true altitude can be ascertained from a bench mark.

Inspect the gauge with respect to exposure, installation and state of equipment. The gauge should be so exposed that its horizontal distance from any surrounding object is not less than twice the height of the object above the raingauge rim. This means that no object must subtend an angle of more than 30° from the horizontal, as seen from the raingauge rim. Provided these rules are adhered to, the presence of objects tending to shelter the rain-gauge from the wind is advantageous.

If the gauge is badly exposed, try to locate a satisfactory alternative site on the station. Then explain the matter to the proprietor and obtain his permission before you move the gauge.

The raingauge is set up with its rim horizontal and exactly 30 cm (12 inches) above ground level, the earth being packed firmly round the lower part of the outer can which is sunk into the ground. The positioning of raingauges on top of pillars and wooden poles, for reasons of security, must be discouraged. Where interference from children or animals is feared, a stout fence (not exceeding 30° angle from the rimlevel) should be made round the gauge. Grass around the gauge must be kept short.

In case the raingauge or measure is non-standard, describe the equipment under "remarks" on the report sheets. Make a note on the ownership of such equipment.

Check whether all metal parts of the gauge are free from leaks and corrosion. Replace them where necessary. Blow through the stem of the funnel to make sure that it is not blocked. Remove any blockage or debris in the stem by immersing and shaking the funnel in water. Check the rim which must be horizontal, circular, without dents and of 5 inches (12.7 cm) diameter.

The glass measure must be free of cracks, clean and the scale well legible. Vim and a bottle brush will remove any algae deposits. Glass measures should be graduated in mm. Where a new mm-measure is issued to replace an inch-measure, the latter should be retained as spare in case of breakage.

Request to see the person who reads and records the rainfall. Make sure that he

1) reads the gauge at the correct time,
2) reads the rainmeasure correctly,
3) enters NIL when no rain occured,
4) keeps station records on a permanent file,
5) has sufficient return cards for the remainder of the year,
6) knows that he should mail return cards on the first day of the month,
7) has an "Instruction for Rainfall Observers".

In case the station is reporting weekly or monthly rainfall, make sure that the observer is familiar with computation, recording and transmission procedures.

WATER AND RURAL DEVELOPMENT: A REVIEW OF WORK FROM TANZANIA

by L. Berry

ABSTRACT

The present status, needs and future development of water supplies in rural Tanzania are viewed in this paper from an economic and social angle.

RESUME

Cette contribution fait le point des aspects économiques et sociaux de l'état actuel, des besoins et du développement futur des ressources en eaux dans les régions rurales de la Tanzanie.

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INTRODUCTION

In much of Africa, drinking water for man and beast is poor in quantity and quality. A major effort by the Government, private institutions and individuals in the last decade has been made to improve the situation in rural Tanzania. Now the country has firmly committed itself to a further 20-year effort, during which period all Tanzanians, rural and urban, will drink from an improved, clean and healthy water source.

In a country of scarce resources, both of manpower and finance, such a massive commitment suggests a very high national valuing of water and an instinctive if not defined opinion that this programme will have important economic, social and political results.

The Bureau of Resource Assessment and Land Use Planning (BRALUP) and the Economic Research Bureau of the University of Dar es Salaam have initiated a research programme in support of the rural water development programme and water development in general. Most of the work has begun at various times during the last four years, and although a range of results is available and is reported in this paper, a substantial part of the research programme is still under way.

Research undertaken ranges from hydrology and meteorology through planning studies to aid the physical and economic layout of projects and their integration with other activities, to specific studies of water use and other parameters of design. They all relate to the central theme of this section of the conference, "The application of hydrology and hydrometeorology in social and economic development in Africa". The work includes:

(i) Water resources - existence, quantity, quality;

(ii) Water needs - perceived, latent, current and future;

(iii) The economics of investment in rural water supply - costs and benefits, least-cost approaches, planning implications, design criteria;

(iv) The impact of rural water development;

(v) Research and development implications, integrated surveys, project selection etc.

Implicit in the research approach is the need to provide better frameworks for the implementation of the rural water programme, yet at the same time to provide a feed-back on the results of the programme. Even a well-designed, finely executed water scheme may have unforeseen and indeed unfavourable as well as favourable impacts on an area. The provision of good water may make for bad land use, at least in the short run.

WATER RESOURCES

The Government of Tanzania supports an extensive and growing monitoring of its major rivers through a well-designed gauging-station network, and a raingauge network which though numbering 700 gauges has recently come under critical comment (BRALUP Research Papers 11 and 12). There is no similar network for groundwater observations, though the importance of such studies has been recognized. At a local level in any particular area, there are little data available on small catchment flows, even on periodicity of flow and on flow fluctuations. Yet in rural water developments, on small and medium scales, such data are often needed, and very brief (one or two years) measurements of minimum flow are all that is available. A localized mapping of resources and testing of them is needed, and current research programmes attempt to decide the best way of doing this.

WATER NEEDS

Three per cent of Tanzania has permanent stream courses, and the rest makes do with various degrees of intermittent surface flows. Some people live close to good potable water, others may walk up to 10 miles (and seasonally more) for this basic commodity. There is then a varying degree of need and a resultant ordering of priorities in rural water development. The pressing need for many areas is proven by the constant demands for help through the regional development committee and other agencies.

Given a need for water - how much and how near, and what quality, become vital social and economic questions. Table 1 illustrates a range of data obtained in Tanzania on per capita water consumption in rural areas, nearly all from central stand pipes.

Distance to water is an important factor in time used. The spacing of distribution points is important in terms of cost and the effects of improved water supply. Studies suggest that where a distribution point is within five minutes of the home, water use increases and time savings are important. The scattered nature of the population will mean that even with improved supplies people will still have to walk up to a mile for water unless they wish to concentrate their housing near the source. Quality of water provides another basic imponderable. A clean source is obviously called for, but available basic data suggest that as long as the tap is outside the house, many of the health benefits may not be realized. Primary infection such as bilharzia may be eliminated at the source, but secondary pollution is a great hazard. As finance will not normally allow inside connexion, future work must aim at reducing the secondary pollution.

THE ECONOMICS OF INVESTMENT IN RURAL WATER SUPPLY

Tanzania commitment to rural water supply is couched in social rather than economic terms, though it is clear that in relation to the way in which water development is carried out, least-cost alternatives are vital, and these may lead to choices of one set of projects over another. There are also major problems of assuming the benefits of rural water inputs, and these will be considered in the next section.

Table 1

Rates of water use

Name of investigator	Number of sites	Per capita daily consumption in litres	Remarks
Stanislawski	1	Daily range 14.6 - 41.8 Average: 23.2	Probably underestimated
Crawford	1	Average: 59.1	Likely overestimated
White et al.	19	Site range: 4.4 - 20.8 Average: 11.4	Only include water carried to the house
Warner, unpiped	21	Site range: 5.0 - 26.4 Average: 12.7	- " -
Warner, piped	11	Site range: 9.1 - 22.7 Average: 14.1	- " -
Ferster	6 (But measured in daily range; wet and dry season)	14.2 - 27.4 Average: 18.7	- " -
Tschannerl et al.	2 areas	Average: 12.7 15.0 Range 5 - 40	
Kajula et al.	4	Averages: 9 - 23	- " -

The economies of cost relate to type of resource, type of supply area, design criteria employed, strategy and tactics employed, etc. All of these things need to be considered together in project design to achieve true economies. For example, a least-cost dam site (least cost in terms of Shs. per m^3 of stored water) may be expensive if the area and design criteria employed will result in only 30 per cent of the stored water being effectively used.

BRALUP research has been aimed at improving the planning process in rural water development, involving:

(a) Methods of obtaining basic population figures for the area and investigations of immigration and emigration effects to obtain more effective long-term population figures; this is vital when design periods may spread over 20 years.

(b) Problems of most effective location of outlets to:

- (i) Serve present population needs;
- (ii) Encourage nucleated settlement in line with government policy;
- (iii) Promote the most effective future land use procedures, particularly when cattle are to be served;
- (iv) Relate water to integrated development.

(c) Problems of water quantity used in various circumstances.

THE BENEFITS OF RURAL WATER SUPPLY

In a long-range programme of rural water development, there is a real possibility of lessons from one stage of the operation being incorporated into later phases. One of the undefined aspects of rural water development is the type and scale of benefits, social and political, which it brings. There are many problems in evaluating such benefits, firstly because of complementary changes which occur in the area, and secondly because of the expensive type of research this involves. In Tanzania, Mr. D. Warner of the Economic Research Bureau has conducted a survey of 26 villages in 10 districts, and in 10 of these a follow-up survey after improved water was installed was made. BRALUP has made studies of the impact of rural water supply in Ismani (Iringa District), in Nzega District (McKay, Conyers and Ferster), in Geiro area of Morogoro District and in Lushoto District. Results from these studies should at this stage be considered as tentative.

Heijnen and Conyers in an earlier review came to the following conclusions:

(a) Effect on distance travelled to obtained water: Warner's figures indicate a significant decrease after improved supplies.

(b) Time and energy spent on getting water: Generally it can be stressed (White, 1969; Warner, 1970 and Ferster's work) that there are considerable time savings with improved supplies, but in places queuing at the tap may be time-consuming.

(c) Quantity of water used: There is no clear answer yet to the relation between improved water supply and quantities used, if the improved supply is not a house connexion. Some increase does appear to occur, but a number of factors are involved (White, 1969).

(d) The use of time saved: An improved supply saves time and labour, but so far no research has found an answer to the question of how this time is used. We generally hypothesize that for savings of women's time in particular, this may be an important benefit.

(e) The effects of improved water supplies on livestock husbandry: These are multifold - sometimes possitive, sometimes negative - and the answer relates very much to the over-all context of the animal/land system and the care with which additional water is related to other aspects of the animal industry (Murray-Rust 1970, Nzega Reports BRALUP 1970/71).

(f) The effect of water in encouraging nucleation of settlement: Although in the long run the presence of water may promote growth of settlement, the evidence so far gathered suggests that water may not be the main factor in promoting settlement, at least unless it is accompanied by other influences, particularly roads.

The general conclusions from research so far completed point to the importance of an integrated approach in rural development. The impact of water appears to be greatest when it is linked with other infrastructural or community projects.

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A WELL-DESIGNED AND OPERATED HYDROLOGICAL NETWORK IS A PREREQUISITE TO AN ECONOMIC DEVELOPMENT OF WATER RESOURCES

by Teshome Workie

ABSTRACT

A nation exploits its water resources to better the living standard of its people. Full utilization of water resources calls for short- and long-term planning. Hydrological data are the basic ingredients in sound and economic planning and development of water resources. The first step in hydrological data-collection is a well-designed hydrological network. This paper stresses the well-planned hydrological network as a fundamental requirement to any sound water-resources project. The factors affecting the design of hydrological network (surface water) and the value of hydrological data have been pointed out. Even though the final goal is the establishment of an optimum network, the paper realizes the difficulty the developing countries have in order to achieve this goal, and recommends establishing the minimum acceptable hydrological network.

In the absence of any set of formulae, the paper cites the experience of Mr. Langbein and the general rules adopted by WMO as useful guides for designing minimum acceptable density of a hydrological network. It also enumerates some of the problems that stand against establishing a minimum stream-gauging network in developing countries, and concludes by stressing the need to give higher priority to hydrological operation in order to reduce structural and economic failures.

RESUME

C'est pour améliorer le niveau de vie de ses habitants qu'une nation exploite ses ressources en eaux. L'utilisation à fond des ressources en eaux demande une planification à court et à long terme. Des données hydrologiques sont à la base d'une planification et d'un développement solide et économique des ressources en eaux. Un réseau hydrologique bien conçu constitue le premier échelon d'un rassemblement de données hydrologiques. Le dépliant met l'accent sur un réseau hydrologique bien organisé, ceci étant une condition fondamentale pour tout projet de réserves en eaux bien fondé. Les facteurs qui jouent un rôle dans la conception d'un réseau hydrologique (eau en surface) et la valeur des données hydrologiques ont bien été mis en relief. Bien que le but soit l'installation d'un réseau en tout point favorable, le depliant se rend compte des difficultés auxquelles les pays en voie de développement doivent faire face afin de réaliser cet objectif et recommande d'établir un réseau hydrologique minimum acceptable.

Par manque de formules, le dépliant cite les expériences faites par Monsieur Langbein ainsi que les directives générales adoptées par l'OMM comme guide utile pour la conception d'un réseau hydrologique minimum acceptable. Il y figure également une énumération des problèmes défavorables à l'établissement d'un réseau hydrométrique minimum des pays en voie de développement et se termine en appuyant sur la nécessité de donner plus de priorité à l'opération hydrologique en vue de réduire des défauts structuraux et économiques.

INTRODUCTION

Comprehensive water-resources planning of a country is directed towards the complete inventory and the full conservation, control and utilization of the country's water resources. A prerequisite for efficient and sound planning is a carefully designed hydrological network that provides a detailed and continuing inventory of the water supply of the nation. This inventory includes the amount, the fluctuation and the distribution of both surfacewater and groundwater supply with respect to geography and time. It also includes the variability of quality and temperature of water and the amount and concentration of sediments.

The hydrological network is a representative placing of measurement or data-collection stations. The network of stations is first established to provide the basic data for making the original detailed water inventory. Since developments in water utilization have an impact on further future developments, the network must be elastic enough to permit modifications to meet changing conditions. Therefore, the original network of stations has to be updated or expanded or improved to give more accurate and reliable information.

DENSITY OF NETWORK AND LENGTH OF RECORD

The ultimate goal of any stream-gauging operation is the establishment of an optimum network.

There are no numerical formulae to compute either the optimum density of hydrological stations in the network or the optimum length of record to be collected at any station. The locations of key stations where long-term records are required are often obvious to the hydrologist, but the location of the supporting stations requires careful consideration. Long-range plans of water-resource exploitation must be considered if optimum benefits are to be realized from operation of the network. At those regions where future development is more or less imminent because of high economic feasibility, detailed water data should be collected for many years. Apart from providing adequate information on discharge variation and stage fluctuation of a stream with time, a long-period record is desired because the sampling error inherent in a short-period record of measurements cannot be overcome by even the most sophisticated stochastic manipulation of the data. A shorter period of record is justified at those sites where the data will be used to fill minor gaps in the knowledge of the areal hydrology of a basin, or at those sites that have a low priority for future development.

In the countries where exploitation of water resources has just begun, establishment of an optimum network would take a long time. Therefore, the more immediate need is the planning and establishment of networks of minimum acceptable density. The minimum density is one which will avoid serious deficiencies in developing and managing water resources of the country.

Before location of any station is decided upon, it should be well confirmed that the station location represents the area. A measurement of the flow in a river represents only the flow from its particular catchment area. It should be kept in mind that there is a limit also to this area representativeness. The greater the number of stations, the more accurate will be the results obtained.

VALUE OF HYDROLOGICAL DATA

To design a hydrological data-gathering system properly, the relative value of alternative types of data must be assessed. The value of any type of data must be measured in terms of its ultimate uses. One use is to provide general regional information, and this has transfer value. It represents natural conditions and may be used in combination with similar data at other sites to gain a regional description of the streamflow of an area. A second use is for project operation and design. Data may be obtained for operation or flood warning. A surfacewater streamflow gauge may be maintained at a potential reservoir site to gain information on which to base the design of a water-resource project. Sometimes such a gauge has two measures of value. Although its primary worth may relate to its project design purpose, if it measures a natural basin, its inherent information has transfer value at least until such time as the dam is built and water stored in the reservoir.

A measure of the value of data used for project design may be assessed by measuring the value of net benefits foregone as a result of the lack of data. If a true optimal design and the associated costs and benefits for a given project are known, the change in value, as a result of non-optimal design based on a sample of data, can be measured in terms of the net benefit foregone through under-design or over-design.

Unreliability in the ultimate design results in part from errors in hydrological data, both measurement errors and sampling errors. Measurement errors may be reduced by more and better equipment and manpower, so as to obtain more accurate or more frequent measurements of flow. Therefore, there is a need to have some criteria for choosing the level of accuracy desired for each type of data. The accuracy desired should be related to the ultimate use of the data, which determines its relative importance in relation to other types of collected data. Thus, the relative importance of an established streamflow station is related to the planned use for the data. This importance determines both the accuracy required and the maximum feasible cost necessary to obtain that level of accuracy.

Sampling error is a much larger component of total error than is error in streamflow measurement. If a streamflow record is to be used for reservoir design, the sampling error is of the overriding importance in determining the final design.

Any set of data collected over time at a site provides an estimate of what may occur in the future at that site; the longer the record, the better the estimate. The deviation of this estimate of the future from what will actually occur during the period of interest, say the project's economic life, is essentially a result of sampling error.

DESIGN OF MINIMUM HYDROLOGICAL NETWORK

The hydrological (hydrometric) network usually consists of the following stations: streamflow; river, lake and reservoir stages; sediment transport and sedimentation; quality of water and water temperature. The main objective of the hydrological network is to assume an adequate record of time variations in streamflow and stage, including floods and droughts; in sediment discharge and concentration, and in quality and temperature of water.

Some of the factors that affect network design are climate, water use, hydrogeological characteristics of the region, population and accessibility. These factors have to be given thorough consideration if the designed network is to be useful and successful.

The desirable or the most useful density of hydrological networks should reflect the hydrological regimen of an area as well as the ultimate use to which the data are to be put. It is difficult to specify the required density of gauging stations on a unit area basis. But the experience of other countries on area densities of their networks and the recommendations put forward by WMO provide useful guides.

Mr. Langbein has made a study about the densities of stream-gauging stations of various countries, which has shown a very striking comparison. He has found that the areal density of stream-gauging stations varies between zero and 5 per 1 000 km^2. The median is about 0.3 stations per 1 000 km^2. Nevertheless, all contain inadequacies to some degree. Even in a region where there are five stations per square kilometre, there would be a lot of small streams that are ungauged. Even though it is virtually impossible to establish a perfectly adequate network, the figures of the numbers of gauging stations in the various countries of the world allow one to establish a comparative scale of adequacy.

The figure attached shows the data on density of gauging stations in the various countries. Densities are shown in terms of number of stations per 1 000 km^2 of total area. The "relative density" lines represent the percentage of the various countries that have densities less than indicated. These lines can serve to compare the relative adequacy of gauging stations.

Most European countries, with the exception of Great Britain, have densities that approximate 70 per cent to 90 per cent adequacy on this diagram. The areal density of the USA plots at about 70 per cent. According to this diagram, the gauging station densities in the developing countries are only 10 per cent adequate or less. Note the positions of Ethiopia, Congo (Kinshasa) and the Sudan.

This international evidence indicates that a gauging station density of about 0.2 station per 1 000 sq. km should be conceived as a minimum programme. This density is the horizontal hatched line on the figure. In arid regions with few streams and sparsely settled, this density may set a goal that is too high. Therefore, in the figure the "reasonable objective" is decreased for regions of low population density. In the same way, for densely populated areas, a density of 0.2 station per 1 000 km^2 may be too low; and the "reasonable objective" is increased for regions of high population density. The "reasonable objective" represents a compromise between uniform adequacy in regard to population and that desirable on a purely geographical basis.

Considering the areal variation of rainfall and runoff, the population density, the accessibility of the region and other factors, WMO has adopted some general rules. These rules are clearly indicated in the WMO "Guide to Hydrometeorological Practices". Since the guide is familiar to practically all of us, there is no need to elaborate on these general rules in this short paper.

ODDS AGAINST MINIMUM HYDROLOGICAL NETWORK

There are many odds against establishing even the minimum hydrological network in most of our countries. These odds are very striking and are almost the same in practically all African countries. They are scarce financial resources, accessibility of the region and lack of understanding the importance of hydrological records.

The establishment of the hydrological network, no doubt, would incur a fantastic initial investment. The operation and maintenance cost of the network, especially hydrological stations, is a continuing expense. This, of course, puts heavy weight on the scarce financial resources a developing country can provide. This makes most of the responsible people reluctant to give high priorities to the collection of hydrological data But there is one point to be realized. That is, for any project the cost of collection of sufficient hydrological data and its analyses is very insignificant when compared to the total project cost. Therefore, there is a need to understand the advantages and benefits obtained from long-term and reliable hydrological data in order to improve the density of a hydrological network.

Most African countries have tremendous problems of accessibility. Because of very few all-weather roads, establishment and operation of a minimum acceptable network are either difficult or exceedingly expensive.

The minimum acceptable network may call for key stations to be established in very remote and inaccessible areas. To establish and operate these stations would require the use of helicopters or small fixed-wing planes. This makes the undertaking very expensive, and it thins out the network. For high-flow measurements, remote stations would require the stationing of crews at the isolated sites for about three to four months. With helicopter operation, our experience in the Blue Nile River has shown that sometimes one streamflow measurement would cost more than US$500. Therefore, in designing the network, the area representativeness of the station, the cost of establishment, operation and maintenance of the station should always be weighed and kept in mind.

The lack of understanding the importance of hydrological records and the consequences of inadequate data by most decision-makers have created much delay in the establishment of adequate hydrological networks. The return on the investment on hydrological establishment may not be imminent in a very short time. Investment on hydrological operation is similar to that of statistical research. It takes time, patience and constant effort. Experience has shown that undermining the importance of the hydrological record has led to disfavour of the timely establishment of a hydrological network. This in turn affects the economic and safe development of water resources.

CONCLUSION

Hydrological data are the fundamental basis for the design of all types of water-resources development projects. Adequate and long-range hydrological data are essential in the planning of development schemes, the design of hydraulic structures and the optimum development and management of water resources. These data are the deciding factors for determining the economy and safety of hydraulic projects. The lack of such data may also lead to delay in embarking upon projects.

The hydrological network design is the first step in the collection of hydrological data. Good and sound design of the network leads to a more representative and reliable record, which leads to more economical water-resource development. The pressing need of systematic and wise development of our practically untouched water-resources potential calls for giving higher priority to hydrological operation than it is enjoying at present.

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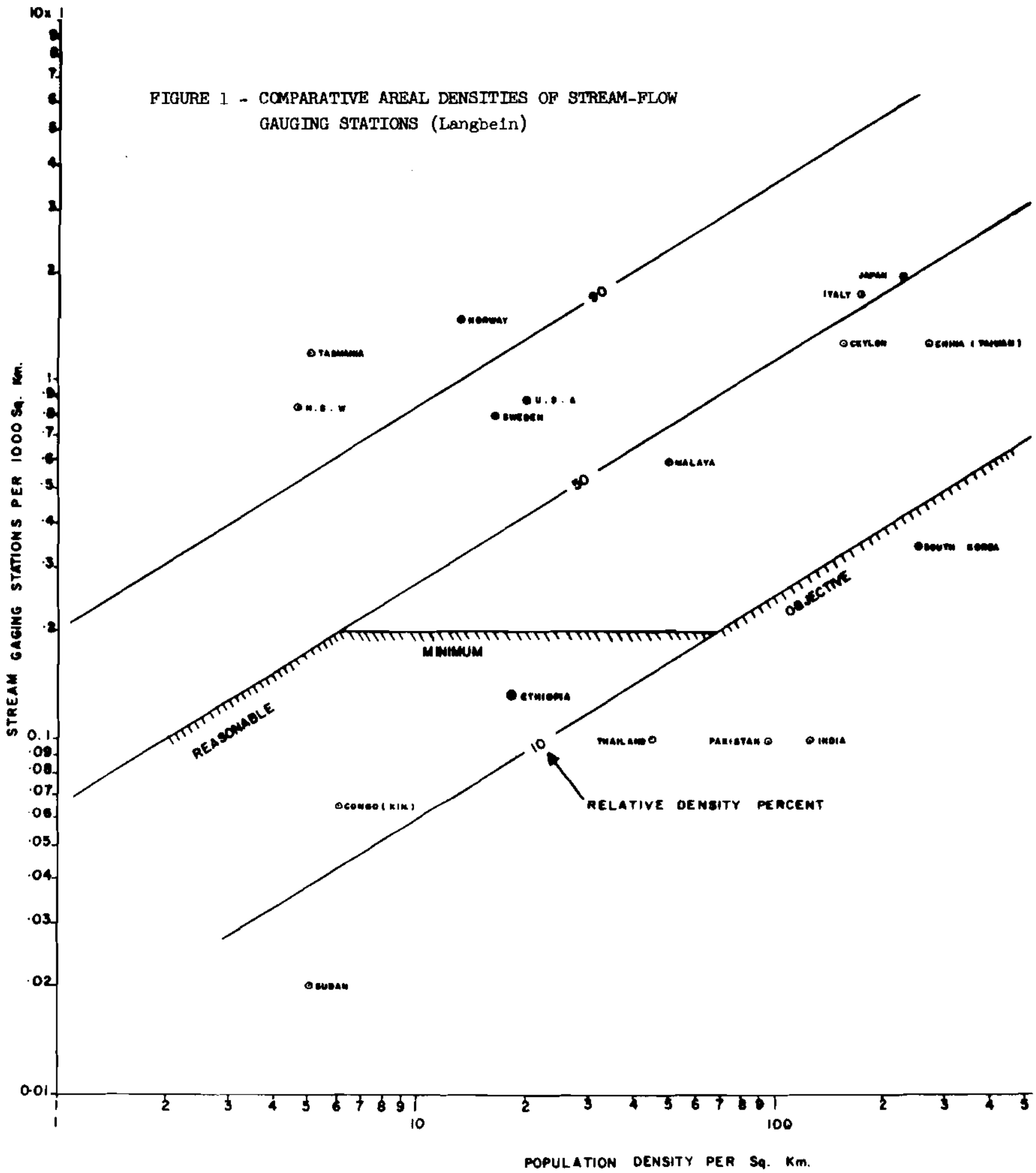


FIGURE 1 - COMPARATIVE AREAL DENSITIES OF STREAM-FLOW GAUGING STATIONS (Langbein)

CONCEPTION ET FONCTIONNEMENT DES RESEAUX D'OBSERVATION METEOROLOGIQUE ET HYDROLOGIQUE EN TUNISIE

par la Division des Ressources en Eau de Tunisie

1- INTRODUCTION - CONCEPTION DES RESEAUX

Le réseau d'observation hydrométéorologique Tunisien est relativement ancien, les premières mesures datant de la fin du 19e siècle.

La mise en place de ce réseau a été réalisée par trois ou quatre générations d'hydrologues, ce qui explique une certaine hétérogénéité due à des conceptions et surtout à des motivations différentes suivant les époques et les urgences du moment.

Nous en venons finalement au défaut originel essentiel de ce réseau : comme beaucoup d'autres il a été créé à la demande, sous la pression des facteurs économiques à court terme.

Il en est résulté la mise en place d'un réseau lourd à gérer comportant trois cent trente-trois points de mesure dont 83 équipés d'au moins un limnigraphe, 47 équipés d'une échelle limnimétrique simple, les autres étant des points de mesure périodique des débits d'étiage (pour 71) ou non périodique (pour le reste).

Ce réseau, tel qu'il est, est efficace quant aux besoins actuels du pays. Cependant il ne fonctionne pas de façon optimale du point de vue économique et ne couvre sans doute pas tous les besoins futurs. Depuis quelques années nous en avons entrepris la réforme de façon à aboutir à une exploitation rationnelle répondant à la fois aux objectifs à court terme des autorités nationales et aux objectifs à long terme de connaissance des régimes hydrologiques, indispensables au développement futur du pays.

Parmi les objectifs à court terme nous devons signaler la priorité accordée au réseau d'annonce de crue.

L'installation des stations hydrométriques répondait généralement à des besoins précis de données hydrologiques, par exemple :

- Projet d'aménagement de Génie Civil (barrages, ponts etc...)
- Projet d'aménagement hydro-agricole.
- Annonce de crue etc...

Des critères classiques sont utilisés pour le choix des sites de mesure : si possible stabilité de la section, sensibilité, accès facile etc... On peut donner l'exemple de Sidi Saad sur le Zéroud :

- Cette station contrôle la plus grande partie du bassin versant du Zéroud (8900 km2).
- L'emplacement choisi est l'un des rares à partir duquel on puisse tenter de faire des mesures (cependant très difficles).
- C'est un poste avancé pour l'annonce de crue dans la plaine de Kairouan : on dispose en effet d'un délai de quatre heures pour prévenir les effets de l'inondation à Kairouan après le passage de la crue à Sidi Saad.

Nous devons signaler qu'un réseau d'environ cinq cents pluviometres et cent trente pluviographes fonctionne parallèlement au réseau hydrométrique, sous le contrôle des hydrologues, constituant l'essentiel du réseau d'observation pluviométrique de la Tunisie.

La réorganisation actuellement en cours aboutira dans sa phase finale à la structure suivante :

1°) Stations primaires :

Un nombre limité de stations primaires seront sélectionnées sur l'ensemble du critère ci-après :

- Station stable (si possible)
- Mesures faciles (ou au moins possibles)
- Importance pour l'annonce de crue
- Position intéressante dans le bassin versant.

Cette liste n'est pas limitative.

2°) Stations secondaires :

Stations pour lesquelles les critères de choix seront moins sévères. Elles seront étudiées pendant une durée limitée (5 ans en moyenne) en corrélation avec les stations primaires. On y procèdera à un grand nombre de mesures.

Après cessation des mesures on y conservera des échelles à maxima.

3°) Stations tertiaires :

Stations établies à la demande en vue de besoins particuliers. Le réseau sera modifié également de façon à mieux étudier les régimes hydrologiques du Sud et du Sahel, grâce à une meilleure répartition des stations.

2 - FONCTIONNEMENT :

Le réseau hydrométéorologique est organisé en cinq secteurs géographiques chaque secteur étant sous la responsabilité d'un Ingénieur. La station de Sidi Saâd sur le Zéroud est considérée à elle seule comme une sixième région eu égard à son importance.

Chaque secteur est divisé en zones, plus ou moins nombreuses (1 à 3 suivant l'importance du secteur).

Dans chaque zone réside une équipe composée :

- d'un chef de zone (Adjoint Technique)
- d'un Agent Technique
- d'un Manoeuvre et d'un Chauffeur.

Tout le matériel nécessaire à l'exécution des mesures est à leur disposition.

Le responsable de secteur fixe le programme de travail des équipes des zones, contrôle le travail et coordonne les activités.

Le Chef du réseau coordonne les activités pour l'ensemble du secteur.

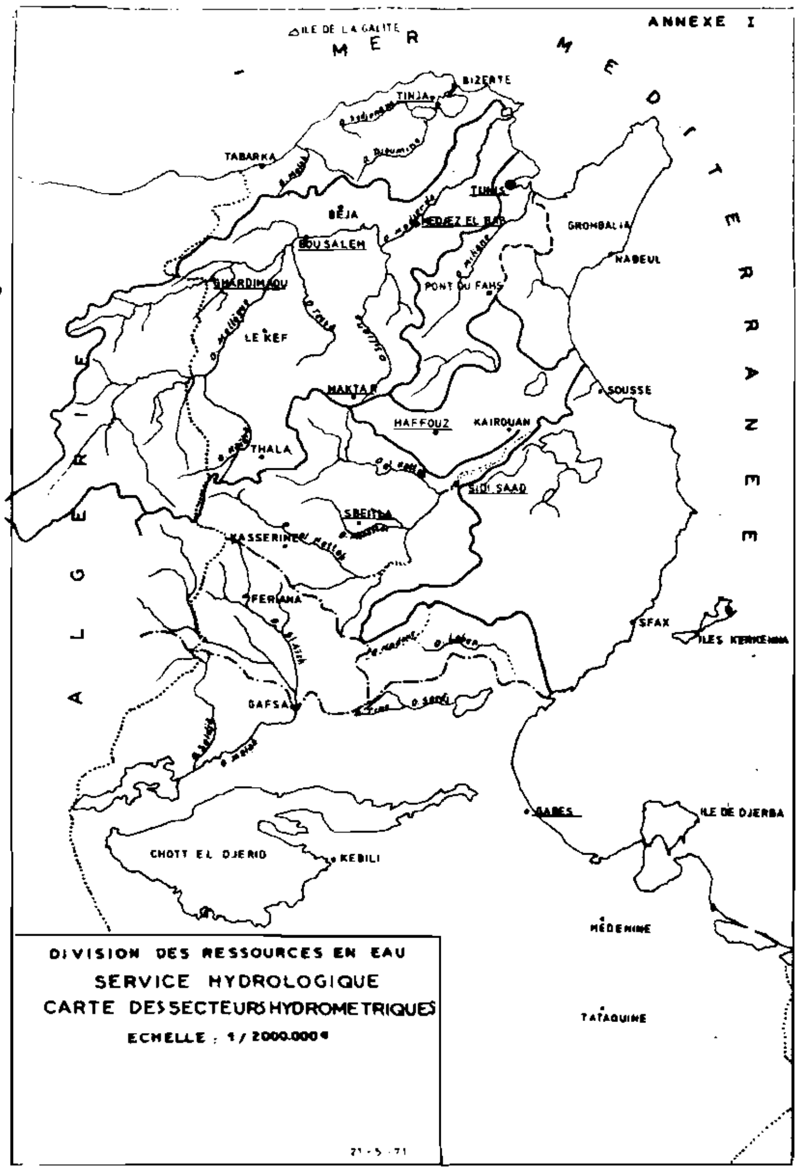
Le fonctionnement du réseau d'annonce de crue mérite une mention particulière.

La violence et la soudaineté des crues sont fréquemment la cause de dégats considérables en Tunisie. Les inondations catastrophiques de 1969 en sont l'exemple le plus récent. Ceci justifie l'importance attachée au système d'annonce de crue.

Le bureau d'annonce de crue du Service Hydrologique (B.A.C.) centralise à Tunis les renseignements hydro-pluviométriques en provenance des zones soit par radio (6 postes en service), soit par téléphone. Le fonctionnement du Bureau d'Annonce de Crue est permanent, trois équipes de 2 agents se relayant toutes les 8 heures, un Ingénieur de permanence supervise le fonctionnement du bureau et est habilité à prendre toutes les mesures pratiques qu'il estime indispensables en dehors des horaires normaux de travail.

En particulier il peut mettre les équipes des zones en état d'alerte permanente dans les périodes dangereuses.

Les autorités civiles sont averties en temps utile des dangers éventuels d'inondation de façon que les mesures de protection soient prises à temps. Ce système a parfaitement fonctionné en Octobre 1969 et a sans doute permis de sauver de nombreuses vies humaines.-


ANNEXE I
ILE DE LA GALITE
MER MEDITERRANEE
ALGERIE
BIZERTE
TINJA
TABARKA
TUNIS
BEJA
MEDJEZ EL BAB
BOU SALEM
GROMBALIA
NABEUL
GHARDIMAOU
PONT DU FAHS
LE KEF
MAKTAR
HAFFOUZ
KAIROUAN
SOUSSE
THALA
SIDI SAAD
SBEITLA
KASSERINE
FERIANA
SFAX
ILES KERKENNA
GAFSA
GABES
ILE DE DJERBA
CHOTT EL DJERID
KEBILI
MEDENINE
TATAOUINE
DIVISION DES RESSOURCES EN EAU
SERVICE HYDROLOGIQUE
CARTE DES SECTEURS HYDROMETRIQUES
ECHELLE : 1/2000.000e
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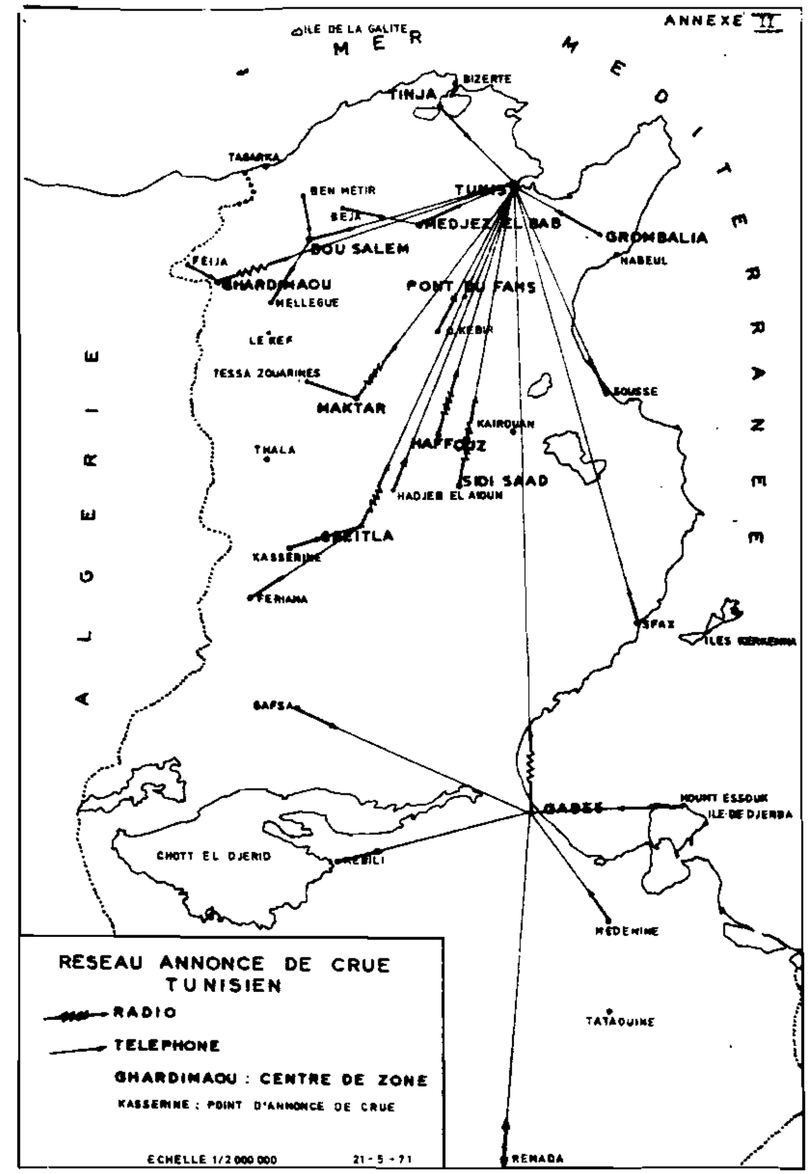
ANNEXE II
ILE DE LA GALITE
MER MEDITERRANEE
ALGERIE
BIZERTE
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BEN METIR
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GROMBALIA
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BOU SALEM
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MELLEGUE
PONT DU FAHS
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SIDI SAAD
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FERIANA
SFAX
ILES KERKENNA
GAFSA
GABES
HOUMT ESSOUK
ILE DE DJERBA
CHOTT EL DJERID
KEBILI
MEDENINE
TATAOUINE
REMADA
RESEAU ANNONCE DE CRUE TUNISIEN
RADIO
TELEPHONE
GHARDIMAOU : CENTRE DE ZONE
KASSERINE : POINT D'ANNONCE DE CRUE
ECHELLE 1/2 000 000
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TRAITEMENT DES DONNEES DE BASE. COORDINATION
DU RASSEMBLEMENT DES DONNEES ET DE LA DIFFUSION

par la Division des Ressources en Eau de Tunisie

Le volume des données brutes recueillies par le Service Hydrologique Tunisien depuis plus de 70 ans est énorme tant en ce qui concerne les hauteurs d'eau que les jaugeages (exécutés par dizaines de milliers depuis 1946), les analyses d'eau et les mesures de transports solides. Jusqu'à ces dernières années l'exploitation qui en avait été faite était assez réduite et se limitait généralement à la publication des données brutes. La décision relativement récente de procéder à l'étude rationnelle des résultats obtenus a conduit les responsables du Service Hydrologique Tunisien à utiliser les moyens modernes de traitement de l'information.

Depuis deux ans le Service utilise un atelier mécanographique BULL et loue les services d'un ordinateur IBM 360-30. Le but que se sont fixé les responsables est de parvenir à traiter les données brutes au fur et à mesure de leur arrivée au Bureau Central de Tunis après avoir rattrapé le retard accumulé depuis la création du service.

Parallèlement l'exploitation scientifique rationnelle des données élaborées est prévue par la publication de monographies par exemple. Pratiquement le schéma d'opération actuel en ce qui conerne les données hydrométriques classiques est résumé par le tableau ci-joint. On peut constater que les opérations manuelles sont conservées pour la vérification des hauteurs limnimétriques et leur mise sur cartes perforées, ainsi que pour le dépouillement des jaugeages de crue et d'une partie des jaugeages d'étiage.

Trente six programmes de calcul en langage COBOL ou FORTRAN ont été élaborés par les Ingénieurs du Service depuis 2 ans et permettent le traitement des résultats pluviométriques, des résultats hydrométriques, des résultats d'analyse d'eau et de transport solide.

Grâce aux programmes traitant les résultats pluviométriques il est possible d'éditer un bulletin pluviométrique mensuel pour 600 stations, de traiter les résultats par la méthode des doubles masses, de calculer les coefficients de corrélation interpostes et les formules de régression de poste à poste pour les totaux mensuels et annuels et de publier à l'issue de ces opérations un annuaire pluviométrique.

Les données hydrométriques d'une station peuvent actuellement être éditées par l'ordinateur soit sous forme d'un tableau annuel des débits journaliers pour les débits seuls avec les moyennes mensuelles et annuelles, les volumes écoulés, la lame d'eau écoulée et le débit maximum, soit sous forme de tableaux semestriels si l'on désire en plus publier les salinités journalières des eaux et les tonnages de sel transportés.

Des programmes permettent le dépouillement des jaugeages avec commentaires détaillés, l'établissement des barèmes de traduction hauteur-débit des stations hydrométriques, les barèmes d'étalonnage des hélices, des moulinets, etc..

Pour conclure, en ce qui concerne la mécanographie nous signalons qu'en deux ans environ 400.000 cartes ont été perforées dans le service permettant dans une certaine mesure de combler le retard accumulé.

Nous souhaiterions en définitive pouvoir constituer une "banque" de données hydropluviométriques qui seraient accessibles à tout utilisateur par l'intermédiaire de l'ordinateur qui, questionné, fournirait la réponse rapidement sous la forme d'une feuille de résultats imprimés. A cet effet nous avons commencé à utiliser les disques ou bandes magnétiques comme support d'informations élaborées.

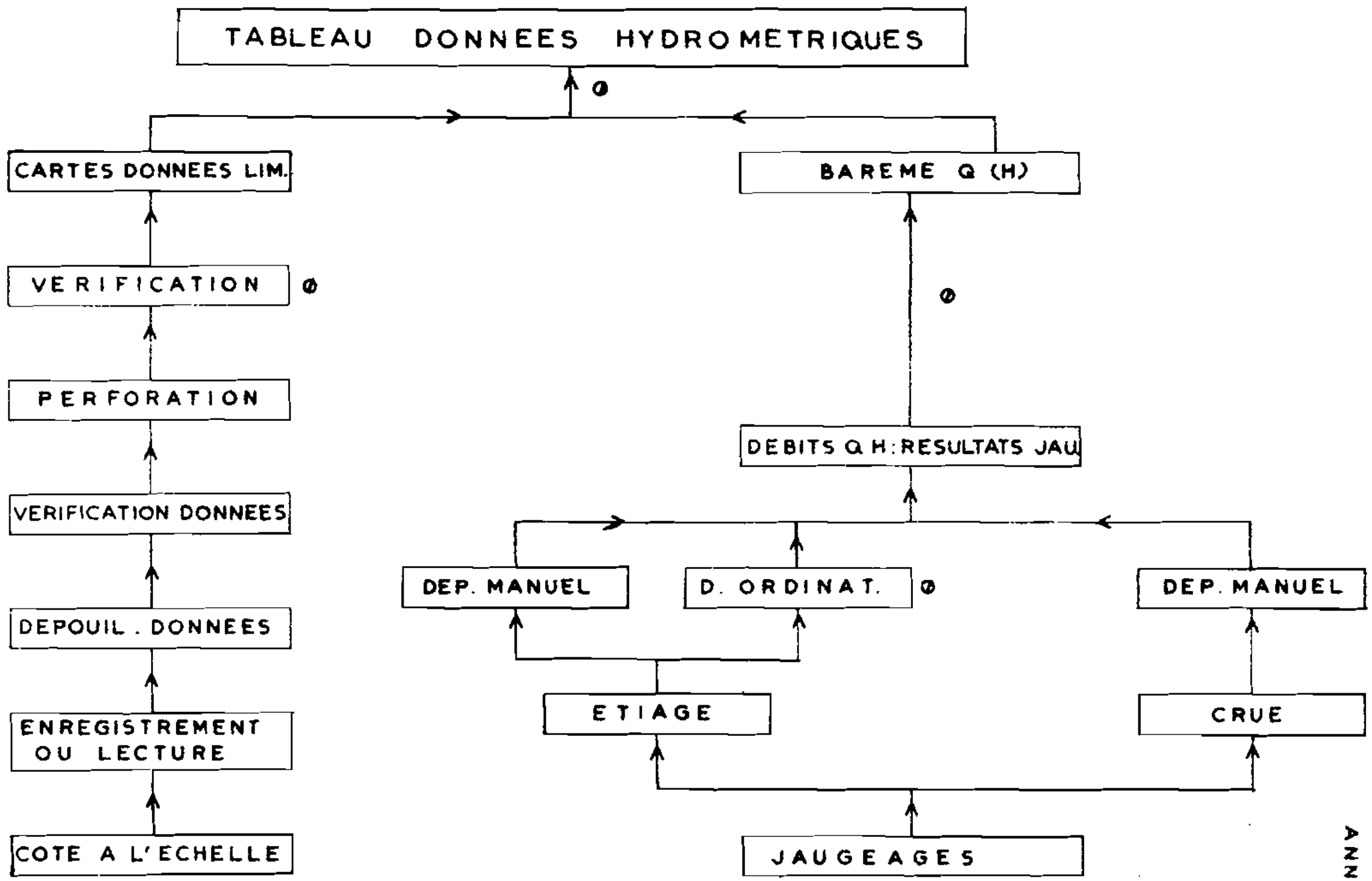
Ce stade ne pourra sans doute pas être atteint avant quelques années.

L'exploitation scientifique des données élaborées ainsi obtenues est commencée, et nous pensons pouvoir publier dans le courant de l'année 1972 la Monographie de la Medjerda, l'un des fleuves les plus importants du Maghreb. Ce sera la première monographie complète d'un fleuve important d'Afrique méditerranéenne. Ultérieurement des études analogues seront poursuivies pour les autres fleuves de Tunisie.

Parallèlement des études sur bassins représentatifs sont en cours qui devront aboutir à une meilleure connaissance des conditions de ruissellement.

D.R.E/S.H

TRAITEMENT DONNEES HYDROMETRIQUES EN TUNISIE



Ø : PASSAGE A L'ORDINATEUR AVEC 1 PROGRAMME APPROPRIE

ANNEXE

INVENTAIRE ET PROSPECTION DES EAUX SOUTERRAINES, EVALUATION DES RESSOURCES DISPONIBLES ET PROGRAMMATION DE LEUR EXPLOITATION

par la **Division des Ressources en Eau de Tunisie**

SOMMAIRE

L'inventaire des ressources en eau souterraines a été entamé depuis 1930 en Tunisie et a été à l'origine de la création du premier service national dans ce domaine, qui porte d'ailleurs le nom du Bureau de l'Inventaire des Ressources Hydrauliques (B.I.R.H.).

De là sont parties les premières prospections des eaux souterraines à l'aide de sondages, puis d'études sur la base des essais de pompage - Des moyens modernes de prospection sont utilisés actuellement dont notamment la Géophysique.

L'évaluation des ressources en eau est l'aboutissement de ces travaux ; elle vise essentiellement la mise sur pied d'un programme d'exploitation d'abord, puis de conservation et de recharge ; la surveillance des nappes joue ici un grand rôle de même que les modèles analogiques.

Nous relatons dans ce qui suit l'expérience tunisienne dans ce domaine.

1°- Inventaire des ressources en eaux souterraines

Alors que l'hydrogéologie n'était encore que de la Géologie Appliquée les géologues travaillant dans le pays ont senti la nécessité de réaliser un inventaire des ressources en eaux souterraines et de disposer d'un classement des données recueillies sous forme d'un catalogue.

1°- Phase

Dans sa premiere phase, l'inventaire a répondu à des objectifs à court terme voire immédiats : alimentation en eau de centres urbains essentiellement.

L'Inventaire s'est même développé du fait du manque de moyens de prospection modernes, à savoir les sondages surtout. On cherchait en effet à trouver des sources où des puits de surface pour résoudre les problèmes posés.

Le classement de ces données est à l'image de cette conception de l'inventaire ; du fait du peu de données disponibles et de leur liaison étroite aux problèmes régionaux, on a choisi un découpage calqué sur l'organisation administrative du pays à l'époque, soit 5 Régions - Chaque point d'eau inventorié porte un numéro d'ordre auquel était adjoint le numéro de la Région ; on réalisait deux types de fiches

- Une fiche modèle "A" comportant les caractéristiques du point d'eau et notamment les moyens de pompage.
- Une fiche dite "B" donnant l'analyse chimique de l'eau.

La base du classement est la carte topographique au 1/50.000 du pays qui sert uniquement de support à ce catalogue, car nous l'avons dit plus haut, les points d'eau ne portent que le numéro d'une des 5 Régions, lesquelles couvrent plusieurs cartes chacune.

2° Phase

Le développement de l'irrigation qui commençait à utiliser les eaux souterraines de façon de plus en plus intense d'une part, le développement de l'Hydrogéologie par ailleurs ont amené une intensification de cet inventaire.

En effet on commençait à faire des études hydrogéologiques d'ensembles ou d'unités naturelles, études qui nécessitaient le maximum de renseignements ; d'où l'inventaire complet des points d'eau. Des méthodes nouvelles furent alors mises en application, comme l'utilisation des photos aériennes qui permettaient un repérage aisé et de meilleurs conditions de travail.

Ainsi en quelques années, le nombre de points d'eau inventoriés augmentait considérablement. Toutefois nous n'avons pas pour autant modifié le classement existant car il permettait encore une manipulation relativement aisée et surtout parce qu'il perpétuait une méthode rigoureuse de travail, bien assimilée, qu'il était dangereux de remettre en cause avec des cadres moyens nouveaux et encore insuffisamment formés.

PHASE ACTUELLE :

Plus de 70.000 points d'eau sont inventoriés ; le catalogue des eaux est devenu un service fonctionnel de la Division des Ressources en Eau qui a remplacé l'ancien B.I.R.H.

Nous arrivons enfin à la phase où la somme et la diversité des demandes ainsi que l'état avancé de l'inventaire des points d'eau des principales nappes du pays nous amènent à envisager un inventaire systématique.

Il importait alors de mettre sur pied une division plus rationnelle du pays en régions naturelles dont chacune constitue une section régionale du Service d'Hydrogéologie - Le travail de base de ces Sections consiste désormais à réaliser l'inventaire sur la base des cartes au 1/50.000 qui, tout en demeurant le support de l'inventaire, en deviennent l'élément de base.

Dans le nouveau classement, chaque point d'eau porte le numéro d'ordre et le numéro de la carte au 1/50.000 ; une mention est faite de l'ancien numéro de catalogue pour réaliser la soudure avec le classement précédent. Les fiches de renseignement deviennent spécifiques du type du point d'eau :

- Source
- Puits
- Sondage

Des agrandissements au 1/20.000 des cartes sont prévus pour les zones à fortes densités de points d'eau.

La prochaine étape sera la mise sur cartes perforées des renseignements et leurs traitement sur ordinateur ; cette nouvelle étape a d'ailleurs été envisagée lors de la mise sur pied du classement actuel.

2°- Prospection des Eaux Souterraines

Là aussi, nous avons évolué en Tunisie, à travers une série d'étapes.

1° Phase :

Les premières prospections des eaux souterraines étaient des inventaires des points d'eau mis dans un cadre géologique approprié, à partir desquels on se livrait à des calculs théoriques sur la base des formules établies pour aboutir à l'estimation des volumes d'eau infiltrés ; on aboutissait généralement à des propositions de captage de sources par des moyens divers où les galeries étaient fréquentes.

Puis les forages ont commencé à intervenir de façon plus fréquente ; mais les résultats qu'on tirait des essais de pompage qui avaient lieu dans les cas positifs se bornaient généralement à la détermination du débit de pompage, du rabattement correspondant et de la qualité chimique de l'eau. Il faut reconnaître que jusque là l'Hydrogéologie était faite par des Géologues.

PHASE RECENTE ET ACTUELLE :

Le développement de l'Hydrogéologie en tant que science nouvelle a permis la formation d'hydrogéologues qui ont introduit des méthodes nouvelles de prospection des eaux souterraines.

Les nombreuses demandes de sondages ont provoqué la formation d'un Service des Sondages au sein du Ministère de l'Agriculture service utilisant une vingtaine de machines (moyenne profondeur) et réalisant une centaine de sondages par an soit un linéaire de l'ordre de 30.000 mètres.

Mais les sondages coûtent cher.

Ceci a favorisé le développement de la Géophysique et en particulier des méthodes électriques. Celles-ci mettaient en effet à notre disposition des renseignements qui rentabilisent sérieusement les travaux de sondages lesquels vérifient désormais des hypothèses, d'où moins de forages pour des résultats plus complets.

Nous avons ainsi mis sur pied une Section de Géophysique au sein de notre Service d'Hydrogéologie utilisant 2 équipes de terrain et réalisant une douzaine de prospections par an. Elle intervient au deuxième stade de la prospection après l'inventaire et propose un programme de reconnaissance par sondages, celui-ci devient ainsi le troisième stade de la prospection des eaux souterraines.

Quant au quatrième stade, il est constitué par les essais de pompage.

Nous effectuons en Tunisie beaucoup d'essais de pompage sur les puits notamment lors de l'étude des nappes phréatiques ; ces essais sont commodes et réalisables tantôt avec les équipements de pompage existants, tantôt à l'aide de petits groupes moto-pompes du Service d'Hydrogéologie ; dans ce domaine les pompes submersibles présentent beaucoup d'avantage pour l'installation et pour leurs possibilités. Il arrive souvent que l'on puisse utiliser des puits proches comme piézomètres ce qui améliore sérieusement la connaissance des paramètres hydrodynamiques de l'aquifère. Les méthodes d'interprétation sont variées et couvrent un large éventail de possibilités.

Les essais de pompage sur les forages sont aussi importants et ont amené la création, au sein du Service d'Hydrogéologie, d'une Section de Pompage disposant d'une game variée de pompes avec leur matériel de fonctionnement et d'installation. L'utilisation de piézomètres pour la mesure et l'interprétation des pompages est relativement difficile du fait du coût de ces ouvrages notamment quant il s'agit de profondeurs au delà de 200 mètres ; pendant longtemps nous nous sommes contentés d'interpréter les resultats des forages d'essai uniquement, lesquels sont actuellement insuffisants. Cette pratique commence toutefois à se normaliser et finira par s'imposer totalement.

A signaler que les essais sont de deux genres : les premiers sont des essais de réception à trois paliers de 6 H et de 12 H respectivement 6 H, 6 H et 12 H soit 24 H au total pour la réception technique du forage. Ils sont immédiatement suivis après l'observation de la remontée d'un essai dit de longue durée soit 72 H à 120 H au débit moyen obtenu lors des essais de réception.

L'interprétation des mesures est relativement aisée du fait de la multiplicité des méthodes et de l'expérience acquise.

3°- Evaluation des Ressources en Eaux Souterraines et Programmes d'Exploitation :

Les informations rassemblées par l'utilisation des methodes ci-dessus décrites sont utilisées pour l'évaluation des ressources en eaux souterraines et la mise sur pied de programmes d'exploitation.

Nous calculons généralement en Tunisie les ressources dynamiques annuelles des nappes ainsi que leurs réserves géologiques.

Les ressources dynamiques proviennent de l'alimentation interannuelle des nappes par les précipitations et correspondent à la partie de la nappe comprise entre les fluctuations des basses eaux et des hautes eaux du niveau piézométrique. Elles sont dépensées généralement en exploitation et en pertes aux exutoires soit sous forme de sources ou de débit pérenne d'un Oued, soit sous forme d'évaporation dans les zones où le niveau piézométrique est subaffleurant. Cette notion est surtout sensible pour la partie septentrionale de la Tunisie où la pluviométrie est supérieure à 300 mm/ an; elle joue un grand rôle pour la détermination de l'exploitation.

Les réserves géologiques correspondant aux volumes d'eau emmagasinés sous le niveau piézométrique des basses eaux et proviennent d'une alimentation pluri-annuelle. C'est souvent le principal facteur qui est pris en considération lors de l'étude des grandes nappes du Sud Tunisien.

PROGRAMMES D'EXPLOITATION

C'est le but de la prospection des eaux souterraines. Ils découlent des résultats obtenus plus haut.

Généralement, nous programmons comme ressources exploitables la totalité des ressources dynamiques notamment dans le cas ou une partie de celles-ci est perdue aux éxutoires ou par évaporation ; ce programme tient compte bien entendu de l'exploitation existante qu'il vient renforcer.

De plus en plus, nous sommes amenés à inclure dans nos programmes d'exploitation une partie des réserves géologiques pour faire face à des demandes plus importantes et notamment dans le cas des secteurs vitaux de la mise en valeur agricole ; c'est ainsi le cas de la région de Grombalia, productrice de la plus grande partie des agrumes en Tunisie et où l'exploitation actuelle dépasse nettement les ressources ; pour sauvegarder les agrumes nous sommes amenés à puiser sur les réserves.

Généralement, cette opération est programmée sur une durée limitée, au bout de laquelle de nouvelles ressources devront être trouvées à moins que les objectifs visés n'aient été atteints.

METHODES UTILISEES

Pour l'évaluation des ressources disponibles et la programmation de leur exploitation nous faisons appel généralement aux méthodes classiques de l'hydrogéologie utilisant des calculs relativement simples qui permettent jusqu'à une prévision limitée de l'évolution des nappes suite à leur mise en exploitation.

Des méthodes nouvelles viennent ici jouer un grand rôle et sont de plus en plus utilisées; il s'agit de la simulation par modèles analogiques ou mathématiques.

En effet, ces outils nouveaux permettent de reconstituer, en modèle réduit, l'acquifère considéré et d'y simuler un certain nombre d'interventions sur la base des éléments hydrogéologiques à savoir cartes piézométriques, transmissivités, conditions aux limites. Les avantages que l'on peut en tirer sont multiples :

- Vérification des conclusions hydrogéologiques de l'étude classique, étant donné que les modèles fonctionnent sur la base de principes physiques.
- Simulation des exploitations projetées et détermination du comportement et de l'évolution de la nappe, d'où la possibilité d'un meilleur choix notamment quand on fait intervenir les réserves.
- Possibilité d'examiner le comportement global d'une très grande nappe, comme celle du Continental Intercalaire du Sud Tunisien, que les moyens classiques de l'Hydrogéologie ne permettaient de considérer jusqu'ici que par zones séparées.

La Tunisie a réalisé, avec le concours étranger, quelques modèles; l'interêt des résultats obtenus et la somme des travaux à effectuer nous amènent aujourd'hui à la mise sur pied au sein de notre Division des Ressources en Eau, d'un laboratoire de modèles analogiques ; du personnel tunisien est actuellement en formation dans ce sens.

4 - SURVEILLANCE DES NAPPES - RECHARGE NATURELLE ET ARTIFICIELLE

Une fois qu'un programme d'exploitation est proposé et mis en application, il est indispensable de suivre ses effets par la mise sur pied d'un réseau de surveillance

Cette notion était encrée dans les esprits en Tunisie, dès le début des travaux sur les eaux souterraines ; elle nous a permis aujourd'hui de nous rendre compte à temps de certaines catastrophes (contamination par la mer des nappes côtières intensément exploitées, épuisement des nappes soumises aux mêmes conditions d'exploitation) et de prendre à temps les mesures nécessaires.

RESEAU TUNISIEN DE SURVEILLANCE DES NAPPES.

Nous avons mis sur pied en Tunisie, un réseau qui couvre la plus grande partie des nappes du pays.

Dans sa situation actuelle, ce réseau est essentiellement constitué par des puits de surface et intéresse de ce fait les nappes phréatiques ; quelques nappes profondes seulement sont suivies à la faveur des forages d'exploitation ou de quelques forages non utilisés ou abandonnés - La notion de piézomètres de surveillance commence toutefois à se matérialiser et un vaste programme est envisagé pour créer un réseau national de piézomètres ; sa réalisation, qui a été entamée, dépend des crédits disponibles ; elle prévoit également l'équipement des piézomètres, de limnigraphes (dotés d'autonomie mensuelle) pour enregistrer les fluctuations du niveau piézométrique.

RECHARGE NATURELLE ET ARTIFICIELLE DES NAPPES

Le réseau de surveillance des nappes sera à la base de l'observation de la recharge naturelle et artificielle des nappes.

La recharge artificielle intervient quand on maîtrise suffisamment l'hydrogéologie et quand les conditions suivantes sont réalisées :

- Disponibilité d'eau pour la recharge (généralement à partir des cours d'eau superficiels).
- Bonnes dispositions des aquifères pour la recharge (niveaux piézométriques suffisamment rabattus donc nappes surexploitées).

Disons toutefois qu'il s'agit d'une méthode nouvelle qui suppose une certaine expérimentation pour s'adapter aux conditions locales et dont le prix de revient pourrait être un facteur limitatif.

Une experimentation dans ce sens est actuellement en cours en Tunisie avec l'aide des Nations Unies ; nous avons choisi quatre cas différents d'aquifères représentatifs de l'Hydrogéologie du pays et nous essayons de trouver ou d'adapter dans chaque cas la méthode appropriée de recharge.

En cas de réussite, la recharge artificielle permettrait d'envisager le "management des eaux" du pays c'est-à-dire l'utilisation combinée des eaux de surface et des eaux souterraines dans le cadre de plans directeurs régionaux.

CONCLUSION

Les eaux souterraines jouent un rôle prépondérant en Tunisie, d'autant plus qu'une bonne partie du pays est pratiquement dépourvue de cours d'eau de surface.

L'inventaire et la prospection permettent l'évaluation des ressources disponibles et la programmation de leur exploitation. A partir de là commence la conservation ou la recharge des nappes, phase pour laquelle un réseau de surveillance est primordial.

Les méthodes mises aujourd'hui à notre disposition évoluent rapidement ; l'expérience tunisienne a pu juger de l'intérêt de la Géophysique dans la prospection générale des eaux souterraines et des Modèles Analogiques pour l'évaluation des ressources disponibles et la simulation de leur évolution compte tenu de l'exploitation existante ou prévue.

Nous en arrivons à envisager l'utilisation intégrée des eaux de surface et souterraines dans le cadre de Plans Directeurs Régionaux.

FORMATION EN HYDROLOGIE

par le Comité National Tunisien de la D.H.I.

SOMMAIRE

La mise en valeur hydro-agricole, prédominante en Tunisie, passe nécessairement par la formation des professionnels et des techniciens en hydrologie d'où l'importance que nous accordons à ce domaine.

L'Hydrologie tunisienne fait intervenir également les eaux de surface et les eaux souterraines, c'est pourquoi nous sommes intéressés à la fois par la formation de professionnels et de techniciens dans les deux domaines.

Si l'enseignement secondaire technique a permis la mise sur pied d'une formation de techniciens, il n'en est pas de même pour les hydrologues et les hydrogéologues ; en effet la jeune Université Tunisienne n'a pas encore atteint ce stade. Nous avons alors recours à l'étranger et plus particulièrement à la France pour des questions de langue.

Alors que la formation d'hydrogéologues s'avère relativement aisée, il n'existe pratiquement pas d'Institution donnant un enseignement spécifique d'hydrologie (l'ORSTOM excepté, mais dans des proportions très restreintes) ; c'est pourquoi nous préconisons la création d'un Institut Régional dans ce sens.

1 - Formation de techniciens en hydrologie

Nous donnons ci-après un aperçu sur l'expérience tunisienne dans ce domaine qui a permis, en l'espace de cinq ans, de fournir tous les cadres techniciens nécessaires à la bonne marche de notre Division des Ressources en Eau soit : - 40 Agents Techniques (Observateurs)

- 30 Adjoints Techniques (Techniciens).

1.1 - Qualification des besoins

La Division des Ressources en Eau de Tunisie est structurée en un Service d'Hydrologie (Eaux de surface) et un Service d'Hydrogéologie (Eaux Souterraines) disposant chacun d'un siège Central à Tunis et de Sections Régionales réparties à travers le pays. Elle est chargée d'effectuer l'Inventaire des Ressources en Eau en assurant notamment le fonctionnement de deux réseaux de mesure dans les eaux de surface et les eaux souterraines.

Nous avions ainsi besoin :

- d'Observateurs (Agents Techniques en Tunisie) pour effectuer les lectures et l'entretien des instruments ou les mesures simples sur le terrain.
- de Techniciens (Adjoints Techniques en Tunisie) pour assurer l'encadrement des observateurs et la direction des Sections Régionales ainsi qu'une première interprétation des mesures effectuées sur la base des méthodes établies ou des instructions reçues. Les Techniciens aident également les Hydrologues et les Hydrogéologues dans la préparation des études.

1.2 - Cours de formation - Conditions d'admission

Nous avons bien entendu commencé à travailler avec un personnel formé sur le tas et dont le niveau d'instruction allait de la 3° Année Secondaire à l'équivalent du Baccalauréat.

Les possibilités de carrière et de salaire limitées et l'impossibilité d'inclure ce personnel dans le cadre de la Fonction Publique d'une part, l'insuffisance de formation technique et les lacunes de formation générale par ailleurs nous ont amené à rechercher une solution transitant par les Lycées Techniques.

En effet le Lycée Technique de Tunis assure une formation maximale de 6 ans et minimale de 5 ans sanctionnées respectivement par un diplôme de Technicien (Adjoint Technique) et un diplôme d'Agent Technique (Observateur), ces deux diplômes étant reconnus par la Fonction Publique de Tunis et assurant ainsi une carrière dans l'Administration.

Nous avons mis au point, pour chaque catégorie, un cours spécial en théorie et exercices pratiques concernant les années terminales ou de spécialisations où on ménageait, à coté des matières de base (mathématiques, langue etc...) un horaire important pour l'hydrologie (voir annexes 1 et 2) et les sciences qui lui servent de base ou de complément.

Au début, devant l'importance des besoins nous avons été dans l'obligation d'assurer une formation globale couvrant à la fois les besoins en hydrologues et en techniciens de l'hydraulique en général, puis nous avons évolué vers une spécialisation au point d'avoir une classe pour l'hydrologie de surface et une classe pour l'hydrogéologie.

Les élèves qui nous étaient proposés, avaient suivi normalement le cycle régulier d'enseignement du Lycée Technique et optaient eux-mêmes pour notre spécialité à la fin de leur avant-dernière année, ceci avait donc pour effet de disposer d'éléments ayant déjà une bonne formation générale.

Les cours étaient assurés par les hydrologues, hydrogéologues et Ingénieurs des services tunisiens pour les matières de l'hydraulique et de l'hydrologie et par les professeurs du Lycée Technique pour les matières de base.

Les examens comportaient à la fois les matières de base et les matières hydrologiques, ces dernières étant affectées d'un coefficient élevé (voir annexes 1 et 2) et se décomposant en épreuves écrites, travaux pratiques et épreuves orales.

1.3 - Débouchés

Les diplômés Agents Techniques et Adjoints Techniques sont intégrés dans les cadres de la Fonction Publique qui a prévu des statuts particuliers à leur effet.

Ils passent une période initiale de 2 ans en qualité de stagiaires au cours de laquelle ils sont initiés à leur métier puis ils sont titularisés et évoluent normalement dans leurs cadres.

1.4 - Recyclage

Les services intérieurs de la Division des Ressources en Eau prévoient des recyclages réguliers pour leurs techniciens.

Par ailleurs les cours régionaux de l'UNESCO sont d'un excellent profit et demanderaient à être multipliés. La Tunisie a déjà manifesté son intérêt dans ce sens par sa participation massive (26 Techniciens Tunisiens) au cours organisés en Tunisie en 1967.

2 - Formation des hydrologues professionnels

2.1 - Formation des hydrogéologues

Les hydrogéologues tunisiens sont en majeure partie des géologues universitaires titulaires de l'ancienne Licence des Sciences de la Terre (aujourd'hui maîtrise de Géologie) et qui vont suivre en France une année de 3° cycle en hydrogéologie (D.E.A) sanctionnée par un certificat ; les étudiants rentrent en Tunisie pour préparer une thèse, généralement l'étude hydrogéologique d'une région donnée qui demande deux à trois années et qui une fois présentée devant un Jury d'Examen leur donne le Titre de Docteur 3° cycle.

Ce diplôme obtenu au terme de trois années d'études et de travail après la Licence (ou la Maîtrise) a été reconnu en Tunisie comme donnant le titre de Géologue Principal, cadre équivalent à celui des Ingénieurs Principaux.

Ainsi a été résolu le problème de la formation des hydrogéologues ; on compte aujourd'hui 7 hydrogéologues Tunisiens qualifiés; trois sont en formation et de nouvelles candidatures sont envisagées pour 1972.

2.2 - Formation des hydrologues

Notre pays souffre de manque d'hydrologues pour deux motifs dont essentiellement celui évoqué plus haut et concernant l'absence d'Institut de Formation.

Les cours post-universitaires organisés ou subventionnés par l'UNESCO dans ce sens nous semblent insuffisants, car ils sont souvent orientés vers un objectif trop précis pour donner une formation générale en hydrologie et il ne sont pas suivis de stages, sur le terrain, suffisants.

Aussi estimons nous qu'il serait d'un grand intérêt de mettre sur pied, dans le cadre de la D.H.I et avec l'aide de l'UNESCO, un Institut Régional de formation en matière d'Hydrologie pour les Pays Francophones.

En même temps que la formation des hydrologues africains, cet Institut favoriserait une prise de conscience des gouvernements de l'importance de l'hydrologie et pourrait amener une amélioration sensible des possibilités de salaire et de carrière.

2.2.1 - Attributions de l'Institut

Cet Institut pourrait assurer la formation de deux catégories d'hydrologues :
- Hydrologues professionels
- Techniciens hydrologues.

Il serait également chargé d'un recyclage périodique des deux niveaux.

2.2.2 - Conditions d'Admission

Il importe d'insister ici sur les conditions d'admission si l'on veut donner à la formation un niveau suffisamment valable et tenir compte des disponibilités en diplômes du pays.

2.2.2.1 - Hydrologues

Il y a généralement une double origine, soit les Universités, soit les Ecoles d'Ingénieurs.

Pour les universitaires, il sera nécessaire qu'ils soient titulaires d'une Maîtrise (ou du diplôme équivalent) dans les spécialités de la Géologie, de la Physique ou des Mathématiques.

Les diplômes des Ecoles d'Ingénieurs doivent être équivalents, au minimum, à la Maîtrise et concerner particulièrement l'hydraulique et le Génie Civil.

2.2.2.2.- Techniciens Supérieurs :

Ils doivent servir d'intermédiaires entre les Techniciens et les Hydrologues en déchargeant ces derniers d'un certains nombre de tâches concernant notamment l'exécution des travaux.

Cette catégorie de personnel est généralement peu représentée mais devrait permettre de mieux suivre et rendre plus efficaces les travaux effectués ainsi que le dépouillement des données recueillies.

Nous pensons qu'il serait utile de prévoir l'accession du personnel Technicien hautement qualifié à coté des diplômés.

Pour ces derniers, il serait nécessaire qu'ils soient titulaires d'un D.U.E.S en Géologie Physique, Mécanique des Fluides (1er cycle Universitaire) ou de deux C.E.S relatifs à la Physique et aux Sciences de la Terre ; pour les Ecoles, les diplômés d'Ecoles d'Ingénieurs Génie Civil ne donnant pas l'équivalence de la Maîtrise pourraient être admis.

Pour les techniciens qualifiés on pourrait exiger 5 années d'expérience professionnelle dans le domaine de l'Hydrométrie.

Quoiqu'il en soit, il est nécessaire de prévoir un examen d'entrée qui pourrait être diversifié suivant les différentes origines de candidats.

2.2.3 - Formation :

2.2.3.1 - Hydrologues :

Nous prévoyons une formation théorique et une formation pratique. La formation théorique serait :

- une année universitaire pour les diplômés des Ecoles d'Ingénieurs (trois années de scolarité).
- deux années universitaires pour les titulaires de Maîtrise ou les diplômés des Ecoles dispensant 2 années d'enseignement (dans ce cas la première année sera réservée à la préparation des candidats en matière d'Hydrologie Générale).

La formation pratique consisterait en un stage obligatoire d'une année dans un service hydrologique étranger bien structuré et serait sanctionnée par un rapport de stage.

Il est utile que ce stage se passe dans un pays étranger au candidat pour maintenir psychologiquement et pratiquement celui-ci dans un cadre de formation et éviter l'aspect"installation"qui revêt très souvent le retour du diplômé à son pays.

Il est également nécessaire d'inclure ici le recyclage périodique des diplômés pour maintenir et améliorer leurs connaissances et leur expérience; nous prévoyons pour cela deux mois tous les trois ans.

2.2.3.2 - Techniciens Supérieurs :

La formation théorique comporterait une année universitaire avec des travaux pratiques de laboratoire. Il sera également nécessaire de prévoir une formation pratique de 5 mois effectifs sur le terrain à l'étranger sanctionné par un rapport de stage.

Il faudrait prévoir un stage de recyclage de 2 mois tous les trois ans.

2.2.4 - Diplômes et Débouchés :

Les Etats ayant présenté des candidats devront s'engager à les accueillir dans leur administration à la sortie de l'Institut.

Les diplômes seront délivrés à la fin du cycle d'études théoriques, les rapports de stage seront en même temps que la condition nécessaire pour tout recrutement, à verser pour un avancement dans le grade.

2.2.4.1 - Hydrologues :

D'après notre expérience tunisienne nous pouvons suggérer que le diplôme de l'Institut donne accès au cadre des Ingénieurs Principaux ou à un cadre équivalent de la façon suivante.

Les anciens élèves des grandes Ecoles bénéficieront des avantages de leurs titres, le diplôme obtenu donnerait l'équivalence de la titularisation et le stage pratique permettrait un avancement spécial.

Les Universitaires pourraient être nommés Ingénieurs-Principaux après l'obtention de leur diplôme et titularisés après le stage pratique.

2.2.4.2 - Techniciens Supérieurs :

Le diplôme de l'Institut donnerait le grade d'Ingénieur des Travaux.

Les candidats déjà diplômés d'Ecoles accèderaient à une titularisation immédiate.

Le stage pratique permettrait de leur donner un avancement ; pour les autres catégories, ce sera la titularisation.

CONCLUSION :

Des efforts considérables ont été effectués en Tunisie dans le domaine de la formation des cadres moyens et supérieurs en Hydrologie.

Quand les structures de l'enseignement du pays le permettent, ou quand on trouve aisément à l'étranger l'enseignement nécessaire, la formation peut se réaliser assez aisément, malgré les difficultés que l'on rencontre souvent pour l'intégration et la promotion des diplômés.

En Hydrologie de surface, par contre, une grave lacune subsiste, notamment pour ce qui concerne les professionnels. C'est là un obstacle majeur que nous proposons de franchir par la création d'un Institut Régional de formation en matière d'Hydrologie pour les pays Francophones ; cette initiative pourrait peut-être intéresser également les pays Anglophones.

L'aide de l'UNESCO est hautement souhaitable, et l'Institut devrait, à notre avis, être mis sur pied par cet organisme avec l'aide et la collaboration des pays intéressés.-

ANNEXE 1

FORMATION DES AGENTS TECHNIQUES (OBSERVATEURS) EN HYDROLOGIE

PROGRAMME DES COURS ET DES EXAMENS

Les élèves suivent 5 années d'enseignement dont la dernière, qui nous intéresse ici, est sanctionnée par un examen permettant l'obtention du diplôme d'Agent Technique. Nous donnons ci-après les programmes des Cours et des Examens concernant la formation des Agents Techniques en Hydrologie de surface ; les mêmes programmes légèrement remaniés nous ont permis de sortir des Agents Techniques en Hydrogéologie.

1 - Programme des Cours - (en heures par semaine)

+ Arabe	: 2	+ Hydraulique Appliquée	: 3
+ Français	: 2	+ Aménagements hydrauliques	: 2
+ Droit	: 2	+ Climatologie	: 4
+ Métré	: 4	+ Hydrométrie	: 4
+ Topographie	: 5	+ Hydrogéologie	: 2
+ Education Physique	: 1	+ Législation	: 1
		TOTAL :	32 H.

2 - Examens

Ecrit		T.P.		Oral	
+ Arabe	: 3H Coef. 2	Métré	: 3H Coef. 1	Législation	: Coef.1
+ Français	: 3H Coef. 2	Climatologie	: 4H Coef. 2	Pratique	
+ Droit	: 2H Coef. 1	Hydrométrie	: 4H Coef. 2	Service,	: Coef.1
+ Climatologie	: 3H Coef. 2	Topographie	: 4H Coef. 3	Climato.	: Coef.1
+ Hydrométrie	: 3H Coef. 3	Educat. phys.:	1	Hydrométrie	: Coef.1
+ Hydrogéologie	: 2H Coef. 1				
+ Aménagement Hydraulique	: 2H Coef. 1				

ANNEXE 2

FORMATION DES ADJOINTS TECHNIQUES (Techniciens) EN HYDROGEOLOGIE

PROGRAMME DES COURS ET DES EXAMENS

Les élèves suivent six années d'enseignement, dont la dernière que nous présentons ci-après est sanctionnée par un examen permettant l'obtention du diplôme de Technicien. Nous donnons ci-dessous les programmes des cours et des examens concernant la formation en Hydrogéologie ; les mêmes programmes légèrement modifiés ont permis la formation de Techniciens en Hydrologie de surface.

1 - Programme des Cours - (en heures par semaine)

+ Philosophie	: 2	- Hydrogéologie	: 4
+ Mathématiques	: 5	- Technique de sondage	: 1
+ Hydraulique Générale et Génie Civil	: 2	- Hydrologie Générale	: 1
+ Métré	: 2	- Agronomie	: 1
+ Géologie	: 2	- Organisation de chantier	: 1
+ Topographie	: 3	- Législation	: 1
+ Dessin Technique Cartographie	: 3	- Education Physique	: 1
		TOTAL :	29 H.

2 - Examens

Ecrit

+ Philosophie	: 3H Coef. 2
+ Mathématiques	: 3H Coef. 2
+ Hydraulique Générale et Génie Civil	: 3H Coef. 2
+ Hydrogéologie	: 4H Coef. 4

Travaux Pratiques

+ Métré	: 3H Coef. 1
+ Levé Topo.	: 3H Coef. 1
+ Dessin Technique Cartographie	: 3H Coef. 1
+ Hydrogéologie	: 3H Coef. 2

Oral

+ Hydrogéologie	: Coef. 2
+ Hydrologie Générale	: Coef. 1
+ Géologie	: Coef. 1
+ Hydraulique Générale Agronomie	: Coef. 1
+ Législation et règlementation	: Coef. 1
+ Organisation de chantier	: Coef. 1

GROUNDWATER IN THE SOMALI DEMOCRATIC REPUBLIC

by A. Popov, A. L. Kidwai and Said A. Karani

The Somali Democratic Republic occupies a sizable area in north-eastern Africa, known as the "Horn of Africa". It lies along the Gulf of Aden in the north and the Indian Ocean in the east. In the south it is bounded by Kenya and in the west by Ethiopia. The country is elongated in shape with an area of about 640,000 sq. km. It possesses 3,200 km of coastline, the longest in the African continent.

Hypsometrically the country is a part of the eastern slope of the Ethiopian mountainous area which descends towards the Indian Ocean. Based on the character of the surface, the degree of its dissection and the prevailing altitudes it is possible to establish three main morphological units - i.e. (a) plains: these occur as a narrow strip in the north but increase in width in the south-west along the Indian Ocean; (b) inland plateau: it occupies the major part of the country with a gradual increase of elevation from east towards west from south towards north; (c) mountainous zone in the north with an asymmetrical structure. The mountains slope gently in the south and steeply in the north.

Hydrography mainly consists of two permanent rivers - the Giuba and the Scebelli - which rise from the Ethiopian highland and drain into the Indian Ocean after traversing the southern part of the country. The remaining part of the country is devoid of any important permanent surface-water supplies. There are a few seasonal, short-lived streams which contain water for only a few days just after the rains. Surface reservoirs are few and are far scattered; they contain rainwater for a few days to three to four months. In the north-east of the country there is a small stream in the upper reaches of the Nogal Valley which is fed by groundwater.

Air masses of equatorial monsoon leave all their moisture on the western slope of Ethiopia and descend over the Somalian plateau as dry, hot winds. North-eastern trade winds from Asia also carry hot, dry air. Humid winds blowing from the Indian Ocean are usually parallel to the shore line and do not contribute to the moistening of the inland areas. Average annual rainfall for most of the country is 200-300 mm, but along the Gulf of Aden coast in the north, the annual precipitation is less than 100 mm. However, in the south-western part of the country, annual rainfall exceeds 500 mm. No data are available regarding evaporation, but there is no doubt that it is much more than the annual rainfall taking into account high temperature and dry winds of high velocity.

The following geological rock formations are met with in Somalia.

(a) Pre-Cambrian; (b) Jurassic; (c) cretaceous; (d) tertiary and (e) quaternary. A brief description of each of the formations met within the country is given below.

Pre-Cambrian rocks outcrop in the north as well as in the south (Bur area) of the country. They are represented by massive igneous and metamorphic rocks. Jurassic and cretaceous rocks occupy relatively small areas in the north but are well developed in the area lying between the Scebelli and Giuba rivers. They are composed of limestone, sandstone and marls with thick layers of gypsum and anhydrite with subordinate inter-layers of clays. Tertiary sediments cover the rest of the territory and mainly consist of shallow water and lagoonal facies (coral and detrital limestone, sandstone, marl and bands of sandy clays, gypsum and anhydrate). Quaternary sediments are represented by fragmental formations of temporary streams, eolian sands which form large dunes on the coast of the Indian Ocean and alluvial sandy clays sediment which are well developed in the south-western part of the country.

Groundwater in Somalia acquires top priority because the major part of the country depends on it solely. The study of groundwater has been neglected in the past. Some data concerning groundwater of the northern province of the country can be found in the reports of Macfadyen (1951) and Hunt (1944-50). Data concerning groundwater of some portions of the western provinces are given in the reports of Carfitzen and Kinzy (1950); Usoni and Parisini (1951). These data are related to agricultural projects in Somalia. A report by T. P. Ahrens (1951) titled "A Reconnaissance Groundwater Survey of Somalia, East Africa", divides the territory of Somalia into 12 main groundwater provinces based on stratigraphical units. G. Wilson (1958), who carried out a hydrogeological survey in Somalia for about two years, pointed out potential sources of groundwater and recommended their future development. He also suggested that a codified water-resources law should be worked out. A detailed description of the water resources of the Scebelli is given in the report of Faillace (1964), and the final report of FAO, which deals with groundwater between Scebelli and Giuba. A brief outline of climatic conditions and groundwaters of Somalia was given by Robert E. Dijon (1967). He has drawn up a clear programme for the study of development and utilization of groundwater resources. His recommendations served as a basis for the hydrogeological investigations stipulated in the Plan of Operation of the Mineral and Groundwater Survey Project (Phase II). During 1970-71, the project carried out hydrogeological investigations of the whole country; visited 2,000 water points and collected 800 water samples for chemical analysis. The work resulted in the compilation of the first hydrogeological map in the history of the country, on a scale 1:2,000,000. A more detailed hydrogeological map on a scale 1:1,000,000 is being compiled.

On the basis of the investigations carried out the country has been divided into 13 hydrogeological units. A brief description of each of the hydrogeological units is given below.

1. Coastal zone of the Gulf of Aden is characterized by the development of a narrow strip of coarse-grained deluvial-preluvial fans and sediments of young marine terrances. The deluvial-preluvial sediments are water-bearing at the mouth of some of the valleys. Water usually occurs between 10-15 m, its mineralization being 1.5-2.5 g/1. Marine sediments contain water at 3-8 m depth with mineralization ranging between 3.5 g/1.

2. Sloping plains occur in the north-west of the country and are composed of deluvial-preluvial sediments which are water-bearing at depths of 30-50 m. Mineralization of water ranges from 1-5 - 2.5 g/1. At places it is more mineralized. Elevated hills composed of basalt rocks are practically waterless.

3. Mountainous zone stretches as a wide strip parallel to the Gulf of Aden coast all along the northern portion of the country. Here occur rocks of different age and composition from pre-Cambrian to recent. Recent loose sediments fill in numerous valleys and are water-bearing in the middle part of the valleys. Water occurs here at depths 1-3 m and its mineralization is 0.8 to 2.5 g/1. Massif host rocks are poor aquifers, but often yield groundwater in sufficient quantity for practical interest in the areas of major tectonic faults. This water is fresh with mineralization ranging from 1-2 g/1.

4. Darror depression represents a graban composed of Miocene and Oligocene sediments. The sediments are water-bearing from depths of 15-40 m and with mineralization ranging between 3-5 g/1.

5. Nogal depression and Taleh plateau occupy a considerable area and are filled with Taleh formation (lower and middle Eocene) which is represented by dolomites, siltsontes and clays with thick bands of gypsum and anhydrite. Groundwater is mainly of the karst type. Its mineralization is 3.5-5.5 g/1 and higher.

6. High plateau - The north and west of the country is characterized by the development of preluvial sediments of Auradu formations (lower Eocene-Pliocene and cretaceous rocks). Water occurs at depths of from 50-60 to 100-150 m. Mineralization ranges between 1.5-2.5 g/1.

7. The Mudugh plateau is situated at the centre of the country and is composed of continental and near-shore sediments of the Miocene age. The formation has numerous lenses of groundwater which occur at depths of 1-3 m and 25-30 m with mineralization of 2.5-4.5 g/1. Deeper horizons (50-60 m) contain water with TDS 2-3.5 g/1.

8. The Indian Ocean coastal zone - this zone is characterized by shallow (1-3 m) waters which occur in eolian and coastal marine sediments. The mineralization bearing 0.8-2.5 g/1. There are numerous small water springs in the north-east of the country between the Cape Quarderfui and the city of Eil. They drive water from Oligocene sediments.

9. Benadir area occupies the eastern part in the southern portion of the country and is characterized by Miocene sediments (clays, sands, sandstones and limestones); they are water-bearing from fresh to saline with TDS concentration ranging from 2.5-4.5 g/1.

10. Hiran and Upper Giuba is characterized by the development of Jurassic and cretaceous sediments which are composed of marl, clays, limestone with interlayers and bands of gypsum. There are numerous lenses of groundwater at depths of 1-3 m and 15-18 m. The mineralization of groundwater is variable, TDS values range from 1-2 and 4-5 g/1. The water-bearing properties of deeper water-bearing horizons have not been studied as yet.

11. Lower Giuba is situated in the south of the country. This area is characterized by the development of recent alluvial sediments of sandy clay composition. They are underlain by coastal marine sediments of Pliocene-Miocene age. The water is saline to a depth of 50-80 m with TDS concentration as high as 30-35 g/1. At places water is encountered at depths of 120-140 m with mineralization ranging from 2.5-5 g/1.

12. Bur region is situated in the interfluvial area of the Giuba and Scebelli rivers and is composed of crystalline pre-Cambrian rocks. Highly mineralized water (TDS up to 30-60 g/1) occurs in the zone of weathering, along fissures and tectonic faults. Groundwater lenses (TDS 0.8-4.5 g/1) are contained in the loose, recent sediments of temporary streams present in the area.

13. Valley of the Giuba and Scebelli is composed of recent sandy alluvium which contain groundwater and this water is connected with river water. Alluvial sediments contain water at depths varying from 3-8 m and the mineralization in the majority of cases ranges between 1.5-4.5 g/1.

14. Hot springs - There are some hot springs in the north of the country. Most of them are of low temperature ($40^{\circ} - 64^{\circ}C$) and low mineralization (1,000 to 4,000 ppm). The discharge of the springs ranges from 0.15 to 8.5 l/sec.