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COLONIAL OFFICE

Report on The Water Resources of the Bechuanaland Protectorate Northern Rhodesia · The Nyasaland Protectorate · Tanganyika Territory · Kenya and the Uganda Protectorate

By

FRANK DEBENHAM, O.B.E., M.A.

Professor of Geography at Cambridge University

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FOREWORD

FOLLOWING a suggestion made by the Colonial Office in July 1945, Professor Frank Debenham paid a six-months visit to Northern Rhodesia, Nyasaland and the Bechuanaland Protectorate, to survey the water resources of those territories, and in the accompanying report he reviews the existing position as he saw it and furnishes his recommendations on problems which appeared to him to be of particular importance. On his journey back to the United Kingdom he was able to pay short visits to Tanganyika and Kenya, and his report contains short chapters referring to the position in those territories and in the Uganda Protectorate.

The report throws much light on a subject which is likely to be of great importance in the future to the Governments of the territories concerned, and about which relatively little has hitherto been written. The report has still to be considered by the Colonial Governments, and must therefore be regarded as merely expressing the personal views of an acknowledged authority on this particular subject.

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SUMMARY OF RECOMMENDATIONS

FOR THE sake of simplicity the recommendations in the body of the report may be classified under the heading of General and Particular. Of the latter some relate to specific problems, both major and minor, while others concern methods of treatment which may be common to any or all of the Territories.

GENERAL RECOMMENDATIONS

Over a great part of the African plateau the rainfall is adequate in amount but awkward in its seasonal incidence. The object of much of the development of water resources must therefore be to conserve or at least delay the run-off during the dry season. The means recommended for achieving this aim include the encouragement of indigenous forest, the placing of cheap check-weirs at the headwaters of streams, the gradual introduction of village-scale reservoirs and the treatment of damboes (marshes) so as to reduce the loss by evaporation.

The emphasis is on the small scheme of conservation rather than the large, on construction work carried out largely by local African labour rather than by contract, and on the inculcation of a sense of responsibility towards water supplies on the part of the African native authorities.

An ideal village project is outlined as a basis for such local schemes. These are, on the whole, long-term measures, and can come into being only slowly. The short-term plans for drilling and well-sinking in each territory are fully supported, but suggestions are made as to using a small and mobile type of drill for reconnaissance work in siting bores.

For sandy or alluvial country the use of a jet-drilling outfit in a mobile form is strongly recommended, as also is the idea of horizontal jet-drilling into water-bearing sands and alluvial banks. Suggestions for the treatment of "sand" rivers are made in the text and in an appendix. This form of conservation of the slender supplies of arid and mainly pastoral districts is considered to be of prime importance, deserving strong encouragement. For areas of higher rainfall the importance of the dambo as a natural reservoir is underlined and suggestions as to their treatment are collected in an appendix. Methods of improving the yield of springs by simple and local means are treated fairly fully. On these minor points the aim has been to describe those which can be undertaken by settlers without any engineering knowledge and by native groups with occasional supervision by a technical officer or by a district officer.

The need for more data as to water resources is very great and recommendations of two kinds are made with this in view. The actual observation of rainfall, river discharge, etc., can be carried out fairly easily by residents, either officials or settlers, and a pamphlet describing such observations was written for the Northern Rhodesian Government, which has printed it. This has been made available to the Governments of other territories.

For major projects it has been the rule that visiting engineers have had either to carry out elementary reconnaissance surveys themselves or to make wide assumptions before drawing up their recommendations. It is suggested that for such projects this waste of a professional expert's time can be avoided by encouraging small expeditions of junior engineering, geology or geography students to make the reconnaissance surveys of a hydrological type.

PARTICULAR PROBLEMS

Certain major problems concerning water were given special but brief priority.

Nyasaland. The cause of the "cyclical" rise and fall in level of Lake Nyasa receives full treatment. The problem of remedial measures has been undertaken by expert engineers and this report does not contain recommendations under that heading. Certain supplementary measures are outlined, however, which are not alternatives. Similarly the control of the Lower Shire River has been fully reported on by Mr. A. E. Griffin and such recommendations as appear in this report for that area are supplementary to his findings.

Northern Rhodesia. The periodic flooding of the Bangweulu Swamps was the subject of a ten-day tour, and theories as to its cause are outlined in general terms. A fuller reconnaissance survey is recommended and a programme for such a survey is fully set out.

Improvements to navigation on the Upper Zambesi were examined in a brief trip. The substance of a special report on this visit is included, but in general terms only, since a further and much more thorough investigation by professional engineers has now been communicated to the Colonial Office.

A project for the development of hydro-electric power in the Gorge of the Kafue River is described with a strong recommendation for an engineers' survey. The fully surveyed scheme for the Kariba Gorge was seen, and it is important that the alternative Kafue scheme, which is likely to give much cheaper power, should be examined before it is too late.

Kenya. The development of the watershed of the Uaso Nyiro River receives some notice. The recommendations made are supplementary to those of Dr. Dixey in his earlier report on the Northern Frontier District; they relate to the possibility of piping supplies for watering points.

In the Taveta district certain recommendations concerning the reclamation of irrigable land at Lake Jipe are made, also an outline scheme for the use of the large body of water in the crater lake of Mount Chala.

TRAINING FOR WATER CONSERVATION

Strong recommendations are made for establishing courses of training for Africans in the simpler constructions required for water development. The psychological value of a measure of self-help concerning water supplies is stressed throughout the report. An outline of the scope for these training courses is given in the section on the Bechuanaland Protectorate.

The value of demonstration schemes in the treatment of water is underlined, provided that arrangements are made for Africans from other but similar areas to see the demonstrations. The suggestion is exactly analagous for water to what is already done for agriculture.

INTRODUCTION

THIS REPORT contains a broad survey of the water resources of less than one-sixth of Africa. It examines in outline the general problems of development of those resources and occasionally plunges into detail on special methods of attacking those problems, or on individual projects.

It would be easy to regard that as the whole object of a pleasant eight months' visit to those somewhat remote corners of the Empire, but it would not satisfy. No one can regard the development of resources from the narrow viewpoint of immediate and local benefit alone, least of all should a geographer, since he is supposed to be able to view the world as a whole. Planning on any scale must have its proper place in the world setting or it will merely repeat the mistakes of the past, mistakes which by encouraging prejudice, or breeding isolationism or cut-throat competition have helped to make the first half of the Twentieth Century so gloomy and so ominous for the future.

It is obvious that those who called for this report had the broader picture in mind, and it will be as well if the readers also, some of whom will be called upon to guide this development, should share that picture and be fully aware of its background while they themselves are painting the detail into the foreground.

Leaving international problems of the political type out of the question for the moment, there are two basic facts in the world today which are vital. They are a rapidly increasing world population and a serious lag in the production of the basic needs of that population, food in particular. No amount of political bargaining will alter those fundamental facts and there is no ultimate remedy except a drive for increased production and its corollary, improved methods of distribution.

The trend towards this state of affairs has not passed unnoticed. One has merely to instance the writings of Sir John Boyd Orr and Sir Alexander Carr-Saunders, to quote only British observers, but the world as a whole has perhaps been taken unaware and is at the moment feeling rather frustrated and confused in consequence.

The immediate reaction is for the more fortunate parts of the world to make sure of their own food supply and control of immigrant population, but the ultimate effect will have to be world planning and development on a continental scale. Nor can this world production be based on world philanthropy, for there is as yet no such thing except in the minds of the few, and it will have to be planned in the main upon the general economics of supply and demand, on barter in the widest sense and in spite of bickering ideologies and occasional narrow nationalisms. We must take the world as we find it, because we are in a hurry, and do the best we can.

The first step is awareness of the position, and an understanding by the man in the street, who ultimately votes for or against this development, that the plea for United Nations action for peace, for food, for the " securities ' in general, is not just idle theory but a prime necessity if disaster is to be avoided. He must be told in blunt terms that the population of the world has increased by more than 25 per cent since this century began, that the present world food shortage is not just the result of the six years of war, and that the undernourishment which he himself is beginning to feel has been chronic in many countries outside Europe for centuries. He must further be told that it is the white races alone, and particularly the Anglo-Saxon peoples, who are not increasing in numbers and be reminded sharply that English-speaking peoples comprise both the United States of America, the richest nation in the world, and the British Commonwealth of Nations, which is spread throughout the world.

If he is to be frightened in this way by a vision, all too real, of the hordes of Asia increasing and food supplies falling behind that increase, the man in the street should also be comforted by the reflection that there are still undeveloped spaces in the world and that these are to a large extent controlled, either actually or economically, by the two nations which hitherto have shown by practice as well as precept the best appreciation of the situation, the British and the Americans, closely followed by the French.

It is the Northern Hemisphere of the world which is experiencing these pressures and shortages and where saturation point in many parts is rapidly approaching. In the Southern Hemisphere, Java alone is about to suffer in the same way, as a penalty for providing the most alarming instance in the world of rapid increase in population. Partly owing to her favoured climate and soil, but more still to a beneficent rule by a European nation, she has multiplied tenfold in little more than a century and doubled her population in the last fifty years. It is the Southern Hemisphere which contains most of the spare land and it must therefore assume the duty of assisting the Northern.

Broadly speaking, one might call Africa and South America the subsistence continents in the sense that over the greater part of their area they are providing a living for their own inhabitants and not much more. This is less true of the temperate zones of those continents than of the tropical and subtropical, where it is hard to refute the allegation that those are the " take-it-easy " parts of the world. It is there that, on the whole, the inhabitants find subsistence level easy to reach, especially since European administration or infiltration has mollified their worst ills, tribal wars, disease and backward practices. There, too, lies isolationism in its most pronounced form, independence of the rest of the world for the basic needs. It has indeed been the policy of most of the administrations of these areas to preserve the countries for their own population, to keep them free from immigration and economic struggle.

A time of world need has now arrived when that policy must be reviewed, when no people can be allowed to be self-sufficient and nothing more, when in the interests of the rest of the world they must be induced to join in the drive for production. It is a pity that it should be so, that a change of tempo if not of outlook should be impressed upon the established system of trusteeship, protection or temporary occupation which is characteristic of several of the great nations in their tropical dependencies.

This regret must apply in particular to the British rule in Africa which, in spite of wilful misunderstandings by other nations, has set an example in the treatment of backward peoples which is entirely new in world history. That example will endure but it must develop, for world pressure is imminent. The nation has already reversed Cecil Rhodes's concept of empire as being based upon " philanthropy plus 5 per cent return " into " philanthropy which will cost 5 per cent, with little prospect of any return ". The principle behind the Colonial Development and Welfare policy remains, but it must take on a new aim as well—namely, progress in production for a world in need.

To admit, as we must, the existence of this external pressure of world events upon our colonial empire does not involve any real change in policy, but it does mean a more rapid implementing of our policy. Such changes as will be necessary are more in the nature of stronger directives to the native peoples. Unfortunately the world cannot wait for them to choose slowly whether they will join in the production market beyond subsistence level, whether they elect to be citizens of the world as well as of Africa. Guidance need not be coercive in any unpleasant sense, but it will have to be more direct than in the recent past until the African himself appreciates the benefits of coming fully into the world system of trade. It is not only that he cannot afford to remain outside that system, but he will come into it with several initial advantages, such as cheap land, reasonable water supply and a good crop-growing climate, which are at a premium in other parts of the world, and these gifts can be offset against his general backwardness, his difficult communications and his rather low standard of health. Under proper guidance he will ultimately claim a very respectable place in the statistics of *per capita* production.

There should therefore be no need for change in our proclaimed purpose of developing Africa with the interests of the natives in a paramount place. Nor should there be need for much change in our attitude towards immigration. Mass immigration from the crowded sections of the world would be fatal and would not afford any real remedy for congestion.

The immigration of capital is another matter and does not require earnest thought. Capital is essential where large-scale projects are concerned. There is no reason why judicious planning should not enable capital to secure the returns it must have as inducement and yet advance the welfare of the Africans at the same time. Naturally the administration will make better terms with capital than in the past, when concessions were made for purposes which seemed justifiable at the time but were apt to grow out of harmony with policy later on.

This brief outline of the position of Africa with regard to world tendencies must suffice as preface. It need be taken neither as a warning nor as a threat, but it must be an ever-present background to our consideration of water resources, which are one of the several pre-requisites to the increased production for which the world is calling. We may define this production as mainly that of raw materials if we include food in that category, and though water resources do include possibilities for industry that is not the first need, except for a certain amount of processing of raw materials.

Most of the raw materials and all foods are biological products and have a direct relation to such things as the area of land available and the water supply which can be applied to that land. This relation is not altogether responsive to mathematical calculation, though in a thoroughly surveyed country such as England it is possible to calculate the total productive capacity. In Africa there is a number of factors, such as the varying character of the soils for instance, which impair any estimates of this kind. Yet some such estimates must be made as the different types of survey are concluded, of which that of water resources is but one, and these will have to be based on the very complicated relation between area of land available on the one hand and such factors as water, labour, transport, etc., on the other.

In the meantime we can say at once that Africa has already the potential ability to produce far more per head of population than it needs for its own use, and could continue to do so whilst keeping pace with its own expanding population. It is in fact so far from saturation either in population or in production that the eyes of the Northern Hemisphere are naturally turned upon it as a potential source which is not being developed at a rate commensurate with the world's demands upon it.

Lord Hailey, in his "African Survey", has pointed out that Africa's share in world trade is very small, being about 3 per cent only for the continent south of the Sahara, whereas its population is well over 8 per cent. Its production is in fact about the same as that of Oceania, which has only one-half of 1 per cent of the world's population.

Such comparisons, while they are impressive, are not conclusive; in other words there are many reasons for Africa's small share in the past, some of them being incontestable. Nevertheless the broad conclusion of "African Survey" is that development has been slower than need be, and that lack of knowledge combined with a measure of indifference have been two causes of the delay. The survey itself began to remedy the first and now the sharp reminders of war and world shortages are removing the second.

Such are the fundamental reasons, or some of them, for a closer survey of water resources of a portion of Africa. The raw materials and food which are the basic shortages in the world at present are, in the last analysis, the product of the soil, sunshine and water. Africa has land and sunshine to spare, the question is whether she has the third essential in sufficiency and available at the right place and season. The answer of this report is that potentially she has the necessary quantity of water, but that without artificial aids it cannot be used with full efficiency, since much of it is awkwardly placed as to both season and locality. Labour and capital are therefore needed for the development of the water resources, with adequate planning and supervision.

It is impossible to resist the conclusion that lasting benefit, both to Africa itself and to the world, can only come if a fair and reasonable combination of those three requirements, Labour, Capital and Direction, is arrived at in the general plan. Labour must come from the African himself and he must have due reward and a sense of partnership. Capital must, for the present, come from external sources, mainly European, and it must get its dividends, whether it be public or private capital. Direction must remain in the hands of, or be fully controlled by the administration, and it must in the end be paid for by the production.

Such tripartite division of effort and responsibility is nothing new, and there are many examples of it on a smaller scale, examples providing experience with which to avoid the pitfalls and misunderstandings which beset the path.

The main responsibility lies upon the Directive authority, for it is that which invites the co-operation of Labour and Capital, and its first task is to acquire the information and draw up the plans. For that task it has the aid of the Colonial Development and Welfare Act and it is as well that readers should credit the originators of the colonial development policy with wisdom and foresight. At a time when much publicity was being given to "Five year plans" of other nations our own authorities were quietly conceiving a scheme which is only now being tardily understood. First there were broad appreciations of the possibilities, of which "African Survey" was the outstanding example. Then there were more particular surveys in great number, of which this report is but one, and many more are due. Welfare and development have long since been started in parallel with such plans, and the British taxpayer has, perhaps unwittingly, already contributed towards great and promising advances in Africa.

Throughout the territories there is an undercurrent of feeling as between European settlers and Africans on the question of the occupation of land and consequent use of water resources. This feeling is practically absent in Uganda but reaches an unfortunate climax in Kenya, and since it affects the plans for water development, it requires some mention in this report. It is an admittedly difficult subject, and not one for detailed discussion by a visitor, nevertheless its repercussions upon a water policy may be profound.

From the point of view of world progress and the general opening up of Africa to play its part in world affairs, the case for General Smuts's conception of a backbone of white settlement in Africa is a good one. Where there is a fair field and no discriminatory legislation there can be nothing fundamentally unethical in such a juxtaposition of white and black occupation, and probably Africa would be far more backward than it is were it not for the pioneer settlers who have indirectly as well as directly advanced the native attitude to progress considerably if but slowly. In any case the process of establishing a ridge of white settlement has gone too far now to be recalled, so that policy must concern itself in the future with demarcating privilege rather than allotting it.

Sooner or later such privilege will include water resources where now it mainly concerns land. There can be few clashes of interest over small schemes of conservation and irrigation, since, as the burden of this report attempts to prove, any development along such lines makes for the improvement of the country as a whole and downstream inhabitants from the white occupied uplands should benefit considerably. Schemes on the large scale, which are bound to come, are in a different category, since they are liable to deny water to downstream inhabitants in some degree even when compensation water is allowed for. On the other hand since, in most of the territories, the lower lands are in the occupation of natives, it is they who will benefit most from such schemes provided that the dual or tripartite principles mentioned above are followed.

The case is less simple where the amount of water available is limited or where tapering rivers are concerned, as in the vicinity of the highlands of Mounts Kilimanjaro and Kenya, which are considered more fully in their respective sections.

A certain amount of redistribution of population is called for in various parts of the Territories, and fortunately the African is not steadfastly averse to such mass moving, provided that the benefit is clearly demonstrated and that it is handled with care. The great hindrance to a reasonable distribution of population is the presence of the tsetse fly in belts otherwise available, particularly in Tanganyika Territory. Research on that problem is possibly the most important of all the prerequisites to a more satisfactory occupation of the spare lands of Africa.

REPORT ON THE WATER RESOURCES OF THE BECHUANALAND PROTECTORATE NORTHERN RHODESIA · THE NYASALAND PROTECTORATE · TANGANYIKA TERRITORY KENYA AND THE UGANDA PROTECTORATE

PART I

THE GENERAL PICTURE

THE CIRCUMSTANCES and the needs of the territories of Central and East Africa are sufficiently diverse to require a separate section for each one. Yet there are several factors of general application which may be reviewed at this preliminary stage so as to form an outline sketch of their common background. It is hardly necessary to add that the development of water resources depends at least as much upon this background of physical, economic, social and even political factors as upon their actual abundance.

We are dealing with a section of Africa which, except in certain localities, is but little past the pioneer stage, where development is nearly all to come and where a wise choice as to the direction of such development can still be made. Yet, if the field of opportunity is wide the burden of responsibility is heavy, for we have, even in Africa, warnings of countries where hasty and individual development has brought disaster, where marginal lands have become desert and rivers have ceased to run, or where present profits for the few have ruined the future prospects of the many.

On the other hand, there are shining examples, again in Africa itself, where a wise foresight and a bold policy have turned desert into garden and brought both prosperity and unity to communities which had never before dreamed of the opportunities at their door.

From other continents we have much to learn in water development, yet we must carefully note the differences in aim, in climate and in people before we speak glibly of T.V.A. or Murray River schemes. If analogies are to be used they must be chosen with care; China and India should be more readily quoted than the large temperate countries, and even there the basic differences of race and intelligence must be emphasised.

Whilst on the subject of warnings we should recall that the engineer, although he is perhaps more responsible than any man for the water development of the pioneer countries and has indeed changed the face of Africa already, is not the only man to be called in to plan. His training and his outlook enable him to perform miracles with nature, but it is man who is to benefit and only the student of man, the administrator, can be the final judge of what should be done. For that he must weigh the advice of many other specialists before he calls in the engineer, and amongst these are the economist, the physical geographer and the social anthropologist.

Fortunately for the pace of progress there are administrators who combine in themselves some of these specialities, who can see the picture clearly and as a whole, but they are rare. For the rest of us there must be drawn some general outline of all the factors which control this fair field of opportunity, even though each of us, according to his outlook, will lay emphasis in different places.

THE CLIMATE

Ranging as they do from 5°N to 25°S, the territories with which we are concerned experience what is usually, and somewhat loosely, called a "tropical" climate.

The term is misleading in so far as it calls up a picture of a climate dependent mainly on latitude, whereas, as we shall see, the effect of other factors, such as relief and aspect, constantly overrule the influence of latitude.

Yet, subject to these more local factors, we may expect the tendency of the tropics to be present, namely a rainy season lagging somewhat behind the sun in its apparent path from one tropic to another and back again each year. A strict climatologist would not care to ascribe the rainy season so directly to the overhead sun, but for our purpose we may assume the connection, however indirect it may be in fact.

It means, of course, that towards the Southern Tropic, that is to say, for Bechuanaland Protectorate, the Rhodesias and Nyasaland there will be only one rainy season. Nearer the Equator there will be two rainy seasons, often called the "Long Rains" and the "Short Rains", and these affect the East African territories.

Accordingly we shall expect to find that in the more southern of our six territories the real difficulty is to bridge the long dry season by conserving the water received in the other part of the year. In the East African territories this difficulty is rarely so pronounced.

Besides its connection with the passage of the sun, the rainfall is associated with the oceans and their prevalent winds. Broadly speaking we may say that the Indian Ocean affects in dominant fashion the rainfall of the intermediate four territories, while at the extreme ends the Atlantic effect is appreciable.

So we find that Bechuanaland (and the south-western part of Northern Rhodesia) shares the dryness of the west-facing desert belt, characteristic of all continents in that latitude. Similarly, Uganda benefits from rainfall which in part appears to come from the Atlantic air circulation as well as from the Indian Ocean.

The particular aspect of Climate with which we are concerned is the Rainfall, the ultimate source of all fresh water.

No one who knows the drier parts of the United States or Australia can fail to be impressed by the total figures for rainfall in these African territories. They are, for the most part, well rained upon, if not always well watered. It is true that the total amount of rain falling in a year is, for man's purposes, far less important than its frequency and its seasonal incidence. In other words, the critical factor is the length of the dry season rather than the intensity of the wet season. Nevertheless, in an enquiry of this kind it is instructive to find out the total amount of water which falls on the land, however ill-distributed it may be throughout the year. That is the ultimate source of our water and if it is really deficient no amount of ingenuity will turn it into a water resource or fund upon which to draw.

For such a calculation the number of rainfall records in the territories is inadequate both as to distribution and number of years. Consequently the figures quoted below may be as much as 20 per cent in error, but even so they give an illuminating result. We can give them here in such a form as to provide a picture of the quantities with which we are dealing.

Thus, for all the territories together, the depth of water falling on the surface in the year averages about two feet, ranging from over three feet in wet Uganda down to one foot in dry Bechuanaland Protectorate. This quantity of water is represented by a square lake of 100 miles side and 300 feet deep, or by the volume of water in the Victoria Nyanza if we take its average depth as about 100 feet.

Such figures do not of themselves provide us with more than a vague idea of quantity, so we may view them in another way. If we convert the same figures into a form which represents the number of gallons falling on each acre in the year, we find that it is nearly one million gallons for Uganda, while at the other end of the list comes Bechuanaland with a quarter of a million gallons.

These pictures are unreal in the sense that they are averages over large areas which have considerable variations within those areas, but they do illustrate the statement that most of the territories are well served as far as quantity of water reaching the ground is concerned.

A more useful general figure would be the amount of surface water running to waste each year, for it is this fraction which is, to some extent, available for use. In countries where evaporation is high, relief is strong and the soils are often very porous, this fraction is somewhat variable and uncertain. There has, however, been considerable study of this run-off percentage in Africa, particularly by Dr. Kanthack of Johannesburg, and we can allot percentages for the different territories with some degree of confidence. In this way we arrive at the following table, which uses the convenient unit of an acre-foot. An acre-foot is the volume of water which would cover an acre to the depth of one foot, and is rather more than a quarter of a million gallons.

Volume of Run-Off Water

	Percentage allotted	Volume in millions of acre-feet	Volume in millions of gallons
Uganda	10	19	5,000,000
Kenya	6	17	4,500,000
Tanganyika	7	41	11,000,000
Nyasaland	8	5	1,500,000
Northern Rhodesia	8	32	9,000,000
Southern Rhodesia	5	7	2,000,000
Bechuanaland Protectorate	1	2	600,000

The purpose of such a table is served if it shows that on the whole these African territories have considerable water resources, some fraction of which is available for development. We might go further and say that, excluding certain dry areas in Kenya, and Tanganyika Territory, and a large part of Bechuanaland, the territories are exceptionally well favoured with water resources as compared with other similar large areas in the world. It is therefore not the total amount of rainfall which presents the problem but rather its seasonal distribution, and the aim must be to conserve it so as to make it available for use over the dry season.

Here again mere rainfall data are both meagre and misleading since they are subject to wide variations just where they are most vital, namely in marginal country where a few inches of rainfall more than the average may spell prosperity and a few inches less means disaster. We must therefore beware of averages, since grass, crops and stock cannot live on averages. In more settled countries there is a sufficiency of data to compile Reliability of Rainfall figures and diagrams, but these are as yet rarely available in our territories. It is therefore a case of hoping for the best year but preparing for the worst on which one must base plans for water development in these more difficult areas. In the more fortunate districts one must do the same thing in expectation of flood years, design of constructional work being based upon the worst flood to be expected.

Nor are cycles of wet years or dry years as yet of much value as guides, for in the present stage of climatology their relation to external factors which are predictable, for instance sun spots, are little understood. As long as forecasting even the daily weather is still fairly uncertain, it would be folly to depend upon forecasting of seasons. Yet while the actual figures for rainfall variation are sparse, there are other guides to the type of climate of the past which are becoming more valuable as knowledge of them increases. Probably the most important of these is the indigenous tree-cover, which does indeed live by averages. Planning therefore need not wait unduly for more climatic data, though it must be cautious.

Seasonal variation in rainfall is of great importance and we may say that its study is in hand, but in some ways the receipt of water is less important in our resources book-keeping than its loss. Hardly has it arrived before it begins to disperse by running away in streams, sinking into the ground or disappearing into the air, processes which are sometimes more picturesquely described as:

(i) "Run-off" (loss by surface streams).
(ii) "Cut-off" (loss by percolation).
(iii) "Fly-off" (loss by evaporation).

Reliable figures for any of these are rare, and such as do exist are almost staggering in their variation. For instance the "cut-off" on Kalahari sands or some Tanganyika limestones or some Mt. Kenya lavas may be over 90 per cent of the rainfall, while on certain granite areas of Northern Rhodesia it may be less than 10 per cent. Variations in evaporation losses may not be so wide, but they are certainly less measurable and less noticeable. They are peculiarly important in that they have a very direct effect on surface vegetation and shallow impoundings (such as the "pans" of Bechuanaland) so that the influence of cloud and wind may quite upset calculations based on heavy but short rainfalls.

Data on these points are therefore more difficult to procure and far more local than those for rainfall, yet are of prime importance, and must appear in the accounts.

As one might expect over so wide a stretch of country, the climate is full of local surprises. Some of these are due to the mountains producing rain shadows on their leeward sides, of which the classic cases are Mts. Kenya and Kilimanjaro where, at precisely equal altitudes but on opposite sides of the mountains, the rainfall may be up to 70 inches on the south-east and down to 15 or 20 on the north-west. There are other and larger areas of low rainfall, especially in Tanganyika Territory, due to the same cause.

These areas of rain shadow are now recognised and can be allowed for in planning, but the uncertainty of the date of onset of the Rains and their sporadic character in the first few weeks are at present quite unpredictable. The planting of certain crops, and in some cases even the preparation of the ground, has to be dependent on the coming of the rains. If they are late the whole crop may be jeopardised by the reduction in time for its growth, a frequent cause of famine in Bechuanaland. It is almost equally disastrous to have a false start for the rainy season, to be followed by partial or even complete loss of the crop by wilting when it is young, a fairly common occurrence in Nyasaland.

As elsewhere in the Tropics the early part of the rainy season is apt to take the form of very heavy local thunderstorms. Phenomenal rates of fall seem possible almost anywhere and may do an enormous amount of damage. The record for 1946 seems to go to the vicinity of Fort Johnston in Nyasaland where, in February, 10 inches fell in some 12 or 15 hours and so flooded one short section of the large Shire River that it flowed in both directions for some days, downstream as usual and also upstream back into Lake Nyasa. In December of the same year a fall of 26 inches in 40 hours near Zomba was even more disastrous.

The significance of such visitations for the water engineer is that he must in all cases study to make his designs for the most violent conditions, and allow a far larger factor of safety in all his construction. In England it is usual to assume a "design-storm" of three-quarters of an inch per hour, that is to say designs are made on that basis. The data for Africa are so incomplete as yet and the area is so wide that similar figures are useless, so that local memory is almost the only guide. Whereas in England the expectation of a rate of fall exceeding one inch per hour is between 10 and 15 years, in parts of Nyasaland it must be less than one year.

So serious is this frequent occurrence of phenomenal rates of fall that special precautions must be taken in all small works for conserving water in streams. To the visitor it is a surprise to find the spillways beside dams to carry off waste water apparently larger than the original stream bed must have been. Instances of sudden floods coming down comparatively small streams are innumerable in Africa, and the figures measured during one incident witnessed by the writer give it special interest. Crossing the Mwampanzi, a short but steep tributary of the lower Shire in Nyasaland, at mid-morning the discharge was 150 cubic feet per second. At six in the afternoon it was measured again and gave a discharge of 2,500 cusecs, the result of a storm over the headwaters of the river.

RELIEF

Except for the coastal strips of Kenya and Tanganyika Territory the whole of our area is part of the great African Plateau, that is to say most of the land is more than 3,000 feet above sea level, and this fact carries important consequences. Mere elevation does not, of itself, increase the general rainfall to any marked degree, in fact it often tends to localise rain and to produce awkward rain-shadows in the lee of the higher land masses. Yet it does produce an amelioration of the climate as to habitability and reduces the evaporation by lowering the temperature. From the point of view of man, and particularly of the white man, we may conclude that Africa is fortunate in not having a vast low level tropical area like the Amazon basin where man has hitherto been almost powerless against vegetation and disease.

The fact that most of the rain reaches the ground several thousand feet above the sea produces interesting consequences from the point of view of the water-engineer. It gives him what he calls "command" for his irrigation and power schemes, that is to say he is able to lead the water where he needs it by the aid of gravity. On the other hand it produces high gradients in the rivers and denies their use as prime avenues for communication. Except in a few special cases there can never be navigation canal systems on any large scale, and this is a disadvantage which far outweighs the value of "command". That does not mean that canals will not be built; indeed for the bulk products which Africa can most easily produce at its present stage every opportunity for canals must be seized, but they will be expensive to construct and to operate in comparison with those of other countries.

The great plateau of Africa is due in the main to at least one long period of time in the geological past when the surface was levelled off by erosion approximately to sea level. When it was raised again to its present elevation, not suddenly or as a whole it should be remarked, it became what is known as a peneplain, or rather a series of peneplains. That is to say, the tops of the hills in any one area are approximately at the same level, being the remains of the original low level surface, while the rivers, rejuvenated by their elevation and increased gradients, have been busily cutting out sharp V-shaped valleys and even gorges.

Broadly speaking, therefore, the pattern of the higher country now available for man consists of comparatively wide upland areas of rather poor soil separated from a series of narrow but moderately fertile valley bottoms by steep slopes where cultivation has to suit itself to those slopes and where the rivers are apt to be rapid and intractable for conservation, and mostly intermittent and seasonal. Where the streams do have a moderate gradient, that is on the uplands and in the broader valleys, the tropical climate has produced features of the utmost importance to man, namely swamps, and these will be considered in detail later on.

The African plateau cannot be fully explained in quite such simple terms as we have here used, but, neglecting most of the complications, we must mention yet another geological episode which has profoundly affected the relief and therefore the drainage.

As it happens every one of the territories shares some part of the extraordinary longitudinal depressions in the land surface which are known collectively as the Great Rift Valley. The singular noun is somewhat misleading since there are many rifts or faults, and many secondary valleys either parallel to the main line of the rift or branching off from it. The rifts are directly responsible for all the major lakes with the exception of Lake Victoria, the only large tropical lakes in the world, and they have determined the direction of drainage in their vicinity. A more important result still, from man's point of view, is that these breaks were assocated with a prolonged series of volcanic eruptions, not yet completely quiescent. These have produced soils which are beneficial in some areas and very porous lavas in others which are the reverse of beneficial.

These and other effects on the water resources are so widespread over the territories that they claim our further attention. We cannot follow the geologists in their debates as to the precise origin of the faults and fractures of the crust which have produced the rift valleys. Yet we should note that the process has been going on for a very long time, even by geological standards of time. Beginning, possibly, as far back as the era of our Chalk or Cretaceous the slow relieving of earth pressures over these thousands of miles has lasted to the present time. The occurrence of occasional tremors shows that there is still movement, and indeed this activity is often quoted, somewhat unwisely, as a reason for not undertaking large construction works on the lakes and rivers. The movements therefore began long before the appearance of man and, as Dr. Leakey is showing in Kenya, man adapted himself quite easily to the slow but monumental changes of relief going on under his feet. The popular conception of sudden vast sinkings of the crust and catastrophic eruptions producing the phenomena we now observe is therefore to be modified, inasmuch as the process was a gradual one over very long periods, which no doubt had its livelier incidents.

Similarly we must avoid accepting the rift valley scenery as seen in and pictured from Kenya as typical. Here are the most striking developments, where there are twin rifts and a sunken area between with volcanoes in it, the perfect text-book example. More perfect examples still are hidden from us under the Lakes. Were Lake Tanganyika emptied of its water, for instance, we should find ourselves looking down a mighty chasm from 3,000 to 6,000 feet deep, 50 miles wide and more than 400 miles long. Lake Nyasa would be little less striking, and their bottoms would be up to 1,000 feet below the level of the sea.

It is these grand manifestations of fracture and sinking which gave rise to the name of the Great Rift Valley, so aptly chosen by Dr. J. W. Gregory. Yet in other parts the same forces have produced rather different results and these have affected the drainage no less than the symmmetrical type. A common modification is the disappearance of one of the twin faultings so that the depression is unsymmetrical, and one looks over a single steep escarpment, as at Lake Manyara in Tanganyika Territory. It must be realised too that the fault or line along which fracture has occurred is rarely single. Usually there are a series of parallel faults so that one reaches the bottom of the rift by a series of giant steps. These are apt to be tilted away from the main depression forming small unsymmetrical valleys with a steep slope on the side facing the rift and a gradual slope up to the rim of the next parallel escarpment.

This local structure, which is most pronounced in Kenya, has the effect of reducing the area of watershed for the rift valleys, the divide being close to the escarpment. Further, since one side or the other of the valley is liable to be in a rain shadow, the general effect is that the sunken portions are apt to be dry areas. Owing to the irregular sinking of different sections there are many areas of inland drainage to salt or brackish lakes. More important to the pastoralist trying to find underground water beneath the porous soil, the salt is not confined to the visible lakes but is apt to permeate the water over large areas where the seepage has been slow, or where in the past there has been no free exit for the underground water at all.

Speaking generally for the rift valleys of Kenya and Tanganyika Territory, the country tends to be dry and is adapted mainly for the pastoral industry. This is balanced to a small but very important extent by the occurrence of volcanoes in and close to the rifts, from the large calderas of Menengai, Suswa and Ngorongoro, to the most massive type of true craters such as Meru, Kilimanjaro, Kenya and Sattima. The marked local effect of some of these mountains on the rainfall will be discussed in the individual reports.

It is indeed difficult to get away from the effects, of one kind or another, of the Great Rift Valley on all of the Territories. It is a dominating factor over the drainage. Even where there is no very clear evidence of faulting, the pattern of the rivers seems to be connected with the direction of the stresses which produced the actual rifts. Thus it is generally considered that the Luangwa River valley in Northern Rhodesia is a subdued section of the rift valley, and it is easy to continue this theory to fit the curious north-eastern direction of flow of the Zambesi upstream from its junction with the Kafue. The same line can be continued further south-west to find a somewhat thin explanation for the shallow depressions in Bechuanaland as far as Lake Ngami.

The imagination of the geologist is easily spurred to draw in further stress lines. For instance, one can be drawn to follow the line of the Chambesi into the Lake Bangweulu swamps and out again by the Luapula. The same line continued from Kapalala at the extraordinary bend which turns the Luapula towards the Congo, passes over quite inconsiderable higher ground to fit the upper Kafue exactly, and this river does not sweep round to join the west-east drainage pattern until it has reached its "hook".

Whether this game of tracing drainage to the rifts is really profitable does not concern us, but it is of some importance to note, from the map folded at end, that the drainage pattern is peculiar and, while in parts such as Northern Rhodesia it is highly favourable for water supply, it is quite the reverse in others such as central Tanganyika Territory.

THE LAKES

The pattern of the lakes of East Africa is due in the main to the Rift Valley fractures, with the extraordinary exception of Lake Victoria, a large but very shallow lake perched in some insecurity on a vast warped upland area between the two great arms of the Rift Valley series. "Insecurity" is but a relative term and refers mainly to two somewhat intriguing possibilities which nature, or even man were he so minded, could bring about. It has often been pointed out that a comparatively shallow entrenchment at its south-eastern corner could empty the whole lake towards Tanganyika Territory. Similarly, a deepening of its present outlet at Ripon Falls of a mere 50 or 100 feet would empty it towards the mouth. It would be equally simple from an engineering point of view to raise the outlet height at Ripon Falls and make the lake a still more efficient reservoir for the whole Nile system.

In this section, however, we are concerned more with the mass effect of the large lakes than with possible beneficial or disastrous alterations to them. A natural query is as to their possible effect on climate and this we are as yet unable to answer with any certainty. We can say that the evaporation from these large surfaces of water must ameliorate the temperature considerably, and it might be possible to calculate in round figures the amount of such effect. That, however, is of less interest than the possible effect on the rainfall in the vicinity of the lake and here we are on most uncertain ground. It is probably safe to say that there is such an effect, but that it is rarely a significant one. One might arrive at such a conclusion by considering what would be the effect on the supply of water vapour to the air above it if Lake Nyasa, for instance, were replaced by an ordinary valley which passed on the water from its existing watershed without impounding. We should remember that marshy land probably loses more water to the air than a clear water surface, and that the actual surface area exposed to evaporation after a shower would be greater from the ups and downs of a valley than from the flat surface of the lake. Under those circumstances one would expect no very marked difference in the total amounts evaporated in each case.

The most obvious mass-effect of the major lakes is that they are vast reservoirs of water. We might calculate the amounts of water impounded by each of these reservoirs, but such figures would be of no value, for we must remember that a reservoir in the utilitarian sense of the word "reserves" only as much as we can take out of it. That means that a reservoir only impounds as much useful water as we can run out of it by its outlets or channels. With this aspect in mind we see that the deep lakes of Tanganyika and Nyasa are exceedingly wasteful reservoirs, impounding vast amounts of water of which only the upper score or so of feet can be used. Quite apart from that, no reservoir can supply more water than runs into it, so that even if we were able to use the bottom water of those deep lakes, we could only do so in the sense of expending capital.

Nevertheless these lakes are most valuable assets, even if we can only count the surface water as true reserves, and they exceed the dimensions of any man-made dam in existence. Since they are all at considerable heights above sea level we can regard them as potential power-sources as well as irrigation reserves. Either use depends on command, that is to say it can only serve areas lower than the outlet.

A reservoir of any kind has a very definite secondary use in addition to actual conservation. Its value even in absorbing heavy flood rains may be very high in countries with tropical storms, but it is greater still in storing the wet season rainfall and letting it out slowly during the dry season. The lakes have other more specialised values varying in the different cases, such as a source of economic fisheries, and as an aid in transport and communications, both of which will be mentioned under the individual territories concerned.

There is one feature of the lakes which has gained them a certain amount of notoriety and that is their changes of level over periods of years. There is naturally a certain range over which the lake level varies during the year owing to the seasonal rainfall. In addition to this annual range, which of course is itself variable, a kind of cycle appeared to be in operation according to which the lake would rise for a period of years and then would fall, the total range being considerable. When the earlier figures for these cyclical changes of level were first assembled it was concluded that the cycle was more or less universal and therefore attributable to some cause common to all the lakes. Various possible factors, including the cycle of sunspot frequencies, were brought in with doubtful success as explanation. As more extended data became available it became increasingly difficult to prove that the different lakes were "in phase" in their cyclical changes of level. This lack of harmony, together with a much closer study of the lakes themselves, has now established the fact that in the majority of cases the changes are not cyclical in the usual sense of the term, but are due to the opposing and roughly balanced effects of erosion on the one hand and the growth of tropical swamp vegetation on the other. This usually affects the outlet of the lake, as in the cases of Lakes Nyasa and Tanganyika, but in a special case, Lake Bangweulu, it affects the inlet in a curious way because that lake is for the greater part a vast swamp. In yet another case, on a far smaller scale, in Lake Naivasha, it appears to be due to alteration in the underground seepage below the lake. The known variations of rainfall, in something of the nature of a cycle, do of course appear in the curves of change of level, but they cannot account for the very wide range of level.

Naturally such changes, even if they were truly cyclical, must prejudice most seriously the economic value both of the shores of the lake and of the valley of the outlet river, each exposed to periods of flooding followed by periods of low water.

The prime necessity, therefore, before any long-term uses may be made of these vast natural reservoirs, is first to find out the precise causes of the fluctuations and secondly to construct some form of control for the stabilisation of the lake level. Possible means of carrying out such surveys and an outline of measures of control are dealt with in this report in those sections relating to Lake Nyasa and Lake Bangweulu.

In the long run, whether the future of territories with rights over the lakes lies in agriculture or in industry, the resources provided by these great reservoirs must be developed. Such developments should be foreseen in outline if not in detail, especially as in almost every case there are political and judicial reasons for international agreement on the form the development should take.

VEGETATION

The influence of vegetation on water resources in providing natural conservation and extending the period of run-off is most pronounced in Africa, and in my own view its importance is constantly underestimated.

In any climate the vegetation ultimately strikes a natural balance with the rainfall which the land receives, more as to its seasonal occurrence than as to its total amount, a balance which man must recognise and not disturb without a full understanding of the consequences. This balance is a more delicate one where there is a long dry season and the vegetation is therefore slow growing and xerophytic, a type which is very common in Africa.

One may say generally that perennial vegetation will adapt itself to such water as it can get on the average during the year. This means that areas with a long dry season will have a comparatively sparse tree cover even where the total rainfall is high. Consequently, on such areas, the proportion of the rainfall run-off will tend to be high and short lasting. This applies to a large part of Northern Rhodesia. Conversely, where the rainfall is well distributed, as in parts of Uganda, a rain-forest type of cover is produced, which grows all the year round and is, roughly speaking, adapted to use practically all the rain it receives. A dry-type forest cover therefore has to some extent a surplus of water running away in the wet season, while a rain forest tends to arrest more water than is really needed for its growth.

For grasses the process is in the opposite direction in dry season country. The first rains bring up the herbage which grows fast and forms some degree of mat which conserves the water in the soil and makes the most of it, at the same time extending the period of stream flow. Left to itself grass continues this effect throughout a great part of the dry season, but if burned or overgrazed it leaves the soil exposed to high evaporation and to such erosion as scattered thunder showers can easily initiate.

The above is merely a restatement of facts which every pastoralist knows or should know, but it leaves out the most important feature of a great part of Africa—namely swamps—that is, more or less level areas covered by water-loving vegetation. These have different names in different parts of the continent. They are called "vleis" in the Union and Southern Rhodesia, "damboes" (plural of "dambo") in Nyasaland and Northern Rhodesia, "mbugas" in Tanganyika Territory, and "swamps" in Uganda and Kenya. Their origin is much the same as that of the ordinary swamp of temperate regions, where a low gradient allows vegetation to establish itself which further clogs the drainage and spreads the swamp. The famous "muskeg" of the Canadian lakelands is due to the same thing on a larger scale. What is different in the African picture is that the rate of formation is so much more rapid, and by consequence the necessity for an initial low gradient so much less. Many of the damboes of Northern Rhodesia, and even more noticeably the swamps of Kigezi in S.W. Uganda, have such an astonishing gradient that it seems at first glance that they cannot be swamps in the sense used in temperate climates. In Nyasaland they have a special word—a "dimba"—for what may be called a dambo with a steep gradient. These dimbas may occupy the whole length of a valley and are only slightly less impressive than the steep swamps of Kigezi.

The area covered by these swamps is accordingly much greater than one would expect from a consideration of the rainfall figures above. The proportion of area under swamps ranges from up to 25 per cent in parts of Uganda, through 20 per cent on much of the plateau district of Northern Rhodesia to 5 per cent in parts of Southern Rhodesia and the Bechuanaland Protectorate. They are, of course, the natural conservation features of the country and are largely responsible for the perennial character of the minor rivers and the comparatively steady flow of the major rivers. As such they are a vital factor in the water resources, but unfortunately they are also fertile and easily drained, and much of the disastrous change in agricultural land in the Union is directly due to the incautious draining of its swamps, there known as "vleis".

There are ways of using much of the dambo soil for agriculture and its water for general purposes without seriously affecting its storage value. These will be described in the detailed report on Northern Rhodesia, where individual farmers, under the guidance of agricultural and water development officers, have already begun some successful schemes, and in an appendix at the end of this report.

The prime importance of vegetation in the preservation of water resources cannot be dismissed with the above notes, which are mainly descriptive, and we should consider it more closely at this stage since it affects all the territories in greater or less degree.

In the past the "shifting cultivation" practised by the natives did not affect the natural conservation very much since it allowed a reasonable period of regrowth. Similarly, their practice of burning off large areas of dry grass, while it hindered the formation of a dense mat and a good layer of humus, was sufficiently dispersed originally to be a comparatively slight factor. The native could not, for lack of knowledge and tools, attempt drainage of the damboes or serious deforestation in rain forests. The coming of the white man to Africa has made both these alterations of the natural balance feasible and has moreover increased both the general and local density of native population so that their methods of cultivation and grazing are now affecting the vegetation cover to a noticeable degree. The danger of their more intensive use of fires, shifting cultivation and interference with slopes has long been recognised and control of one kind or another is being introduced. The dangers of the large-scale draining of damboes and deforestation, introduced by the white man, seem to have received less attention, partly because the effects are obscure enough, and slow enough, to permit people to differ in opinion as to their being dangerous at all.

While both swamp draining and the cutting down of forests are disturbances of the former balance between vegetation and water supply, there is a fundamental difference between them which must be appreciated. This difference lies in the fact that the artificial drains of a swamp can be artificially blocked again and the original state recreated in a very short space of time. One can therefore, to some extent, experiment with a swamp, conscious of being able to put it back should the experiment turn out to be dangerous. The forest on the other hand, even in Africa, cannot be recreated except at considerable expense and over a long period of years, and one can only experiment with forests at grave risk. In other words, swamp draining is a process which is reversible at short notice, while deforestation is only reversible over a long period.

The swamp, as we have seen, is an entirely natural conservation of water, due in the main to the rapid growth of vegetation which arrests the drainage. It therefore, as stated above, tends to prolong the period during which water will drain from it into its associated stream and thus extend the time during which that stream water is available during the dry season. To that degree the influence of the swamps has been highly beneficial while the land has been sparsely occupied by man. Indeed it has been proved only too disastrously that to remove all swamps leads to a number of evils, not the least of which is the rapid run-off of the rainfall which must then be countered by large and expensive schemes of artificial reservoirs.

On the other hand we may well ask whether the natural undisturbed swamp really makes the best use of the water, in fact whether a degree of disturbance of nature's balance is not only valuable for economic reasons but even desirable in order to save water.

Considerable work has been done on the amount of water used by growing crops and transpired by them into the air. Much less work has been done on the effect of plants growing in standing water or waterlogged soil. Such experiments as have been made have reference mainly to conditions in temperate climates, though India has provided data which are applicable to Africa. There appears to be no absolutely conclusive answer to the question whether a swamp loses more water to the air than would an equivalent expanse of water, yet there is a strong tendency in such experiments as have been made to suggest that it does. That is to say, it seems that the protection from wind given by the grasses to the water in which they are standing is quite outweighed by the extra surface for evaporation provided by the grass leaves themselves. In shallow water with swamp vegetation the loss of water may be as much as two-and-a-half times as rapid as for water alone. While this is not quite the same thing as a dambo in which most of the water is below the surface in the peaty mat, it seems highly probable that such a swamp does lose an excessive amount of water to the atmosphere.

That provisional conclusion leads us to another query which must be answered as far as possible. Does the water vapour thus provided by the swamps affect the climate and the local rainfall? If it does then clearly the wholesale stoppage of this source of water vapour may have serious consequences. Again the answer is far from absolute or conclusive. One may clear the ground for this controversy to some extent by saying that where the rainfall is orographical, that is induced by mountains, or where it is monsoonal, that is conveyed from the oceans, the effect of local swamp evaporation must be quite insignificant. On the other hand, where the rain is mainly of what is called the "instability" type, that is to say, due to the local disturbance of a delicate balance between upward movements of the air and its degree of saturation, it is possible that local evaporation may assist in upsetting the balance. This type of rainfall is common and perhaps even dominant in Uganda, a region of swamps, and will be dealt with more fully under the section dealing with that Protectorate.

If these suggestions as to the relative effect of swamp draining are sustained by further experiment it means that, under control, a great deal may be done with the African swamps, both in using their fertile soils and in saving more water from the thirsty atmosphere. This would be particularly the case in the longitudinal damboes of Northern Rhodesia and the dimbas of Nyasaland. Vast areas of swamps such as those of Bangweulu, Lukanga and the Kafue Flats, to mention only Northern Rhodesian examples, merit a different kind of treatment, both on account of their size and their function. In some areas, notably in Barotseland, the whole economy of native life depends upon the annual flooding of the large swamps. Such enlightened swamp dwellers will easily learn such refinements as the white man can add to their present practices, and indeed they must do so to cope with their steady increase of population. Possibly the word "refinement" is hardly the appropriate one in this connection, since a great deal of the development of swamp areas will depend on the mass removal of the dense vegetation, some of it anchored, some of it afloat, which has come to reserve for itself the name "sudd", derived from its place of maximum extension, the upper reaches of the White Nile.

We have seen already that a very large area of Africa is covered by swamps, and where the water is deep the vegetation is called "sudd". Its most imposing constituents are *Papyrus* and a giant *Phragmites* reed, but there are hosts of other species belonging to this extraordinary plant association.

We must ask ourselves therefore what purpose, good or ill, is served by having these deep swamps clogged by sudd, and how far its removal should form part of the due development of the water resources. The answer appears to be that in one set of circumstances it is useful as it stands as a giant check to too rapid a run-off. The writer was unable to see the Lukanga swamps, but they certainly delay the flow of the Kafue and in effect they smooth out the flood curve in what is possibly a vital way for the inhabitants of the lower parts of the river. If that be so then caution must be observed before any interference is undertaken.

The Bangweulu swamps would seem to be an intermediate case where a certain amount of clearing of sudd for navigation channels, fishing sites and so on is clearly necessary, leaving enough to control the Luapula flow and maintain levels for the benefit of the lower river. An extreme case where nothing but ill is derived from the sudd is in the Caprivi Strip and to the south of it. Here two major rivers, the Okavango and the Linyanti (or Chobe), lose themselves in hundreds of square miles of dense swamp, much of it floating sudd. Their combined discharge is not far short of that of the Zambesi itself, yet its value to mankind is almost nil.

It will be remembered that a great controversy has raged in the past over theories as to dessication in the Upper Kalahari. Livingstone found Lake Ngami a wide if not a very deep lake; it was a mere pond a few hundred yards long after the wet season of 1946. There is ample evidence on the ground that the Makarikari "Lake" and the Mababe depression have been filled to their brims at various times in the past. Livingstone himself accused the Victoria Falls of having robbed these lakes of their former supplies, Professor Schwartz called in cycles of dessication and other causes such as local silting. A most excellent expedition in 1925 under Du Toit made a survey of these areas with a view to a giant scheme for using Zambesi water to fill some of these depressions and irrigate others.

It is perhaps somewhat presumptuous for one who has seen only the edges of the Okavango and Chobe swamps to suggest that what is required if these things are to be carried out is not giant works of construction, weirs or barrages, but giant works of destruction of vegetation, opening channels through for the water again to run into the lakes and valleys as of old. In the writer's opinion there is no need to ascribe this apparent dessication to earth movements or a change of climate or any other remote cause. It is rather to be considered as a major instance of the same kind of "cycle" as has caused the changes of level in Lake Nyasa, that is to say the growth of vegetation which itself induces silt deposition and causes stagnation of the water over such a wide area that practically all the discharge of those two rivers is lost by evaporation. If the process were left to itself there would presumably come a time when a succession of high floods or some other catastrophic event would force a main channel open for a period when the depressions would fill again as in Livingstone's day.

Further consideration of what might be done is given in the section on Bechuanaland. It is given space here merely to emphasise in the strongest terms the overwhelming importance of swamp vegetation in Africa.

The function of forests in the preservation of water resources seems to have been the subject of a certain amount of debate in Africa and needs clarification.

In the first place there is a surprisingly small proportion of typical dense rain forest in the territories with which we are concerned, mainly because of the well defined dry season which prevails. All types of forests, both dense and sparse, if left to themselves will establish a balance with the available water throughout the year and will adapt themselves by various means—sparseness of growth, size, season leafage, etc.—to the wet and dry seasons. Consequently on the uplands the trees are more resistant to drought and more sparse than in the valleys where the soil water is available for a longer period, but they stop at the damboes, where water is too abundant and the soil too acid for trees. Immense areas of all the territories are occupied by this comparatively thin type of *Brachystegia* forest, varying in tree-height according to the amount of water available and permitting varying amounts of herbage to grow between the trees. It is too sparse to make use of much of the heavy rainfalls in the wet season, and although it does conserve water to some extent and check the run-off its value in that respect is not overwhelming. It can be, and is, removed for pasturage and cultivation provided simple precautions against soil erosion are taken. The zone of the railway in Northern Rhodesia is a good example of such country, the rainfall being from 30 to 50 inches annually but having a long dry season. In such places, and there are others in Nyasaland, Southern Rhodesia and even Bechuanaland, a regular cultivation or pasturage economy probably conserves soil water better than the original thin forest with its hard floor and sparse undergrowth. It may rob the smaller streams of some of their volume, but it should not affect their period of flow very seriously.

Under the management of European farmers or enlightened natives there should be no harm done to the water resources by deforestation in such areas. Harm can be, and has been, done where a concentration of native population has led to a wholesale destruction of the forest combined with their practices of firing the grass, cultivation on steep slopes, and over-grazing.

In the valleys, and especially close to the streams, the forest growth is denser and locally is of the "impenetrable" rain forest type. This strip of forest delays the run-off, protects the stream banks and furnishes a small amount of big timber. Legislation has attempted, with partial success only, to prevent its destruction by the natives.

As we proceed north and reach the zone of double rains, the density of the forest increases, reaching a maximum on the higher mountains where the precipitation by both rain and mist is fairly persistent throughout the year. It is these denser forests which are the subject of so much debate as to their effect on water resources, the arguments being briefly on the following lines.

The plea of the forest-minded man is that the dense growth delays run-off, protects the soil and generally exerts a steadying influence on the water supplies. He may even assert that the trees attract the rain, but here he is on more debatable ground. The argument of the agricultural or pastoral man is that the forest uses an undue share of the rainfall and therefore starves the plains below. If he is indiscreet he is liable to add that the same areas under grass would be of greater benefit, as shedding more water.

It would appear that, as in most cases of violent opposition on such matters, both sides are right in some degree in the cases which they select as examples.

Turning to our balance of nature again, it is probably correct to say that in a tropical climate with continuous precipitation the forest vegetation will use all the precipitation it can, its limits being only those of ground space and light. It will tend to withhold and use all the lighter forms of precipitation, mists and light showers, and only pass on those heavier rains which it cannot use. In that sense it does rob the plains of some of the stream water, but there are two or three points which must be noted. One is that it is not the timber trees themselves which are the chief robbers, but the dense undergrowth and quick-growing vines, so that a controlled forest, if that is possible, will not use more than a fair share. Another point is that on such steep slopes with heavy rainfall the rate of run-off is prodigious unless it is checked, and the floods which the dense forests help to prevent would be of little value to the plains unless controlled by artificial means further down.

The proposal that such forests should be removed and replaced with grasses appears to be peculiarly unsound. Apart from the almost inevitable soil erosion which would result it would be very difficult to establish pasture grasses. There would be a constant battle with thickets of brush, the natural association in such a situation after deforestation, and the water released would almost certainly take the form of frequent and disastrous floods.

The fact is that the disputants on both sides are constantly referring to a small area where their conclusions may be true, and applying them to a large area where they are not. It is true, for instance, that some of the quick growing exotic trees, such as eucalyptus and wattles, use an excessive amount of soil water. These, if planted where the rainfall is marginal, must rob the lower lands of a significant amount. On the other hand, planted where there is a high local rainfall and replacing a denser and even more thirsty original undergrowth, they may be of the greatest value to the plains below.

The very fact that it must be the local circumstances over comparatively small areas which must govern judgment enables us to leave the debate merely outlined at this stage for further treatment in later sections of the report. One must, however, record the fact that in other parts of the world it has been found that deforestation almost always adversely affects water resources. It is in any case most unwise to be rigidly dogmatic when dealing with large areas under varying conditions of climate, relief and soil. The all-forest policy may be just as dangerous as the no-forest policy, and the all-exotic timber enthusiast may produce more positive harm than the no-exotic man who wants to leave things as they are. What is needed, of course, is further experiment, and this we may leave in the capable hands of the forestry and agricultural departments.

There is, however, one type of experiment with vegetation which belongs more to the water engineer than to any other specialist. It is a pity that we do not know more about the effect of water plants on the evaporation of the water in which they live. This, as mentioned above, is important, but a small section of the same enquiry is still more important—namely, what means might be employed to reduce the evaporation from the surface reservoirs in Africa. The amount evaporated in a dry season may easily run up to five feet and more, and this, for the shallow reservoir which must be the rule rather than the exception, is often half of the total conserved.

The need for some experiments in African conditions is therefore manifest, and enquiries showed that a few had been made in Kenya, but without any conclusions being reached. The measurement of loss by evaporation on a field scale is by no means simple, but it is far from impossible, and the following suggestions are made in the hope that more water engineers will interest themselves in the matter.

Ordinary marsh and shallow water vegetation almost certainly induces a greater total loss, but this is largely because that type of plant enormously increases the surface area exposed to the air. For flat-leaved plants, such as the lotus lily, the case should be otherwise. Theoretically the transpiration from a living leaf cannot be as great as the evaporation from a water surface where the areas of exposure are the same. How much less it may be is the subject of the chief experiment which is required. No doubt there will be other difficulties in introducing any plants which turn out to be successful as moderators of loss to the air, but we do not yet know that such plants exist. The small floating plant known variously as the Nile cabbage or the Shire cabbage succeeds very well in covering reservoirs in the Eastern Province of Northern Rhodesia and is said to be useful in clearing the water of matter in suspension. Being cabbage-like in miniature it may have so much exposed surface that its transpiration does equal evaporation, but if that is so it should at least be established by experiment.

For smaller reservoirs some more artificial means of reducing evaporation may be the reward of research. Fine pumice has been tried without any marked success, but that is hardly surprising since pumice would increase rather than decrease the area of water film exposed to the air. What is required is a greasy (i.e. water repellent), non-toxic dust —something like lycopodium powder—which would form a thin film over the surface. Several substances suggest themselves for trial, such as powdered bark, powdered bitumen, soot, etc. There is a series of what are known as "polar compounds", mostly derivatives of waxes and resins, which are used in stabilising soils for roads, such as Vinsol, which may be obtained in either liquid or powdered form, and these should be tried. A promising line of enquiry would be the use of one of the ordinary solid waxes to be melted and sprayed into the air over the water to fall as tiny pellets or wax dust. Finally those heavy oils, which are almost insoluble in water and form a skin only a few molecules thick, might be tried.

Such artificial methods might only be applicable to the tank type of reservoir for the watering of stock, as they might be inimical to plant, insect and fish life. A small section of the tank would be protected from the floating skin for the stock to drink from. It is in places like the N.F.D. in Kenya, the Masai plains of Tanganyika and parts of Bechuanaland that some such device would be extraordinarily useful if it reduced the loss by evaporation to a reasonable degree. A comparatively short series of experiments under natural conditions in those places would cost very little and might well produce valuable results.

THE USE OF WATER RESOURCES

Having reviewed the main natural factors affecting the water supplies—the climate, the relief and the vegetation—we may now consider the objects to be kept in mind in this survey of water resources.

These territories are all, in varying degrees, at a stage when a number of concurrent factors renders it essential to take stock of their position and needs with regard to water. These factors may be social, such as the rapidly increasing populations; economic, such as the world need for a greater supply both of raw materials for industry and of foodstuffs; political, such as the impatience of other nations; even strategic reasons impinge on the subject.

Whatever choice the reader of this report may make from amongst this array, it is to be hoped he will realise that the development of water resources is only one of a number of lines along which advances must be made together in unison and in harmony. To the African administrator this must be fairly obvious; to the Englishman at home it may not be so. Therefore it is not idle to put an illustration or two in proof. We may start almost anywhere in the list of needs and arrive at the same chain of interrelated activities, all of which are mutually self-supporting, none of which can be omitted without jeopardising the attainment of the goal.

Do we start at the need for a better distribution of a rapidly increasing population? Then we immediately call upon the doctor to improve the health conditions, who calls upon the agriculturalist to find better soil for better crops, who calls upon the water engineers to find water over a wider area, who calls upon the veterinary people to free fresh country from tsetse fly, who call upon education people to convince the natives that keeping cattle mainly for "bride price" is foolish, and so on down the line. Better health, housing, communications, water supply, education—where all seem fundamental who shall award priority? Yet first things must come first, and sound judgment and planning must provide the sequence appropriate to each district, water supply in one, communications in another, and so on. Such planning can only be wise if there is a full appreciation of the whole aim, and this applies especially to the allotment and development of water resources.

We may therefore spend a little time in analysing the broad purpose so far as water is concerned.

One might begin by repeating that the general and overall aim is to find a use for all the water that reaches the ground. This does not mean that no water should be allowed to reach the sea, for in places there is navigation to be served, and in any case that is an impossible feat where there is heavy seasonal rain. One might paraphrase the exhortation to make two blades of grass grow where one grew before by saying that for all the intermittent streams of Africa the aim is to make them run for two days where they formerly ran for one. Conservation of one kind or another is therefore the general theme, but there are priorities in the uses of water which must be considered before the plan of conservation can be decided upon. Water for domestic use, for man and his animals, has a clear priority. It is not merely that villages are at present sited only near surface water, neglecting areas which would be useful but for their lack of water, a neglect which in many places, especially amongst the pastoral tribes, is a prime cause of misuse of the land. There are at least two other reasons why the domestic water supply must have development and control, and perhaps the first of these is the prevalence of diseases directly due to a shortage of water in the dry season when the African, whether he likes it or not —and it is true he does not seem to care very greatly—must use water which has all the concentration of germs and salts and soilings which a drought can produce.

The second reason is ultimately an economic one. The amount of man power, or more accurately, of woman power, which is used in fetching water for human consumption over long distances is prodigious. Moreover, the African is by nature a cleanly person, more so than many of the Oriental races at all events, and when water is scarce he not only reduces his washing but combines it with his drinking needs at the same water hole in a way which outrages European standards and must assist in the spreading of disease. Centuries of such customs in the matter of water have hardened him to these practices and tradition has to be overcome, but until that is done the economic output will remain low. A measure of compulsion may be necessary in the early stages and should be faced. In the philanthropic sense, and ultimately in the economic sense, the provision and improvement of domestic water supply should therefore be a first charge on the funds available for water development.

The second aim should perhaps be the general increase of food production, whether in arable or pastoral areas, which, since both grass and crops are seasonal, seems a difficult or at best a very long-term process. It amounts to taking steps to increase the quantity of water in the ground available for plant growth, or in more scientific terms, to delaying the run-off and raising the water table, that is to say the depth at which there is free water in the soil. Many ways of effecting this are available, such as better cultivation, contour-bunding, surface dams, etc., and these will come in time no doubt. The point raised here is that their immediate and local effect is not the only or even the best reason for an active campaign for these means, especially for the small reservoir. The controlled use of swamps comes under the same heading.

As soon as we approach the subject of irrigation we find ourselves forced to distinguish between projects for European estates and those for natives, a subject which is dealt with more fully later. Here we may say that the opportunities for irrigation in Africa are abundant, on both the large scale and the village scale. The large scale projects to be considered in the not too distant future will be maintained with the caution that their feasibilty is likely to depend far less on the water and the ground than on the markets for the products and the transport to enable them to reach those markets. Village scale irrigation will depend also, but to a less extent, on economic factors, for the native even when taught the main principles of irrigation will not use them for his own food, which he can raise by seasonal rains, but only if he has the urge to grow a surplus for other markets. That he can learn the art of irrigation has already been proved, and the difficulty will ultimately be rather that of controlling his use of water in that way than of persuading him of its value.

In the same way there is plenty of scope for the extraction of power from the streams all starting several thousand feet above sea level. On the large scale it is a matter for Europeans and the difficulties are almost entirely those of economics, not of construction. On a minor scale the use of water power should gradually appeal to the native, though the initiative will have to come from the women's side. It is quite extraordinary to the European to see so much power tumbling downhill to waste, when the time women spend in pounding their corn is quite comparable with that spent in fetching water. Yet the native is conservative to a degree and it will be hard work for some district commissioner to convince him that with very little ingenuity, mainly in carpentry, he could make the stream by his village grind the communal corn. His first answer will be that the women will then have nothing to do, but when the economic pinch comes, whether in the form of dependence on consumer goods or of an increasing density of population, he will probably follow the example of other races and use such gadgets as he can buy or contrive, to give him more earning power.

Such developments deserve encouragement and example because the use of streams for power usually means conservation in some form and the more conservation there is the brighter the future of the country as a whole.

METHODS OF DEVELOPMENT

It is not generally realised what powers of control man has over water or how much choice he has in its development. He may, for instance, aim at arresting the rainfall in the soil itself by contour furrows, by dry farming and other devices. He may prefer to hold it in surface reservoirs from which he can draw at will and under the influence of gravity. Finally, he may decide to rely on underground natural reservoirs and obtain his water from wells and bores.

To some extent one may call these three methods of conservation the Long Term, the Short Term and the Immediate methods, provided they are not considered to be alternatives, since they should be parallel. There may be extra emphasis on one of the methods, however, according to circumstances and needs, and in any policy of development the choice of emphasis must be considered.

Before the war the task in front of the usually inadequate staffs for water development in Africa was to produce a water supply for individual communities, mostly native, wherever the need seemed most urgent, and by the quickest methods. The pressure on the staffs and their equipment was such that the immediate programme, mainly for providing bores, left little time for long term policies, though in most cases these were outlined and appeared as reports to be followed up as circumstances permitted.

That urgency for the immediate production of water supplies has not disappeared; it has in fact been increased by the long hold-up due to the war. The drilling programmes, to take only one side of water supply technique, have grown longer than ever and the tardy reappearance of equipment and technical staff has been one of the main preoccupations of water engineers in all parts of Africa. Yet in spite of this urgency, and partly because of it, there is need perhaps for an expansion of the general plan of development, aided by the increased grants, and possibly for a change of emphasis on the different methods of conserving water outlined above.

Speaking generally, therefore, the emphasis in the past has been on the drilling of bores and the sinking of wells, both tapping natural sources, not creating new ones. There were adequate reasons for this choice at the time, and indeed the programmes must by no means be reduced but rather amplified. Yet the value of other and more constructive methods of obtaining water is such that their case must be fully stated.

Apart from the water of permanent rivers and lakes, which is there for the taking, we are concerned with a comparison between underground water, which is naturally conserved and has to be found and tapped, and surface water, which has to be conserved by artificial means.

The advantages of deep-seated water obtained by bores are obvious enough. The supply is normally pure and potable, it is constant and reliable and it is protected from surface pollution. The shallower water obtained from wells is not so pure or reliable and is often subject to surface pollution. Nevertheless, a good well is distinctly comparable to a bore. They are also comparable in the expense of sinking and maintenance; indeed, in Nyasaland, the records show that bores are cheaper than wells.

Water from small surface reservoirs can never be as pure as bore water under African conditions, though it can be made satisfactory for human use without very much difficulty.

The relative capital costs are not easy to estimate, but for equivalent yield of water the bore hole is probably at least as expensive, to which must be added the cost of maintenance, pumping, etc., which if capitalised will usually double the initial cost.

Comparisons of this kind between surface reservoirs and bore holes are unsatisfactory because they should not really be alternatives. Where there is a stream of sufficient discharge, even if intermittent, a surface reservoir is the cheapest method of supply. Where there is no stream there can be no other source than a bore or well. Africa has vast stretches where there is underground water and where only bores and wells can furnish it, so the programmes of sinking must go on. It also has a very large number of small streams with sufficient flood discharge for a dam, and this should not be allowed to run to waste.

There are two paramount reasons for a large increase in the number of surface dams or weirs. The first is a social or perhaps a psychological one. The African has become accustomed to the white man doing things for him which he cannot imitate, and the bore hole with its pump is one of them. It is to him an entirely Government mechanism, towards which he feels a minimum of responsibility, and in which he has no part. It is not that he is idle and likes water to be provided for him; it is merely that he cannot join in the operation of drilling nor can he really understand the source of the water since he cannot see it. Now he can understand a surface reservoir, and with very little supervision he can construct one, and therefore he can very soon be taught to acquire responsibility for its maintenance. It becomes a communal property for the village in a way which the magic bore hole never does.

Another but more subtle advantage of the surface reservoir may, in the long run, be of the utmost benefit to the country as a whole. We have seen that the quite adequate rainfall runs away because it is seasonal, and the first thing is to check that run-off, especially in the upland districts. Every surface reservoir holds up from twice to five times the volume of water that is actually visible, since it raises the water table in its vicinity, and the first effect is to extend the time during which the stream runs during the dry season.

Anyone who has not experienced heavy seasonal rain or seen upland streams flooding in the rains and bone dry for the rest of the year is apt to think that any reservoir would rob the downstream inhabitants of water and would cause the stream to run dry even earlier. He founds his opinion on the type of dam seen in more developed countries, where the aim is to impound nearly all the water of the stream, and not on the type suitable for Africa, which is really a weir or barrage designed to pass the greater part of the flood and conserve only a fraction of it. It is in fact often a surprise even to the European engineer to find that every weir he puts in along a stream helps rather than limits the weirs below it and that what was an intermittent stream becomes a perennial one. The weirs must, of course, be designed in accord with the flood discharge, and if they are built for extensive irrigation this general benefit to the stream lower down may not take place. A reasonable amount of irrigation is usually possible, because again it is raising the water table and some of the water comes out again into the bed of the stream.

The general conclusion, therefore, is that while the boring and well-sinking programmes must continue, they should be backed by a schedule of surface weirs to be built mainly by the Africans themselves under supervision. These weirs, ranging down every stream bed in steps or series, must of course be under control to see that they are used properly, are maintained, and do not bring such evils as malaria in their train. That means that nearly all the technical services are involved as a team in the development.

To sketch a model scheme, which in its entirety is impossible in any one region, is apt to be disheartening to those who try to realise it in practice. Nevertheless, the outlining of such a scheme is often the clearest way of describing all its component parts. We will, therefore, attempt such a description in relation to a definite valley, or type of valley. In the southern part of Northern Rhodesia there is a large number of rivers similar in type to the Maramba, flowing past Livingstone, the Kaleya, near Mazabuka, or a larger one still, the Magoye, flowing past Monze. These are selected as types only because anyone going by road or rail will see them, and in point of fact one of them, the Kaleya, has already had some such treatment as is about to be described, but under private European enterprise. They are all liable to be either tapering or intermittent streams, either vanishing in the dry season or flowing only a few miles from their parent springs.

On the watershed of the smallest and dryest of these three, the Maramba, some 40,000 million gallons falls during the rains, of which some 3,000 million runs off, This run-off, properly distributed, should give a discharge of about six cubic feet per second throughout the dry season, which would supply 300,000 people or head of stock with ten gallons per day. What happens in fact to this river is that it is in heavy flood for from two to perhaps four months and then it tapers off to complete dryness or a succession of muddy pools.

The model treatment of such a valley, only about twenty miles long in the case of the Maramba, would be to begin with a small check weir from half a mile to a mile below each of its many sources (probably from ten to twenty or so in number, including its tributaries). These would be of the roughest type of rock-with-earth, with a spillway to prevent their being washed away, and could hardly cost more than £20 to £30 each. They might in time tend to silt up and form small damboes, in which form they are almost as useful as check weirs. On the main stream, at suitable sites and intervals, rather more impressive earthen weirs with spillways would be constructed, costing perhaps an average of £300. They should be something like one and a half miles apart or according to the location and number of villages. Each of the weirs would be surrounded by a village forest reserve where wood could only be cut by permission and all access to the water by animals or man would be prevented. The village would be supplied, under the best circumstances, by piping from the weir—under the worst, from a small well dug in the stream bed some hundred yards or so below the weir, or from small tanks or ponds enlarged in the stream bed as it became perennial.

The cost of such development would depend on the available sites for the weirs, suitable material for them, and other factors such as labour from the local people. A rough calculation from examples of such weirs in other parts of Northern Rhodesia would put it at about £30 each for the headwater check weirs and £300 for the main stream weirs. Allowing twenty of the first and ten of the second, the total cost comes to about £4,000.

That such treatment and such results are not mere armchair fancies is proved to a great extent by pointing to certain examples of partial treatment of the same type. Private enterprise in the Kaleya valley itself has already proved that check weirs and main stream weirs will render a stream more nearly perennial, even though in that case there is irrigation. In the small valley of Chilanga near Lusaka the same thing is being proved, as well as the efficacy of weirs built by natives under supervision which is not highly skilled.

The important elements in such treatment of a valley stream are first that the valley should be treated as a whole, each weir planned and sited in relation to the entire scheme, and secondly that, as far as possible, the valley inhabitants should be brought into the work, made to feel responsible for the weirs and for observing the simple rules as to the use of the water, cleaning of the weirs and supply tanks, etc.

There is indeed not very much in the constructional part of such a scheme that is experimental and it is hoped that the Government may select some small valley in a native reserve and develop it along these lines as a demonstration. The experiment is in fact far more a social than a physiographical one, to see how far the African can be persuaded to join in it and maintain it without constant control from the white man.

It will be realised that the larger the valley and the stream therein the more expensive would be the treatment. For instance, the Magoye River, over sixty miles long, would require large works. In such a case, of course, the main stream would hardly be tackled at all, but only the tributaries running into it. Even better examples of suitable valleys for such comprehensive plans occur in the Eastern Province, but the writer is not so familiar with the local conditions there.

On the whole the emphasis here is on the necessity for many small and cheap weirs on small streams, rather than for a few large and costly ones on large streams. The more the small streams are weired the more likely the larger streams are to become perennial.

There is a secondary consequence of such weir treatment which will be appreciated by the agricultural expert but may not be fully realised by the layman and therefore deserves mention. All seasonal crops depend on the depth below them of the water available for their growth, that is how far the roots have to go to reach the vicinity of what is known as the water table. The water table follows the side of a valley in a characteristic curve which is well below the surface on the higher ground and reaches the surface at the stream bed, if it is running, as shown on the left-hand side of the diagram. If there is a weir in the valley, this curve of the water table will be flatter, as shown on the right-hand side, and the strip of ground available for crops will be much broader. The water thus raised in level in the soil seeps down gradually both into the weir and into the stream bed below it, and it is this seepage water which is the main cause of the stream becoming longer and stronger than before the weir was there.

It is obvious that such a policy as here outlined, of a large number of small weirs, cannot be put into immediate effect, nor can it cover large areas for a long time to come. It is not only a long term policy, and consequently somewhat suspect by those who call for quick returns, but it is also an expensive policy unless the co-operation, and largely voluntary co-operation, of the natives is enlisted. This aspect is dealt with later in a special section, but it deserves just as close attention as the physiographical aspect, since it is a vital part of the whole scheme of development.

Certain arguments against this form of widespread conservation, which might more properly be called arrestment, will appear and some may be met in advance. The most urgent is that the silt brought down in the annual floods will soon fill the weirs. There are two answers to that, the first being that a reservoir filled with silt must not be written off as useless, since it still holds one-third of its original supply, and as far as raising the water table and arresting flood water is concerned, it still functions in the main as before. The second answer is that the checking of silt in the small head-water rock weirs is partly the purpose of the whole scheme of development, which is to reduce soil erosion as well as to furnish water supplies.

Another and rather more serious argument, since it clearly has a sinister weight, is that surface water in the wrong form, that is, in shallow stagnant pools, is a most fertile breeding place for the Anopheles mosquito. This is dealt with in a section on the medical aspect of water development.

There are other parts of Africa, particularly in Bechuanaland, Kenya and Tanganyika territory, where the porosity of the stream beds and the rate of evaporation quite prevent such ideal schemes of stepped weirs of surface type. In such areas the streams run strongly for a short period in the rains, to be measured in days only in some cases. Here there can only be a pastoral industry, supported by local crops in favoured places. The object of development then becomes the provision of stock watering points, spread over as large an area as possible to distribute the grazing, which is usually good in quality but sparse in quantity.

These more uncommon conditions will be best discussed in detail under the territories concerned, but a few general remarks may be useful at this stage.

The first is that for a pastoral economy with its sparse population, often nomadic, the actual amount of water required is small, but it should be dispersed and it should be protected as far as possible from heavy evaporation and loss by sinking into the porous ground. Here, then, the bore-hole should come into its own and programmes of drilling should be vigorously pursued. But where the bores have to be deep and costly, especially near the sandy rivers so characteristic of this type of country, a method of sub-surface catchment offers considerable possibilities. Cheap conservation of sub-sand water is discussed elsewhere in the report.

There is another method of providing water points for stock in districts which have neither underground water for bores nor sand rivers for reservoirs, and where surface tankage is rapidly lost by evaporation, and that is by piping water from mountain streams or reservoirs on large rivers. At first sight such a method appears to be a very expensive and inadequate one, but certain hopeful elements in it should be stated, to be applied to any particular case which might make it a suitable one.

In Kenya, Tanganyika and to a less extent in Bechuanaland, there are many places where the streams rising in mountainous areas of good rainfall run out on to the arid plains and gradually disappear. They are known as tapering rivers. Their water must be counted as almost completely lost to man, nor is there any way of preventing their disappearance, which is as much by sinking into the river bed as by evaporation. We therefore have the sorry spectacle of streams running perennially in their upper sections with a discharge of several cubic feet a second, which have totally disappeared a few miles lower down.

Now a flow of one cubic foot per second provides sufficient water (at ten gallons per day per beast) for no less than 50,000 head of cattle. If there is a suitable gradient, such as 200 feet in a mile, this quantity of water can be delivered by a five-inch pipe, from which smaller pipes would take off to distribute to the points of delivery over the area required.

It is easy to get lost in figures which cannot be applied in practice, but we may pursue them a little further to show the order of expenditure that would be required for this one premise of one cubic foot per second flow.

Fifty thousand beasts would require about 1,000 square miles on the thin grazing of such country, so we need water points over a belt, say 40 miles long by 25 miles wide. The 40 miles of piping would not need to be five inches in diameter all the way so we might say its average cost, laid, should be between £1,000 and £2,000 per mile, a total of from £40,000 to £80,000, at first sight a prodigious figure. This is, however, merely a capital cost of something like £1 per beast spread over the life of such a pipe, which should be about twenty years. The cost of 1*s.* per beast per year for water, during which it drinks about 3,000 gallons, would not be at all excessive under ordinary pastoral conditions of production for sale.

The conditions under nomadic native methods are far from being ordinary, however, and we must leave this somewhat ideal figure to be used as a basis for application to actual conditions. It does at least show that piping for water points is not completely ruled out on account of cost, particularly as the method provides for a minimum of waste of water and assists in the grazing rotation which is so badly needed in native management of cattle.

The case for bore water supplies over the same area for the same number of stock would be somewhat as follows. We should have to make the rather generous assumption that bore water could be obtained suitably spaced at an average depth of 200 feet and at a rate of not less than 500 gallons per hour per bore. Allowing also a proportion of 50 per cent successes in drilling to this result, we should require 20 bores costing about £1,000 each. Arriving at a rough figure for the cost of pumping and maintenance, we might capitalise this at £1,000 per bore. These are on the whole minimum figures and under the best conditions as to underground water supplies. The total for the area of some £40,000 is less than, but at least comparable with, the total for the piping scheme.

One might summarise by saying that for Kenya and Tanganyika conditions such piping schemes are worthy of closer examination. For Bechuanaland, where the bore water is closer to the surface and there are few mountain streams, there is probably little merit in piping.

THE ORGANISATION OF WATER DEVELOPMENT

The development of water resources has for a long time past received considerable priority in all the territories, but they have differed a good deal in their organisation for carrying it out.

In some cases the Public Works Department has been responsible for all water development. At the pioneering stage this was an entirely practical approach, since the Public Works Department, for its other activities, had much of the machinery, the workshops and the transport which are required for the constructional work involved.

In other cases the reconnaissance section of water development was given first importance and the whole organisation was handed over to the Geological Department. In yet others the responsibility was shared, or there was a subdivision of the Public Works Department for the purpose. Other departments were constantly concerned in the water resources, particularly Agriculture, and either their schemes were put through by such means as they had to hand or they had the work done by the department which had the tools and the men.

This diversity of organisation for the same general purpose was natural enough in the circumstances, and as usual the machinery of organisation was on the whole less important than the man who controlled the machinery.

Yet there are good reasons for the fact that most countries do, at a certain stage of progress, tend to create a special department to deal with water reconnaissance and supply. Southern Rhodesia is an example, and it is now being followed by Tanganyika Territory and Northern Rhodesia. The best of these reasons is that it makes for more efficiency to keep a tool at work on the job for which it is made rather than to alter it continually to suit other jobs. The highly trained geologist and the constructional engineer have shown themselves capable of dealing with drilling programmes and siting of wells and so on, yet they do have to switch themselves on to ore deposits and building bridges. They are unable to give their undivided attention to either aspect of their duties. So a natural step in the evolution of government machinery has been the creation of a separate and more or less independent department for Water Development. There is some danger in the frequent use of the word "independent" in such a connection, for no Government department is independent in the full sense of the term and least of all one which deals with Water Development, a matter which closely concerns every other department. It may be independent for purposes of accountancy, equipment and personnel, but in every other respect its main object must be close co-operation with and mutual dependence on the other departments.

The particular value of a separate department for Water Development lies in the fact that it must cover three rather different aspects—Reconnaissance, Construction and Policy—which are so intimately related that it is more efficient to have them under single direction. Moreover its field of operation is clearly defined, and its interlocking with every other department is so obvious that co-operation with them should be almost automatic. It is, for instance, not easy for an administrative officer or a European farmer who wants an investigation of his villages or farm for underground water to go to a Director of Public Works engrossed in a house-building programme, or a Geological Director busy with a survey for mineral resources. He will receive attention of course, but it will be divided attention and there will be delay while the houses and the minerals have their turn.

A Water Development department therefore has a clear field, and it is also a very full field, especially in Africa, where so little has yet been done. It would be of little use to outline either its organisation or its exact duties in this report, but it might be as well to outline its scope, both to justify its establishment and to underline the nature of its responsibilities as well as the type of work required.

A certain section of its work would be under the general heading of Reconnaissance. The immediate duties of a reconnaissance unit would be the search for underground water, and the siting of bores and wells. These will call at the least for a man who is trained in geology and at best for another trained in geophysical methods of finding water-bearing strata. It should also have a mobile experimental boring outfit as part of its equipment.

A second duty of the unit would be the search for sites for surface conservation which involves measurement of the discharge of streams and a considerable amount of rapid mapping and levelling. Normally the areas for surface conservation schemes would not be those scheduled for a drilling programme. It would, however, be frequently concerned with reports on the treatment of swamps and for small irrigation schemes. It therefore calls for a man with some training in physical geography, geology and surveying, and with some experience of dams, drainage and irrigation works on a small scale.

As a background to these reconnaissance duties there would be the very important activity of a general hydrological survey of the whole country. Except in very favourable circumstances it would not be possible to allot staff for this fundamental task, which in the long run would save so much time and expense in planning development, and would provide so much information for other technical departments. It would therefore be a piecemeal activity, compiled at headquarters for the most part from the data of the field parties. Since very few countries in the world as yet possess anything approaching a hydrological survey it may be as well to explain that it is nothing less than a complete survey of all the water resources. Every item of measurement in the field, such as depth of water table, yield of wells and bores, discharge of streams, proportion of run-off, etc., is collated into maps or lists of data, so that there is information for any form of development, including even navigation and hydro-electric power.

The reconnaissance units would provide the data and sites upon which the division of the department concerned with Construction would act. The activities of this division are fairly obvious and it would carry out the drilling and well-sinking programmes, the smaller conservation and drainage works and indeed all hydraulic works except those of a size and duration requiring the employment of a contractor. The staff would include a civil engineer capable of designing such works, but would consist in the main of a number of experienced foremen and supervisors, and small teams of natives with some training. Most of the conservation, draining and irrigation works would be done by local natives under the supervision of one or two members of the staff, either European or native, according to the magnitude of the task. This division would need to have a maintenance and repair workshop for its more technical equipment and/or a working arrangement with the Public Works Department for the services of its district workshops.

The Headquarters Division would have certain specialised activities besides the obvious ones of Direction, Planning, Records and general Administration. Two important ones will be mentioned.

It should include a section which is occupied with the training of natives, a subject which is dealt with more fully in a later section of this report, and one which is possibly the key to the ultimate steady progress of the native population. A less impressive but very vital activity would be carried out by an *Experimental* section, probably under the immediate direction of the Head of the Department. The necessity for such a section will appear from the reports on individual territories, where evidence is given of the need for new methods of approach to the unusual conditions ruling in Africa, whether this concerns the mode of occurrence of water supplies, the nature of local materials, the capabilities of the native population, or even the effects of evaporation, transpiration and porosity peculiar to each district.

One suspects that on reading the above, a Director of Recruitment will wonder what kind of a technical officer he is to select for work which covers such a wide field. The fact is that for water development as it stands at present in Africa there is no direct training, no label which a man can carry denoting his fitness for such work. The hydraulic engineer, who is a kind of civil engineer, is not, as such, the man, for he has usually acquired his experience in building dams, canals and irrigation schemes on a large scale in countries where the reconnaissance work has long been done. Nor is the mining engineer any more apt for the post. The geologist does understand the reconnaissance part of the work but is new to the engineering part. The agricultural specialist may be the best guide as to the uses to which most of the water is to be put, but he too would have to learn the other sides of the business. There is no such thing at present as what might be called a "hydrological" engineer, who would combine the knowledge of the physical geographer, the geologist, the surveyor and the engineer, and step straight into a water supply department in Africa.

Since that is so, the next best thing for the recruiting officer to do is to select either a physical geographer or a geologist and give him a year's practice at water engineering, or a civil engineer and send him to learn the reconnaissance side of his work in a geological or geographical department.

In the meantime the water development organisations will continue to sway their geologists towards engineering and their engineers towards geology by giving them field experience so as to produce this new breed of hydrological engineer.

THE MEDICAL ASPECT

The prevalence of a group of diseases in Africa which are either directly, as in the case of dysentery, or indirectly, as in the case of malaria, dependent upon water, makes it necessary that the medical aspect of all water development should have the closest attention.

The co-ordination of the medical and the water services on this matter is of prime importance, and it has not always been the case in the past. On the other hand, the medical authorities have often been the first to give support to plans for a safe water scheme, whether for human or agricultural use. It is not unreasonable to conclude that the special emphasis given in the past to securing water supplies from bore holes has been due to the fact that except in very special cases it is the purest form of water obtainable in Africa.

Any expansion of a system of surface conservation must therefore meet the criticism of the health authorities, which also means that those authorities must understand the particular benefits to be gained from such surface methods.

In this general section we can only consider the broad principles of this vital co-ordination.

The main types of infection to be discussed are probably those of malaria, hookworm and bilharzia. The sources of all of these are well known, and the appropriate preventive measures are comparatively simple on a small scale, but quite prohibitive in expense where large areas are concerned.

To some extent the preventive to all three diseases is drainage, yet we have seen already that severe drainage of all surface water would be disastrous to the country as a whole. If Africa is to expand in population and general prosperity, it is essential that the general water policy be that of increased conservation, either by natural or by artificial means. It remains to be considered, therefore, in what way this conservation can be arranged to meet the requirements of hygiene.

In anti-malarial practice, for instance, it is now established that if the water is open to wind action, if it is more than two or three feet deep, and if its surface is kept free from reeds, the *Anopheles* mosquito larvæ will succumb. The use of certain small fish, such as the *Gambusia*, is also a valuable deterrent.

Now it is far easier to see that these requirements are met in a surface reservoir than along an extent of a stream which has pools and stagnant sections with marsh under natural conditions. Again, the value of the quick-growing eucalypt in Italy and other malarial countries appears to be mainly or perhaps entirely due to its capacity for using very rapidly any surface water near its roots. Consequently the practice of planting eucalypts close to the overflow sections of any reservoir will reduce that source of casual water for mosquito breeding. This has been shown by the anti-malarial work in the vicinity of Ndola in Northern Rhodesia.

In general, it should be far better to have all surface water draining into a reservoir which can be controlled than to leave it scattered in pools and swamps over too large an area to be under inspection. To that extent the medical authorities would welcome surface reservoirs.

Bilharzia and hookworm, on the other hand, are due to contamination of the water used for drinking and washing, for which the fouling of the surface water by the unhygienic habits of the native is largely responsible.

Quite apart from the campaign for latrines and other obvious reforms, there is a need for denying general access to surface water by man and stock. This is not an easy matter to arrange, but it would be less difficult if all or most of the water for human use were in a reservoir or directly derived from one.

This question of protecting the main water supply from general access was discussed with a number of administrative officers, and it must be confessed that the majority of them considered it would be difficult to introduce. They agreed that it was highly desirable but that it would depend very much on the local headman concerned. Probably mere injunctions or "tabus" by themselves would be of little avail, in their opinion, but if it were made easier to get water or do their washing or stock watering in specially allotted places, then the desire to go to the main reservoir would disappear.

With these difficulties in mind a scheme was drawn up involving the the co-operation of the medical, agricultural and forestry authorities, as well as the administrative service, and put to them either individually or collectively for comment. It had to be an ideal scheme, rarely attainable in practice because of local variations in topography, water supply, etc. The opinions expressed by the officers consulted varied widely as might be expected. None would accept it as a whole but most would admit that certain elements of the scheme were practicable while others were not, in the localities they knew. On the whole a majority were interested in it as a plan to be considered, and a few were genuinely anxious to attempt something of the kind in a selected place as a test. Actual figures were preferred to a mere general scheme, though estimates of cost of the labour required had to be omitted since they would depend on local circumstance and particularly on the lay-out of the stream, the village, the native gardens, etc.

In the writer's opinion the main value in sketching such an ideal scheme lay in the discussion and interest it evoked, and even when the comment was adverse it often led to some constructive amendments. The crux of the problem lay, in almost every case, in the type of native concerned, and while the administrative officers rarely said outright that their people would fall in with the standard scheme, many said they would like to have a trial.

No apology is offered therefore for detailing the scheme here.

Village water supply: standard scheme

A village of about 100 persons with 100 head of stock is taken as a standard unit for calculation. It is situated on or near an intermittent stream, such as is so common in Northern Rhodesia or Nyasaland, which floods in the wet season and degrades to a string of pools or disappears under the ground in the dry season.

The water requirements for a dry season of say 200 days would therefore be about 1,500 gallons a day, allowing 5 gallons and 10 gallons per head per day for man and beast respectively, totalling 300,000 gallons for the period. Three hundred thousand gallons of water would be the run off from less than 200 acres with a rainfall of 25 inches in the rainy season, so quite a small side valley would have an ample catchment.

This quantity of water is quite small by comparison with normal surface reservoirs, but we can represent it by a dam which is about 50 feet broad by 200 feet long with an average depth of 5 feet, having an embankment which is 12 feet high at its maximum. This does not allow for evaporation and seepage, but neither does it include the large amount of water held back in the soil at the sides of the dam, these two quantities being taken as roughly balancing each other.

The amount of earth to be excavated and placed as an embankment would vary with the site but may be taken at an average of 400 cubic yards. A man can deal with from one to three cubic yards per day with native tools, hoes, baskets, etc., depending on the nature of the material, length of carry, etc. At two cubic yards the actual construction would therefore occupy 10 men for 20 days or 20 men for 10 days. Allowing for some difficulty in excavating the spillway, fetching antbed for the core, etc., we may say that 20 men could construct the dam in a fortnight. It would therefore be a village-scale operation if supervision were provided, and would be done in the dry season when there was little or no water in the stream bed. On a favourable site the above quantities would be very substantially reduced.

It should be realised that the actual amount of labour required is comparable with that which is constantly provided by the men of the village for clearing land for their shifting cultivation. Nor is it any more skilled, provided that it is done under some supervisor, native or European.

The finishing layers of earth for the embankment would be taken from the edge of the future reservoir so as to ensure that there should be little or no really shallow water at the edge. This deepening of the sides is actually more easily done during the dry season as the water shrinks from its maximum. Also the mud deposited on the banks in this way raises them and makes them less suitable for the host-snail of Bilharzia, while the bench thus formed is an appropriate site for planting eucalyptus some 10 or 15 feet from the water's edge.

To make the dam difficult of access to man, stock and game some form of "zariba" or thorn fence would be necessary in the first place, to be succeeded by thorny or hedge plants in due course. Further, an area round the reservoir of some fifty acres would be declared a village forestry reserve so that no timber would be cut except by permission and young growth would be encouraged.

We now have the reservoir reasonably protected from pollution and misuse, and the lay-out of the rest of the scheme would be somewhat on the following lines.

Since no people or stock must go to the dam, some method of drawing off the water is required. Ideally this would be by a pipe through the embankment; a one-inch pipe would be large enough for the unit chosen, and about 60 feet would be needed. It would be bedded very carefully in rammed clay (ant bed material) while building the embankment. Alternatively it could come through the upper three feet of the embankment and be used as a syphon. It would empty into a small furrow or leat running down the side of the valley to the village. This leat should have a drain just above it to catch the storm water and should be lined if the soil were very porous. The sheaths of banana leaves make a good temporary lining for a small flow such as this, but rammed ant bed or flat stones in clay would be more permanent. Since a leat means a certain amount of maintenance, which is not a strong point with natives, it would be better in most cases to have enough piping, say 200 or 300 feet, to bring the water all the way from the dam.

Should the conditions put all piping out of the question, one would fall back on the seepage from the dam. In this case the embankment would be purposely made to allow seepage, using coarse material, from gravel down to heavy boulders, at the downstream toe of the embankment. The seepage would then be collected and run into a leat leading down to the village just above the original stream bed.

At the watering point the leat would discharge down a bamboo or a banana leaf sheath or a hollow trunk so that the pot or "debbi" could be placed under it, standing on a flat stone just above the washing pool or as near it as convenient. No water would be allowed to escape into stagnant pools, but all would be led to a watertight washing pool made by digging a hole of suitable size, lining it with at least six inches of ant bed and embedding stones in it, the largest on the top.

From this pool the water would again flow through a trough or rough flume to wherever the stock watering point was. This might best be above the true stream bed so that the annual floods would not disturb it. This pool also should be dug so that it is not too shallow, and have a deep foundation of stones to prevent undue fouling by mud. (It would perhaps be too much to expect the indigent African to hollow out a log, something in his canoe style, from which the stock would drink and from which the water would run clear away to the stream bed, but it should be considered.)

All this part of the work could be done quite thoroughly and permanently by our 20 men in one or two days, including fencing off the washing pool from stock.

The scheme could be varied from the above within fairly wide limits, but as it stands it is intended to be cheap and within the mechanical capacities of the native, to fulfil most of the medical requirements concerning malaria, and to reduce the possibility of the nematode worms breeding.

The existence of swamps near villages is apt to be a sore point with the medical authorities, since they are often the worst possible sources of *Anopheles*, and any compromise which can be arrived at between the water resources engineer and the anti-malaria officer is worth discussing.

Leaving really large damboes out of the question, it is possible to devise a fairly simple scheme which should be of value to the village and at the same time minimise the malaria risk to a great extent.

Most damboes have a gradient, though it may be slight, and are composed of peat upon clay. An occasional dambo is due to a rock bar checking the drainage, but most have been formed by the clogging of the original channel by vegetation which, as it grew and thickened upon its dead self, expanded the dambo upstream. The soil is naturally porous though it has a proportion of clay and grades into the typical black-cotton soil. The dambo is never uniformly level and the real home of the mosquito larvae is in the shallow ponds which are scattered over the surface for a month or more after the rainy season. If these can be drained the rest of the water under the surface is of no danger to hygiene and serves the purpose mentioned elsewhere of keeping the issuing stream flowing throughout part or all of the dry season.

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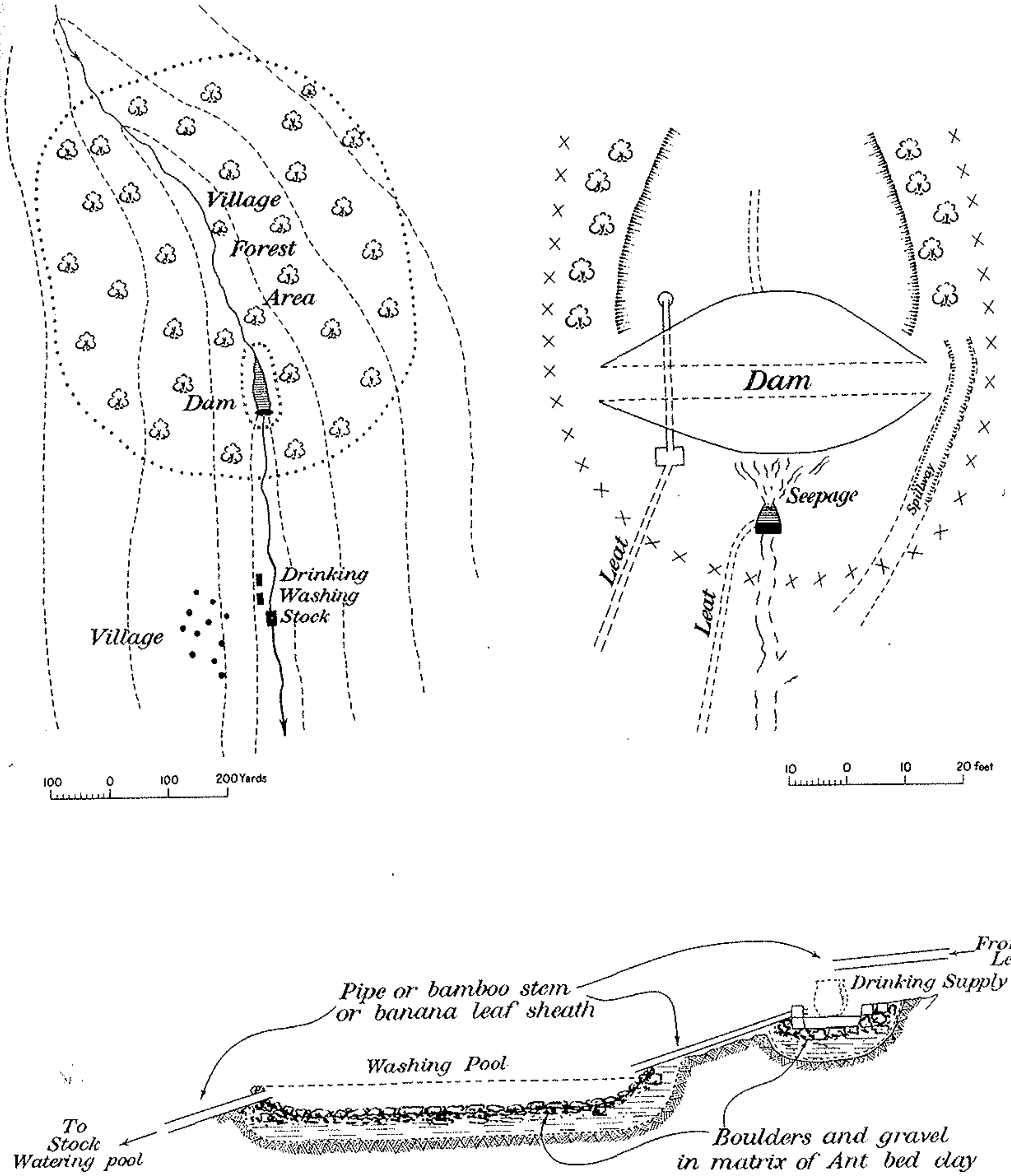

DIAGRAMS TO ILLUSTRATE MODEL VILLAGE
DAM & WATERING SCHEME

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hundred acres, is merely a matter of digging, and of very easy digging at that, towards the end of the dry season. The general principle is a tank at the lower end and a drain up the centre, with herring-bone drains off it if necessary; in many damboes the tributary drains are hardly required, the soil being sufficiently porous.

The tank should be shallow, say three or four feet, both for ease in digging and because the clay bottom must not be pierced. Its size depends rather on the size of the dambo, but since it should have a secondary purpose in providing fish, the larger the better. Referring to standard figures again, a tank 200 feet long and 150 feet wide would provide sufficient water, with the drains, for a reasonable supply of fish. To dig such a tank, involving about 3,000 cubic yards, is a fairly prolonged task, say the labour of 100 men for a fortnight, but its permanent value and comparative freedom from maintenance when dug is a counter-balance. The sides are shaped to a one-in-one slope, so that the water will everywhere be too deep for the mosquito larvae.

If the dambo has a steep gradient, the tank may fill and overflow at the lower end, while if the dambo has very little slope, the water level may tend to sink rather low in the dry season. For both eventualities the remedy is a small drain to the exit of the dambo. This must have a sluice, which can either be of wood of ordinary pattern or consist merely of sods thrown in or cleared out according to whether more or less water is to be allowed to drain away down the valley.

Such treatment of a normal dambo should have three beneficial results. The drainage of surface water into a deeper tank should deny breeding places to the *Anopheles* for most if not all of the year. The land near the edge of the dambo will dry out sufficiently to grow crops, and finally the tank, if large enough, may be a source of protein food. At the same time the dambo does not part with its general value as a reserve for the run off of the streams below it.

It should be clear therefore that conservation of surface water in dams and tanks can be so arranged that it acts rather as a preventive of disease and would receive the support of medical authority.

The case is not so simple for irrigation projects, yet these must ultimately become a feature of African agriculture if it is to keep pace with the expansion of population and the growing of marketable crops. On the other hand this is a problem which has had a great deal of attention in the past and needs no special reference here. From the point of view of malaria the worst crop is rice, yet it is one which will appeal to the African who is suitably situated with regard to water. Something may be done in the form of an injunction against planting rice nearer to a village than a specified distance, but it would be difficult to see that such an ordinance was carried out. For ordinary irrigation also an injunction against irrigation at night would be helpful, but this too needs a degree of supervision which cannot be arranged except in a few favourably situated localities.

For the ardent irrigating engineer there is some comfort, of a sorry kind, in the assertion of many of the doctors that that there is greater menace from a single stagnant puddle inside a village than in an acre of flooded ground away from it.

The full development of water resources touches the department of health at almost every point and requires the closest co-ordination of effort and understanding of aim on the part of the doctor and the water engineer. There are magnificent examples of such close co-operation between health and administration within a single district in a territory where the social welfare of the natives has had the greatest benefit. There are also instances in melancholy contrast where there have been strong divergences of opinion and appeals to higher authority, which rarely knows the local conditions, for a decision on priority. This is sometimes due to the personalities concerned, but more often it is induced by the tendency to work in closed compartments without mutual information as to the policies and aims of each section.

LEGAL ASPECTS

It is almost a truism to say that the older a country, or the more ancient its civilization, the more tangled is its water law. Conversely, the younger the country the simpler should be its ordinances regarding water, but this can only be so if legislators have taken early and wise decisions.

Most, but not all, of the territories with which we are concerned have already framed Water Ordinances or passed Water Acts which are well suited to the circumstances of their present state of development. One might cite the Water Act of Southern Rhodesia as an example which, in the main, aims at simplicity and justice, and except in certain minor points seems admirably adapted to that country's needs. Northern Rhodesia has for long had a Draft Ordinance which is now being amended in certain respects, while Nyasaland is about to frame one to suit her own special circumstances.

Since none of these can be really final, even though alterations are apt to introduce complications, no apology is offered for a section on the legal aspects of the development of water resources. It can hardly amount to more than comments by an observer who has had no legal training, yet who has had enough experience with water resources in different countries to be aware of the pitfalls presented by either too much or too little legislation. In a young country embarking on widespread development of all its resources there is perhaps nothing which can affect so deeply its rate of progress as a wise or unwise law concerning water. In general, unwise enactments are due more to the framers' lack of close experience of the manifold uses of water than to the oft alleged preference of lawyers for the devious and the circuitous.

For a pioneer country the first requirement in a Water Ordinance is that it should encourage the development of its water resources and not hinder it; its general tone as far as possible should be permissive rather than preventive. At the same time it must act as a safeguard of rights, whether of the native village or the settler or of the Crown itself. Finally, it should be as simple as possible, and need the minimum of machinery for its operation. It should be, in fact, the very opposite of some water ordinances which bristle with clauses denoting "Thou shalt not", which are ambiguous or circumlocutory in their language and which therefore invite the law's delays, counsel's opinion, and litigation in general.

Some of these characteristics may perhaps be inevitable in the laws of older lands where original ordinances have had to be constantly altered to accord with changing circumstances, and yet are hedged about with ancient rights, sacred customs and vested interests of all kinds. They should not be necessary for countries which are starting with a clean sheet.

There are certain fundamental principles which should be borne in mind in framing water law for pioneer countries, the neglect of which has certainly been responsible in some cases for awkward clauses.

The first of these is the distinction which, by its nature, is inherent between water as property and land or buildings as property. Although the ultimate source of water is rainfall, which might be said to accrue to the land on which it falls, the product is mobile and is immediately distributed by natural means or even artficial ones and soon leaves its original site. Consequently one cannot say that water belongs to the land it is found on or in, at least not in the same sense as in the case of soil, natural vegetation or minerals. To appreciate that this natural characteristic of water may have considerable force one has only to imagine the difficulties that would arise if top soils carrying crops were apt to wander downhill from one property to another.

This mobility, by the accidents of relief, fissures in rocks, or even the absorptive power of soil, does in fact bring greater water benefit to some lands than to others. Since these accidents improve the value of such lands, which appears in the price paid for it, there has arisen the convention that water may be regarded as part of the land property along with soil, timber, etc. Minerals under the ground and the air above it, have in the past often been regarded, in law, as in a different category to the soil and timber, and it would appear that water, as property, requires in practice a separate category also in recognition of its quality of mobility.

It is this commonly accepted principle, that water may be regarded as property attached to the land on which it lies, which is responsible for much of the difficulty in framing ordinances. It must be regarded as property in one sense since it has value, yet it is a property which may move away to other land or be stopped at source. In virtue of this it has somewhat the character of communal or public property and this must be recognised in the laws which regulate it.

Some at least of the difficulties in framing ordinances can be avoided if it be laid down as a premise that all water, wherever and however it may occur, is the property of the Crown, and that the Crown does not part with this property, but only with "rights of use". Such rights have a value which is somewhat similar to complete ownership in that they go with the land to which they refer and can be bought and sold with the land as "appurtenances" or "enhancements". Yet the scope of the rights can be defined precisely in the ordinance.

In many water acts the definitions of "private water" as opposed to "public water" give rise to difficulties precisely because water is in general moving off the land and can be withheld to the detriment of the owners of neighbouring land which in nature would receive some of that water. The use of the term "private water", in some of these cases at least, seems to refer to access to water on private land rather than to the water itself. In so far as this is so there is nothing to be gained by the phrase "private water", since lawful access can be regulated in other ways. Moreover, the private ownership of water must usually be accompanied in the ordinance by abatements to that ownership providing that if the water is not used beneficially by the owner the right to use it may be conferred on others.

On these and other grounds, therefore, it is arguable that an ordinance is simpler and more easily operated if it omits all definitions of private and public water by vesting ownership in the Crown.

All legislation governing the use of water must in some way specify different categories of such use. In Africa the usual categories are:

1. Primary use—for domestic purposes, including domestic animals.
2. Secondary use—for irrigation purposes.
3. Tertiary use—for power and other industrial purposes.

At the present stage of development of the territories these definitions are probably adequate, but it is easy to foresee circumstances under which they would have to be made more precise.

For instance, primary use as so defined in relation to domestic animals may be held to include herds so large that they are beyond a subsistence value and are just as much a means of profit as are crops under irrigation. On lands where water is limited it might be necessary to specify more exactly the limits of primary use for stock.

Similarly, the secondary use of water for irrigation must obviously be related to the amount used and may require further definition distinguishing between irrigation for subsistence and irrigation for profit. Some such distinction will, in any case, be easier to regulate than that implied by the term "beneficial use" which occurs in some ordinances.

Such modifications of definition and further distinctions as to the use of water may be left to the foresight of those who frame the ordinances, and we pass now to a fundamental corollary to the suggestion that all water should be the property of the Crown.

Under the acts which define private water as giving sole and exclusive use to the owner of the land there is nothing to prevent that owner from selling the water, since he owns it while it is on his land. Usually the amounts of such saleable water are so small as to need no specific treatment in the act. But there are cases, which may well increase in number, where such ownership of private water for sale may be of far greater value than the land on which it occurs and may even reach the status of a monopoly. For instance, a large supply of water from a spring (which is usually included as private water) or from a mine is of great monetary value if it occurs near an urban centre, and some form of legal control is required. If the water is defined as privately owned there are difficulties in the framing of such control. On the other hand, if all water is the property of the Crown the requirement of a licence to sell is implicit, and royalties or other necessary conditions are automatically applied.

Considerations such as these occur naturally to a visitor to these territories who has come from other countries where water for secondary and tertiary use is almost invariably paid for, and fully regulated. Such arrangements will come into practice in due course in Africa and it would be as well for the water legislation to foresee and prepare for them.

It should be realised that such firmer control of water by the Crown as is recommended by these means is not a hindrance to the development of water resources, but is designed to bring such resources into line with others, such as forests, communications, minerals, etc. All the territories spend large amounts already on water development and should spend more still, but very little of it produces returns in the form of water rates. A rate charged on the primary use of water would be out of the question in normal circumstances, but for secondary or tertiary uses it should be more or less axiomatic; nor is it an abatement of the privilege of ownership of land if the rate is fixed in relation to the cost of water development and control by the Government.

There are two physical features in Africa which must be kept in mind when the legal aspects of water development are being discussed—namely, the damboes, or swamps, and the sand rivers. It has been shown elsewhere in this report that the treatment of swamps is one which requires firm control lest ill consequences follow, yet the typical dambo is so small and so widespread in some territories that local inhabitants might easily consider them as their own for any treatment they desired. Permissive powers must therefore be held by the Government as to such treatment, powers again which would be easy to exercise if all water belongs to the Crown, but inviting difficulty if it is regarded as private property. In the case of sand rivers, on the other hand, which usually occur in drier and predominantly pastoral country, private ownership may easily prevent their proper development as a source of water for stock far beyond riparian land.

Lastly, the legal aspect of water resources is closely bound up with all the other relations affecting white settlement and native reserves. In some territories these water problems have already achieved an unfortunate notoriety and they are likely to appear in all in due course. It is submitted that here again the conception of all water as belonging to the Crown as against that of private ownership should at least simplify whatever legislation is required to carry out the policy chosen. It must be accepted that in process of time the native will acquire the knowledge and experience to use water for irrigation as does the European and that laws must be framed with that future development in view.

To the European settler, who is usually energetic and farseeing enough to develop the water on his land, the ordinances must lend encouragement in every way short of granting exemptions from the fundamental restrictions. It has already been explained that in countries with a pronounced wet season every check weir or work of any kind which holds water back is in effect an improvement to the land lower down the stream. Even irrigation projects when they are small in relation to the total discharge of the basin act as an improvement.

A water ordinance should therefore empower its board to reward any enterprise which does in fact benefit the country as a whole, while reserving in the background certain sanctions against those who work in the other direction.

NATIVE CO-OPERATION

The native tribes of the territories differ so widely in habitat, in customs and in state of development that it is impossible to treat them alike under this heading. Some, like the Chagga of Mt. Kilimanjaro, were water-wise even before the white man came to Africa; others are so backward that they seem to have no glimmerings of common sense about saving or using water.

The suggestions made in this section must therefore be applied not as a whole but only where there seems some prospect of value to be gained.

It has often been remarked that since the African has but recently emerged from an age when tribal wars and slave-raids were chronic we must not hurry him along roads which are strange to him; and that we should not expect those tribes which are lacking in a communal sense to swing over to co-operative effort within the space of a generation.

It is true that it is little more than sixty or seventy years since the population of much of Central and East Africa was largely divisible into the two categories, the Slavers and the Enslaved, or more accurately, the Raiders and the Raided. Even though this lasted at its most intense phase only for about fifty years, its effects sank deeply into the tribal outlook and character. Yet to a visitor for the first time, who had read of these unhappy results, the general impression is that the African is, on the whole, willing to walk along the new road, has already come some way and, in many respects, needs little urge to hurry.

It is sometimes said that the native needs more education before he can fully co-operate in what is really his own salvation. It might be said with equal force that in material matters such as the development of water resources, what he needs is more demonstration of what can be done and more invitation to join in, more emulation of those who have advanced.

In the past it was usually necessary for the Government to go the quickest way to work in providing water supplies by bores, masonry lined wells, sealed-in pumps, and so on, all of them beyond the capacity of the African and often beyond his understanding. One cannot fully acccept the statement often heard that the native is lazy and complacent even over his scarcities and is all too ready to stand aside and let "Government" provide his water. It may be suggested that he is at all events not inherently so but has been constrained to lack co-operation because generally he is quite unable to co-operate in such works, except as a labourer. A stage in development appears to have been reached when the native leaders, whether ranked by status or intelligence, might be given a far more direct encouragement to join in both the responsibility and the practical operations.

There are two cogent reasons for this: the one quite a material one—the reduction of cost—and the other a psychological one—the sharing of responsibility and appeal to their sense of pride and satisfaction, even if that sense be somewhat latent.

In this report there are recommendations for action on two different scales which may be called the public utility scale —large conservations or drainings—and the village scale. It is on the village scale that it is suggested that more co-operation might be sought. With but a brief knowledge of the territories I could not detail the exact means which would be appropriate for seeking that co-operation. I would imagine, however, that there are always two main methods. One is the personal appeal and advice of the district commissioner, backed as it has so often been with admirable results by that delicate hint of "I shall be displeased if you do not carry this out", which has so often benefited the African in spite of himself, and yet does not offend by being a coercion. The second method, already proved to be an efficient one in some fields, is that of example. If one headman or chief can be cajoled into some communal action which is easy to see and understand, and if others can be shown the beneficial results, the spirit of emulation or envy—for no doubt both operate—may well work wonders.

This suggestion is intended to extend beyond the excellent method of native authorities and native treasuries to be seen in many places which, under advice, originate and carry through work which is paid for. Good as it is that method is still apt to leave too great a gap between the people who do the work and the people who benefit, and to neglect the natural inclination of a community to help themselves by doing the work without any money payments. Most operations for water development benefit the whole community just as obviously as does the cutting and maintenance of a road, and where, as in road making, it needs nothing but labour and their own tools, it seems an ideal type of operation to be done on an entirely voluntary communal basis.

Nor is such a voluntary basis by any means a new thing to most tribes, however much affected they may be by the more civilised attitude that all work should be paid for in some degree. Hunting and war, for instance, have in the past been largely communal, or at least without pay except by the spoils. Whether the benefit of more and better water can be represented to villages as the spoils of work remains, I imagine, a problem for the district officer. At least it should not be treated as a new or foreign idea to the African, who is in many respects in the same stage as we ourselves were less than a thousand years ago, when village activities from harvesting to hunting, from digging leats to improving routes, arose as often from communal enterprise as from feudal commands. One is indeed compelled to say that just as such concerted action improved our national character in those days, so it should operate on the native African who, now that the white man protects him from war and famine, is all too apt to sink back into an isolation and independence of village or family which the world as a whole, and Africa in particular, cannot afford to encourage.

Granted that the capacity for such communal effort be there, though latent in him, the African does need advice and, in certain operations, supervision. This naturally leads to the consideration of the training of natives in all the simpler operations required for water supplies. What is being done admirably for agricultural advancement in several territories should, I submit, be done for water development—namely the holding of courses of training in the ordinary type of work required. This must gradually produce a number of competent operators and supervisors who, whether they are ultimately employed by governments or native authorities or merely return to their villages, would provide a nucleus of water-wisdom and experience of the greatest value. The cost of such training courses should be small in any case since, while training, the classes are producing works of some value, but it is not a matter for profit and loss argument, it is far too fundamental for that.

If we take, for example, the time-honoured method of the native himself for water supplies—well-sinking—we find at once that a comparatively simple training in the, to us, well known methods of sinking wells through loose ground and lining them, would quickly put the native in a different world for his water supplies. It is almost incredible the extent of land where water is known to be within twenty or thirty feet of the surface by the native himself but which experience has taught him to leave alone because he cannot deal with the sand which inevitably rolls in on his work if he sinks beyond a few feet. Well-sinking and well-steining is a craft well within his powers, but it must be taught. The same is equally true of the small-scale earth dam, which indeed he could always build fairly well, but he could never see that a dam without an adequate spillway is bound to be washed away in the next rains.

Drilling for water comes into a different category altogether, but the very fact that there are now a number of native capitãos who have worked in drilling-crews and are capable of putting down a simple bore-hole shows what the native can learn if he likes.

The training courses under discussion would not normally include drilling, but be restricted to fairly short courses of six months or so in well-sinking, contour ditching, small weir construction, etc. There would soon be men from the initial course with the capacity to go further and learn something about siting of wells, measurements of stream discharge and setting out work for weirs or irrigation schemes, or the simpler uses of water as power. If possible the native authorities should be closely linked with the training courses, even to the extent of providing some of the money, perhaps on token terms only, for sending a representative to the course, who would in that case return to the district and become available as a foreman or minor supervisor of the work being done under the authority.

In other words, the basis of the scheme is to provide a number of reasonably qualified men for the development of water resources by the natives themselves rather than to produce more and better teams for the Water Department. It is in fact a step in the direction of enabling the native to help himself instead of sitting back while the government provides the water by its own magic means.

The psychological effect of calling upon the African to help in working out his own salvation is not new or mysterious, for it is evident already in other spheres, such as coffee, tobacco and cotton growing, in fisheries, and to a minor extent in simple carpentry. Against these successes in participation in the white man's assistance towards development one may set many cases where there has been next to no reaction in that direction. The classic case is that relating to hand pumps for well water. Most engineers in Africa will say that there is no known form of pump which the native will not break, and that to design the unbreakable pump for native use is on a par with squaring the circle. Before we join in the chorus of blame for such a state of affairs and speak of a complete lack of intelligence in the African, we should do well to remind ourselves of our own failings over such things as wireless receivers. The average wireless servicer or expert will say precisely the same thing of the normal owner of a set, that he breaks his set through lack of common sense as to what a condenser is for or what amplifying means. In their differing degrees the reason for being clumsy is the same in each case. The average native woman, for instance, has no conception of the principle of the lever and not much of the wheel, so it will be merely amusement or variety for her to turn the wheel backward, or overload the pump handle till it breaks. Still further beyond her mental grasp is the idea of suction bringing the water up the pipe or the function of valves; the whole contraption remains a white man's magic and if it breaks down there is no help for it, at least not from black brains and hands.

On the other hand, after seeing the craftsmanship of some native carpenters and motor mechanics one is loth to accept it as an axiom that the African is unhandy and unintelligent with tools and mechanisms. Obviously he can learn—why then does he not begin to apply his learning to his village life?

Here we come up against much more fundamental reasons than mental capacity, and some understanding of them is necessary if the development of water resources is to go smoothly. Governments cannot go on for ever providing facilities for water to be misused by natives, nor is it wise to plan large schemes, as for irrigation, to benefit the natives if they are not going to accept the benefit.

At any sundowner party in Africa when the conversation happens to light upon the subject of native ineptitude and lack of initiative, one hears a dozen reasons for it. We must allow for the white man's exasperation which drives him to use unhelpful adjectives for the native, such as "bone-lazy", "primitive", "congenitally ham-handed", and so on, especially as the same white man in calmer mood will speak of his boys' essential loyalty, considerable degree of honesty, and occasional forethought. More thoughtful members of the party will qualify the African deficiencies by adding, "Why should he work, why should he think, why should he join in the mad scramble for progress?" Or they may indulge in clichés such as ascribing it all to the essential conservatism of the native women, or to their chronic state of latent malaria or other diseases sapping their vitality, or asserting that he is not yet grown up. The still more thoughtful will introduce historical and anthropological arguments, pointing out that the Bantu is still potentially a wanderer over the face of Africa, that he has not yet recovered from the sense of insecurity which made him a wanderer, either warring or warred upon, or that he still has the slave mentality.

It has to be admitted that most of these assertions have a measure of validity. They can be regarded as contributory causes in varying degree, and it is not for the passing visitor to enter the lists with any firm assertions of his own, yet he is able to cull something from such conversations and combine the impression gained into a general hypothesis. He cannot but observe that the African lacks the contemplative faculties of the Oriental; in other words, he does not sit and think, he merely sits. His conversation with his kind is rarely true debate, it consists of statements of fact, or fancy, and its object is to entertain rather than to convince. Nor has he the instinct for business and love of barter that is so fundamental in the East. The idea of amassing personal wealth is, on the whole, foreign to him; personal property is something to him, and so is family property, but on the village scale his ideas are more communal. The money lender or food hoarder of the Asiatic village appears to be almost unknown amongst the Bantu either because such practices do not appeal to him or because such a character would have short shrift.

To be fair one should not think of these attributes only in the negative sense of something lacking, for they imply something positive also, something kindly. He may not do much thinking, but neither is he a plotter or an agitator; he does not haggle and hoard, but neither is he out for selfish personal gain at the expense of others. He is, in fact, much more apt to share than to cheat, and his object in life is contentment, not competition.

We can apply some of these characteristics, with caution, to the question of progress in general as we understand it, and to the development of water resources in particular.

The African usually prefers to use his muscles rather than his brain; labour he understands and even enjoys in company, but the idea of saving labour by a little forethought or planning does not come naturally to him. The best illustration of that is the story of the contractor who bought wheelbarrows for his labourers only to find they carried them on their heads. The women are even more conservative and it would never occur to them to dig a furrow to bring water to the village to save their daily walk to the stream to carry water in their pots. On the other hand, if it occurred to someone else the women would appreciate the saving of labour.

The fact of the matter is, they have a reasonably ordered life, now free from warrings, and there is no particular urge to make it easier, or to make it pay better. However, the thin edge of the economic wedge has been inserted, and when consumer goods are available the expectation is that the native will want to become a producer in order to buy them. In other words, what has happened in the more developed parts of nearly all the territories will spread to the villages away from the railways and main roads, and then, but not till then, will the African want to be shown how to obtain more water for his stock and crops.

HYDROLOGICAL SURVEYS

The frequent references throughout this report of the lack of data concerning water resources, however true, are not very helpful, and some suggestions towards a remedy seem to be called for.

A scarcity of measurements is inevitable in the case of territories which are still in the pioneering phase of development, and is not primarily due to lack of official support so much as to a dearth of funds, of instrumental equipment and of specialist officers.

Nor is it likely that in the immediate future there can be any marked increase in the official means of measuring and recording the data required, even where it is realised that in the long run it may save expenditure on a multitude of of specialist surveys.

In countries so dependent upon rainfall it is natural that attention has been paid to this aspect of climate. Some territories are reasonably equipped in the meteorological branches, others are only beginning. Climatic data, however, are always interesting and there is no doubt that the authorities are anxious to extend their records as funds permit. It is not only a matter of funds, however, since the distribution of recording stations depends mainly upon the location of bomas or administrative centres, which cannot be based upon such things as the need for climatic study.

To a certain extent it is possible to say that meteorological records, especially of rainfall, are as comprehensive as can be expected and will steadily grow in number and value. In many respects it is the collection and co-ordination of past records, including 'unofficial' ones, that is a more urgent need than the amplification of stations.

There are, however, other types of hydrological data which are more difficult to obtain and are of more immediate importance to any schemes of water development. These concern both surface and underground water and, in one form or another, come under the general term of 'yield' or 'discharge' of all types of supply, rivers, streams, springs, wells and bores. Except in the last category, that of wells and bores, which are usually proved or measured by the engineers who have sunk or drilled them, there is an almost complete absence of discharge measurements in Central and East Africa.

On the other hand, there is a great deal of local knowledge about water which is related to discharge in one way or another, such as the length of time for which a stream runs during the dry season, the number of people supported by a spring, the dates at which game forsakes a certain area, and so on. Amongst the settlers there are many shrewd observers of such things and a large number of administrative officers also become keenly water-conscious about their districts.

Here, then, is a first step towards a hydrological survey, namely, the collection of this information which can be had for the asking.

The best means of obtaining such data must be left to the territory concerned, but the general suggestion is that it might begin with a questionnaire, in simple form, directed to all settlers. It would ask for information on such matters as:

- Private wells and bores and their yield.
- Surface dams and weirs and their performance.
- The duration of flow of streams and estimates of their discharge.
- Flood data.
- The existence of springs and seepages.
- Records of rainfall and climate.
- Miscellaneous information and suggestions as to resources.

If this preliminary enquiry were conducted in a reasonable way, explaining why the information was being sought, there can be little doubt that the majority of settlers, whose livelihood largely depends upon the development of water resources, would give freely of their intimate local knowledge.

The assistance should, however, be mutual and there should be sent with the questionnaire such data as were already available concerning the district, in the form either of a map or of a table of rainfall data. This exchange of information should convince the recipient that it was co-operation that was being sought and not merely an 'official return' with all the implications of that term.

The enquiry should also ascertain how far the recipient was prepared to continue or amplify his observations on rainfall, height of water table, etc.

The response to such a general appeal might not be universal, but it would be very sincere in a large majority and the results would be of considerable value. For the native reserves the same general information would come in more slowly via the district officers. A pamphlet recently printed in Northern Rhodesia, entitled "Notes on Water Reconnaissance", was written for the purpose of guidance in the simple measurement of water resources, and if this were distributed to officers and settlers who asked for it their interest in the matter would probably be further stimulated.

It must be realised that the data thus obtained would be of minor value until they were analysed and correlated, and that means the services of an additional officer in the department concerned. Even so, the scheme represents a very inexpensive way of obtaining a great deal of information. In that connection it should be remembered that during the war many members of the W.R.N.S. and the W.A.A.F. were trained in meteorology and proved very capable at the same type of work as this would be. The collection and analysis of these water resources data might therefore be entrusted to a woman, preferably a University graduate, who had had some preliminary training in related subjects. Since the work involves the use of distributional data on maps and some knowledge of climatology the officer required would probably be found from a department of geography.

It is strongly recommended that the authority responsible for water development in each territory should consider some such means of collecting the available data and thus using the considerable amount of knowledge concerning resources which is at present hardly tapped. If the officer responsible for the enquiry were also allowed to visit the various districts he (or she) would probably be able to spur the amateur observers to further useful measurements. As the "Notes on Water Reconnaissance" endeavours to show, there is no reason why stream discharge measurements of real value should not be made by anyone with a moderate amount of ingenuity and with the simplest equipment.

In my tour of the different territories perhaps the most striking thing was the existence of many specific problems concerning water which could not be tackled or even properly outlined because of the lack of data concerning them. Some of these are mentioned in the report, such as the recurrent flooding of the Bangweulu Swamps, the 'cyclical' rise and fall of lakes, drainage problems of the Okavango, navigation problems on the Zambesi, and so on. The first necessity in nearly all of these is a reconnaissance survey, and in the majority of cases this survey does not call for highly qualified engineers and surveyors in the first instance.

They involve visits of some duration to somewhat inaccessible places by young men who will not be deterred by difficulties and minor hardships, who have sufficient knowledge to use survey instruments and make simple hydrological measurements, who are interested and energetic and who possess what might be called the expedition spirit.

Now these are qualities which are possessed by a proportion of graduating university students to a marked degree, and in the recent past they have sought an outlet in short expeditions of one kind or another, often to the polar regions, which have been supported by university and college authorities as well as by the Royal Geographical Society.

Africa has already benefited from slightly more senior expeditions for specific purposes, e.g., fisheries, geology and anthropology. In the case of hydrology, however, there is no one department which can be called upon, since it is not as yet an organised subject in university curricula, yet the right kind of man can readily be found from departments of engineering, geology and geography. Such men should have had sufficient practice in field observations of one type or another, especially of the more rapid types of survey, to enable them to turn very easily to the specific measurements required. Moreover, the benefits would be mutual, since the men are seeking experience in the field as well as an outlet for their energy, while the colony requires preliminary figures and reports for which they cannot spare their technical staff. Generally speaking, the expedition would bring up-to-date instruments and methods to the work, while the territory would furnish facilities as to transport and local help, and in particular an officer who would be in charge of these matters. The type of problem which might be attempted varies very much, from what might almost be called exploration standard down to something nearer a routine survey, which in Africa cannot be called dull or humdrum work.

Thus a hydrological traverse of the middle section of the Zambesi is urgently required, for a variety of reasons, yet it is a task of some magnitude and some hazard, not to be undertaken lightly. With a good leader of local experience, however, a small group of three or four men, properly equipped with transport and instruments, could, in a single dry season, produce a survey and report on potentialities in a very satisfactory preliminary way.

At the other end of the scale one might mention as an example the preliminary mapping and levelling required to ascertain the irrigation possibilites of a small area such as the Taveta district in Kenya, the Mlanje district of Nyasaland or parts of the Ruaha watershed in Tanganyika Territory, work which requires energy and interest rather than judgment and experience, and could be done in a period of two or three months. Discharge measurements of rivers would be one of the regular duties of all these expeditions and they would leave gauge stations at suitable points which could be read at intervals by local people to extend the period of observations in the way essential in all hydrological surveys.

The matter is already receiving some attention from the Colonial Office end and the purpose of referring to it in this report is to call the attention of colonial administrations to the possibility of obtaining by this cheaper method the kind of preliminary surveys without which no professional engineers can advise them fully on projects of water development. One might go further and add that each territory has amongst its officers men who are themselves of the expedition temperament and who would make entirely suitable leaders or local liaison officers for a group of technical but inexperienced visitors. If such could be seconded to that duty for the required period there would be no risk that the real purpose of the expedition would be subordinated nor of any misapprehensions on the part of the African population as to what was being done.

One cannot omit reference to the part which can be played by the central advisory councils on research which is in process of establishment in East and Central Africa.

In so far as their function includes scientific matters which are of wide extent and application, beyond the boundaries of any one territory, their attention would naturally be drawn to such things as the co-ordination of climatological work, the inception of surveys such as the one just mentioned on the middle section of the Zambesi, or even the more routine work of seeing that information on water resources obtained in one territory was available to neighbouring ones.

In some of the biological problems, for instance, that of the tsetse fly, the research is so obviously appropriate for combined action that there can be no question as to the propriety of its being co-ordinated and even controlled by a central authority. The case is not so clear with regard to problems of water development, which at first sight would seem to be the whole duty of the individual territories concerned.

Yet there are certain aspects of hydrology which can hardly be dealt with by a technical department in a colony, aspects which come under the category of general research and therefore should be dealt with by some central body. It is not suggested that such a body should undertake fundamental research, which is best left to large and well-equipped organisations in Europe and America. On the other hand, there are several problems of a general nature which can only be investigated for Africa under African conditions. One may instance such unknown quantities as the relative rates of evaporation from water surfaces and swamp surfaces, the part which swamp vegetation plays in natural conservation, the rate of seepage in sand rivers, the origin of 'brak' soils and so on.

Again, the over-riding importance of climatology in any study of water resources might well be recognised by having an officer attached to a central research body whose whole duty was the interpretation of the meteorological records of the associated colonies amplified by special stations, probably temporary ones, required to fill gaps in the records, and a great deal of travel.

It may be remembered that the Australian Government for many years found very useful employment for such an officer, who was called the Chief Physiographer to the Commonwealth. His work on the climatology of Australia and his deductions as to its habitability and resources remain a standard of reference which is in constant consultation.

Other directions in which general research should be undertaken could be mentioned, but enough has been said perhaps to show that as the work of the advisory councils expands it will be found that attention to problems concerning water will be urgently required.

A final word may be said as to the type of technical officer required for assessing water resources. As already pointed out in the chapter on Organization there is as yet no clearly defined training for a hydrological expert. He may begin as a geologist or an engineer or even a physical geographer, and except for the fact that he must be a field scientist he might have still other origins.

It is, however, necessary for him to have a wider view than his original training would, of itself, give him, since he is concerned not only with the existence of water, but with its potential uses. He therefore finds himself called upon to estimate social, economic and even political values in his work, and these judgments may often be of greater actual importance than his purely scientific training in finding or measuring water.

PART II

1. BECHUANALAND PROTECTORATE

IN THE PAST several factors have tended to make the Protectorate less known and more remote than any of the other territories included in this report. For instance, its vast area, 275,000 square miles, which is exceeded only by Tanganyika Territory and Northern Rhodesia, and its low density of population, less than one per square mile.

Then there is its inaccessibility by normal means of travel, and in this respect it is almost unique, for the railway line from the Cape to the north passes inside its eastern border for nearly 400 miles, so that nearly everyone resident in Central Africa has passed "through" the Protectorate, though only one in a hundred thousand has ever stopped to have a look at it. Those who do stop find that travel towards the west, away from the main road, which closely follows the railway, is difficult for cars at any time and impossible at certain seasons. The names which are used for the vast plains which stretch away to the west as the passing traveller makes his comfortable rail journey are themselves discouraging—"The Kalahari Desert", "The Great Thirstland", and so on. He is unfavourably impressed by the infrequency of stations on the railway line, the numerous small bridges passing over dry rivers of sand, the rarity of native villages. Knowing that the railway line passes through the most populous part of the country he wonders, with some reason, what measure of aridity and dreariness he would find if he were to go into the heart of the country. Nevertheless, the discerning traveller will notice many things which incline him to amend his first impressions. He will be amazed at the luxurious growth of grass in the rainy season and equally surprised at the good condition of the stock in the dry season when there appears to be no grass. He will balance the scarcity of population against the fact that the people he does see look healthy and contented and, on the whole, fairly busy, for Africans. Should he have the opportunity to discover it, he would be most agreeably surprised to find a fair proportion of them able to speak and understand English, while if he met one of the senior chiefs he might find himself listening to English as good as his own. He will also make the correct deductions from the fact that he sees very few white men in authority. Firstly, that the people are so law abiding that a police sergeant may run thousands of square miles of country separated by 150 miles from his nearest district commissioner. Secondly, that such scarcity of white men in authority, especially on the technical side, cannot be wholly intentional but is due to the lean resources of the Government.

So, on his long journey from Mafeking to Francistown, the observer will note a number of brighter patches in an otherwise somewhat monotonous picture. The pleasant little township of Lobatsi with its surrounding hills and its imposing and efficient hospital; the welcoming atmosphere of Gaberones with its fine little hotel and the hint that only three miles away is the "Camp" with a happy community of at least fifteen European families, the picturesque and progressive centre of Mochudi looking down on the almost perennial Notwani River. The somewhat ominous name of Artesia and its rather forbidding flatness will at least be lightened by the thought that there is water below the ground if not above, while at his next two stations, Mahalapye and Palapye Road, he will notice something approaching a bustle of stores and centres for P.W.D. Agricultural and Veterinary depots, and will be duly impressed by the information that thirty miles to the west of Palapye lies Serowe, reputed to be the largest purely African town south of the Equator with a population approaching 30,000. At Francistown he will detect a stronger element of settlers and miners in the bystanders since he is there in the Tati Concession for farms and gold mines, and will conclude that the wide sand river passed over near the town, the Shashi, must on occasion run deep and strong.

In short, this not altogether imaginary traveller of discernment will cross into Southern Rhodesia near Plumtree with considerable regret at having seen but the fringe of an interesting country and wondering how far those romantic names of the Thirstland and the Kalahari Desert are really appropriate.

We may go behind the scenes for a moment and say that had he seen the western half in the dry season he might have agreed, but in the wet season he would have resented the term "desert". He would have remarked almost everywhere the extreme sandiness of the soil and absence of surface streams. On the other hand, if he had gone to the north-west he would have seen so much water that he would have dreamed vain dreams, with the late Professor Schwartz, of watering all the Thirstland with its surplus. He would in fact end by considering that here indeed is a country with great opportunity, but that that opportunity is very thoroughly obscured by sand, by distance and by backwardness. Probably he would also say that it was the black man's opportunity, not the white man's, albeit unattainable without the white man's help. Moreover, he would recognize that it was marginal country, that is to say only capable of development if strict control were maintained, for any misuse of the land would bring on truly desert conditions.

It is probably not unfair to say that the Protectorate has suffered from an excess of large-scale projects, promoted and reported upon by outsiders, while the more humdrum job of getting on with development on a practicable scale has been left to a very small group of administrators and technical staff with very small resources behind them.

However that may be, the author of this report considered these larger projects, mainly concerned with the north-western rivers and lakes, as already sufficiently explored for the moment, and though comments will be found later in the report, he regards a general development of far smaller scope as of much more present value.

The natural divisions of Bechuanaland Protectorate

Rainfall, relief and soil combine to suggest a three-fold division of the Protectorate for the purpose of planning developments.

I. The Eastern Zone, which might equally well be called the Railway Belt since it comprises a strip of country from 30 to 80 miles wide bordering the railway.

Its rainfall is uncertain, but the average over a period of years is round about 20 inches, decreasing rapidly towards the west. Serowe, for instance, only 30 miles west of Palapye, has only a 12-inch average compared with Palapye's 18 inches.

This belt is almost the only part of the Protectorate which has rocky hills, sometimes grouped into actual low ranges, and consequently it has well-defined river valleys, some of which have streams which are perennial in any but drought years. In the rainy season most of these streams have impressive discharges and there is a sufficiency of promising sites for reservoirs to encourage a policy of surface conservation, which has already begun in the south-east, at Kanye and near Ramoutsa, with irrigation as part of its object.

The fertile Kalahari sand has drifted over the railway belt, and in its central section it is deep and in the form of large low dunes, which are now fixed and stable. The soil therefore produces a pasture which is quite astonishing both in amount and in quality, rivalling and probably excelling the famous grasses of some of the mid-western areas of the United States or the back-blocks of New South Wales in Australia.

This excellent pastoral country has two great drawbacks, the lack of watering points for the stock and the prevalence of cattle diseases, the latter being partly due to the former.

The natives are naturally pastoral people and seem to be amenable to instruction in pasture management and the principles of breeding to a degree hardly found elsewhere in Central Africa. Subsistence crops are grown throughout the zone, and in certain parts surplus crops for profit are possible. The Bakhatla in their reserve round Mochudi, are particularly skilful farmers, while the Bamangwato, further north, are but little behind them. The crops, unfortunately, are often badly delayed or even destroyed by winter frosts, and are therefore a somewhat uncertain element in the economy.

II. The Central Zone of the Kalahari. This is a very wide belt, occupying some three-quarters of the Protectorate, which has in the past received the names of Desert and Thirstland. It runs from the extreme south-west right up to the Zambesi border in the north-east and is bounded on its northern and western border by the line of the Chobe river, the Thamalakane river, Lake Ngami and the Ghanzi district.

Its rainfall is so unreliable that average figures mean very little, ranging from 5 inches to 10 inches. It has few hills and is more or less uniformly sandy. There are, however, very few areas where the sand is moving at present, and it is not true desert, though most inhospitable for lack of permanent water. Towards the south-west it is probably incapable of much development, but in the central part, circling the Makarikari depression, there are opportunities.

The very fertile sand produces a nutritious but rather thin pasture, and with a sufficiency of watering points much of it will carry stock at from 15 to 40 acres to each beast.

It is therefore definitely marginal pastoral country at the best, and development can hardly go beyond the provision of secure stock routes crossing it from the north-west division. It is difficult to cross with motor transport, the sand being heavy in the dry season and the patches of soil with humus in the depressions being impassable in the wet season.

There is, of course, a great deal of underground water, since the sand absorbs up to 90 per cent of the rainfall, and though some of it is brackish a vigorous programme of well-sinking can do much for the comparatively few inhabitants.

III. The North-west Division. This triangular area, bounded as mentioned above by a line running from the Chobe south-westerly through the Ghanzi settlement area is for the most part quite different from the rest of the Protectorate, and presents possibilities for development of an unusual order.

In the district of Olifants Kloof and Ghanzi we are still in marginal country, but the Okavango-Chobe area not only has a better rainfall, of an average round 20 inches, but receives an enormous quantity of water from outside the Territory. The question in this division is therefore mainly one of drainage, directing the water to useful areas rather than finding or storing it.

The Sources of Water

The Protectorate is unique amongst the territories in having practically no rivers, though there are a multitude of dry and rather ill defined water courses which run furiously for a few days in the year. Of the few streams which are sufficiently perennial to deserve the name of river, the Notwani, in the extreme south-east, is the most important. Some of its watershed lies within the Union and for a few miles it forms the boundary, but three-quarters of its watershed above Mochudi is within the Protectorate.

Allowing a mere 2½ per cent run-off for this partially sandy country the mean rainfall should produce an annual discharge equivalent to about 100,000 acre feet. Such a figure shows that while irrigation on any large scale may be out of the question, there should be enough to develop intensive agriculture for export, especially in the Bakhatla Reserve.

This has long been foreseen and plans are well forward for a major reservoir in the vicinity of Ramoutsa, where the river is the boundary. The site chosen, subject to proving the foundations, is a good one and considerably more water could be held up here than is really required for its vicinity. Before the plans are finally passed, therefore, it would be well to consider the Ramoutsa dam as part of a general treatment of the Notwani, the remainder of the plan being left for the future.

Thus, there is much to be said for having a large reservoir here, a portion of which is to act as reserve for the lands much further down the river in the Mochudi area. The extra requirements would be mainly to raise the height of the dam and provide a sluice. The subsidiary dam for the Bakhatla Reserve would then be a wide, low, earthen bank in the neighbourhood of Pilane, giving command for a large area of unusually good land beyond the Mochudi hills.

A still more promising site and river is the Marico at Derdepoort, which certainly invites a survey. The Marico, which ultimately becomes the Crocodile River and then the Limpopo, is the boundary, and the reservoir would therefore serve both the Union and the Protectorate.

There are two other rivers in the Eastern and Central Divisions which merit further survey with a view to surface conservation. They are the Shashi, running close to Francistown and emptying into the Limpopo, and the Nata river, running into the Makarikari depression. Both are purely seasonal sand rivers, but they pass through and over rock bars in places, so that sites for reservoirs are fairly frequent.

Calculations from the data for the rainfall, such as they are, and the area of the watersheds show that, allowing only 1 per cent run-off for the Nata river and 2 per cent for the Shashi above Francistown, their mean discharges should be about 40,000 and 100,000 acre feet respectively.

In point of fact both these rivers are deep sand rivers and peculiarly suited for conservation by the sub-sand reservoir method described in an appendix. The time is certainly not opportune for the building of expensive dams on these rivers at present, but the cheap sub-sand weir would make a great difference to the habitability of the otherwise very attractive country of their watersheds for pastoral economy. This is particularly true of the Nata river where the track to Maun crosses it at Madsiara Drift. With watering points, this country should certainly carry a beast to 15 acres, with subsistence crops for the natives herding the cattle.

The Makarikari Depression itself must not be omitted in any long-term planning. It covers the vast area of some 3,000 square miles and consists of large salt pans in the lower parts, some 100 or more feet lower than the ill defined edges of the depression. In the higher parts there are large areas of what would be called black cotton soil elsewhere which would be cultivable if drained. The almost complete absence of population near the depression, especially on the northern side, is due to the impermanence of the streams and the lack of water, even though it can be found almost anywhere by sinking wells to a very slight depth. There is as yet very little pressure of population anywhere in Bechuanaland Protectorate, but when it does make itself felt the Nata River district will be a most promising settlement area.

Leaving considerations of the Botletle River till later, since it belongs to the north-western division supply system, we have now mentioned all the rivers which can hope to support any large-scale surface conservation. On the other hand, a comparatively large number of other seasonal streams have a considerable depth of sand in their beds and are very

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suitable for sub-sand reservoirs. It is necessary to stress this point because if as seems likely, a cheap method of inserting sub-sand barriers is made available, every sand river will become a string of water points at small expense and that is the first requirement for an increase in the cattle population and the introduction of pasture control.

There remains, however, the vast central or "arid" division which has few stream beds of sufficient relief and gradient to permit sub-sand conservation. Here it is the sand itself which is the conservator and below that large area there must be large quantities of water.

The rainfall is extremely uncertain and local storms may flood a few square miles while neighbouring districts have little or none. A great part of such a downpour, probably up to 90 per cent, sinks into the sand and we have to inquire as to what happens to it then. In the deep Kalahari sand most of it will sink below the reach of plants, though, as described below, certain concretionary layers of hard material hold it up locally in many places.

But whatever assumptions we like to make as to how much is absorbed by the sand and how much is used by plants we are apt to be left with very large amounts of water to account for.

Thus, let us take an area in the central part and allot it an average annual rainfall of 8 inches. Let us assume that only 12 per cent of this rain is totally absorbed, that is, it escapes below the reach of plants. We should then have the equivalent of one inch of water somewhere below the surface, moving slowly in the direction gravity took it. A great deal of work has been done on the rate of movement of water by percolation or seepage through sands. It depends, of course, upon the coarseness of the sand and upon the hydraulic gradient or slope of the water surface under the sand. In the Kalahari the sand is fine and the gradients very slight, and using figures from the United States of America which seem analogous it would seem that this water cannot move more than a mile per year and probably much less.

If, then, the area chosen is, say, 100 miles from the nearest place where the water can either issue as springs or come near enough to the surface to be used by plants there will be the equivalent of 100 inches of water collected over that distance. If we further suppose, as we may, that this water movement follows certain zones or sub-sand valleys then the amount of water in those zones will be immense. A corollary of the very slow movement is that the water will dissolve salts on the way, some of which it will deposit as concretions or layers.

Scattered over the Kalahari there are several local catchments known as "pans" and of these a surprisingly large number are fresh. On the other hand, they are almost always shallow and few of them last more than a month or so of the dry season, being exposed to an evaporation which must be at the rate of from six to ten feet in the year. Everywhere the bulk of the rainfall sinks into the sand and once it has reached a level of from one to three feet below the surface it is not susceptible to capillary attraction back to the surface to be evaporated.

If the subsoil were nothing but sand the ordinary processes of slow seepage down such gradients as there are would gradually remove the water to the river beds or larger pans. But the countless ages during which rainfall has sunk into the somewhat calcareous sand have produced certain deposits which affect this circulation. The commonest of these deposits is called calcrete by the geologists, and is moderately pure limestone enclosing grains of original sand. It is formed at different depths and is often exposed at the surface. Like most concretionary formations it is roughly stratified but may have thicker and thinner layers and even large holes through it. Under those conditions it may or may not be a source of water, but it is at least associated with water beds. In the vicinity of the Nata River, for instance, where the calcrete may be met from the surface down to a depth of 20 feet, the well sinkers say they can always find water in it. It is welcomed by such well sinkers since it is not very hard to excavate yet solid enough for them to dispense with lining the wells.

In other places the calcrete, by some process not thoroughly understood as yet, is replaced by a siliceous concretion known as silcrete, which is essentially a flint. This is much harder and, though it may be so continuous as to be impervious to water, it is not welcomed by the well sinkers.

Now these concretionary layers denote not only water but slow moving water, and they belong essentially to the areas of low gradient. Where there are ancient sand dunes, for instance, the calcretes are found mainly in the depressions between the dunes, while on the slopes of the dunes, where the water has moved more quickly, there is less calcrete or none at all.

These features under the Kalahari Sands have been described in detail because they provide the hint as to the type of development to be tried. A series of bore holes has been put down on the route from Serowe to Rakops and they have in the main been successful at depths ranging from 60 to 200 feet. But drilling at from £2 to £5 a foot with these large machines cannot be done all over the Kalahari. Moreover, the maintenance of bore holes is expensive compared with wells. What is needed is a reconnaissance of the areas where the pasture is good enough for stock by some cheap method of experimental drilling, to be followed up by well sinking or larger bores according to the depth at which water is found.

The Government geologist has asked for an experimental light drilling outfit which is really mobile, and this request is heartily supported since reconnaissance is so much quicker and cheaper thereby than with the heavy drills.

I would like to add two further suggestions for careful consideration for this proposed reconnaissance unit. There is a hydraulic jet method of drilling in sand and light alluvium which is far quicker and cheaper than the percussion or rotary methods, one which would be the ideal method for the Kalahari sands. This method is referred to in an appendix to the report. It would be an alternative method only, to be replaced by either a steel pipe-driving method or a percussion method if calcrete were met with.

The second suggestion is derived from the fact that the water table follows roughly the slope of a hill or dune, though it is deeper at the top than at the bottom. From this it follows that a horizontal bore from the base of a dune will meet the water table at a distance dependent on the slope of the hill and the depth of the water table. The hydraulic jet method is peculiarly well adapted for drilling horizontally, as other methods are not, and a lateral bore into a dune becomes essentially a spring with the supply coming through the pipe by gravity.

The reconnaissance section might be followed by a gang of well sinkers where the water was proved to be shallow, or else by the heavy drills, but its chief purpose would be to make some kind of a map of the underground water table, seeking the general direction of seepage. The commonest description which figures on maps of the Kalahari is "Open grass veldt—waterless". This means that the annual rain is enough to grow the grass, which dies in the dry season, but that the water sinks too far down for the roots of trees or scrub to reach it, that is to say to more than 30 or 40 feet. The limit of depth for a well for pumping by manpower is about 70 feet, but in the broad depressions which have surface pans or soaks the water level will often be found above that level, and a test hole by a light drill will prove whether a well can be usefully sunk. A properly lined well costs rather more than a bore, but its maintenance is more within the capacity of natives, who can even draw the water by rope and windlass if the pump fails.

Testing such a very large area by drilling would be a long and expensive business, and the possibility of applying what are usually called geophysical methods of reconnaissance should not be overlooked.

Thick layers of sand are, in fact, a poor medium for the detonation methods of exploring for bed rock, but they do offer unusual opportunities for the electro-magnetic methods. For instance, in the dry season there must be a fairly distinct transition between the dry sand and the damp sand, that is to say, between the bad conductor and the good conductor. If that is so then it invites the use of a new method of electro-magnetic investigation, namely, by treating the ground as a sort of inefficient condenser and measuring its capacity at different places.

Experiments along these and other lines are now being made at Cambridge. The particular advantage of a capacity method would be the rapidity with which reconnaissance could be done.

The greater part of the Kalahari is so forbidding that for some time to come the programme of water development must be confined to the stock routes only. The losses of stock in droving them from the Ghanzi district to the railway, some 500 miles, are prodigious in bad years, and the owners would probably pay gladly some small toll per head of cattle delivered in return for a secure route from the point of view of water.

The widespread Bamangwato Reserve is rather better country than that of the south-west towards the Nossob and Molopo rivers. The route from Serowe to Rakops passes through land sloping gently towards the Makarikari Depression and it now has bores along it. An extension of these bores and wells, with improvements to the road seem a very natural immediate development, much of which could be carried out by the tribe itself.

I would suggest that Palapye would be an excellent centre for a training course in well sinking such as is described in the introduction to this report. In conversation the regent Chief Tshekedi expressed pride at having over 1,000 wells dug by his people, and was inclined to think that all they needed from the white man was the siting of wells. While disagreeing with this, I certainly received the impression that with a European to plan and supervise, the Bamangwato are capable of carrying out schemes of water development with their own resources which would make an enormous difference to the prosperity of the marginal country to the west of Serowe.

The North-West

The large triangular area covered by the swamps of the Okavango and the Chobe or Linyante is so entirely different from the rest of the Protectorate in physiography that it must be described in some detail. It has a considerable population, with the Batawana people in the majority, and is also a corridor for the steady stream of labour coming from Angola to the Union mines. The main routes for this labour are down the Okavango to Tsau and thence to Maun, or down the Zambesi to Kazungula.

The easiest way to picture the physical geography of this area is to imagine two rivers, the Okavango and the Linyante or Chobe, building their deltas out on to a sea of sand instead of at a shoreline, the two deltas being more or less joined.

The water which formed the deltas is no longer sufficient, for reasons to be given later, to go beyond the fronts of the deltas except in years of unusual flood. When it does do so it makes a small addition to the Zambesi as far as the Chobe is concerned, while the Okavango water fills some depressions and breaks through to pass down the Botletle river towards the distant depressions of the great Makarikari.

In ordinary years the flood water does no more than fill a series of channels following the line of Lake Ngami, the Ngabe and Thamalakane rivers, the Mababe Depression and the Lower Chobe itself, these representing a wide but very shallow furrow running across the fronts of the old deltas.

One cannot consider development in this curious area without reference to the absurd complication of boundaries which is the result of the Caprivi award of last century.

The Caprivi Strip is a corridor averaging about 30 miles in width, which runs for nearly 300 miles from the Mandated Territory of South West Africa proper to the confluence of the Chobe and the Zambesi.

It would be hard to conceive a more unnatural political unit, for it crosses all the drainage and such communication routes as there are. It is therefore practically impossible to travel along the strip, which must be reached from the south or the north; it can never be a route for communications and its population is sparse. Any purpose which may have been in the minds of the German treaty-makers has long been proved impracticable, and it remains as a geographical solecism and an offence to common sense.

Whatever is ultimately decided as to the fate of the Mandated Territory, this provocative strip should be adjusted. To leave it as it is is tantamount in practice to declaring it a no man's land and a permanent hindrance to all its neighbours.

The gradients in this shallow country are so slight that in many of the channels the direction of flow is reversible, depending on which end of the channel receives the flood water first. Thus in a high flood, water from the Okavango will flow into the delta of the Chobe along the Makwegana spillway, at other times Kwando water appears to reach the Okavango delta from higher up. Every year the last six or ten miles of the Chobe fills with water from the Zambesi, which is three feet higher than the Chobe at the Kasane-Mambova line of rapids.

The curious phenomenon of two large rivers emptying themselves into vast swamps without very definite directions in which to flow has excited comment and suggested projects in the past.

The proposal which has had most publicity was one by the late Professor Schwartz, and an examination of this was the subject of an excellent survey made in 1925 by an expedition under Dr. A. L. Du Toit. It was shown that the original proposals were put out of court both by the levels at critical points and by the unsound arguments with which they had been supported. The expedition put forward the alternative suggestion of a very large dam to be built across the Zambesi itself at the Katombora Rapids, with the object of creating a large lake over most of the present swamps and using its surplus for irrigation.

Nothing has been done with this proposal. From an engineering point of view it was sound enough, but presumably its magnitude, the consequent interference with Zambesi water, and the very confused issues raised in the political field were all responsible for its being dropped.

There have been other projects mooted, several of them eminently practicable as far as construction is concerned, but when they are viewed from the social, economic and even biological aspect, a good deal of their roseate promise is apt to fade. Nevertheless, before an analysis is made of some of these aspects, yet another proposal will be mentioned which occurred to the writer after his rapid traverse along the fronts of the deltas and after conversation with men who had been at work in the deltas.

Assuming for the moment that irrigation can be carried out by the natives under supervision and instruction, the best areas for it would be

(*a*) certain parts of the deltas themselves,
(*b*) the floors of Lake Ngami and the Mababe Depression,
(*c*) the low areas along the Thamalakane River,
(*d*) the land near Rakops.

The reason why there is very little flow of water beyond the marshy deltas at present is that it is nearly all evaporated there. To judge from the meagre data available the mean annual flow of the two rivers combined seems to be about 15,000 cubic feet per second, which, incidentally, is only a few thousand cusecs less than the Zambesi itself. We do not know the rate of evaporation of the area, but it is almost certainly between six feet and ten feet per annum.

The discharge quoted above would flood 16,000 square miles to a depth of one foot, or 1,600 square miles to a depth of ten feet. We do not know the area of the land flooded by these rivers either at maximum or minimum, but the mean must be of the order of 1,600 square miles.

It is clear then that, if reserve water is to be obtained, the water surface must be reduced in area rather than increased, as it would be by large dams. The swamps should be drained rather than flooded, and the many channels controlled so that there were only a few, which would pass the water more quickly either to a deeper reservoir or for direct use on the land.

To clear channels of dense sudd and swamp vegetation would at first sight seem to be a prohibitive project, but recent work on a small scale on the Taokhe, the most westerly of the Okavango channels, appears to discount this fear. With comparatively small equipment a party cleared and reopened many miles of channel including cutting fresh openings to shorten the distance, at a very reasonable cost. Moreover, once a channel is opened it is flushed by the annual flood and its maintenance much reduced.

A report by Mr. Brind, the Director of Public Works, on this experimental cutting, gives the figures and, indeed, throws a new light on the whole problem. It may well be that the real solution is control by draining works on these rivers, reducing the swamp area and leading the water down to the areas where it once flowed, and from which it retreated, not because of general dessication or even warping of the earth's crust, but because the swamp vegetation grew strong enough to withhold it all.

A survey of the Okavango delta will be required before such a scheme can be fully considered, but the general outline of the plan would be as follows.

The river has a well defined bed at Muhembo, on the border of the Protectorate, but begins its divagations about 30 miles below that point. The best known of its distributaries from this point is the Teoghe or Taokhe, which marks the western boundary of the delta, and passes through Tsau on its way to the Lake Ngami depression. At present there are many branches off the Teoghe into the swamps, and its former course is blocked by the growth of sudd so that very little water reaches Lake Ngami even in the wet season. On the other hand the channel cutting mentioned above has shown that the sudd could be cleared at reasonable expense, so that the river could be re-created if that were the best thing to do. The channel clearing would be supported by some form of control works at the head of the delta so as to reduce the quantity of water flowing into the other distributaries. If the object were merely to send the main body of water down the Teoghe these works would be simple and cheap, since it is very easy to encourage the growth of sudd blockages by sheet piling which reduces the current, and leads to silting when vegetation quickly takes hold. If, on the other hand, the survey showed that some other branch should be encouraged, such as the Ng-ghoka which has a more direct course towards the Botletle, then similar clearing would be undertaken along that line and blockages created on branches which diverged from it.

It would even be possible to reopen the most eastern of the delta branches which would then flood the Mababe Depression and possibly make the Thamalakane River perennial.

For the Linyante or Chobe the task of making the water serve some useful purpose should be easier. The levels known at present seem to point to a scheme of reopening the western channels of its curiously short but broad delta so as to bring the water to its south-western corner. Here a relatively small amount of work would direct the flow into the old Savaiti channel and pass the water into the Mababe Depression.

The advantage of clearing channels to secure a more direct flow is that it is not only cheap, since the flow itself, once begun, does a great deal of the work, but it also releases land from swamp cover, land which should be eminently suitable for arable cultivation. Maintenance of the reopened channel would be necessary, but not expensive, and the diversion works at the head of the deltas, even if they involved some masonry construction, would be very much cheaper than a main dam.

As far as the feasibility of such works is concerned the pre-requisite is a survey which would carry out the necessary levelling, explore the existing channels and measure the discharges.

A survey of the Linyante would cover a rather small area, and it would be working far away from established settlements and with poor communications.

A survey of the Okavango delta would be a much longer business, but it would have far more established bases to work from—Muhembo, Tsau and Maun—and better communications.

The expense of such surveys would be considerable, but until they are made it is quite impossible to consider the various projects which have been put forward.

Perhaps enough has been said to show that there is nothing inherently impossible in making use of these abundant waters now going to waste. From the engineering point of view the choice of practicable schemes is fairly wide, but it must be emphasised that the main difficulties are a high rate of evaporation and a rank growth of vegetation. Constructing large reservoirs does not really avoid these difficulties, whereas inducing a quicker drainage minimises them.

It is now our duty to show that the engineering aspect of the delta triangle is quite the least part of the whole problem as to what might best be done with it. Many factors far more complicated than mere topography rear their heads and require analysis, and while none of them is entirely intractable, they all invite a degree of caution before any large schemes of development are undertaken.

The Economic Aspect

It must be obvious that economic factors are inseparable from the development of the water resources of the North West Division of the Protectorate. In course of time that Division, with its ample supply of water, can become a second Sudan, growing cotton or other products for export under somewhat similar conditions, always provided it has reasonable access to the sea. The most natural access would be by means of a railway to Walvis Bay or to a new port at the mouth of the Cunene. A preliminary survey for a trans-Protectorate railway has already been made, running from the Rhodesian Railways in the vicinity of Wankie to the South West African railway at Gobabis, a matter of some 600 miles. It could almost equally well go to Grootfontein.

The future of the northern province of the Protectorate is almost entirely dependent on some such railway, without which it can never grow export crops. With such an outlet it would show an even more striking analogy with the Sudan, having water supply, sandy irrigable land and a route for export. The native population of the North West Division comprises mainly the Batawana tribe, and it remains to be considered whether they bear any resemblance to the Sudanese. At first sight they seem to be worlds apart, but one has but to go back to the Sudan of fifty years ago to find certain similarities and considerable promise for the development of the Batawana along the same general lines.

Perhaps the most important thing is that there is a considerable population there already, even though at present they have no urge towards development, and little knowledge of irrigation methods or of crops such as cotton. Like the Sudanese of fifty years ago, they have only recently emerged from a state of constant wars or threats of wars, and even now feel an uncertainty towards their future which is constantly in the minds of their leaders. All one can do is to quote the opinions of some of their past administrators, who, in general, regard them as a people who can develop if they are given a lead.

It is probably unwise to go further than this point in considering plans for development in water resources, since they depend so vitally on the political future. They also depend very much on the long term plans for the Protectorate's internal economy.

RECOMMENDATIONS

The recommendations which follow are intended to assist the administration, which alone is able to judge which of them can be undertaken under current circumstances. The only advantages over the local technical officer which a visitor can claim are those due to his being able to view projects and development as a whole, freed from the meticulous detail with which the local officer is usually so surrounded that the trees are apt to obscure completely from him a view of the whole wood. Except in very special cases, therefore, a visitor cannot assess priorities or proclaim his own projects as essential, but he can bring a new point of view and occasionally suggest new methods of attack on any problem. With this understanding, that the recommendations are for consideration, we now embark in some detail on a review of the possible directions of development in the immediate future.

It will be convenient to follow the division of the Protectorate described above and begin with

The Eastern or Railway Zone

The zone includes practically all the land which in one degree or another has been alienated for white farms, namely the areas known as the Baralong Farms, the Lobatsi, Gaberones and Tuli Blocks, and the Tati Concession. Nevertheless, it would be difficult and probably unwise to differentiate between development in these blocks and in the native reserves adjacent to them, and the recommendations are based upon the physical conditions and not upon the ownership of the land concerned.

The southern third of the Zone includes the arable areas where, even now, a surplus of grain can be produced, as well as the best of the pastoral land, and the greatest proportion of hilly, that is to say, of rocky land.

Consequently it is an area where surface conservation is possible up to a point, as has been already described. Such conservation must be for irrigation, and the possibilities are already being explored. To the west of the railway line, however, it is a greater number of watering points for stock that is most required, and a more exact plan of drillings will certainly be the first result of the return of drilling equipment. This plan will no doubt be the product of consultations between the agricultural and the drilling departments, while in the broader valleys with a higher water table there is obviously room for far more well sinking, preferably by the natives under some supervision.

In this country, far hillier than the bulk of the Protectorate, erosion troubles are a constant threat, and the only way to combat them is the rather unpopular, because unproductive, method of check weirs near the heads of the valleys. Their ultimate value is so great, however, that I would suggest a demonstration valley in the Kanye district, where there are one or two suitable sites amongst the kopjes in the watershed of the Lotlakani stream, and doubtless others not visited by the writer. One must again offend by visualising a model scheme which, in practice, has to be modified by circumstances. It should, if possible, be a co-operative scheme with the direction coming from the Government and the labour coming from the valley inhabitants who, on the basis of advantages to accrue, should give their labour at little more than subsistence cost.

Each of the better defined headstreams would have a rock-and-rubbish weir thrown across them, the basis being the largest boulders available backed on the upper side by smaller boulders and then by rubbish of earth and bushes weighted down by it. In most cases there should be no need for a spillway unless there is a scarcity of convenient sites and adjacent large boulders. Further down the little valley, where its gradient decreases and there is some prospect of land for native gardens, a more ambitious weir or dam would be built with a core of ant-hill clay and a generous spillway. Though it could hardly hold more than 12 feet of water with such materials, it would provide a seepage stream for the greater part or all of the dry season. According to the amount of its flow the inhabitants would be allowed to utilise this seepage for purposes which, in the best circumstances, would include what might be called subsidiary irrigation. In most seasons the rains begin with a false start, and the native crops, anxious to benefit from the warmer season of the year, frequently go in too early and are apt to be lost by wilting. A comparatively small amount of water at that stage makes all the difference to the young crop, carrying it over to the main rains and enabling it to avoid the frosts which are liable to catch a late crop. Such early water is equally useful in starting the vegetable crops which play a small but important part in the native diet.

Further down the streams the sand is deeper and may in places be suitable for subsand reservoirs, as suggested for the next section of the Railway Zone. It is at all events quite certain that in this southern section with an average rainfall of about 20 inches and rocky catchments there is opportunity for more surface conservation. On the other hand, the bore water is harder to find, since it is rock-fissure water for the most part and depends for its occurrence on minor fractures, faults and dykes of harder material which require siting by a skilled geologist.

The middle section of the Railway Zone may be taken as the area round the quadrilateral formed by the two railway settlements of Palapye Road and Mahalapye with the two native towns to the west, Serowe and Shushong. It has pronounced ranges of hills which give a higher rate of run-off than the sandy stretches, consequently it has many sand rivers. These provide the water points for the natives who dig down in the well-known places for a supply. Comparatively cheap construction work along these sand rivers by grouting with cement, lime or clay would increase the supply by many times, as suggested in the Appendix on the treatment of sand rivers.

There are many wells in the Serowe and Shushong districts, most of them dug by natives, and not a few bores. These must obviously be increased in number and be further distributed. The wells in particular would be far more permanent and serviceable if and when a training course for natives is instituted as outlined in the next section. The Bamangwato are probably the tribe most likely to fall in with a progressive policy in this direction.

There is one river in this division which merits closer surveys for conservation schemes in the near future. The Machokwane rises to the west of the Shushong and Makhware Hills and pierces the latter by a picturesque gorge known as the Kuchwi Pass. The rainfall on these hills may not be more than 12 to 15 inches, but they must have a good percentage run-off judging by the appearance of the river bed in the Pass. At the time of our visit, mid-March, the sand was saturated to the surface, but there was no running water. The indications on the banks, however, were such as to permit an estimate of a discharge of at least 200 cusecs when in flood. Such a mean discharge for 10 or 12 days out of the 60–90 days in each rainy season would produce a volume of about 200 million cubic feet. Moreover, there is at least one site in the gorge where the rocks are of a favourable type for foundations for a masonry dam some 50 feet high and not more than 200 or 300 feet long.

For full irrigation duty such an impounding would be of little value since it represents little more than 4,000 acre feet, but for subsidiary irrigation and general purposes such a dam might well pay its way in the future.

A site on the same river, but to the east of the railway line, has good command but bad foundations. Probably a series of subsand reservoirs in the neighbourhood of Palapye Road would give better value for the local supply than a surface reservoir.

In the northern third of the Railway Zone the main rivers are the Tati and the Shashi, both of them sand rivers with a strong flow for a short period. Both are ideal rivers for sub-surface conservation by stepped semi-permeable diaphragms or blockages as described in the Appendix, for which the Shashi River at the Matangwan crossing on the road to Maun is taken as an example.

With the slightly higher rainfall at this northern end of the railway belt the difficulty as to water is rather less, and the farmers in the Tati Concession have bores or other supplies.

The Central or Kalahari Zone

To his great regret the writer was unable to visit the southern section of this zone, and he has no grounds for specific recommendations of any kind. The route from Kanye to Lehututu is much travelled by stock and even by an occasional car and lorry during the dry season. Nevertheless it is clear that in such marginal country, with great unreliability in its average rainfall of from five to eight inches, development must be mainly confined to making the stock routes secure with watering points.

Towards the Makarikari Depression the prospects are better, and some development by bores and wells should permit the country to carry more stock than it does at present.

On the northern side of the depression as seen from the W.N.L.A. road from Francistown to Maun these prospects become certainties. That is to say, there is a large area here at present almost unpopulated which is available if and when population pressure becomes acute further south.

The road from the crossing of the Shashi River to the Nata River, a distance of some 100 miles or so, runs over some 50 miles of granite and ancient rock country with an occasional low kopje and then crosses the more typical plains country of the main Kalahari, with limestone (calcrete) on or near the surface. The rocky belt is well wooded with trees up to 25 feet in height, and the mealie patches in cleared spaces show that both soil and rainfall permit some subsistence cultivation.

Towards the depression itself the trees thin out giving place to well grassed plains with a few palms, and the presence of migratory game shows that it would be fine cattle country but for the lack of surface water. Yet the water is close to the surface and, according to local assertion, can easily be tapped by wells which would rarely be more than 12 to 20 feet deep.

At the Nata River itself there are really impressive possibilities for water development. It is, of course, an entirely intermittent stream, but it has a watershed of at least 1,500 square miles, and consequently it produces an immense discharge for a short period in each rainy season, all of which runs into the lower, salty parts of the depression. In 1946, for instance, a rainy year in that district, the flood level and certain rough data given by the W.N.L.A. officials, pointed to an amount of water passing the Madsiara Drift of the order of 200,000 acre feet. Even if we take one-quarter of that amount as an average over a number of years we have a very impressive figure, and a direct invitation for a closer survey with a view to development.

In the early days there was an attempt to settle a portion of the Bamangwato tribe on the Nata River which appears to have failed on account of a combination of bad health and political dissent, and perhaps isolation. The river itself forms the boundary between Crown Land and the Bamangwato Reserve, so that it is open to either direct or indirect development by the Administration. The Nata River district is certainly the most promising area of the Kalahari for a closer investigation, and I would therefore strongly recommend a survey of its potentialities by a small party. There would seem to be far more prospect of quick returns on capital expenditure here than in many other projects mooted for the Protectorate.

My brief visit hardly permits detailed suggestions for either the survey or the lines along which development should take place, but in broad outline the main queries to be settled are:

(*a*) The possibilities of finding water in the river bed and by means of wells in the surrounding country.

(*b*) Whether subsistence crops can be grown for the predominantly pastoral industry.

(*c*) Whether the stream bed itself may be used ultimately for surface conservation.

The first of these enquiries could be settled by a comparatively brief traverse of the river bed by a reconnaissance party strong enough in manpower to sink trial wells and make a rough map of the river bed with a view to sites for subsand blockages. Probably a six weeks tour by one or two Europeans with a party of well sinkers would provide all the initial information required.

The next stage would presumably be the establishment of a trial settlement of natives with cattle. This would no doubt have to be on a large enough scale to be a real experiment and to counteract the effect of isolation and novelty on the settlers, who should, of course, be volunteers in so far as that term can be applied. This would involve some initial outlay, but unless I have grossly misjudged the prospects it could be of the nature of a loan to be repaid by a per capita toll on cattle marketed in the future.

Until the settlement was well established there would not be sufficient local labour for larger schemes with any agricultural aim, yet if the river bed is found to favour surface conservation the ultimate development of the Nata River settlement would be in that direction.

Its comparative proximity to the railway, the existence of a moderate road over fairly well wooded and watered country, and the existence of wide areas unembarrassed by claims or alienation would appear to mark out the Nata River for priority in development, which here does not, as in the Okavango and Chobe areas, wait upon political developments or depend upon decisions as to transport and markets. Here if anywhere in the Kalahari there is a clear prospect for both pastoral and agricultural development at the same time, and scope for schemes which will finally settle whether the native can make full use of his country.

The North-West Triangle

As already outlined, there are possibilities for the development of the Okavango–Chobe water resources which are vast to the degree of embarrassment. At present they depend so much upon factors which are either unknown or unpredictable that it is useless to discuss them in further detail. On the other hand, since some such development is bound to come in course of time, it will be as well to initiate surveys and even experiments well in advance.

A survey of the delta lands has already been mentioned as a pre-requisite to any planning of large-scale diversions, channel clearings or control of any kind with a view to large schemes in the future. Such a survey would have to be composite, that is to say, besides a considerable amount of levelling and some map making, a number of hydrological measurements would be required. It would be a considerable tax upon even a fully-staffed Survey Department, and quite beyond the powers and resources of the Protectorate.

I would therefore suggest close consideration of a method of effecting such a survey, and on even broader lines, which will probably be used in other parts of Africa in the near future. This is by the encouragement of scientific expeditions, chiefly of young men not yet fully embarked on their careers, assisted by whatever facilities and guidance the Administration is able to provide.

A mixed party of young surveyors and biologists working in the Okavango delta for six or eight months would provide much of the data required for a general appreciation of the potentialities, at a cost far below that of a party of professional engineers, and it would at the same time appeal to scientific bodies as a contribution to knowledge.

Quite apart from such technical enquiries, however, there are a number of minor experiments which ought to be made as part of the general preparation for development. The Batawana tribe are reasonably skilful farmers and without any great urge they have produced a surplus of crops at various times. They, like the Barotse, are well able to take advantage of the gradual subsidence of flood waters to plant their crops at the right time and place. What they do not seem to appreciate is that with a very small amount of furrow digging they could command the watering of their crops and therefore the season of growth. The whole length of the Thamalakane River from Maun to the Mababe depression provides opportunities for the simplest type of irrigation if they were given a little instruction.

It would be an ideal valley for a small demonstration farm for irrigation methods, either with or without instruction at first. It must be realised that the success of any schemes for the future depends on the ability of the natives to carry out the agriculture under a system which will be new to them unless they are able to see it in practice. A single example of a successful area under irrigation will do more to persuade them to further trials than any amount of precept. As far as the natural advantages of good soil and command are concerned, the Thamalakane valley is very well endowed, and it could obviously grow an enormous food surplus with a very small amount of ditching.

[See Northern Rhodesia]

2. NORTHERN RHODESIA

IN SPITE OF its great area, Northern Rhodesia enjoys comparatively uniform climatic conditions, the variations in rainfall conforming closely to altitude and latitude, while the higher temperatures proper to an approach to the Equator are offset by the greater height of the plateau in that direction.

From the comparatively dry areas of Barotseland in the south-west, with a rainfall average of about 20 inches, there is a steady increase of precipitation up to the north-east, with averages well above 40 inches. The rainy season begins earlier in the north and lasts longer because of the proximity to the Equator.

There are no great extremes of rainfall in the Territory, just as there are no exceptionally low areas or very high mountains. The Central African plateau is here at its greatest uniformity and the scenery is consequently somewhat monotonous, as is the indigenous vegetation, which varies but little for hundreds of miles along the road and rail route from Livingstone to the Copper Belt. This impression is partly due to the fact that the ordinary visitor rarely leaves this particular route, which follows the divide; there is nothing monotonous about the great Luangwa valley which separates rather effectively the Eastern Province from the rest of the territory. The escarpments defining the valley and proclaiming it to be one of the Great Rift series are little less impressive than those of Kenya though lacking the latter's picturesque volcanoes.

The geological history of the country has produced a curious pattern for its drainage, a pattern which has endowed the territory with a share in some very notable rivers. Almost any map will show the main features of this pattern. There is, for instance, what may be called an east–west tendency, best illustrated by the 500-mile stretch of the Kafue-Zambesi from Namwala to Tete, and paralleled by the 200-mile stretch of the Zambesi from Sesheke to Walker's Drift. It is customary to consider this direction of drainage as the original one, consequent upon the general slope of the ancient, Mesozoic, Africa.

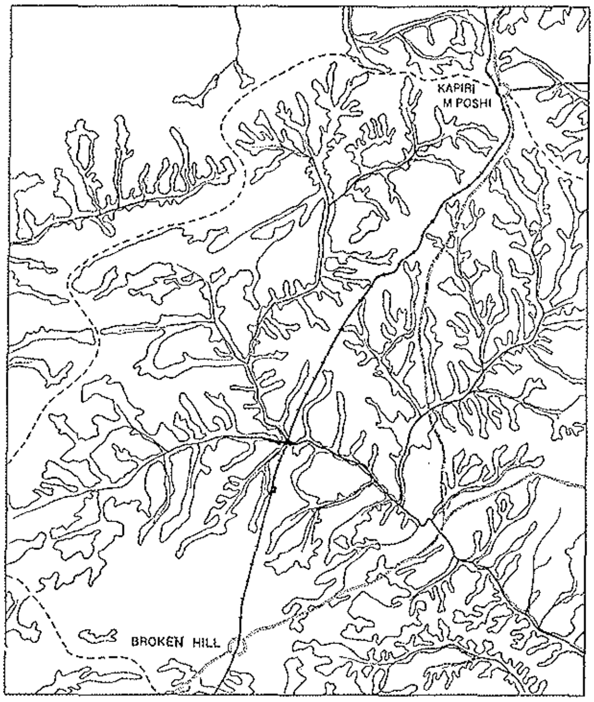
Whatever its origin this earlier pattern was radically affected by the forces responsible for the Great Rift Valleys which, as we have seen, tended to follow two directions—a north-south, as shown by Lakes Tanganyika and Nyasa, and a north-east to south-west direction.

This latter trend is dominant for over 800 miles from the source of the Luangwa along its whole length and continuing with the section of the Zambesi from Feira up to Walker's Drift. It is shown nearly as well, but with less continuity, by the course of the Chambesi from its source to its abrupt bend to the north near Kapalala, and the same trend is taken up by the Upper Kafue down to the Kafue Hook. The "hook" motif is in fact very prominent in the whole drainage pattern. It is a sharp hook where the Luangwa turns to enter the Zambesi, a more gentle curve in the Kafue Hook itself, and is reflected a third time in the broad sweep of the Kabompo into the Upper Zambesi.

The mileage of perennial large rivers is therefore quite remarkable in the territory, and places it in a very favourable position compared to Southern Rhodesia or Tanganyika Territory.

In addition there are some large swamp areas which must most assuredly be reckoned among the water resources. Of these the largest by far in area is that of Bangweulu Lake, but there are others in the Northern Province, while the Lukanga Swamps on the Kafue, the seasonally flooded areas of Barotseland and the Kafue Flats are, physiographically, of the same type.

In addition to possessing these large swamps, Northern Rhodesia is the real home of the "dambo", the small valley-swamp usually due to a combination of a low gradient and a vigorous growth of vegetation. Nearly every small stream on the plateau has its string of damboes, and the total area of these linear swamps is truly immense, as witness the map below, which shows part of the watershed of the Mulungushi River near Broken Hill, being adapted from a map made by Dr. Kanthack in his surveys for power projects. The best use of damboes is consequently of prime importance to the territory, since their part in the natural conservation of water is considerable and their soil, a mixture of humus and silt, should not be wasted. An appendix to this report deals more fully with suggestions as to their treatment, the essential feature being control of their use.



DISTRIBUTION OF DAMBOES, NORTHERN RHODESIA

The sparseness of African population along the divide which carries road and railway up to the Copper Belt is due almost entirely to the lack of surface water in the dry season. The soil from the ancient rocks is so deep and the water-table so low that it is usually beyond the reach of wells. The villages are therefore placed further down the slopes, where the water absorbed on the divide seeps out to render the streams semi-perennial, or where shallow wells or natural springs invite settlement.

The distribution of settlement has two disadvantages; first that the cultivation is liable to be on slopes which invite erosion, and secondly that the surplus produce is rarely within economic reach of the railway.

The Problems of Water Supply

From the broad description just given, it will be clear that the water resources of Northern Rhodesia, while potentially adequate, need considerable development before they can be realised. This development falls naturally under several headings as follows:—

(i) Domestic water supplies for native villages and European settlements.

(ii) Supplies for secondary use, of which the chief are irrigation on European farms and sub-irrigation for native crops.

(iii) The prospects for major schemes of navigation and hydro-electric power.

Domestic Water Supplies

Careful studies by Dr. Kanthack seem to show that the run-off from rainfall on the plateau is about 8 per cent of the rainfall, a very reasonable ratio if it were not that the length of the dry season makes it impossible for the smaller streams to remain perennial, even where they are assisted by damboes along their courses. The rainy season is fairly well defined and may be taken as from December to March inclusive, though rain may fall in November and April. The dry season therefore lasts for at least half the year, and the whole economy of vegetation, and of crops, is conditioned by that fact. The trees are of moderate height only, resistant to fire and spaced from five to thirty yards apart according to rainfall. They are associated with a comparatively thin carpet of grass and much of the soil is leached. Consequently the run-off is fairly rapid, and there is little holding capacity in the soil.

On the other hand, there seems reason to suspect that some of this poor capacity is due to the treatment the soil normally gets from the almost universal firing in the dry season which destroys the dead grass and effectively precludes the foundation of a surface mat or humus. A second factor which prevents the soil becoming richer in humus is the presence of termites everywhere which leave no shred of dead vegetable matter.

The natural soil is therefore thin and poor, yet it has already been shown that where the land has been cleared of trees and cultivated so as to keep the termites in check a moderate pasture does come in with consequent benefit to the soil. The cost of clearing in this way is too heavy to make it worth while on a large scale to clear for pastoral farming, except in the vicinity of a dambo.

The poverty of the soil is more apparent than real and reminds one of the granitic soils in Australia used for sheep farming. While trees dry out the ground the land appears to be quite hopeless, but with their removal grass takes hold and a reasonable pasture comes in after a year or two which will carry a beast to five acres.

Unfortunately, the prevalence of tsetse fly over a large part of Northern Rhodesia effectively prevents any such use of the land, a use which would otherwise be natural enough, in view of the presence of considerable game. Under a pastoral, rather than an agricultural, economy the soil would have a chance to form.

The more immediate problems of water supply for native villages in the reserves arise from the fact that during the long dry season surface water disappears almost entirely from headwater streams.

The problem of domestic water for African villages is thus greatly complicated by a group of factors which consititute a form of vicious circle. Perhaps the most important of its elements are the poor upland soils and the wide spread of the tsetse fly.

The absence of cattle over the greater part of the territory prevents the use of animal manure. The African, therefore, must use one of his various systems of burning the bush to fertilise his land. The burning, usually over a wider area than the crop land itself, necessitates a shifting cultivation and frequent moving of the village. Yet the village cannot move too far from the valley where domestic water is to be found. Consequently, a native reserve is felt to be crowded when only a portion of the land is actually being used and much of that at an uneconomical distance from the habitations.

There are various ways of breaking into this circle, but most of them, such as the introduction of artificial fertilisers, are out of the question at the present stage of development.

The provision of more satisfactory water supplies away from the valleys is another way, and this has been done, for special reasons, in some parts by means of bores or deep wells. The programme of drilling must continue and even be amplified, but it must be supported by the improvement of the valley water supplies.

As outlined in the General Section, this can only be done by providing check weirs at the headwater areas of valleys supplemented by larger weirs, stepped down the valleys. Obviously, the closest co-operation between the medical, agricultural and water supply departments is necessary for this mode of attack on the circle, since there are risks in encouraging a permanent site for a village below a weir. Unless due control is maintained the surface water is liable to be contaminated, and breeding places for bilharzia and malarial mosquitoes are liable to be created. Erosion on the valley slopes will be started unless contour cultivation is insisted upon.

Yet if these dangers are warded off, the advantages outweigh the risks and the increased population density in the valleys may even create further fly-free areas, leading to the mixed farming system so urgently desirable.

For the same reason the greater use of dambo areas, both for water supplies and for cultivation, is to be strongly recommended. Agricultural officers have already devised methods for counteracting the slight acidity of dambo soil by rotations and drainage, while on reasonably large damboes the possibility of good grazing where the fly permits is well understood.

The methods of dambo and dimba cultivation which are outlined in the appendix are not, it is fully realised, capable of universal application, yet they represent an aim which can be followed gradually with good results, and they have the advantage of not requiring tools and equipment which are beyond the reach of the African.

Some of these methods have been put into practice in the Railway Belt by European farmers with or without the assistance of agricultural officers.

The provision of domestic water by bores drilled for fissure water is a very natural development throughout Africa. Except for considerable uncertainty over the siting of bores, now decreasing with the help of geophysical methods of reconnaissance, the whole system is well understood and fully planned in Northern Rhodesia. The name of Dr. Dixey is closely associated with the development of drilling in Central Africa, and wherever the land has been of sufficient value the system has paid good dividends. It is almost the only method of obtaining domestic water on the flatter parts of the plateau and the supply is usually adequate and always pure.

On the other hand, it is one of the more expensive methods of providing water and usually requires power pumping. Consequently, wherever slopes are present, and particularly in native reserves, any cheaper sources of water must be tried. Where the local conditions are favourable, special attention might be given to the possibility of using the methods described in an appendix, under the titles of "Winged Springs" and "Apron Catchments".

Irrigation on Farms

A question of considerable interest to the European farmers of the Railway Zone in particular is the extent to which the local water resources will permit some form of irrigation. Such irrigation would normally be for winter wheat or pasture, and the answer depends to some extent on the "duty" expected from the water, that is to say the depth of water per acre regarded as necessary to mature the crop.

Of the various ways of calculating the amount of water required for a given area to be irrigated, perhaps the simplest is that of acre-feet required per acre cultivated.

For the conditions in Northern Rhodesia it seems that from two to four feet of stored water is required per acre cultivated. (One cubic foot per second flowing for twelve hours is equivalent to one acre-foot.) This figure allows for the heavy losses by evaporation and seepage in furrows. In other words, given a storage reservoir of one acre in area (say 200 feet square), each acre irrigated will take from two to four feet depth from the reservoir.

It will be seen, therefore, that full irrigation requires a great deal of storage, and is expensive, especially if the land requires much grading. It is quite out of the question from deep bore water and can only be considered where there is either a perennial stream or a dambo of reasonable size.

In terms of flow the duty of water is often stated as the number of acres which can be irrigated with a discharge of one cubic foot per second. Averaging conditions in India and in the Union which are reasonably analogous to those in Northern Rhodesia and Nyasaland, one may take it that the duty is from 50 to 150 acres per cusec, according to the crop irrigated, pasture being near 150 and wheat probably below 100.

If, therefore, the reservoir is fed by even a small perennial stream of one or two cubic feet per second, it will, given a fair volume of storage in the first place, irrigate a reasonable area. Moreover, a moderate number of the streams just below the height of the divide do not cease to run until about half-way through the dry season, so that they are available to make good the water used on the first two or three waterings of the crop.

Already in the Chisamba and Mazabuka areas, to mention only two, there have been experiments in irrigation, and on the whole it may perhaps be left to private enterprise, advised and, if need be, controlled by agricultural officers, to extend these beginnings. The initial outlay for storage, furrows and grading is heavy, but maintenance charges for an efficient scheme are light and the exchange of a certain crop for risks of seasonal variations must be reckoned on the credit side of any argument as to whether irrigation is worth while.

The use of dambo water, naturally conserved, for irrigation, usually by pumping, must not be omitted from this review. Again, the experiments have already been made by farmers, with the advice and encouragement of agricultural officers, of whom Mr. N. Clothier might be specially named.

A dambo may be regarded as a reservoir of water equal to about one-quarter of the volume of the saturated dambo soil. Roughly speaking, therefore, a dambo of average depth, say eight feet, contains sufficient water without replenishment to irrigate about its own area of nearby land. Because of the comparatively slow seepage of water through the soil, the best way to collect it is to cut a drain back into the dambo from the sump at its edge from which the pumping is to be done. Very encouraging results from this lay-out have already been achieved in the dairy farms of Chisamba, where pasture under irrigation for winter milk should give good value.

Under certain conditions the marginal dambo soil itself may be worth irrigation, either by pumping or by using one of the systems outlined in an appendix.

Native Irrigation

The development of small irrigation schemes for Africans is quite another matter, yet it must receive increasing attention if the production of food is to keep pace with both the increase of population and the expansion of its purchasing power. Moreover, it is just where the pressure of population is greatest and the standard of intelligence to make use of irrigation is most promising that the advantages of such development are most evident, namely on land at or below the 3,000 feet contour along the Zambesi, the Kafue and the Luangwa valleys, and those of their tributaries.

This is more a matter of agricultural education than of water engineering, for with the will to irrigate the means to do so will easily be found. One can imagine what the Chinese or Javanese would do with the land alongside the Zambesi above Livingstone, where every few miles there are rapids providing the necessary command and stretches of land which would require little or no grading or terracing. The Barotse are already skilful at using their annual floodings to secure crops planted hard upon the retreat of the water, and it will not be a very long step for them to learn either to control the floods or to use the land further down the valley under the command of those floods. To judge from conversation with officers it seems highly probable that such tribes would soon learn to imitate demonstration schemes on a small scale and then be ready for advice from agricultural officers on more advanced schemes.

Major Problems

Of the major problems connected with the water resources of Northern Rhodesia the following are treated, since they were the subject of some brief field work.

1. The Flooding of the Bangweulu Swamps.
2. The Development of the Kafue River.
3. Navigation on the Upper Zambesi.

It must be repeated here that the planning of development in a comparatively new country must always be hampered by the lack of data, and this is particularly the case where water is concerned, since its provenance depends on so many factors. It may almost be said that the best that can be done by pioneering investigators is to define the problems and decide where more detailed surveys would be most profitable.

The Chambesi River and Lake Bangweulu

In the Northern Province the native population is considerable, and its density is above the average for the Territory. The rainfall being high, though seasonal, the development problems for water supply are not so acute as they are elsewhere. On the other hand, the province is unduly hampered by its geographical position. It is cut off from its best market, the Copper Belt, by the long 'pedicle' of the Belgian Congo and its bulkier products cannot stand the cost of the long road haulage to the Railway Zone. Two wars have shown how important is the route from the south into Tanganyika Territory, known as the Great North Road, of which a stretch of some 400 miles passes through the Northern Province. In each of these wars temporary measures were taken to use the waterways of the Bangweulu Swamps for transport, measures which have pointed the way for further development.

There is another reason for immediate attention to the Swamps and that is the serious flooding in recent years which has displaced a large number of Africans from fertile land within the swamp area. The problem of how to relieve the flooding is obviously linked with that of improving the navigation facilities and they both impinge upon yet a third, namely, the development of the fishing industry of the swamps.

This industry, which is entirely a native one, is already one of considerable magnitude. The fish are caught in the lake itself and the lagoons of the western half of the swamps, they are dried in the sun and then transported by any means available to the still unsatisfied market of the Copper Belt. Any means which can be devised for improving the transport, for broadening the fishing areas and for bringing regularity into a somewhat haphazard industry must be of real benefit.

None of these requirements can be assured until the behaviour or "régime" of the lake and its rivers can be explained and shown to be within power of control at reasonable expense.

The visit to the area had to be brief, but it was made under the guidance of Mr. Brelsford, a former District Commissioner of the area, whose knowledge of the swamps is intimate, and with Mr. Clay, the District Commissioner at the time. It must be recorded that without the knowledge and suggestions of these gentlemen the conclusions of this report could not have been reached.

It will be as well first to consider the whole watershed leading to the swamps, and thence out of them as the Luapula River.

The Chambesi River, which is really the ultimate, most distant, source of the Congo, is already a considerable stream by the time it crosses the Great North Road at a point 40 miles south of Kasama. By that time it has already gathered to itself the rainfall of some 20,000 square miles and its mean discharge for the year at the Crossing can hardly be less than 2,000 cubic feet per second.

The average discharge of a seasonal river is not a useful figure for calculations concerning all-the-year-round navigation. On the other hand, both from observation and from discussion, it seems that the volume of water available is not so much in question as the occurrence of rapids and fast water. The critical points for these hindrances are a few miles above the Crossing, where there is a low falls, and a stretch of some miles between the Crossing and the Bangweulu swamps, where there are rapids which can be passed by small barges and dug-out canoes only at flood time.

I was unable to visit either of these points and can only make a general recommendation that they should be surveyed with a view to proposals for improvement. I am inclined to suggest, after seeing similar rapids elsewhere in Central Africa, that the surveyor should not be content with looking for canal and lock sites, which in rocky country are liable to be costly. The traffic for some time to come could well consist of long steel or wooden canoes carrying from five to ten tons of freight. It is possible to by-pass low rapids with such craft by providing a short stretch of rails over which the barge is hauled by winch power.

Such a project combined probably with a certain amount of checking of flow by the addition of large boulders to the crest of a rapid may well be the best temporary measure.

The River Lukulu, which runs into the Chambesi just below the Crossing, has been used to convey goods by canoe to the neighbourhood of Kasama in the past. Judging from the accounts of those operations, it would need only a small amount of improvement to make it a valuable branch waterway to the main river.

The Bangweulu Swamps and the Luapula

The problem of the Swamps is best approached by a physiographical description of them, without which the apparently cyclical flooding cannot be explained.

As shown on the map, the swamps together with the lake itself occupy a more or less equilateral triangular area with sides about 90 miles in length. This low-lying area may be part of the general warping tendency between the rift valley structures which is best represented by Lake Victoria itself. Whatever the cause, it produced a shallow lake into which the proto-Chambesi entered, with its silt, at the eastern apex of the triangle and from which the Luapula issued at the south-western apex. The Chambesi began to build a delta at its end, while the Luapula ran for the most part fairly clear. The area, therefore, began to fill up with silt from the eastern end.

When the Chambesi reaches the edge of the Bangweulu Swamps it is joined by the Luansenshi River from the north, and together they seem to keep two stretches of water sufficiently clear of dense vegetation to have the name of Lakes Wumba and Chaya. From here the water spreads into the swamps by many channels, but three of them can be distinguished as major ones, to be known in this report as the North, Middle and South channels.

After following exceedingly complex routes, as will be described below, the water finally leaves the area as the Luapula River at the south-west corner of the swamps.

At this point it is worth noting the moderately close analogy of this river-swamp association with that of the Okavango in the Bechuanaland Protectorate.

In each case a large river enters, quite steeply, a large triangular area and gives rise to vast swamps and then passes on, either seasonally, in the case of the Okavango, or permanently in the case of the Luapula. These triangular areas were obviously large lakes at one time which have been filled with the river deposits. In Bechuanaland the filling is practically complete, while in Northern Rhodesia there is still a large though shallow lake yet to be occupied. Though the two cases appear to be at different stages, it is quite possible that their beginnings were contemporaneous. Bangweulu at a high altitude and with a high rainfall has always had a strong-running exit river, whereas the Okavango at a lower altitude and under greater evaporation has long since failed to pass through the swamps as the Botletle river, except at time of flood.

A still further comparison may be ventured, to the effect that sooner or later both of these vast areas of flood land are destined to be of enormous value in food production of both fish and grain.

As shown in the map and the block-diagram the north-west corner of the triangle is the lake proper, occupying about one-third of the total area, the respective sizes being about 1,000 sq. miles for the open lake and 2,000 sq. miles for the swamps.

There is very little drainage into the area from the western side of the triangle, and the drainage out is from the south-west corner. Accordingly, the origin of the water may be conveniently classified in three sections:

(*a*) On the northern side, with a watershed of 4,000 sq. miles.
(*b*) On the southern side, with a watershed of 5,500 sq. miles, and
(*c*) The eastern apex where the Chambesi River enters, gathering its water from an area of 20,000 sq. miles.

As will appear later, these proportions are of considerable importance in any interpretation of the regime of the whole system. By applying the rainfall figures as far as they are available for these separate watersheds the preponderance of supply from the Chambesi becomes still more evident and the proportions work out somewhat as follows:

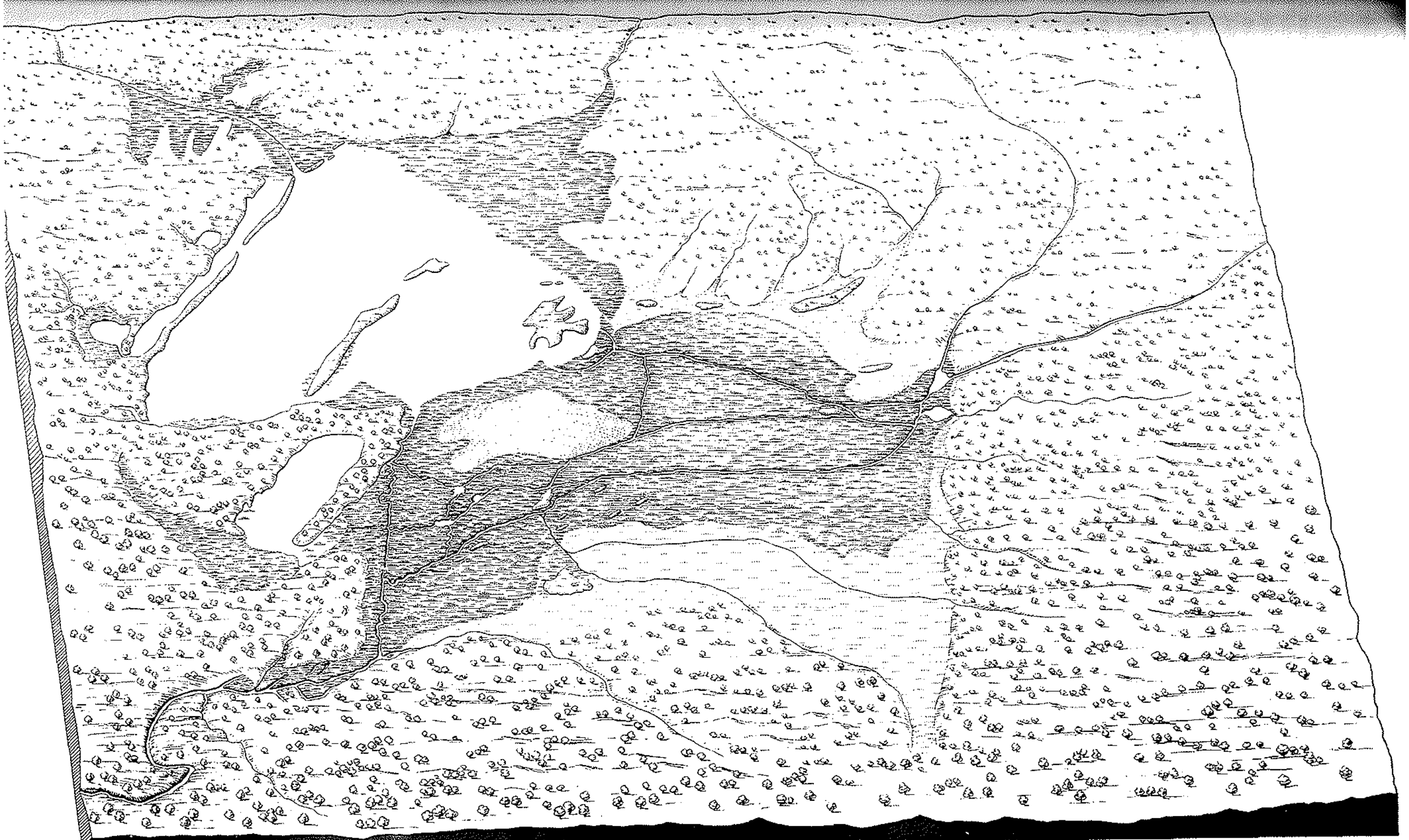
Chambesi	5
Northern basin	1
Southern basin	1

Accordingly we may expect to find that the silting up of the original lake has been effected roughly in that proportion, and that the main delta has been that of the Chambesi itself.

There are faint indications that the western side of the whole depression is due to faulting, possibly connected with the rift valley earth movements, but without going so far back as that period we may assume a depressed triangular area being filled up by a number of rivers and drained by only one, the main Luapula at the south-west corner.

The seasonal rainfall of the region causes an annual range of water level in the area which has been variously assessed as from two to as much as four feet. There are no figures for the silt brought down in suspension by the Chambesi and other rivers, but this too will be seasonal in character. In June, some two months after the end of the rainy season, the water was quite clear in the western half of the swamp area.

Such a series of conditions in a temperate area would give a somewhat confused result as to the places where maximum silting would occur, but in a tropical area with seasonal flooding and an extraordinary growth of water plants the confusion is much increased.



D.C.S. (Misc) 11. (F)

PANORAMA OF LAKE BANGWEULU.

It should be noted at this stage that the swamp vegetation varies considerably in type and density over the area, according to factors which are not well understood and indeed need investigation. The conditions vary from the exceedingly dense *papyrus* association, typical of the Upper Luapula from its exit from the lake down to its junction with the Chambesi. Here in comparatively deep water the density is so great as to prevent any passage even by small canoes except in natural or artificial channels. The papyrus is sometimes firmly attached to the bottom, at other places it is easily detached by rising water causing floating islands. In general, the currents can make no headway in the upper strata of water, but they do pass strongly under the matted growth of that zone to seek an exit below between the roots. In such places the mat is thick enough and sufficiently buoyant to be traversed on foot, somewhat precariously it is true, either by man or by the splay-footed antelope, the situtunga, which makes its home in such habitats.

Further to the east in the region of Lake Chali, for instance, the papyrus is less dominant, giving place to reeds which grow less densely. Amongst these the tall *phragmites* is very prominent, and it appears to favour fresher deposits of silt in shallower water. Thus it often marks the natural levees formed along the sides of main channels, where it grows luxuriantly in from three to six feet of water, rising to ten or fifteen feet above the surface. Its wispy flower heads tower above such channels completely blocking any view, and it is often entirely covered by the charming water convolvulus whose flowers range in colour from pale mauve to royal purple.

Still further to the east, on the line between Ncheta Island and Kasoma, the dominant reeds are much less obstructive and dense, so that canoes can move in almost any direction through the thin grass-like growth. One reed in particular has a single, somewhat fleshy stem of the thickness of a pencil, spaced at from a foot to some yards in distance apart, nearly every stem appearing to have its own special caterpillar or small green frog. At certain seasons this growth is so sparse that it can hardly be called swamp, and some early maps denote the stretch between the southern and middle channels as open water. This seasonal growth of millions of stems way well be of prime importance as to the direction of movement of the water for, as will be seen later, it is the plants which are really responsible for the unusual régime of water circulation.

It should be noted also that the main centres of fishing are in the open lagoons to be found in the deeper parts of the swamps, Lake Chali being the typical fishing lagoon, and that the chief edible fish, *Tilapia*, is herbivorous and cannot be caught by hook but must be trapped or netted, operations which require water fairly free from stems of plants.

We may now turn to the general map illustrating this section, opposite p. 44 and see in greater detail what an apparent confusion there is as to the flow of water alone. The arrows show that a part of the Chambesi water, entering the depression at and near Lake Chaya, passes right across the north-eastern portion of the swamps as the Northern channel and enters Lake Bangweulu north of Nsumbu Island, still as a fairly strong current in spite of having lost a large proportion of its water draining off through the swamps to the south and west. There is, therefore, a definite gradient from Lake Chaya to Chirubi Island.

This Northern Channel appears to have been the largest of the three channels for some time past, and it is navigable in the dry season when the Southern channel, though more direct, is too shallow for large canoes. It was the main route used in the first World War for taking war supplies from the Luapula to the Lukulu by water. It is described by J. E. Hughes, who was mainly responsible for the war transport at that time, as navigable throughout the year, though apt to be choked with vegetation.

The reason for the Northern channel taking the largest proportion of the Chambesi discharge would seem to be the small inflow of rivers from the north and consequent slow growth of silt deposits on that side of the swamp area. It is a vital point in the problem of relieving the flooded areas and will be reconsidered later.

Where channels have been opened into the swamp from anywhere between Chirubi Island and Mpanta Point the lake water runs rapidly into the swamps roughly in a reverse direction, towards the south and east. There is, therefore, a gradient in that direction at that part.

Meanwhile the regular outlet for lake water is down the Luapula channel to the south from Mpanta Point, a channel which continues to be narrowed by the encroaching sides of papyrus until it finally ceases to be a natural channel at all and the water finds its way under and through the plant growth, some of it, quite strongly, eastwards again into Lake Chali.

Of the other more or less natural channels for Chambesi water, the most important from our point of view is the southernmost, the most direct route towards the Luapula and the final exit at the south-west corner. This channel, however, is silted in places and does not carry the volume such a direct route would seem to justify. In other words Chambesi water runs in three main directions, north-west to Lake Bangweulu, south-west to the exit, and, in between these, an indeterminate amount passes through the swamps via old channels or through the plant growth, much of it along what we have named the Middle channel.

It is clear then that the Chambesi has been trying to build its delta across the depression. On the north side its activities have been compressed to a slight extent by the silt brought down by the comparatively small rivers flowing in on that side. On the south side the much larger rivers have compressed it more and have now restricted its most direct channel by silting so that more of its volume has to seek a northern or central route across the swamps.

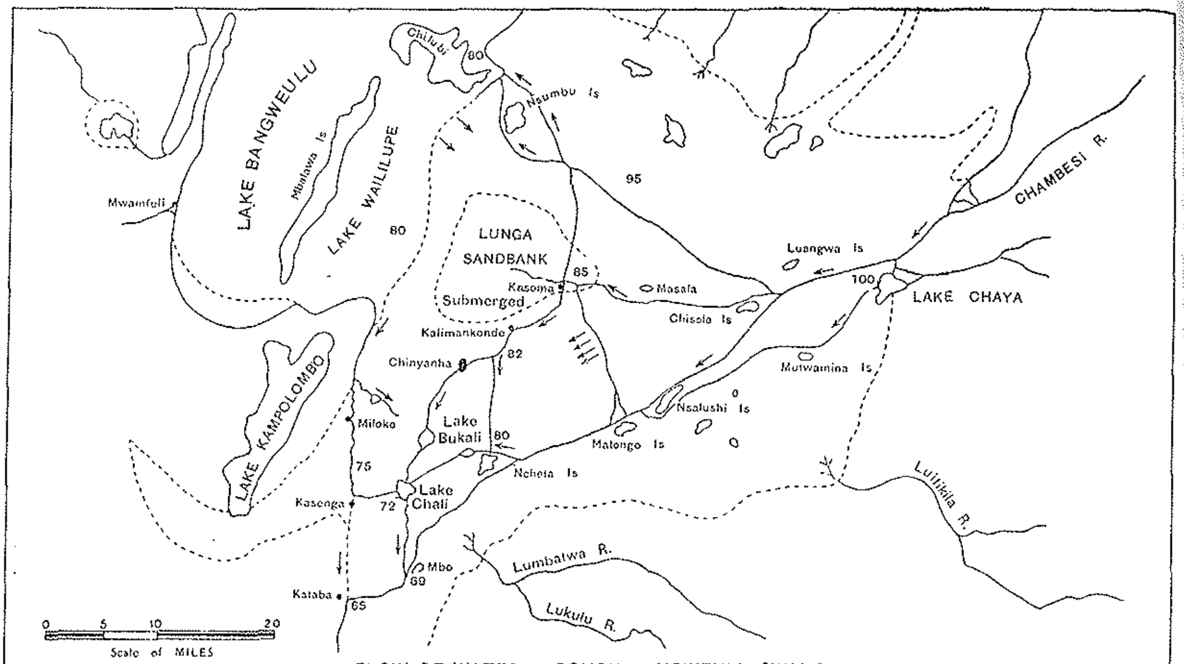
We thus have a cause for floods which is the exact reverse of that usually operating in swamps, which are normally flooded by a choking of the outlet. In the Bangweulu it seems to be due to changes in the channels at the point of entry and has nothing to do with the exit.

I was unable to visit the Lake Chaya portion of the swamps and therefore cannot speak at first hand, but I am convinced that this is the key area for control, if it is possible at all. It was said that the inhabitants once attempted to close one of these channels to avoid local flooding, but their work was not substantial enough and was overwhelmed at the first rainy season, yet it was probably a move in the right direction.

Stated in the above simplified and general terms, no doubt the problem appears to be a straightforward one, but that is far from being the case. It is necessary to realise that the "channels" thus glibly mentioned and drawn on the map are not channels in the proper sense with defined banks, but are merely routes kept clear of papyrus and reeds by natural means, either depth of water or strength of current. Alongside each of them the water is slowly progressing through the growth in the direction of the local gradient.

Further, this gradient may alter suddenly in the most baffling fashion, so that there are local accumulations of water and the current in any of the less important channels may reverse its direction several times along a route.

If the above broad outline has been intelligible it will be realised that the surface of the swamp water is not level, as one usually expects in a continuous water-surface, but slants in a general south-westerly direction. Nor is the water ever stagnant except locally where it is surrounded by unusually dense growth. In such plant-locked lagoons the water may be foul, and the passage of a canoe will cause



FLOW OF WATER THROUGH BANGWEULU SWAMP
and relative heights of surface (estimated)

a line of bubbles of gas to rise from the bottom, a line which persists for a long time as a water-spoor. Elsewhere the water is everywhere in motion, steadily in the major channels, quite violently in some of the narrower cuts (mpetampeta) formed by the natives, and very slowly indeed through the broad stretches of sedgy water between the channels.

If it were not for this continual flow of water through the swamps, if, in fact, they were as stagnant as they sound, they would be an impossible habitat for man and a poor one for beasts. As it is, in spite of the impressions of some visitors, the swamp area is not unhealthy, or only so where the population is crowded densely on the small low islands.

The curious state of affairs with regard to the water movement may best be illustrated by considering the course which a small volume of Chambesi water may take when, after passing through Lake Wumba, it has a choice of channels. Its shortest route would be along the Southern channel, but it could pass down the Middle channel almost to the Lunga Bank and thence by narrow cuts or "across country" to Lake Chali and south to rejoin the Southern channel. At present it seems that its most likely choice is the Northern channel in a very direct route to Lake Bangweulu, reaching it to the south of Chirubi Island and then turning south to go down the Luapula or through the swamps close to the northern edge of the Lunga Bank. In the present flooded state it may cross the Bank itself. Its route by the longest way round would be over 100 miles, by the shortest about 70 miles.

Unfortunately, there are no levels and few figures of current velocities, either of which might tell us why these choices are open to the water. In their absence we are driven to making estimates, little more than intelligent guesses, as to the shape of the submerged delta and the slope of the water which is due both to the delta shape and to the degree of obstruction to movement caused by the plant growth. In attempting such estimates the writer lays himself open to the gibes of future surveyors who will make accurate measurements, but such an attempt will serve to explain the type of problem with which we are concerned.

Taking the level of the water at Lake Chaya as datum one would expect that the level of Lake Bangweulu some 50 miles away is about 20 feet lower, a figure arrived at from nothing better than the few published accounts of the strength of flow along the Northern channel. (The channel does not appear to be silting so the slope or gradient is probably between 1/7,000 and 1/10,000.)

The velocity on the upper Luapula between the lake and Kansenga was observed, and rough calculations from the figures suggest a fall of about five feet in the fifteen miles. From this point there is a moderate flow for the seven or eight miles to Lake Chali, which is therefore placed, empirically, at three feet lower than Kansenga or eight feet lower than Lake Bangweulu.

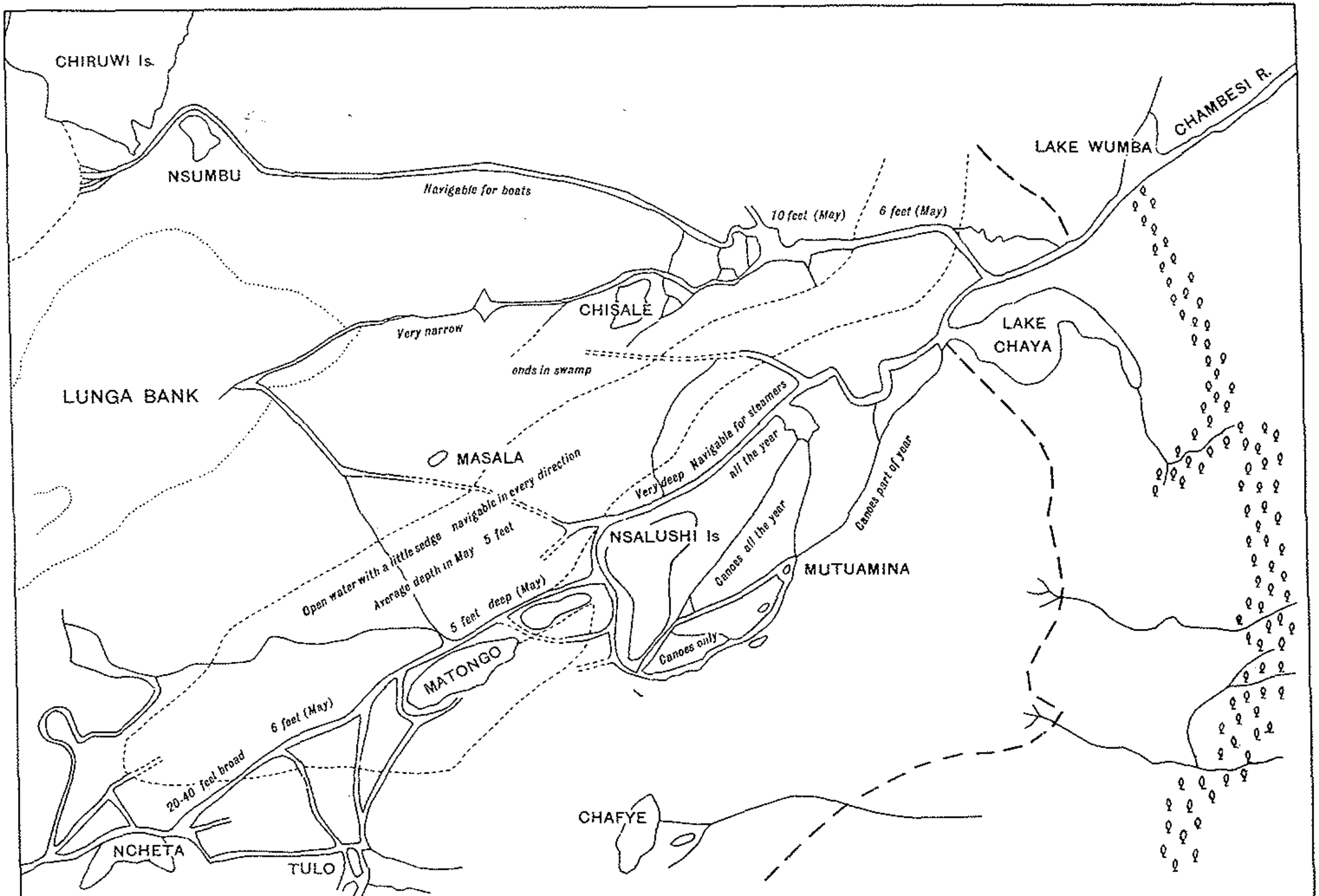
The upper Luapula used to flow underneath the papyrus from Kansenga southwards, but a cut made by Mr. Brelsford during the war has established a waterway once more. Along this channel of about 15 miles the velocity figures suggest a drop of about 10 feet to the junction of the upper Luapula with the Chambesi near a village called Kataba. On the route from Lake Chali to Ncheta Island our canoes met currents of up to three knots in the narrower sections of the cut and accordingly the water level at the island is given a rise of eight feet over the 12 miles.

On the journey from Ncheta to Kalimankonde the currents were slight and occasionally reversed so that village is taken as but two feet above Ncheta. For the five miles on to Kasoma the currents were strong and, therefore, Kasoma, a key point in the circulation, is placed at three feet higher. Finally there is reason for suggesting that Mbo is about three feet lower than Lake Chali.

We may now collect these estimates into a conventionalised map (as above), allotting 100 feet as a relative value to the level of Lake Chaya.

The result of such estimating is naturally untrustworthy to a degree, but it does provide some sort of cartographic picture of what must be the state of affairs as to the water surface. It must be repeated that the channels so clearly marked are without banks and represent little more than reed-free routes with deeper and faster water than the open swamp on either side.

The open swamp carries off a large proportion of the water towards the exit point at the south-west and it appeared advisable to find out what this proportion might be. Accordingly I took discharge measurements of the Luapula at Kapalala, far from the main swamps, which



MAP OF BANGWEULU SWAMP EASTERN END
(AFTER MELLAND 1911)

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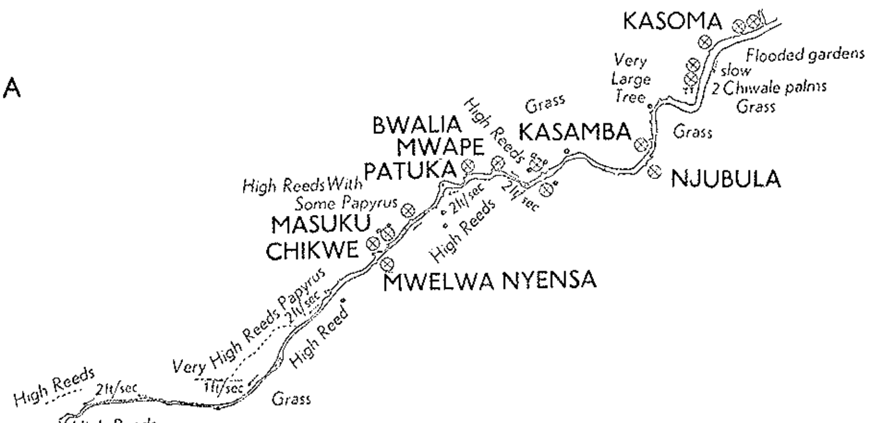
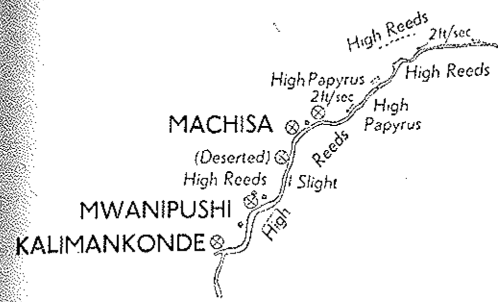
CHANNEL FROM KASOMA
TO KALIMANKONDE
Scale 1: 50,000





gave, on that date, a result of between 18,000 and 20,000 cubic feet per second. Similar but rougher discharge calculations for the three channels, south from Kansenga, south from Lake Chali and in the Chambesi itself, opposite Mbo, gave an aggregate of only about 3,500 cusecs.

This seems to indicate that about three-quarters of the water reaching the south-west exit comes via the reed grown areas and not by the main channels. If this figure is even approximately correct it is clear that the narrow cuts which have been made from time to time to improve navigation can do very little towards draining the flooded areas.

With such conditions one would expect that any channel carrying silt would deposit some of it in the fringe of reeds and form a natural bund or levee. We did discover this to be the case in the lower part of the Chambesi where the depths were 20 feet in the channel, four feet at the edge and seven to eight feet beyond in the main swamp. This leads one to suspect that there may be more pronounced levees nearer the point of entry of the Chambesi, and if so the breaks through of the past are through the levees and not merely by washing away plant growth.

Another puzzling phenomenon is that at the time of the visit the water level at Kasoma was sinking and at the same time there was flooding in Lake Chali. This may be due to the slow passage of the main bulk of the water through the reeds, so that the former flood at Kasoma has taken some four to six weeks to reach Lake Chali. It may equally well be due to some fresh avenues having been opened from the main Chambesi which would thereby be reaching Chali by a more direct route.

The whole scheme of drainage is very complex and a brief visit could not clarify the situation with any certainty, particularly as time did not permit seeing the eastern apex of the swamps which is obviously the critical area.

Accordingly some description of this region must be given, taken from conversation and from published accounts. Of the latter the most useful is embodied in a map by Mr. F. H. Melland, Native Commissioner in that district between 1902 and 1910, which was published in the Geographical Journal for October 1911. At that time the northern parts of the Swamp were experiencing a cycle of high water only two or three feet less than the present, and although the routes of the channels may have altered to some extent in the 35 years, their general distribution may well be the same. The significant information from his map is plotted in the diagram opposite page 64.

It is clear that at that time the Southern channel was carrying a great deal of the discharge at least as far as Nsalushi Island. Between that point and Ncheta, however, he gives depths of six feet in May, which could be only three feet or less in September, and it seems very probable that even then the silt brought in from the south by the Lumbatwa and Lukulu rivers had seriously shallowed the main channel. It is significant that in 1915 when J. E. Hughes was taking war convoys across the swamps he used the long way round, up the Upper Luapula and along the Northern channel, in the dry season, "when the more direct and convenient route via the string of swamp islands did not contain sufficient depth of water to float large canoes".*

The very existence of a "string of swamp islands" is proof of the silting along the southern arm. Melland's excellent map is most illuminating in other respects and naturally leads us to consider the problem of the "cyclical" rise and fall in the level of Lake Bangweulu itself. Figures seem to show that, quite apart from the seasonal range of level due to the rains, up to four feet, there is a "cycle" similar in kind to those in Lakes Tanganyika and Nyasa. At one time it was believed that these cycles were synchronous but that seems to have been disproved now.

In the case of Lake Nyasa it seems to be clear that the alleged "cycle" is no more than a swing from one extreme to another between two opposing factors to be found in tropical Africa. When the Lake is low and the exit river sluggish it becomes increasingly blocked by vegetation and consequent silting. The lake level rises till it overcomes the blockage but since the vegetation is tenacious in the extreme it takes several years to remove it and reach the low cycle again.

One cannot apply such reasoning to the Bangweulu swamp area as a whole, since the true outlet is well below the main swamp level and no control is possible from that end.

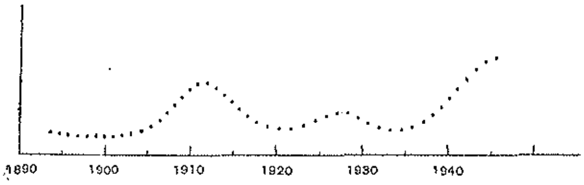
It has been suggested that the periodical blocking of the channel of the Upper Luapula, which undoubtedly takes place, is the cause of the flooding. This choking of one outlet is well described by W. V. Brelsford in the Geographical Journal of July–August 1945, Vol. CVI, Nos. 1, 2, but he also shows that the block seems to have been in operation for a very long time, and his own successful efforts in cutting a by-pass channel for navigation had no noticeable effect on the general level of the lake. As already noted, the proportion of water discharged by the channels as compared with that passing through the open swamp seems to be far too small to allow the blocking of one channel to cause such extensive flooding. While it could be a contributory cause it cannot be shown that it is in phase with

* "Eighteen Years on Lake Bangweulu", by J. E. Hughes, p. 261. Publishers: *The Field*, London.

the period of flooding which is given by Mr. Brelsford in his article, and may be repeated here.

He supplies evidence to show that there was a low level in the 1890's, which seems to have been maintained until 1903. In 1910–11 the level was so high that the Ba-Unga of the Lunga Bank were in distress. The level seems to have fallen by 1920 succeeded by a slight rise to about 1927 followed by a fall ending in 1935. Since that year there has been a steady rise and the present disastrous high level seems to have been reached about 1944.

The graph shown below illustrates these somewhat uncertain records. It must be viewed with caution since both the levels and the times are of the vaguest, and it cannot be taken as a basis for hypotheses.

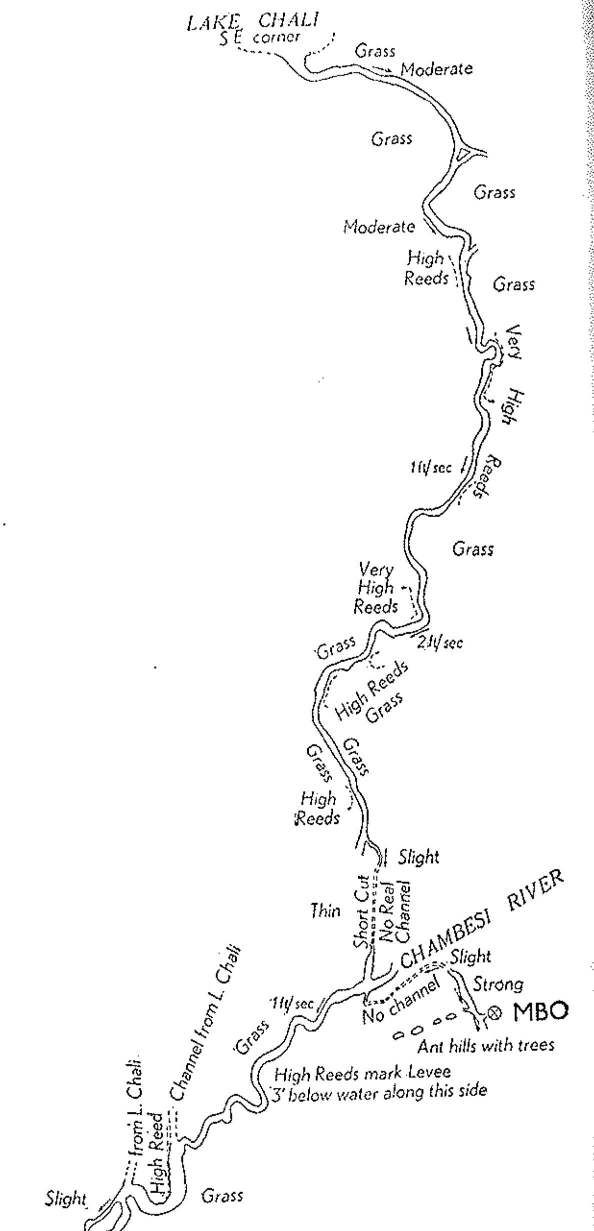


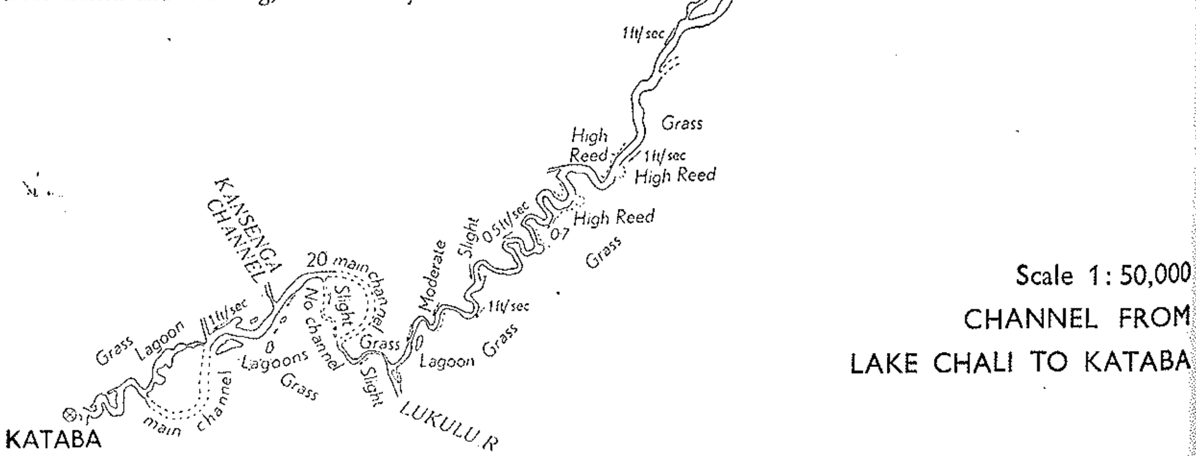
Graph showing relative Rise and Fall of Lake Bangweulu

The undoubted effect of blockages by papyrus and other vegetation cannot be ruled out, since it is so clearly operative in other parts of Africa, but if it is a cause of the flooding it must be acting at the Lake Chaya end whence the supply of water comes. Indeed the best hope of relieving the floods in this case is probably to be found by using the capacity of papyrus to cause blockages and catch silt, directing the mechanism to those channels which require it, and clearing those which have been blocked.

Having discounted the blockage of outlets as a cause for the periodic floodings of the northern part of the swamps, including the Lake, we may now consider the inlets and their susceptibility to alterations. It is obvious that flooding is just as likely to be caused by an excess of water arriving on an area as by hindrance to water escaping from it, and I favour this cause, not on evidence, which is completely lacking in either direction, but because it is simpler.

As already described, there are three main distributory arms or channels opening into the swamp area in the vicinity of Lake Chaya, any one of which may be altered as to its carrying capacity by natural conditions. A temporary blockage in one may put such pressure on the others as to cause erosion and widening, or there may be fresh breaks





Scale 1 : 50,000

CHANNEL FROM LAKE CHALI TO KATABA

in the underwater levees creating a multitude of small channels favouring one or other of the main arms.

It is indeed perhaps the commonest feature of any delta that there is a swing of the main current across the fan of its own detritus which though hardly regular enough to be called a cycle, is yet caused by the inevitable filling up of one channel till it cannot carry the discharge which then partially deserts it for another one. Unfortunately, in the absence of personal evidence as to what has happened in the past, there is no present proof that this action has been the cause of the flooding. A careful examination of the area from that aspect, and questioning of the few natives who know the channels, may possibly elicit evidence.

We are therefore left with the not discomforting assurance that even if it has not been the cause of the flooding it could have been. That being so an attack on the problem of prevention can be made from that end. It is still more comforting from the engineering point of view to reflect that diversion of flow is very much simpler than draining, that in fact one tree trunk or one anchored island of papyrus at the inlet end may do the work of hundreds of cubic yards of excavation at the outlet end.

The Situation at Present

The drowned lands

Having thus stated the problems of ingress and egress of the water to the area and suggested a partial explanation of them, we must now examine the present state of affairs which calls for remedial measures, some of them urgent.

Whether as a result of a rising cycle or something more accidental in the form of new break-through channels from the Chambesi, there has recently been steady flooding of the northern and dryer portion of the swamp area, originally mapped as the Lunga sand bank and thickly populated. This flooding began in the late thirties and caused much movement of the lake people and hardship, until in 1946 there were not more than a few hundred people left in the less flooded villages, some thousands having been moved to the mainland.

As mentioned above, channels have recently been cut in different parts of the swamp, primarily with a view to improving the waterways for navigation. It is not yet clear whether these channels have had much to do with the recent emergence of small sections of the sand bank. In view of the comparatively small discharge of these channels I should be inclined to doubt whether they are having much effect. For instance, the Churchill channel when visited had a discharge of only about 100 cusecs, not in the least comparable with the amount moving slowly through the vast areas of deep reed to the south of it. It is undoubtedly a step in the right direction, but it will have to be much deeper and wider before it can begin to control the level to the north to any marked extent. There is ample gradient for such a large channel in the future to be dug by mechanical means, but I am not convinced that it would be either the cheapest or the most effective means of reclamation. There are reasons for believing that the reclamation of this Lunga sand bank should be the prime object of any control which can be devised, on both economic and social grounds.

To quote mainly from conversations with those who knew the sandbank in its dryer days, it can be described as an area, up to 100,000 acres, of black clay or silty soil of exceptional fertility and it was accordingly densely populated by the Ba-Unga. Mr. Trapnell, in a memorandum, has recorded, "The Lunga plain area in particular was of great fertility and used at one time to be the scene of migrations for garden making from villages in the various sandbanks and even from some other islands in Bangweulu as well as from the outlying villages of the Unga". Bordering the actual sandbank and even elsewhere in the shallower areas of the Swamps there are what the Ecological Survey calls the Swamp Peats, not much inferior to the sand areas for cassava.

One may conclude therefore that were a permanent lowering of the water level achieved there would be ample good land for a great expansion of agriculture with the Copper Belt market not too far away. The rehabilitation of the people in their former habitat is also an urgent matter for administrative and tribal reasons.

The fishing industry

The catch of fish appears to depend mainly on easy access to lagoons and other fish haunts and on the level of the water permitting the establishment of temporary, semi-floating fishing camps. There seems no reason to believe that there is any tendency to over-fish the area as a whole. The economic factors of transport and price are a much more dominant control at present than any scarcity of fish. At the same time there is need for a fish survey so as to curb the optimism of some and relieve the fears of others with whom I discussed the future of the industry.

It would be possible no doubt to drain the area so thoroughly that the industry might be affected, but the existing artificial channels are at present certainly contributing to its welfare by providing a small amount of transport. This transport by motor boat has been somewhat haphazard in the past, but under war conditions it had no real chance to prove itself. Its inevitable expansion will reduce the price of fish in its main market, the Copper Belt, and free more men for the fishing from their tedious method of taking dried fish for over 100 miles by bicycle. It will be necessary to handle that real improvement with care since the fishermen cannot be expected to view a reduction of price from the present figures with any relish. Any hard bargaining by middlemen might easily dry up the source of supply from a people who are moderately independent and whose chief aims are still food and shelter rather than the luxuries of civilized products.

Transport

Under this heading there are two objects in view, namely better waterways for the movement of goods *in* the swamps, and routes *through* the swamps to supply other centres.

The first requirement is already nearly met and can be assisted by widening certain channels and perhaps by building a receiving station on piles near Lake Chali, one of the natural receiving points.

The second requirement is not so simple from either the economic or the engineering point of view. The points to be reached are either Mwamfuli or Nsombo on the lake itself on the one hand, and as near as possible to Kasama up the Chambesi and Lukulu on the other.

The economic problem is that the opening of the new road from Mufulira to Fort Rosebery and beyond should so cheapen the rates by lorry that for ordinary stores and for fish from the northern end of the swamps the land transport would cut out the water transport, in consideration of the time saved. Unless and until heavy goods from the Luwingu district are to be moved to and from the Copper Belt, water transport from the lake itself to Kapalala will hardly be an economic proposition.

The case for the Kasama area is far more promising, and if the upper Chambesi basin were ever to produce quantities of foodstuffs for export, as seems possible, a water route down the Chambesi to Kapalala would be profitable, though the 60 mile lorry haul from that place to Ndola would be a heavy charge on the freight costs. On the other hand a branch railway line to Kapalala from Ndola would be a reasonable project if the bulk of transport increased sufficiently.

There are no engineering difficulties in the route up the Luapala to Lake Bangweulu beyond maintenance of the Kansenga channel.

On the Chambesi route the existence of a lengthy chain of rapids or fast water, which I did not see, may make the establishment of such a route for barges a costly business, though not prohibitively so if the picture is correct as given by eye witnesses.

In spite of these apparent hindrances the problem of water transport is so closely associated with drainage channels that I feel it proper to suggest that when further data are available the question of bulk transport by water should receive the closest examination.

Survey and Control

The one thing which will be clear from the foregoing account of the situation is that there is a deplorable lack of information of any kind relating to the hydrology of the area. Such as there is has been the work of a succession of District Commissioners who have done their best with inadequate instruments to record what their work has led them to observe. It is the penalty, or as some of them would say, the delight, of pioneer administrators that they have to be their own technical staff and to act in both capacities at short notice. Nevertheless, it is time that, for the Bangweulu area, such a demand on their capabilities should come to an end. Nor, in this case, is it likely that the technical staff of the Territory can be spared for long enough to make the survey which is required and which is outlined below.

At this point then we may consider more fully the object of such a survey and to what ends it should be conducted.

The aim of control of the swamp water is threefold, namely:

(i) The relief of periodic flooding, particularly of the Lunga Bank.
(ii) The establishment of waterways for navigation.
(iii) The further development of the native fishing industry.

At the same time the means of control must be inexpensive, that is to say, they must rely as far as possible upon local labour and materials. The first necessity is a hydrological survey, but it may be instructive to consider what the engineers may advise when the results of that survey are available, even though we may have to assume some of those results in advance, in particular that the Lake Chaya end will be the one for control works.

One of the aims of such control works will probably be the deflection of some of the flow from the Northern channel into the Southern; how is this to be done cheaply, and mainly with local facilities? The answer is that the natural mechanism of African rivers must be used to the full, particularly the growth of swamp vegetation. The reduction of flow through an excessively active channel would best be accomplished by guiding floating islands of papyrus into the channel and anchoring them by artificial means until they have anchored themselves and have checked the flow enough to induce the deposit of silt. This would be easy or difficult according to the nature of the site chosen. In any case it would be an operation well within the capacities of the skilful native canoe-men, and except for the occasional need for piles or poles, to be brought down the Chambesi, would be accomplished with local material.

It is clear, however, that the partial blocking of channels does not of itself solve the problem, for the backing up of the water which results would probably lead to fresh breaks through in other places. It is necessary therefore to consider the real cause of the excessive flow through the wrong channels, which is the decreased capacity of the former, right channel. At the same time as the blockages are being arranged in the other channels the capacity of the selected channel must be increased. To do this by dredging is almost prohibitive and one must at least try more natural means of enlarging the channel.

One such means is to use the effect of growing vegetation in slackening the current and inducing the formation of natural levees. As already described, this process goes on at present at the side of the more rapid currents and is usually marked by the growth of *phragmites* on the submerged bank so formed. Such natural levees are, however, apt to hem in the channel too closely and in flood time they are broken through and washed down. If these levees could be induced at a wider spacing they would be more stable and their effect in widening the channel for floods would be more pronounced.

This moving back of the levees from the present channel can be accomplished by cutting the arresting vegetation down for the width of channel required and allowing the sweep of the water to remove the inner levee and gradually to build an outer one on each side. This may seem to be a formidable task but there are alleviating conditions to it. For instance, there is no need to attack a long stretch of the channel at once, it can be done in successive sections from above downwards, for as little as half a mile at a season. If the optimum width between the new levees is successfully chosen the roots of the vegetation will be swept away and there will not be serious fresh growth, each flood assisting in keeping the new bed mobile and preventing a reoccupation by plants. Again the removal of the stems only is required, not of the roots as in cutting a new channel, and it can be done with curved implements from a canoe in water too deep for wading, and by native labour.

The process obviously involves the removal of silt in one stretch only to be deposited again lower down, but this is equally the effect of any other method of widening the channel.

A full survey with soundings will no doubt establish the most satisfactory route for the increased discharge in the Southern Arm to follow, particularly whether it should pass to the north or the south of Ncheta Island.

The Need for a Hydrological Survey

It should be obvious from what has already been said that any major operations with the channels might produce unexpected effects and that we cannot predict those effects without many more data.

The most important information required is the level of the water surface at different parts of the area. Without such information there can be no surety that a new channel will be opened in the right place, or even that when it is opened the water will run in the expected direction. Yet levels over the water surface of a large swamp are exceedingly difficult to take and demand unusual survey methods.

Similarly, until we have soundings of some accuracy in such lagoons as Lake Bukali and Lake Chali, good fishing places, we cannot judge what effect on fishing may be caused by large draining or diverting operations.

Again it seems fairly clear that the critical part of the whole water system lies near the point of entry of the Chambesi, and here in particular a detailed survey of depth, rate and direction of current is essential.

There must be fairly simple explanations of anomalies such as were mentioned above concerning flooding in one area and lowering of the water level in another, but these can only be obtained by further gauge measurements at critical points. Further, a complete hydrological exploration of the swamps will assuredly disclose the full reasons for the cyclical rise and fall of the lake.

In short, there is unlikely to be any great advance in our understanding of these associated problems until a survey has been made. It is in any case futile to call in a professional expert on swamp draining, etc., at this stage since he would decline to give an opinion without further data or, more probably, would have to bring a large and expensive staff to obtain that data for him.

Such hydrological survey, though far too large a project for the spare time of occasional district commissioners, is well within the powers of any group of young men interested in surveying and water problems, even those without very much experience, and the work could be fitted into three or four months of the dry season. It is chiefly a matter for energy and interest with a moderate degree of technical skill. Experience and sound judgment would be required when the survey had been made, and then the services of a professional engineer would be desirable.

I would therefore suggest that a scientific expedition could well be entrusted with such a survey, and though monetary assistance would be required it would be far less than for a fully professional survey by established engineers. Another very important point about such an expedition is that it can easily, and very profitably, be expanded to include specialists on related matters such as fish, aquatic plants and entomology

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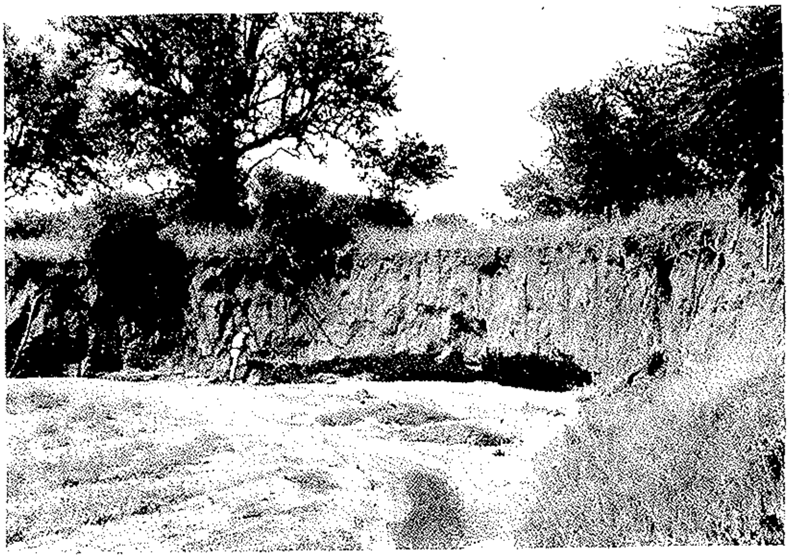
A typical Sand River in the Kukwi Pass, near Serowe, B.P.

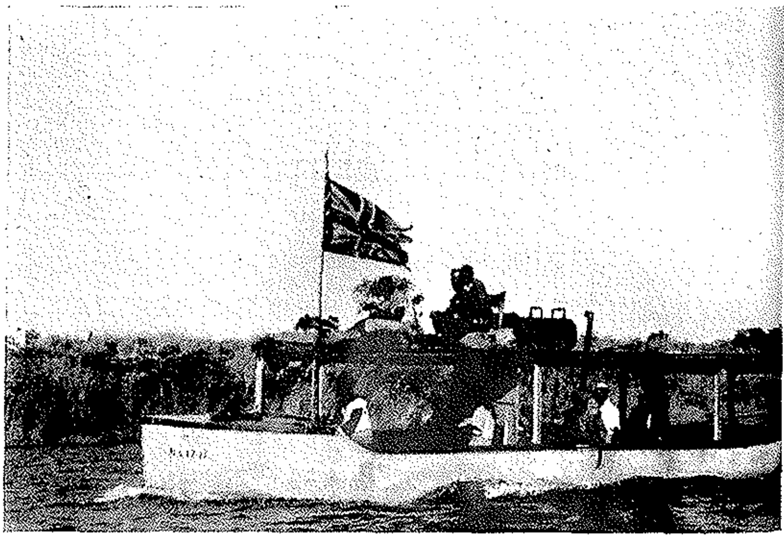


Erosion of a Road, Serowe, B.P.

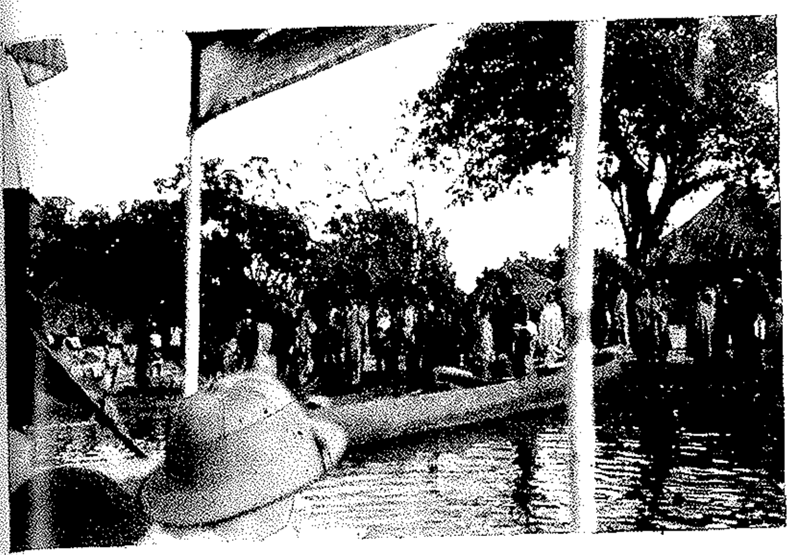
The Fertile Flood Plain of the Thamalakane River near Maun, Bechuanaland Protectorate

The Luapula River at Kapalala, Northern Rhodesia

The Bangweulu Swamps seen from Kansenga, Northern Rhodesia

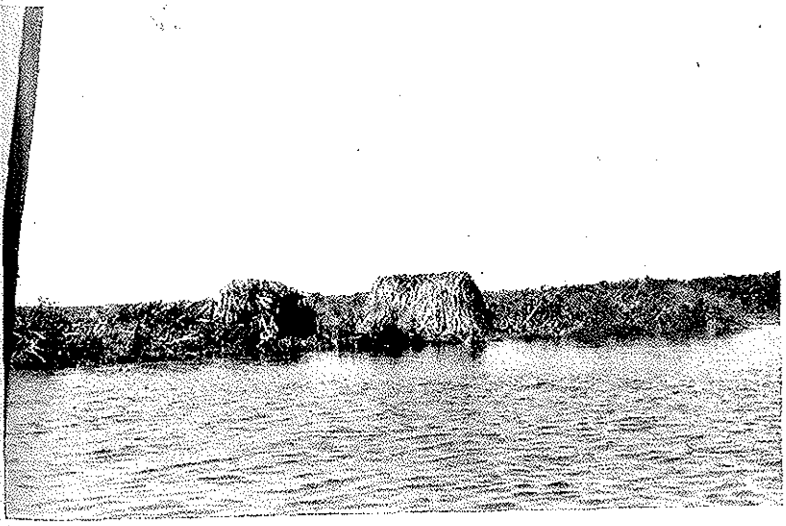


Diesel Launch on the Upper Luapula, Northern Rhodesia

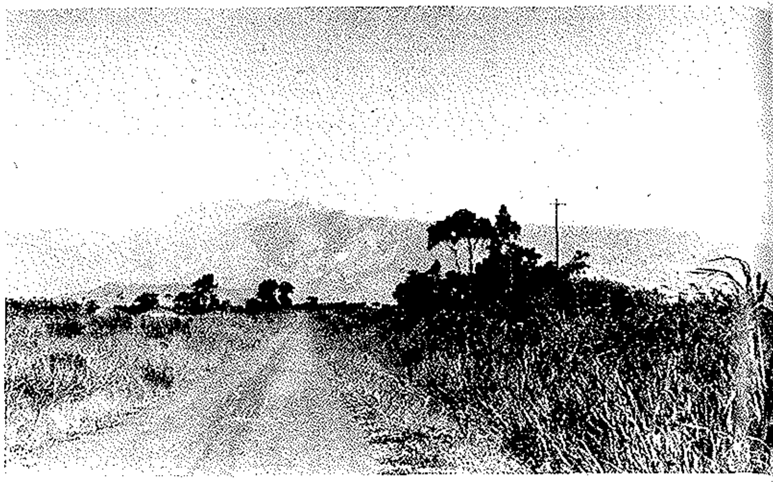


The Village of Kalimankonde, Bangweulu Swamps, Northern Rhodesia

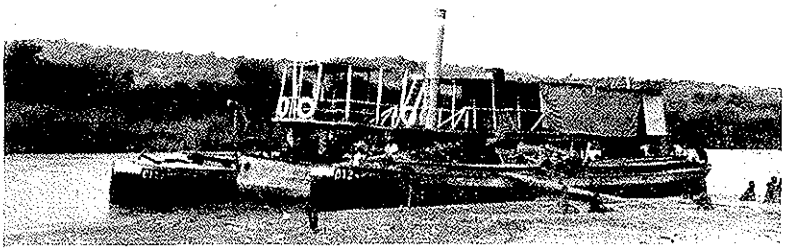
Typical Canoe Channels in the Bangweulu Swamps, Northern Rhodesia



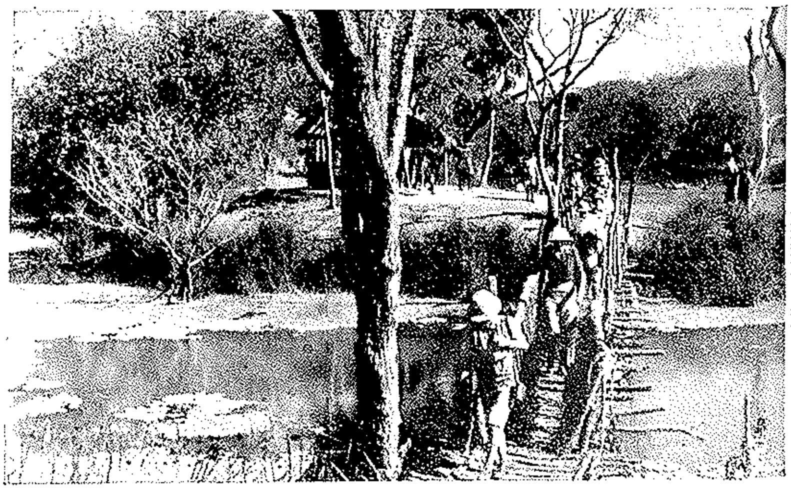
Native Fishing Camp, Lake Chali, Bangweulu Swamps, Northern Rhodesia



Mlanje Mountain,
Shire Highlands, Nyasaland

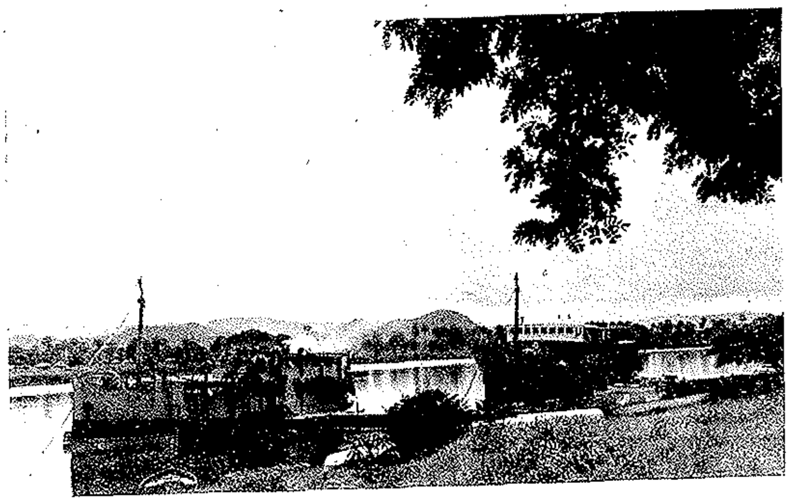


s.s. "Hydra" at the Limit of
Navigation on the Lower Shire,
Nyasaland



Dam in the Eastern Province,
Northern Rhodesia

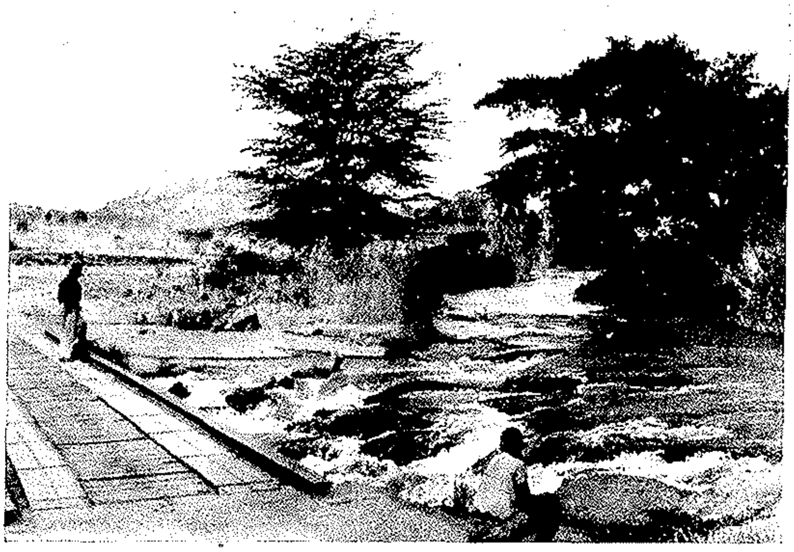
Churchill Avenue, Fort Johnston, Lake Nyasa



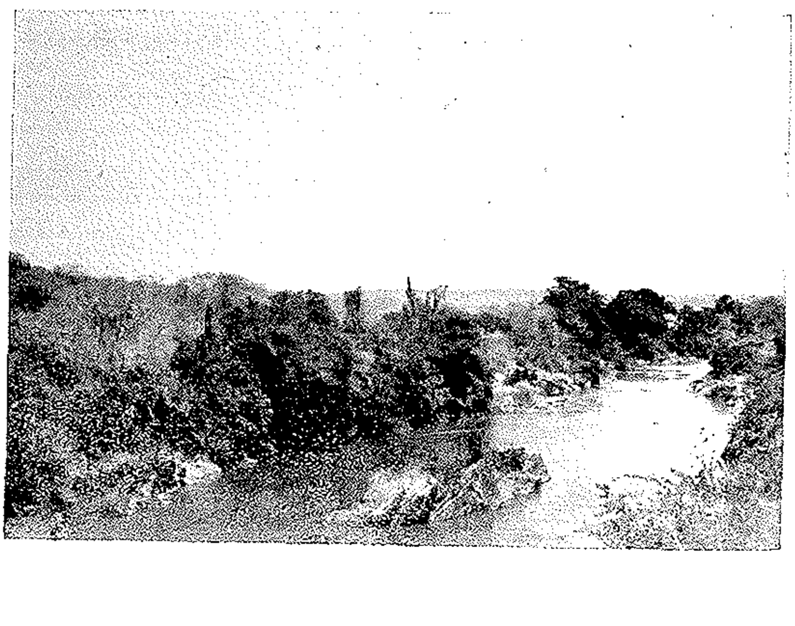
The "Mpasa" and the Ill-fated "Vipya" at Fort Johnston, Lake Nyasa

Remains of the Former Bridge over the Shire at Liwonde, Nyasaland

Flood Plain of the Lower Shire
at Alimanda, Nyasaland



The Tsavo River, Kenya



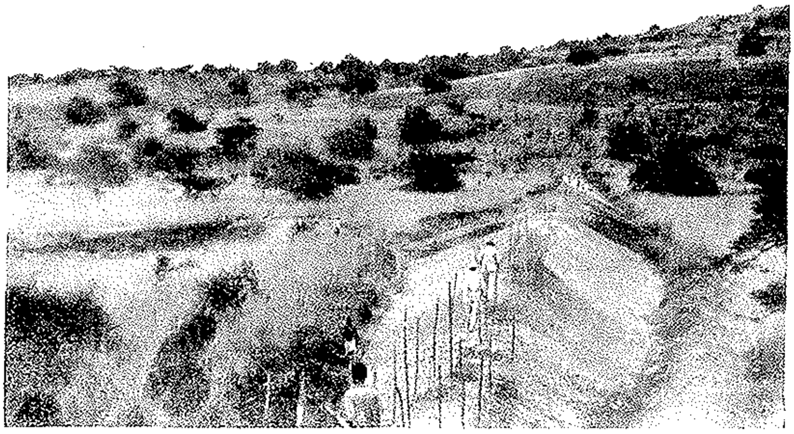
The Tana River on the road from
Kitui to Embu, Kenya

Small Sand River at Garba Tula, Northern Frontier District, Kenya

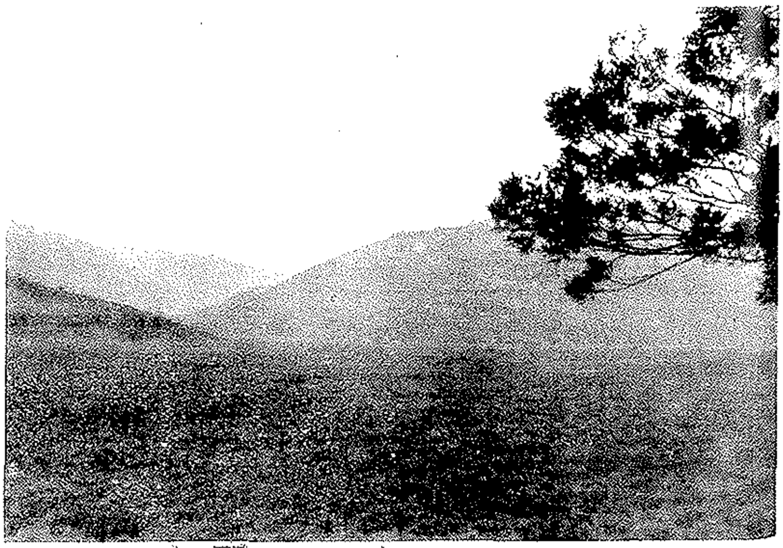
Extinct Craters and Typical Landscape on the road from Isiolo to Garba Tula, Kenya

Typical "Vase" Thorn of the Northern Frontier District, Kenya

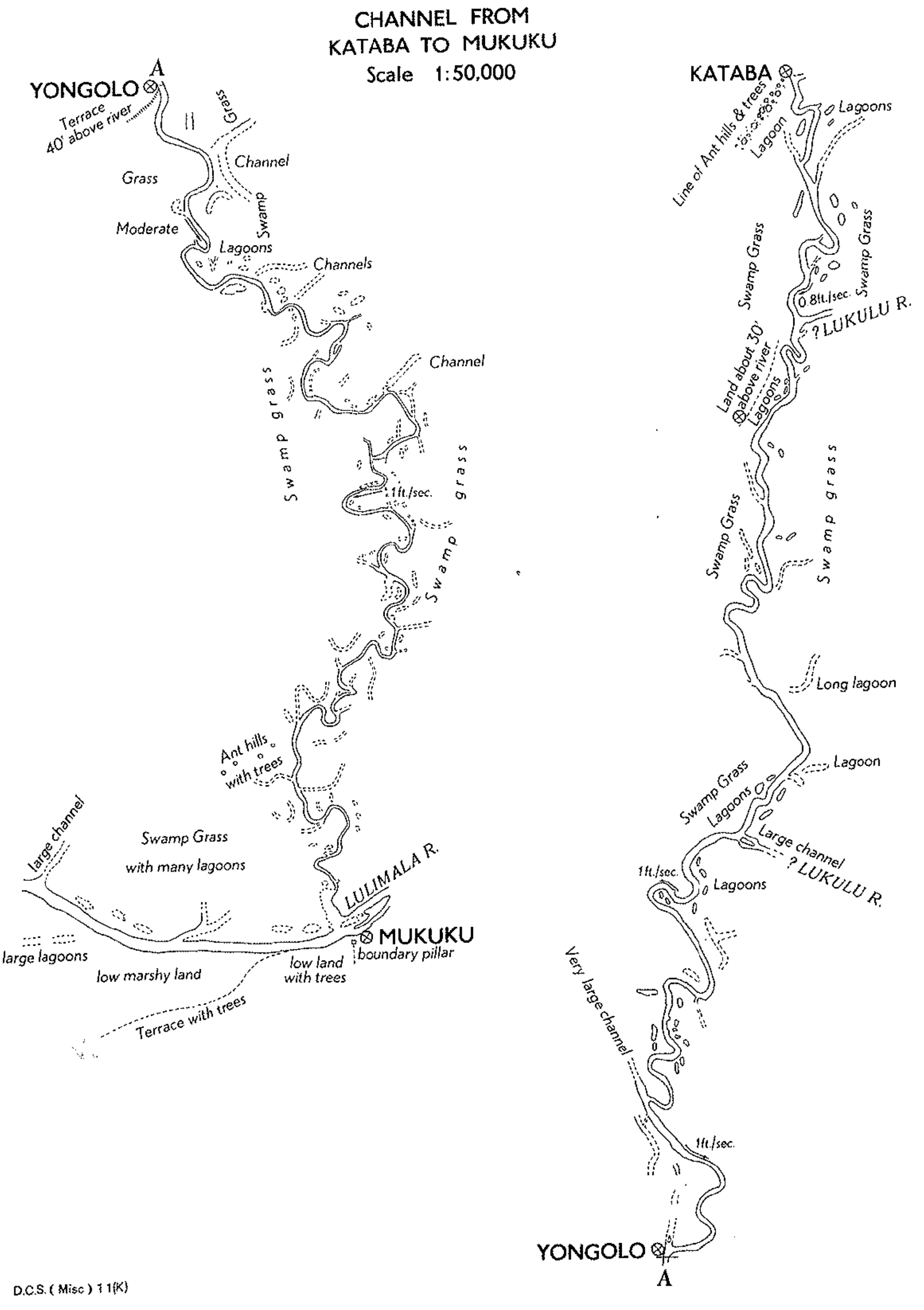
The Crater Lake of Mount Chala near Taveta, Kenya



Earth Dam in Ankoli, Uganda



Typical Valley Swamp in Kigesi, Uganda


CHANNEL FROM
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with trees
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Swamp Grass
with many lagoons
LULIMALA R.
MUKUKU
boundary pillar
large lagoons
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low land
with trees
Terrace with trees
KATABA
Line of Ant hills & trees
Lagoon
Lagoons
Swamp Grass
Swamp Grass
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? LUKULU R.
Land about 30' above river
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whereby the survey can be made far more generally useful than if it were confined to hydrology alone.

It is not very difficult to find young University men who have nearly or actually graduated, with the necessary eagerness and knowledge, who are only too anxious to prove their scientific competence by means of such an expedition, and whose energy and readiness to endure the discomforts of such work make up for their lack of experience. For a short period they would not require more than expenses and an honorarium, since their published work is part of their reward. It is desirable that the leader should be a more senior man, who would need more generous remuneration, and a man with local knowledge of the language and customs of the tribes would certainly be required, preferably as stores and transport officer.

At this stage we need not further specify the personnel required for such an expedition, except to say that the work could be done by two or perhaps three people with knowledge of survey and hydrological measurements backed, as mentioned above, by such specialist scientists as were thought desirable. Six or seven persons in all and a sojourn of say four months in the field should be sufficient to obtain the hydrological data aimed at, though the specialists would doubtless prefer a longer period, perhaps a complete cycle of plant, fish and insect growth.

The objects of such a hydrological survey have already been specified in general terms, namely, to secure data for planning schemes of drainage, water transport and fishing organisation.

It may be as well to suggest the methods to be followed as a guide to anyone called upon to organise the type of expedition which is envisaged.

The fundamental requirement is the levels of the water surfaces over the whole swamp area, and this in itself is no mean task, ordinary spirit levelling being impossible. The method suggested is to use precision theodolites, such as the well-known Wild pattern, mounted on quadrupods on the islands, the observations being made at night to a light on the other islands.

It so happens that the distribution of the islands is such that, except in one or two doubtful areas, they are within 10 or 15 miles of each other, so that quadrupods 20 to 30 feet high, or platforms on trees, will provide inter-visibility. The erection of such quadrupods is well within the powers of natives accustomed to building roofs, but the poles would have to be transported. The instrument would be placed on an inner quadrupod, while the observer would stand on the outer one.

These stations would also provide the framework for a triangulation which would be observed at the same time, a valuable adjunct to the levelling. It is estimated that the mean of a series of mutual observations over such distances, made at night, should give a difference of level with a probable error of between one and two feet.

These stations would probably be at the following points, or on a majority of them, some needing only a short quadrupod:

Mpanta Point
Miloke or Kansenga
Kataba
Nsumbu Island
Kasoma
Kalimankonde
Chinyanta
Mbo
Ncheta Island
Matongo
Nsalushi Island
Mutwamina
Chisale
Lake Chaya

Observation for level from so many stations is a somewhat formidable task and might by itself occupy a period of a month or six weeks, depending chiefly on the skill of the *capitaos* or messengers erecting the quadrupods.

From each instrument station direct levels would be run to the nearest water level, where a temporary gauge post would be set in the water. When a group of stations had been finished and levels obtained, readings of these gauge posts would be made as far as possible simultaneously, that is, on the same day.

From these primary levels subsidiary figures for areas in the swamps would be taken whenever opportunity offered by furnishing every European with an aneroid, read at stated hours during the day, and compared with similar readings on a companion aneroid at the nearest station. There would, in addition, be occasional opportunities for spirit levelling, for instance across Ncheta Island.

The triangulation likewise would be supported by frequent compass traverses in canoes and every member of the party should be able to use that simple method of survey, otherwise many of the rate and sounding observations would be more or less useless.

The map and water surface levels being thus accounted for, the attendant observations would include the following.

Soundings. Besides sounding all main channels as requisite, every canoe should have a pole marked off in feet so that on any of the traverse journeys soundings could be taken by watching the man with the marked pole and plotting the result on the traverse. It will be appreciated that soundings in the swamps, especially in the shallower parts, are just as important as those in the channels.

Current measurements. A current meter should be available for the main channels, and discharges calculated from their readings and the soundings. These discharges will probably only have a comparative value as showing the carrying capacities of the various channels.

The general movements of water in the swamps are more likely to be shown by measuring the rate and direction of the flow through the reeds. This can easily be done from an anchored canoe with surface floats where the plant growth permits a canoe to pass.

The more massive movements of water are probably under and through dense masses of papyrus such as those bordering the Luapula. To determine these the well-known method of using eosin or fluorescein is recommended. A small quantity of this harmless dye is released at a prearranged time and point and a watch is kept for the appearance of the dye wherever it is expected it will occur. This is the best method for finding out where water from rivers like the Lukulu reach the Luapula, their channels being hidden in the reeds.

A comparison of the rates of movement through different varieties of vegetation would naturally be undertaken as part of the general investigation.

These are the three main items for the hydrological survey itself, but many others will occur to the workers, including:—

(*a*) Taking cores of the bottom material with an extensible soil sampler.
(*b*) Experimenting on small channels to find the effect of different degrees of obstruction.
(*c*) Experimenting to find the optimum rates of current to produce erosion of the bottom silt, especially in the Chambesi south of Ncheta Island.
(*d*) Special investigation and surveys of the Chambesi near its entry into the swamps.
(*e*) The mapping and sounding of all natural levees and investigation of the best conditions for their formation.
(*f*) Occasional comparative determinations of the amount of silt in suspension, though these would be of less value in the dry season when presumably the work would be carried out.

If these were the sole activities of the expedition its total cost should be well under £5,000, allowing for the borrowing of the more expensive instruments, and assuming that all the members were from England, with expensive passages to be paid for. It would be as well, however, to include other specialists in the expedition, and, more important still, to allow specialist officers of the Territory, ecologists, water officers, etc., to spend as much time as possible directing the work. With such additions, and allowing for three or four months in the field, the cost might rise to £8,000.

There is some prospect of an aerial survey of the swamp being carried out in the near future. Such a survey will be of great value, but it must be realised that it will not give the information required concerning the relative levels of the water surface at different points nor the necessary data concerning soundings, direction of flow, etc.

The hydrological survey might be done independently, either before or after the aerial survey. It could hardly be done at the same time, since both parties would then be competing for the limited transport available on the lake.

Some description of the large scale maps published herewith is necessary, since they probably look much better than they really are. I did not expect to do any survey work of this kind and consequently had to improvise with such instruments as I had with me.

The traverses were done from the canoes or launch with a prismatic compass for bearings and estimates (with occasional actual measurements) of rate for the distances. As the chief canoe was of steel there must have been considerable deviation of the compass, and as the rate of progress was continually varying because of currents, blockages and changing of paddlers, there must also be considerable errors from this cause. Further, the traverse was not continuous, as the index sheet shows, because in some channels it was not possible to survey at all.

When some kind of a triangulation is ultimately made these traverses will be adjusted to it and the major errors will be reduced.

In the meantime, it may be taken that the details of bends, of velocities and soundings, and of types of vegetation are relatively correct and the maps are therefore published as a guide to future visitors. The field scale was large, about 1/19,000, so as to permit channel widths being shown to scale, and the whole survey was plotted on a small table rigged in the canoe, as we went along. Soundings were by a home-made line for deep ones and by a canoeman's paddle for shallow ones. Velocities were by estimation with an occasional measurement as a check.

Development on the Kafue River

The Kafue is the only large river in Northern Rhodesia, except for the less accessible Luangwa, which is entirely within its boundaries and over which it has complete control.

The following are some of the bare geographical facts about it which bear on the possible development of its resources. It drains approximately 50,000 square miles, most of its sources being on the border of the Belgian Congo, where the rainfall varies from 40 to as much as 60 inches per annum. The mean rainfall over its watershed is rather more than 30 inches.

In round figures, allowing 8 per cent as the run-off, the Kafue system should discharge between eight and ten million acre-feet, or 400,000 million cubic feet per annum. This would mean an average supply of over 10,000 cubic feet per second throughout the year joining the Zambesi. This handsome figure is possibly on the generous side because the water is exposed in two large areas to a considerable reduction by evaporation, at the Lukanga swamps and the famous Kafue Flats. It is exceedingly difficult to arrive at any useful figure for this loss by evaporation. We can apply the results of the very careful measurements of evaporation made by the engineers of the Upper Nile and the Lake Plateau, where the climatic conditions are fairly comparable, but we are not much benefited thereby, since in the present state of mapping we must be very uncertain about the area of water exposed in the two swamps or for how long. We must make the attempt, however, since long-term planning may be seriously affected by the result, though very broad assumptions will have to be made.

We will assume that the mean area of water exposed throughout the year to evaporation is as follows:

Kafue Flats	—	800 sq. miles.
Lukanga Swamps	—	200 sq. miles.

This area of 1,000 square miles of water mixed with some marsh vegetation would be susceptible, by analogy with the Upper Nile, to an annual loss by evaporation and transpiration of between three and four feet. With the higher figure the loss would then be something over two million acre-feet. We shall be wise, therefore, to consider that the mean annual discharge of the whole system is about 300,000 million cubic feet, at a mean rate of about 7,500 cubic feet per second, being thereby confident that we are on the cautious side.

Since we are dealing with round figures we may remind ourselves at this stage of two other round figures which can be used for outline estimates. They are that one cusec should irrigate from 100 to 200 acres according to crop, and that one cusec falling through ten feet should give about one horse power if suitably harnessed. We must remember, however, that we cannot us water for both purposes unless it can be arranged that the irrigation area is downstream from the power area.

The main stream of the Kafue follows a rather extraordinary course. Rising not far from Elizabethville, in the Belgian Congo, less than 400 miles in an airline from its junction with the Zambesi, it makes at least two major loops which with many minor meanderings give it a total length of nearly 900 miles. For the first 500 miles of its course it is a true plateau river, above an altitude of 3,500 feet, and only for the last 30 miles is it below the 3,000 feet contour.

Its gradient, between 3,500 feet and 3,000 feet, is very low for an African high level river, namely about 1 in 2,500, and it is not much more than that in its upper reaches. The general effect of such a gradient, associated as it is with innumerable damboes and swamps of all sizes, is to extend the period of high water after the rainy season in a way never found in the Luangwa, for instance, or the Ruaha of Tanganyika Territory. In this respect it is precisely similar to the upper reaches of the Zambesi.

The outstanding feature of the river is the Kafue Gorge which, beginning about 15 miles east of the railway at Kafue station, drops the river through nearly 2,000 feet in a distance of some 25 miles, giving a mean gradient of 1 in 60.

The possibility of utilizing this fall as a source of power has long been mooted, and in particular by Mr. C. Gordon James, a farmer of the Kafue district, whose local knowledge, energy and foresight were of great value to me in making a reconnaissance of the project.

It is understood that a detailed survey of the Gorge is to be undertaken in the near future which will supersede all the reconnaissance measurements, yet the latter may be quoted here in brief in the meantime.

The gorge is rather inaccessible to land travel, though so near to the railway, and the maps available are not very trustworthy, nor are there any measurements of level for the gorge itself. I therefore had to make the reconnaissance by air, flying down the gorge as close to the water as was practicable. I was accompanied by Mr. T. Longridge of the Water Development Department, and by Mr. Gordon James himself, who was largely responsible for the rough air traverse kept on the flight by aneroid and compass.

Flying over the Kafue railway bridge at a height of 100 feet the plane passed over the Pontoon Ferry, about seven miles east of the bridge, following the curves of the river, whose velocity seemed to be increasing only slightly for the next ten miles, where the first turbulent rapid was seen. Just before that point a wide valley comes into the head of the gorge which should provide reasonable access for a construction road when required. A few miles east of the first rapid the river takes a decided bend towards the south and then again to the east, where the last major rapid was passed. The flying time, at 100 m.p.h. when flying east against a light breeze, from the first to the last turbulent rapid was just under five minutes. Four minutes later, say in seven miles, we were over the debouchment of the river at the foot of the escarpment, and turned south-east to fly over the Chirundu Bridge and then over the confluence of the Kafue with the Zambesi six miles downstream. The Kafue water was very blue and clear and ran alongside the muddy Zambesi water for some miles before mingling with it.

Flying at 100 feet above the water here our aneroids gave us a drop of exactly 2,000 feet from the Kafue Railway Bridge. Aneroid readings were meaningless whilst flying down the gorge, since we had to change height violently at times and in any case could only estimate our height above the river. Yet, using the evidence of the first and last turbulent rapids and our combined judgment, we were able to say that most of the fall takes place over the eight or nine miles between them. If, using caution, we deduct 500 feet from the total fall of 2,000 feet between the Kafue Bridge and the confluence, we have for the rapids section a fall of about 1,500 feet.

A few days later the same party was able to get the only other figure obtainable at the time, a measurement of the discharge at the Pontoon Ferry which, on May 25th, that is to say some six weeks after the rainy season, was about 12,000 cusecs. Judged by flood marks, etc., it had probably been up to 20,000 cusecs at times, but the minimum for the year, measured later, was 1,000 cusecs. 1946 proved to be a dry year, the Zambesi discharge going down to 6,000 cusecs; nevertheless the minimum discharge must be taken in all calculations for power.

The above figures mean that, allowing for loss of head in a canal from the upper rapids to above the lower one and for contingencies as to suitable sites for take- off, power houses, etc., we should be able to count on an effective head of, say 1,200 feet. With a small diversion weir the minimum-flow output of power would be in the neighbourhood of 120,000 H.P. or 90,000 Kilowatts. On the other hand, since the mean annual discharge is at a rate of some 7,500 cusecs, any provision of storage to utilize some fraction of the total will increase the output. Thus, an effective use of 4,000 cusecs throughout the year, which should not be outside a practicable project, would provide 360,000 Kilowatts.

The question to be settled will be how and where to conserve sufficient water to reach any desired target between the lower and higher figures mentioned for output.

Until discharges at the Pontoon Crossing have been recorded for at least a year it will be impossible to say what volume of water would be required, but we can make reasonable assumptions in order to arrive at some sort of figure which will be strictly provisional.

It seems likely that storage will have to supply a deficiency below 4,000 cusecs during part of June to mid-November at a gradually increasing rate. If we take 2,000 cusecs as the mean deficiency over those five months it will require rather more than half a million acre-feet plus the evaporation of five dry months. If this were to be stored in one large reservoir it would require to be 100 square miles in area with a mean depth of 10 feet. It might be preferable to have two reservoirs of smaller size, depending, of course, upon suitable sites being available, for reasons to be cited later.

We must now consider the second most remarkable feature of the river, the vast expanse of seasonally flooded grassland known as the Kafue Flats.

When the river completes its last great bend towards the west, often spoken of as the Kafue Hook, it turns through a right angle and passes eastward through some low hills by what is called, somewhat grandiloquently, the Meshi Teshi Gorge. From this point to the railway line, over a distance of nearly 150 miles, it flows sluggishly with a multitude of meanders through a plain which is flooded in the rainy season and is a sea of grass in the dry season. The boundary is abruptly marked by a tree line marking off the land which is so seasonally flooded as to inhibit the growth of trees.

The Flats are a remarkable sight, whether from the air or the ground, whether a sea of flood water or occupied by vast herds of game and a considerably density of cattle, grazing down to the water's edge as it recedes. The area thus seasonally flooded is between two and three thousand square miles, though parts of it are so permanently waterlogged as to be swamp rather than grassland. The soil itself is a mixture of the Kalahari sand blown there from the south-west with the dark organic clay typical of African swamp lands, which is usually called black cotton soil. With these constituents it provides a wonderful pasturage and, when it can be drained, a fertile arable, though it is difficult to work and impossible to travel over when wet. It is reported that in some parts the soil is 'brak', that is to say, impregnated with salts.

No one with an agricultural cast of mind can view this plain without wondering whether its possibilities cannot be better utilized in the future, and it is only fair to say that opinions are somewhat divided on the subject.

There are no surveys of the area with enough detail to permit calculations either of the amount of water held up during the floods or of the area of grassland in full use during the dry season. The greater part of it is a Native Reserve for the Ila-Tonga tribes with an estimated population (in 1936) of 70,000 occupying five million acres, which is rather below the average density for Northern Rhodesia. Their economy is based on cattle, with fishing as a local activity and maize and sorghum as subsistence crops wherever the floods permit.

The divided opinions mentioned above include those of game lovers, who would like to preserve the game, of European settlers who see land not fully used, of native leaders who resent change in their mode of life, and so on.

While respecting these several points of view one must, in a survey of resources of this kind, consider the potentialities of the area from a much wider aspect, including that of the world shortage of food. In particular it is as well to consider the full implications of any plans for industry such as are included in schemes for the development of hydro-electric power. The industrial population will require food, and the nearer to its centre the food is grown the cheaper it will be.

For these and other reasons, therefore, it is desirable that any scheme for one purpose should be linked with the other so as to ensure mutual support and enable the region to attain a balanced economy for the inhabitants.

Whether from an arable or a pastoral point of view, the Kafue Flats represent a vast potential source of production and obviously it should combine both forms of agriculture, either intermixed or side by side.

If the river is to be controlled in order to provide a higher mean discharge it should therefore be at a point above rather than on or below the Flats.

It is clearly impossible to choose a site for a barrage from the very inadequate maps, yet there are indications as to the general locality which should be searched for such a site, and it is strongly recommended that a preliminary search should be made at the same time as the power survey is being done.

The Kafue makes its right-handed bend to the east at its junction with the Musa stream and immediately below it passes through a line of hills *via* the Meshi-Teshi Gorge. Somewhere in that 'gorge' there should be rock formations suitable for foundations, and the combined valleys of the Musa and the Kafue should give storage depth, at least as far as 25 miles up the Kafue, where there are some rapids. Another promising area for search is a little downstream of Namwala, where there are other, but much lower, hills.

As far as the necessary conservation is concerned, a barrage at either place would not require to raise the water level more than twenty feet or so in order to give the required capacity, especially if there were another storage basin further up the river, but it would be a major engineering work with sluice gates.

Such a barrage would alter fundamentally the present regime of the river over the Flats. Though the rains commence normally in November and soon increase the discharge of the local streams, the main flooding from the upper reaches takes from four to six weeks to make the journey to the Flats, which begin to flood in mid-January or even later, the water driving the game and cattle back over the Flats until they are fully flooded in April and May. The water then begins to recede and is followed down by the flocks during the dry season.

With a control barrage the first object would be to let enough water through to maintain the discharge at whatever rate was required for the power scheme. Suitably designed the barrage would still have water to spare for irrigation of one degree or another, for which the uniform gradient of the Flats would seem to be admirably suited, and the most obvious crops would be winter wheat by irrigation and possibly cotton and rice at suitable seasons.

It would be no easy task to change the mode of agriculture of the inhabitants from one which is almost entirely pastoral to that of mixed farming, but it has been done before in other parts of Africa. An important feature of any such scheme would be a due development of transport on the river to railhead at Kafue.

Unless the topography immediately above the barrage at Meshi-Teshi is unusually favourable, it would probably be impossible to hold back as much of the excess water as is desirable. Ultimately a second barrage higher up would be advisable, and the Lukanga swamps some 150 miles upstream suggest themselves as a possible storage basin. They appear to be a smaller edition of the Bangweulu Swamps, but the area is thinly inhabited and undeveloped though it is only 20 or 30 miles from the railway. At present the swamps take excess water from the Kafue through two-way channels, which run into the area during flood increase and out again during flood recession, the actual swamps being some ten miles from the Kafue.

A shallow depression such as this is not the best kind of storage basin since the evaporation is high, but since evaporation loss takes place in any case the situation would not be much worse in that respect if it were so used.

There would seem to be suitable sites on the Kafue itself for a low barrage near its junction with the Lukanga. In this stretch the Kafue is sluggish and in the dry season probably decreases in discharge so much as to make diversion work during construction a simple matter. The barrage would be designed to raise the level a few feet, the actual amount depending on the results of a survey showing the storage capacity above it. The sluice gates in the barrage would be operated so as to co-ordinate the supply in the lower storage basin with the purposes in view on the Kafue Flats, but there would be an important subsidiary effect on the Lukanga district itself. A large part of the present swamps would become a lake, from which the present small fishing industry would expand considerably, while the flats encircling the present swamp would be under better control for the grazing. It would further appear to be possible to use the Lukanga river for irrigating the northern part of these flats for winter wheat.

In summary, the two holding barrages should in varying degree serve a secondary purpose besides that of conserving water for power.

Very little can be said at this stage in comparing the Kafue scheme with the Kariba scheme, already surveyed. Until surveys have been made of the Kafue, estimates of the cost must be somewhat unreal.

The fundamental differences in the schemes is that in the Kariba Gorge there is practically no fall of water but a large volume, whereas in the Kafue there are many hundreds of feet of natural "head" of water, but only one-sixth of the volume. Normally it is more costly to create "head" artificially than to increase volume by storage.

Navigation Problems on the Zambesi

One of the great disappointments about Africa, in comparison with other continents, is that her large rivers are not navigable. This fact, perhaps more than any other, has been largely responsible for the delay in exploration and settlement, and even for her slow economic development. Africa leads the continents in her potential hydro-electric power but pays for that lead in lack of water communications. Hitherto Africa has been able to offer only bulk products, except for precious metals, which can only compete in the world market if there is cheap transport. Any schemes for improving this state of affairs must receive the closest attention if steady development is to be maintained.

In the case of the Zambesi, we may take a glance at the river as a whole and then suggest certain projects for the upper regions, projects which are practicable in the near future. It will be as well to reserve the term navigability as referring only to barge and tug navigation, using craft of not more than 200 tons.

The river is already of sufficient volume for barge traffic in Barotseland, where it is 3,000 feet above sea level. It has two major and probably insuperable barriers to through navigation. They are the Victoria Falls with the fifty miles of gorge below the Falls, and the Kebrabassa cataracts extending over a stretch of fifty miles and falling through 600 feet.

These two barriers are about 700 miles apart, by river, and with their rapids they account for about half of the total fall of 3,000 feet. The mean gradient of the remainder is therefore about 1/2,000, a figure which, for a river of large volume, is on the high side even if it were not unreal when averaged over such long sections. We may therefore consider the type of problems to navigation in each of the three sections into which the river is naturally divided by these two major barriers.

The Upper Zambesi, that is to say above the Victoria Falls, has a multitude of rapids of which, however, only one, at Katombora, exceeds thirty feet in total fall.

The Middle Zambesi may be said to be unnavigable for fifty miles below Victoria Falls, but from near Wankies it has been traversed on several occasions up and down from the Kebrabassa Falls when the river has been high. It is therefore marked by a number of rapids which are quite impassable at low water but which become merely fast water at flood time. There are about ten of these critical sections. From a study of the limited information available it appears that below Kariba Gorge these sections are far less difficult than above it and are comparatively simple at any discharge above 15,000 or 20,000 cubic feet per second. This estimate is mentioned to show that barge navigation on the Middle Zambesi is dependent upon control of discharge, and if either the Kafue or the Kariba schemes for power were to be constructed the raising of minimum discharge would greatly simplify the navigation below them. It is also of some significance that, owing to the very broken country between the Kariba Gorge and the Victoria Falls, as well as the present routes of the railways, bulk products for export are not so likely to reach a Zambesi waterway there as they are from the Chirundu bridge downwards. In other words, the barrier of the Falls and its fifty miles of rapids might be considered as reaching to a point just below the Kariba. From this point to Chicoa at the head of the Kebrabassa Rapids is about 300 miles by river and there is only one really critical point, about 30 miles above the Luangwa confluence. Even here some judicious blasting of obstructions which narrow the stream would probably reduce the current to a reasonable rate.

It may be assumed, therefore, that for 300 miles of the Middle Zambesi there are no insuperable obstacles to navigation at normal flow for barges of a capacity up to 50, or possibly 100, tons.

The Kebrabassa Rapids extend over about 45 miles and they run through such rough gorge country that there can be no question of parallel canalization even if it were financially possible. If a canal system, or more probably one of barge-on-rail transport, is ever seriously examined the probable route for the by-passing of the rocky gorge will be on the southern side along the valley of the Mesenangwa stream. Since the bulk of the transport will tend to be outwards, down river, a scheme of rail transport for the actual barges merits consideration, the power for which might well be obtained from the rapids themselves.

On the Lower Zambesi the obstacles to navigation are almost entirely those due to shallow water and shifting sandbanks, and these again will be greatly minimized if and when there is flood control on the Upper or Middle sections of the river. Such control would also, but to a less extent, affect the growth of bars at the many mouths of the Zambesi, but it is impossible to say just where the river barge traffic could meet ocean-going ships.

Waterways on the Upper Zambesi

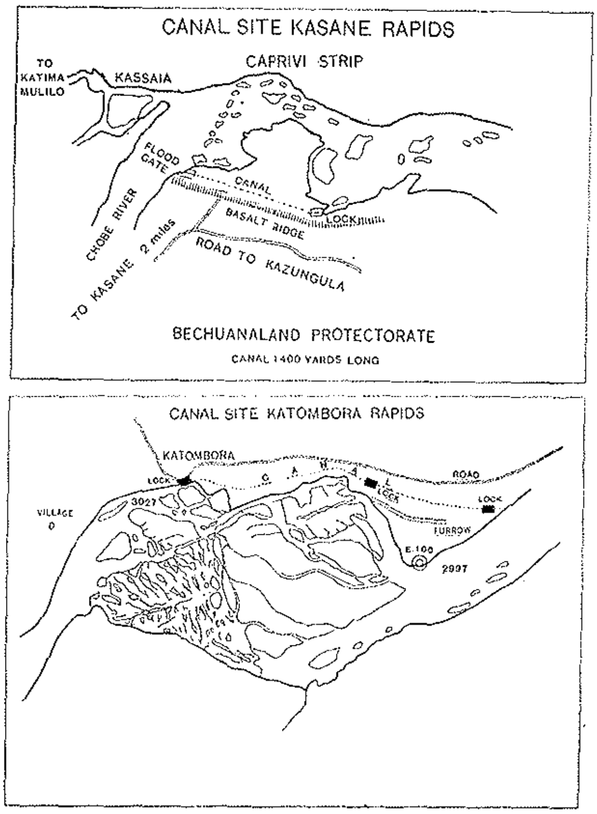
There have been many suggestions in the past for engineering works on the Upper Zambesi, from giant schemes of control to small cuts and minor improvements for canoes. It was a detailed proposal for canalization put forward by Mr. W. P. Ker, of Southern Rhodesia, which prompted an official visit by the Water Development Officer of Northern Rhodesia, Mr. T. Longridge, and myself to report upon Mr. Ker's suggestions.

The hydrology of the Upper Zambesi basin has curious features which cannot be ignored when planning development. The large reserve of Barotseland receives the run-off from rivers rising in Portuguese West Africa and in Northern Rhodesia itself and these waters spread out during the rainy season over the Barotse plain. The whole economy of the inhabitants depends on this annual flooding, and being skilful cultivators the Barotse or Lozi have, in the past, produced an exportable surplus of cattle and, until the recent increase of population, of foodstuffs. They represent a potential market for import and export of some importance when transport can be improved. Needless to say, the Lozi are experienced canoe-men and understand their rivers well.

Some forty miles below Mongu, the seat of administration, the Zambesi enters upon a long stretch of rapids and one or two definite but small falls, which is over 100 miles in length. Though dugout canoes, by running some rapids and portage round others, regularly pass up and down, the passage from Livingstone to Mongu is rarely accomplished in less than three weeks and the cost of transport is excessive, recently over £15 per ton. The lowest of these rapids is at Katima Molilo, when for 70 miles the navigation is simple to the confluence of the river with the Chobe. This river, known as the Kwando in its upper reaches, runs roughly parallel to the Zambesi and under similar circumstances of flooding and tracts of marshland until it crosses the border of Angola into the Caprivi strip. Here it disperses itself in swamps which are only slightly less widespread than those of the Okavango further west. The connection has at times been much closer than one of similarity, since there is an old channel, the Makwegana spillway, which even now sometimes empties any excess from the Okavango into the Kwando, which is here usually called the Linyante. There is good evidence for believing that at one time the Okavango flowed into the Linyante and on to the Zambesi at Kasane. One such piece of evidence is the prodigious width and depth of the river bed towards Kasane.

At present the Linyante marshes absorb or evaporate practically the whole discharge of the river, so that when, once more changing its name to the Chobe, it reaches the junction with the Zambesi, not only has it no contribution to make but it receives water from the Zambesi and there is a reverse current which fills up the deep and wide bed for some 40 miles upstream.

The nature of the confluence requires some attention, since it is one of the key points in any developments of navigation. The Zambesi itself when it meets the rocky bar of Batoka basalt, pours over it as the Mambova Rapids, dropping twelve feet. Above these rapids the Zambesi is some three feet higher than the Chobe, some four miles to the south, at the head of its own rapids. Consequently there is a flow of Zambesi water through the Kassaia channel or channels, easily navigable, to share the Kasane rapids, once occupied, no doubt, almost entirely by the Chobe. It is shown in the diagram below. Below these twin rapids the Zambesi is wide and deep and perfectly navigable for a distance of some fifteen miles to the head of the most formidable of all the rapids of the upper river, the Katombora, which fall through thirty feet over a distance of about one mile measured along the shortest channel.



SKETCH MAPS OF CANAL SITES FROM AERIAL PHOTOGRAPHS

From Katombora the patches of fast water are navigable for another twelve miles or so downstream, after which the current is excessive in places.

On both sides of the Zambesi from the Mambova Rapids down to the vicinity of Livingstone there were formerly large areas of the timber known as " Rhodesian teak ". On the Northern Rhodesia side, the greater part of these forests has now been cut out, the transport being by light railway to the saw mills at Livingstone. On the south side, in territory belonging to the Bechuanaland Protectorate, there are similar forests now being worked by the Chobe Concession Company with its saw mills at the new settlement at Serondellas about 11 miles up the Chobe from Kasane. At present the sawn timber is taken to railhead at Jafuta, 60 miles to the east, by motor transport.

The main long-term object of improved navigation is clearly the development of Barotseland, with possible later development in the Caprivi strip. An immediate need is the cheaper transport of timber, subject, of course, to the timber companies electing to use it if provided. If we accept a point on the north bank about 18 miles from Livingstone as a discharging point for goods to a railhead to be established there, there are only two sets of rapids to be by-passed for as far up river as Katima Molilo, that is to say a distance of about 110 miles, while the Chobe would be navigable to above Serondellas.

Detailed surveys of the two critical points, the Katombora and the Kasane rapids, will have to be made before full estimates can be drawn up. In the meantime the type of construction work likely to be undertaken may be outlined, quoting portions of the report prepared by Mr. Longridge and myself. The specifications refer to a canal capable of accommodating barges of 50 tons capacity with a draught of two to two-and-a-half feet.

The Katombora Rapids

These are situated about 36 miles (by road) from Livingstone and about 22 miles (by river) from the Kasane Rapids. The fall from smooth water to smooth water is about 30 ft. and the approximate line for a canal is from 3,500 to 4,000 yards.

There is at present an irrigation furrow about six feet wide which takes off at the right-angle bend of the northern shore near the house. This gives an indication of the direction a navigation canal would follow but otherwise would not be of much value, the excavation being of small amount and the gradient being too steep. Except for the first 400 yards which is through friable basalt, this furrow runs, for some 1,300 yards through a light alluvium with black-soil patches. The aim would be to use this alluvium as much as possible for the canal. Some proportion of the loose basaltic ground could also be dealt with by harrowing followed by bulldozers.

The plan suggested by us is to have a double lift (of approximately ten feet in each lock) at the lower end, situated near the twenty foot contour above the lower smooth water level. The canal would then be excavated for about 2,000 yards through the alluvium approximately along the contour as far as the former Polish Refugee camp, when it would enter basaltic ground in which there would be approximately 500 yards of excavation to the next lift which would be slightly above the present irrigation furrow intake, near the right-angled turn of the northern bank. This lift would again be of approximately ten feet, bringing the canal water up to the level of a landing basin which would have to be made about 150 yards upstream of the present landing stage. In this upper section the embankment and cut would have to be made in basaltic ground, but it would be helped to some extent by the existence of an old flood water channel. This portion is densely wooded and small clearing costs would have to be included.

Estimation of the amount of cut and embankment is difficult in the absence of any levelling. The length of canal for the upper section would be a little over 1,750 yards, and the total excavation in this portion would be in the neighbourhood of 5,000 cubic yards, with the assistance of the old channel. On this portion there are at least two storm channels coming from the higher ground which would require treatment, possibly by silt traps above the canal.

It is difficult to make anything like a close assessment of the amount or cost of excavation that will be required, and this must be left to a future survey.

The Kasane Rapids

These are situated about five miles up river from the W.N.L.A. Kazungula station and about two miles downstream from Kasane. From smooth water to smooth water below the rapids the fall is nine feet four inches and the distance along a suitable line for a canal is a little under 1,400 yards. With the alignment suggested by Mr. Ker and approved by us use would be made of a basalt bluff at the upper end, which with a small amount of reinforcement would make an excellent foundation for the upper lock or flood gates.

We learned that at Serondellas about 15 miles upstream (by river) the range of flood may be as much as 13 feet. At the Rapids the river is very wide and there cannot be such a range there. Nevertheless we would recommend 18 feet flood gates, the sill being three feet below low-water level.

The course of the canal would follow the line of the abrupt side of the valley which is formed by an amygdaloidal basalt, much decomposed in places and with many cleavage lines. For the first 400 yards the basalt would have to be excavated to a depth from ten feet to zero, for which we may allow 3,000 cubic yards of excavation. The canal would then make partial use of a former flood channel which has cut into, and to a small extent has rotted, the basalt. The amount of excavation would therefore be planned to be only sufficient to build the outer bank of the canal on the north side, adjacent to the rapids. This bank would have to be six feet high at the lower end. It is not easy to estimate the excavation without cross-sections, but we judge it would not be more than 3,000 cubic yards.

The dimensions and structure of the retaining bank would depend on the suitability of the material. We are inclined to think that the lower 200 yards would have to be lined with masonry work unless any clay pockets are found in the near vicinity. The work would consist of straightforward cut and fill, with some blasting.

The maintenance and running costs of the Kasane canal would naturally be less than for the longer Katombora canal.

While any estimates based on a short visit and in the absence of any survey must be viewed with caution, the fact that they are not prohibitive is at least good reason for initiating an engineering survey. The cutting of these two canals would open more than 100 miles to barge navigation with its end point at 20 miles from the present railway. Such a development would reduce transport costs considerably to and from Barotseland and even enable that district to export such surplus food as it can grow.

There would still be the long and difficult stretch of cataracts and rapids above Katima Molilo. At present the large dugout canoes used for transport are hauled up all the difficult sections without leaving the water except at two points, the first at the Ngambo cataract where the portage is about half-a-mile in length, and the second to by-pass the Gonye or Sioma falls, a portage of nearly three miles.

It must be clear that whatever might be done for the improvement of navigation on this section of the river it could hardly take the 50-ton barges planned for the lower section, unless the topography is very favourable for modifications to the river channel. This caveat is entered because the level of the river above the Sioma Falls, themselves constituting a drop of about 20 feet, is probably less than 100 feet above the river level at Katima Molilo, a distance of some 70 miles, which gives a mean gradient of about 1 in 3,500. There must be many reaches of slack water, and were it a narrow river it could easily be improved by demolishing the crests of the rapids. This may not be possible except at great expense for a river which is often 200 yards wide. The two major hindrances mentioned would have to be canalised, and schemes for that must be left to the future. In the meantime the present method of hauling the canoes over the portage could be greatly improved by laying a light rail track with trolleys on to which the canoes could be run, fully loaded, at either end.

If the canals on the lower section are approved there is little doubt that improvement on the upper section will be worth while. Apart from any immediate economic returns there are good political and social reasons for making it possible for Barotseland to employ its people at home instead of allowing a most disquieting percentage of its men to offer their labour elsewhere.

3. NYASALAND

IN SPITE OF its small size, about three-quarters of that of England, or 38,000 square miles, Nyasaland has considerable extremes of relief, rainfall and soil.

Since the area of the lake itself is 11,000 square miles and most of its watershed is in Nyasaland the hydrography of the Territory may be said to be that of the lake and its outlet river, the Shire. Naturally the lake has played a considerable part in the economy of the region in the past and it is destined in the future to be still more dominant as the resources of the Northern Province are developed.

Yet it is not nearly so valuable an asset to the country as one would expect it to be from its appearance on the map. Thus its great depth, over 2,000 feet at the deepest part, and its enormous capacity as a reservoir, holding enough to cover England with 100 feet of water, are in point of fact of no direct value, but rather the reverse. The low temperature of the bottom water probably has a deterrent effect on the fish population however much it may ameliorate the air temperatures for the benefit of the human population. Similarly the only effective part of that vast store of water is the top layer about 20 feet thick, for that alone can be used by man. Moreover, though its 360 miles of length extends for nearly two-thirds of the total length of the country, its undoubted value as a means of transporting bulk goods is tempered by three characteristics of the lake: a dire lack of natural harbours, a great frequency of dangerous storms, and a variable level of the water over a range of nearly 20 feet.

The storms, which have been responsible for many catastrophes, including a particularly serious one in 1946, are beyond the control of man, but the provision of artificial shelter is not, and if the lake-level is ever stabilised by artificial means it will be possible to take in hand the improvement of harbours.

Indeed, far from hinting that Lake Nyasa is Nyasaland's sorrow, we should recognise that its value is bound to increase and no survey of the colony's water resources can disregard its potentialities.

The extremes of relief are an unqualified asset to the country. Nearly 8 per cent of the land area is above the 6,000 foot contour ensuring a heavy rainfall to supply the somewhat short and rapid rivers. If we assume the 3,000 foot contour as the health or habitability contour for Europeans, then over 70 per cent of the country is suitable for the white man. For those who have to work below that level there is nearly everywhere a health refuge in uplands only a few miles away.

On the debit side of the account we must note that the tendency to soil erosion is a constant threat to hillside agriculture, and the silt brought down by the precipitate rivers is a menace to all control of water in the flatter valleys below.

The rainfall is very much a reflection of the relief, intensified, as compared with the Rhodesias, by its proximity to the Indian Ocean. It is markedly seasonal as befits the latitude, but on the highlands there is some dry season (winter) rainfall, which makes all the difference for such crops as tea.

Broadly speaking we may recognise a very wet northern end of the territory, a fairly wet southern end and a dry centre, but these generalisations are subject to local modifications. Thus the most southern district, the Lower Shire, has the least rainfall in the wet season, but that does not hold for the dry season when it benefits from a type of showery weather called after the name of a mountain supposed to be its cause, a 'Chiperoni'. The Chiperonis are so regular though slight in amount that they are definitely taken into account in arranging sowing dates for cotton. There are many cases of local rainshadows, areas robbed of their rain by mountains to windward. The driest district in the colony is a belt from Domira Bay to the Bwanje river valley and its poor supply appears to be due to that cause.

As elsewhere in Central Africa the outset of the rainy season is uncertain. Due in October, it may have a false start or even be delayed until December, and there is frequently a break in January which, if prolonged, may be serious for certain crops. This break is to be attributed to the passage of the sun to the southern tropic and is probably the equivalent of the longer equatorial break between the 'short' and the 'long' rains on the equator.

Nyasaland seems to suffer more than the other territories from locally violent storms in the wet season; few years pass without some catastrophic fall in one district or another. For example in the 1945–46 wet season the district of South Nyasa had a fall of over 10 inches in 24 hours. In the next wet season, in December 1946, there was an even more disastrous fall of about 26 inches in 40 hours centred on Zomba Mountain, which was accompanied by loss of life and widespread damage.

These incidents are mentioned here because they help to explain why the Shire River is so difficult to control, and to emphasise the necessity that any plans for conservation should allow for such prodigious falls as part of the regime.

Lake Nyasa and the Shire River

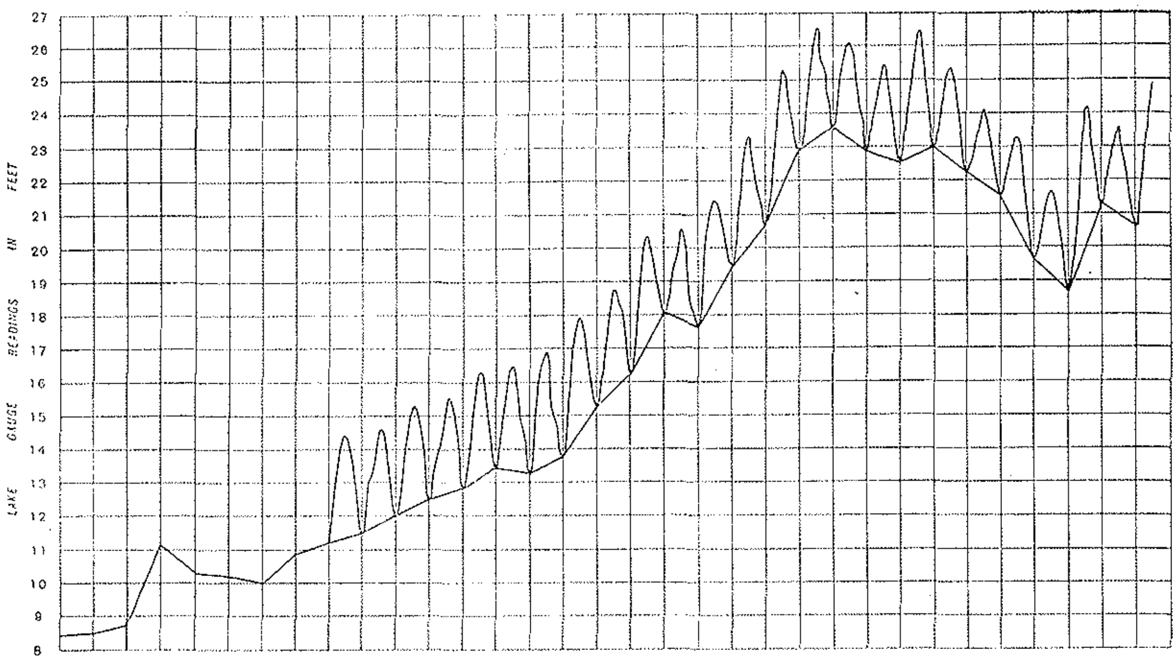
The lake and its outlet river are the backbone of Nyasaland in more senses than one, a fact which has long been recognised. On the vagaries of both lake and river the checks to progress and the advances have been closely dependent.

Much has been written concerning the changing level of the lake, and a short review of its characteristics and causes must precede any consideration of plans for development.

Dr. Livingstone came to the Shire valley when the lake level was high and was able to use the river, except for its middle section of rapids, for boat transport. Indeed Nyasaland became a highway to South Central Africa in the 'eighties' precisely because goods could be taken by water to the lake with only one long portage of about 50 miles. Towards the end of the century the river became less and less navigable until by about 1910 there was practically no flow at all out of the low-level lake.

For various reasons the data concerning the changes of lake level are not very reliable until that time, and the lack of precise data clouded the problem considerably. Various hypotheses were put forward on the basis of the change being a truly cyclical one depending on causes which were periodic. Other theories ascribed the changes to something in the nature of 'accident'. It is interesting to note that Sir Alfred Sharpe appears to have been the first to strike what we now know to be the right note in his paper to the Royal Geographical Society in December 1911 (published in the Geographical Journal, January 1912). He said, "For the present fall in level of Lake Nyasa it is difficult to assign any reasonable cause except a decreased rainfall in the basin, but such observations and records as have been kept at Lake stations during the last few years do not seem altogether to bear out this supposition. A theory which might to some extent account for definite cycles of rise and fall in the level of Nyasa has suggested itself to me, and I advance it for what it is worth."

After mentioning that a somewhat analogous situation on Lake Tanganyika had impressed him he goes on:



GRAPH OF LAKE NYASA LEVELS

"Some few years ago during the dry season Nyasa ceased to overflow and the bed of the Shire at its exit began to silt up, reeds and other plants took root. It would only have needed a few similar seasons for the outlet to have become entirely choked up." [As indeed it did.—Author.] "Is it not probable, therefore, that this has actually taken place at previous periods and that the level of the lake subsequently rose till it overflowed the barrier and finally burst it? Is it not, moreover, probable that these cycles of fall, blocking up, rise and outburst have been going on for ages?"

The graph reproduces the data concerning the lake level, as measured close to the outlet, since 1914, from which year the readings appear to be reliable. The continuous line represents the minimum lake level of each year, and the pecked line shows the maximum of each year since 1923. The scale of feet for the verticals is the actual reading on the Fort Johnston gauge post, but we do not know its precise height above sea level nor is it significant for the present purpose.

The graph shows the half-cycle of rising level from 1914 to 1938 and the beginning of the other half-cycle of a falling level.

Dr. Kanthack has made a careful analysis of this curve and correlates it with rainfall as far as the somewhat scanty data permit. He shows very clearly that "kinks" in the curve such as those in 1932, 1940 and 1945 are directly due to variations in rainfall. This is published in his "Report on the Measures to be Taken to Permanently Stabilize the Water Level of Lake Nyasa", published at Zomba in 1945.

The rainfall figures do not explain the long period cycle for which we must seek another cause.

In considering any schemes for the control of the lake-river system it seems essential to establish beyond reasonable doubt what is the fundamental cause of the cycle in the lake levels.

Unless the cycle itself is capable of control it would be hazardous in the extreme to embark on schemes which the cycle might in time override, and this applies to almost every one of the schemes mooted, stabilization of lake level, irrigation, hydro-electric power or navigation.

Let us consider for a moment how we could produce by artificial means, in a hydrological laboratory for instance, a cycle of successive rises in a miniature lake, followed by successive falls such as Lake Nyasa has experienced since observations began.

Taking a tank we might run in a variable supply of water to imitate the variable annual rainfall (and if necessary some abstractions to imitate evaporation). We should find, of course, that if the outlet were made of iron or concrete or other non-erodable material, we could not produce any cycle. This merely reflects the truism that any lake which has a rocky lip or outlet disposes of any temporary surplus in one year, or at the most two, and there is no long-term cycle of rise or fall.

This is true of most of the large lakes of temperate regions (e.g. the Great Lakes of North America), and invites us to consider what new factors may be peculiar to African lakes which prevent such a normal state of general equilibrium.

Proceeding with the experiment, we should find that the only way in which we could imitate the cycle would be by making the outlet vary in discharging capacity. If, for instance, reducing years into days, we were to continue the irregular supply as before but in addition were to alter the outlet artificially, we could, by trial and error, succeed in imitating any cycle.

Thus, if for a few days the outlet were deepened a little daily, simulating bad erosion, the tank level would fall day by day. If, then, on the following days an increasing amount of obstruction were dropped into the outlet, simulating silt deposit and growth of vegetation, the tank level would rise until at some point the obstructions were unable to resist the pressure and were washed away.

From such an experiment, or others more elaborate and natural, we obtain a strong hint that the outlet itself is probably the cause of the cycle, and then only if it is susceptible to deepening and shallowing by factors which do not balance immediately but successively gain or lose their dominance.

The Outlet to Lake Nyasa

Let us now look at the outlet conditions as they exist at present for Lake Nyasa.

The River Shire has its exit from the lake about four miles north of Fort Johnston and flows through some eleven miles of light alluvium to another depression, Lake Malombe, which at high lake levels is up to 20 miles long by 10 miles wide. Malombe may be regarded as an extension of Lake Nyasa itself, since the flow from the greater to the smaller is very sluggish, and may even be reversed if the smaller lake is receiving temporarily an excessive supply. It did so after the phenomenal rainfall of February 1946. There is a small drop in level to Malombe and the first eleven miles of the Shire may be considered as at least part of the lip or functional outlet of the lake.

The exit from Lake Malombe, near Mwera, is a much more apparent outlet, for here the gradient is more perceptible and a definite current can be observed. Nevertheless, this current flows over soft alluvium for another 24 miles, dropping four feet before it reaches the first rock bar at Liwonde. In other words, the outlet river runs for over 50 miles over an erodable bed, and we have the first condition for a variable outlet, capable of being deepened and widened by erosion. Moreover, for all this distance the flow, at low lake level, is so sluggish that the second condition for a cycle is also present, namely, a suitable environment for the growth of sudd and reeds which can work the opposite way to erosion and tend to obstruct the outlet.

There is an important and possibly decisive accessory to the vegetational blockage in the form of several short rivers which can bring their silt into this first 50 miles of the outlet river in times of exceptional flood. Of these the most important, as obstruction agents, appear to be the Nkazi and the Nkangai, which join the slow-flowing Shire a little below Lake Malombe.

It should be clear, therefore, that the outlet to Lake Nyasa possesses precisely the peculiarities which our experiment required, that is to say factors able to act in opposite directions either to reduce or increase the discharge, and hence alter the lake levels in a pseudo-cyclical manner.

The Supply to Lake Nyasa

The variable supply by rainfall to the Lake catchment area, discussed by Dr. Kanthack in his report, does nothing by itself to contribute to the cycle, though it does produce abnormal kinks in the cycle curve and may well determine the critical points (turning points) for that curve. The figures for rainfall must always be somewhat uncertain, partly from the paucity of characteristic stations for the data, but much more because of our ignorance of the evaporation. Thus an exceptionally dull or cloudy dry season may well affect the evaporation to the equivalent of many inches of rainfall. There is, however, an important source of information on this point which does not appear to have been fully appreciated.

From about 1917 to 1933 it is reported that there was no flow out of the lake. If that be so then the amount of fall in level from the end of the wet season to the end of the dry must be the figure for evaporation over that period, modified by what rainfall may have occurred during the dry season.

For the year 1923–32, for which there are fairly accurate measurements of the maximum and minimum levels, the dry season fall is almost uniform at an average of 32 inches. The average rainfall over the lake watershed in the dry season is about five inches, which is equivalent to a rise in level of about eight inches in the lake. If we add eight inches to account for the rainfall in the dry season we arrive at a figure of about 40 inches for the amount of evaporation in the dryest, though not the warmest half of the year. In the light of this argument it seems possible that Dr. Kanthack's figure of 84 inches evaporation in the year may be unduly high. The data are susceptible of further analysis to elucidate this point, but since it does not affect the final conclusion it has not been undertaken.

It will now be appropriate to apply the criteria cited above, namely an erodable channel with opportunities for blockage, to the last half-cycle of change in the Nyasa Lake levels.

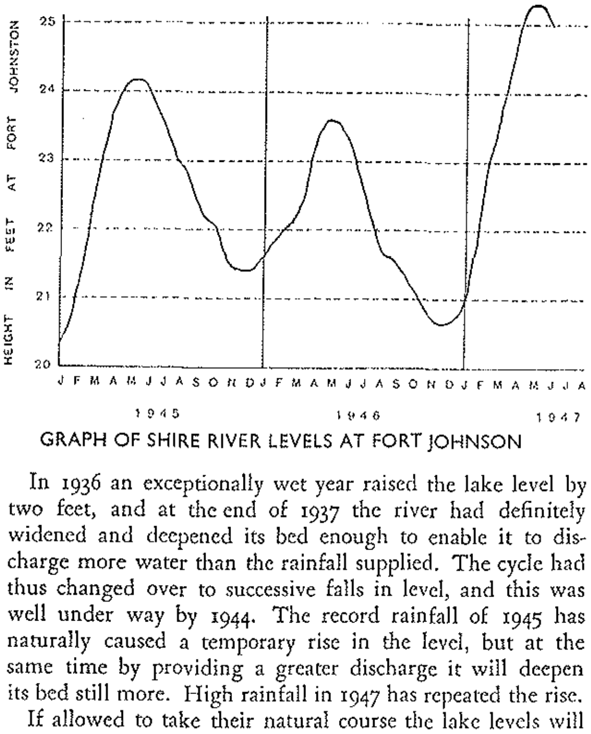
During the first ten years of this century the lake level had been falling steadily each year and the flow from the outlet was more slender and sluggish. The figures at our disposal are not very complete until 1915, when the falling cycle had just changed to the rising cycle, but an important event occurred in 1907, as quoted by Dr. Kanthack, which should be noted.

In that year a "cloudburst" over the Nkazi catchment obviously precipitated the tendency to blockage already approaching completion from other and similar causes. An unprecedented amount of silt was brought down by that tributary and deposited as a delta in the bed of the Shire. This delta was added to in ensuing years and became more and more consolidated by vegetation and debris. At the same time the low level of the lake and the decreased discharge had favoured the growth of sudd and reeds in the upper section of the Shire, particularly around its entrance into Lake Malombe. (It is interesting to note that the very similar "cloudburst" of February 1946 over the same area did not block the Shire with a delta, because the lake is now at high level and the river is running strongly enough to remove the silt, as will be described later.)

The rate of growth of this blockage apparently exceeded the annual rise in lake levels, which had begun about 1913, and by 1917 there was practically no flow out of the lake except by seepage, a condition which endured until 1933, a period of sixteen years.

Naturally the lake levels rose in an upward curve, with the characteristic kinks due to the variable rainfall. As far as one can ascertain from eyewitness accounts, the obstructions at the entrance to Lake Malombe and at the Nkazi delta became more and more consolidated.

In 1933 the lake level had risen to 20 feet by the Fort Johnston gauge, from less than 9 feet in 1915, and had topped the obstruction, though one cannot properly speak of the "top" of a mass of vegetation possibly some miles long, entangled with silt. The Shire began to flow and to fill Lake Malombe which had been quite dry. The river began to remove the blockage and slowly but steadily to lower it. The temporary fall in the lake level for 1933 may represent the discharge over the beginnings of a new outlet, or it may merely reflect the very low rainfall on the catchment in that year. The removal of the surface obstructions was slow and took at least four years, though it was aided by the efforts of the District Commissioner at Fort Johnston, Mr. Barker, who had the sudd between the Fort and Lake Malombe cut up and floated downstream.



GRAPH OF SHIRE RIVER LEVELS AT FORT JOHNSON

In 1936 an exceptionally wet year raised the lake level by two feet, and at the end of 1937 the river had definitely widened and deepened its bed enough to enable it to discharge more water than the rainfall supplied. The cycle had thus changed over to successive falls in level, and this was well under way by 1944. The record rainfall of 1945 has naturally caused a temporary rise in the level, but at the same time by providing a greater discharge it will deepen its bed still more. High rainfall in 1947 has repeated the rise.

If allowed to take their natural course the lake levels will steadily fall until the discharge is so low over the lip of the outlet that the flow is once more sluggish enough to give silt and vegetation time to accumulate and commence the era of blockage which must always follow an era of clearance.

The graph shows most of these phenomena and in addition shows the maximum and minimum heights for each year. As Dr. Kanthack points out, the actual conditions of level are somewhat confused by the fact that the rainy season sets in before the beginning of the calendar year, but we are here concerned with tendencies rather than actual amounts.

At this point we may allude to a curious phenomenon in the rate of seasonal fall, during the dry season, which has puzzled some observers and led them to question theories based on rainfall and evaporation.

The lake level consistently falls more rapidly in June and July, the colder months, than it does in September and October, the hotter months, when evaporation should be, and is, very much greater. This is due to the discharge by river being naturally greatest near the seasonal peak but falling off in September when the level is lower, masking the effect of the greater evaporation at that time.

The above explanation of the cycles is based upon the essential point that the lip of the lake's outlet is not at the rock bar at Liwonde but is an ill-defined length of alluvium which is susceptible to erosion on the one hand at high lake levels, and to blocking by silt and vegetation on the other at low lake levels. The very large storage area of the lake and the small capacity of its outlet are together responsible for making the swing from one set of conditions to the other extend over a comparatively long period of years.

Strictly speaking it is not a cycle in the sense that the period is fixed. It might easily be shortened or lengthened by marked variations of rainfall as well as by flooding by its tributaries.

The Need for Development

It has been shown that Nyasaland is largely dependent upon the lake and the river, and it is necessary to show how far the vagaries of lake-level and river flow have affected progress. It is even more important to consider what benefits might accrue from the establishment of some degree of control over these vagaries.

The territory is at present almost entirely agricultural; it has few mineral resources, and as yet there is no obvious lead towards creating industries of the manufacturing type. It is true that there is coal in the south-west, and that other discoveries of minerals such as that of the bauxite of the Mlanje mountain may be made, but such possibilities cannot be assumed. The prospects for the development of manufactures are rather better since there is ample manpower and the Shire itself can provide considerable waterpower.

Yet it is clear that for some time to come the Territory must base its whole economy on the products of the land, which for export must have reasonably cheap transport. There can never be through traffic down the river because of the Murchison cataracts in its central section which have a fall of over 1,000 feet in some 50 miles, but at high lake levels there would be, and used to be, considerable use of the river for bulk transport to railhead. On the other hand few improvements in navigation or investments of capital in shipping are likely to take place while the cycle of rise and fall continues.

The lake itself would seem to provide a perfect source of cheap transport for a length of 360 miles. It has been used steadily for that purpose, but a full expansion has been hindered by two factors. The Northern Province has great potentialities but they are as yet undeveloped, except on a local scale, partly because access to the lakeside is difficult, but also because the provision of lake transport is as yet on a very moderate scale. This tardy development of transport is again due in the main to lack of harbours—there are only two all-weather refuges—and to the changing level of the lake which makes it impossible to construct jetties for transhipment, which has to be done by the hazardous and expensive method of canoes and barges discharging from or to the ship in open roadsteads.

We may observe here the operation of a vicious circle. The expansion of export agriculture is blocked because the facilities for transport are uncertain and expensive, while the facilities cannot be much improved unless there is more freight. The only way of breaking the circle is to control the lake level so that it will be possible to improve the facilities.

Until some such break is made the development of the northern part of the Territory is likely to be retarded and the economic outlet of the Karonga District will continue to be northward by land rather than southward by lake.

So baffling has been the problem of lake transport that the Bell Report of 1938 on the prospects of further development of Nyasaland hardly mentions it and contains the despairing but all too true remark that "the vagaries of Lake Nyasa and the Shire River since Livingstone discovered the Lake are the most eccentric of the natural phenomena with which man has contended in Nyasaland".

It is of course impossible to assess the cost in money to the Territory of this eccentric phenomenon, but it is obvious that it has delayed development considerably. It might be possible to assess its cost in catastrophes such as the destruction of bridges, loss of shipping, change of routing for the railway, etc., though such a valuation might not by itself be conclusive. As illustration of the nature of such costs we may cite the last example. The natural terminus for the Nyasaland Railway would have been Fort Johnston at the southern end of the lake, one of the two good ports on the lake where transhipment from lake to rail would have been more or less direct. Owing to the uncertainty of lake level it was decided to alter the terminus from Fort Johnston to Salima, which is not at the lakeside, and this involved laying some 60 extra miles of permanent way over more difficult country than the route to Fort Johnston. The extra cost of this change of route must have been of the order of half-a-million pounds sterling.

Arguments of the "what-might-have-been" type are not wholly convincing, however, and it is better for the supporters of any scheme for the stabilisation of lake level to concentrate rather on the direct value which would accrue.

A report on water resources is hardly the place to review the future development fully, but it is possible to outline briefly the lines along which this must sooner or later take place.

The agricultural surveys do not promise large developments in the near future. There are no large and obvious areas for full-scale schemes, but, on the other hand, there are very many small areas of comparatively fertile land, with the prospect of good water supplies from the rivers. These would all receive attention were an export economy made possible by improvements in transport. Moreover a stable level of the lake, that is within the four foot average annual range, would immediately make it possible to plan schemes for rice cultivation along the low-lying land on the western shore

The fishing industry, for export, is at present confined to the district of Fort Johnston, where indeed it has been hampered by the rising lake admitting the fish to areas where submerged tree trunks interfere with the seining. The market for both fresh and dried fish is extensive and would absorb the production from other parts of the lake were there adequate and regular transport available, which again depends largely on the provision of harbours.

It may be said generally that any firm expansion along these lines would inevitably draw other developments in its train, such for instance as a considerable extension of the tourist industry.

Considering the value of stabilisation of lake level by itself it is open to doubt whether its cost would be recoverable in terms of cash in the immediate future, but that is not the only aspect in which the matter should be viewed. The future of the Northern Province and its people depends very closely on such stabilisation, and the cost of developing it by other and possibly more expensive means must be included in any assessment of the whole problem.

Arguments such as these were no doubt in the mind of the Government when in 1944 it invited Dr. Kanthack to report upon the possibilities of effecting such stabilisation. His valuable report was concerned only with that aim, and the cost was estimated roughly at £200,000, a figure which must be much-increased under post-war conditions.

If on the other hand the stabilisation can be combined with such control as would reclaim flooded lands in the Lower Shire valley, render possible some improvements to river navigation, and enable projects for hydro-electric power to rely on a regular supply, the whole picture assumes a different aspect from the economic point of view.

With the object of considering methods of flood control and reclamation on the Lower Shire a visit was made by Mr. A. E. Griffin, M.C., M.I.C.E., formerly Director of Irrigation in the Sudan, in the dry season of 1946. His report has been issued and I have had the honour of seeing it in proof, and of visiting the Upper Shire in Mr. Griffin's company.

The reports of these two highly qualified engineers are both preliminary on account of the lack of hydrological data for the river, and each author has had to make wide assumptions in order to produce some kind of estimate of costs.

Mr. Griffin offers a choice of three schemes for the Lower Shire, which he has to call 'hypothetical' in the absence of essential data, the cost ranging from three-quarters to one and three-quarter million pounds sterling. His rough estimate for the control measures on the Upper Shire, which would in effect stabilise the lake level as well, comes to less than that of Dr. Kanthack, but again is based on wide assumptions.

In view of the issue of these two official reports, which cover their respective fields as thoroughly as the data and length of visits permitted, my own more general review need only refer to certain local details and aspects of the whole problem which do not appear in them. These remarks are intended to amplify the professional reports and do not run counter to them in any way.

The Upper Shire

Two brief visits were made to the Upper River, the second one in the company of Mr. Griffin.

A compass traverse of the first 50 miles of the river was made from a powered whaleboat and this survey brought out several points of interest in the Upper River which are bound to have some bearing on whatever measures of control are decided upon.

In his report Dr. Kanthack mentions four "bars" on the Upper River; accordingly special attention was paid to each of them, leading to the following conclusions.

The Bar at the Outlet of the Lake

As shown in the traverse opposite page 58, the outlet of the Lake, or beginning of the Shire, is wide, and in plan looks more like the mouth of the river than the beginning.

The bar across the outlet often referred to in previous reports was a puzzling feature until this opportunity to examine it occurred. It appears to run from the north-westerly point of the outlet across the "stream" in a general south-easterly direction. It varies in depth of water from time to time, but to some extent keeps in step with the variations of lake level, that is to say it rises with a high lake and falls with a low lake.

It would appear that this "bar" is really an underwater sand spit. The prevalent wind here is from the south-east, and being an off-shore wind at the southern end of the lake it cannot have any effect on the shore. The dominant winds are, however, the less common north-westers, which, having a long fetch, produce heavy waves. These sweep the sand gradually along the shore from Monkey Bay south-eastwards and produce the spit across the outlet in a manner similar to those found on low coasts, e.g. East Anglia. With a falling lake the spit is eroded at the top by the fairly deep action (8 to 12 feet) of the same heavy waves. Even with a stabilised lake, therefore, this bar should not seriously affect navigation, or, at least, it should require very little dredging or groyning.

A more continuous set of soundings than we were able to make should confirm, or refute, this explanation.

The Bar at the Entrance to Lake Malombe

The shallow water at the entrance to this Lake is largely due to the slackening of the river current as it reaches the lake. Its importance lies in the fact that with a low lake and a weak current in the river it would be a likely position for the growth of sudd in the quiet shallow water, as apparently happened in the past.

On the other hand the river, where it begins to shallow, is 400 yards wide, and growth from the sides would tend to canalise the river and keep a passage clear, provided the minimum flow of the river was maintained at between 4,000 and 8,000 cusecs.

No floating islands of sudd were seen either here or anywhere else in the Upper River, and it looks as though the excessive number of these in the years after the break-through of the Lake water (1933 onwards) was due to the uprooting of masses by the rising water in Lake Malombe.

Judging from the very definite current in the river from Lake Nyasa to Lake Malombe in 1946 it seems probable that there is a difference of level of up to two feet between the lakes.

There are no beaches on Lake Malombe and therefore there is no bar at the outlet, though its size is such that considerable waves from the north-west are raised which expend their energy amongst the reeds on the south shore.

At the time of my visit the soundings for Lake Malombe were fairly uniform at from 10 to 15 feet, on our route from north to south, and along the southern shore.

The Nkazi Bar

As shown in the traverse the Nkazi appears to have several mouths into the Shire in the usual fashion of a delta. This is the locality in which the Upper River was completely sealed off by silt and vegetation during the last low-lake cycle. It was the most effective of all the bars and is likely to be the chief hindrance in the future.

The plan of the river and the soundings along this stretch are most instructive. The river, from 1933, began to cut a narrow and therefore swift channel immediately opposite the various tributary mouths, where accordingly the soundings show very deep water, up to 30 feet. Immediately downstream from each narrow cut the debris has been strewn over the bottom and has produced shallows, which at the present day form a temporary bar, and this is being slowly distributed downstream.

The survey was made about three months after the torrential downpour of February 1946 during which the Nkazi and other local rivers brought down an unusual quota of silt, of which there were ample signs in the freshly cut banks of the main river and the tree snags in the shallows. Had the main river been flowing sluggishly as it did in 1907, there is little doubt that a barrier of silt would have again hindered the flow and have begun a fresh cycle of rise in lake level. There is evidence in the banks occasionally, in the form of layers of gravel, that this occasional heavy deposition has been going on for a very long time past from either side of the main valley, and has been at least a contributory cause of the reclamation of the area from what was once part of Lake Nyasa itself.

The "rapids" marked in the map at Namputu were formed temporarily by a group of dead trees half buried in the bed of the river. The shallow water continues for a mile or so below this point after which it resumes its standard depth, from 12 to 18 feet.

The fact that the Nkazi will inevitably experience further "cloudbursts" over its watershed and will produce further heavy silting evokes the question as to whether such an occurrence would block the river when it is under control by a barrage near Fort Johnston.

The question cannot be answered with certainty but any fresh silting should be capable of clearance, either by actual work on the blockage or by letting through more water from the Lake over a short period. It might be necessary to construct swinging weirs or groynes above the narrow stretches which could be brought into position for short periods and produce a local acceleration in the current.

Such clearance would be easier to effect from a barrage above the Nkazi than from one below it.

The Liwonde Bar

This barrier, the fourth of Dr. Kanthack's series, is the first one with a rocky bottom and is the only true and permanent sill to the Lake-River complex. The brick pillars of the former road-bridge are still standing and form a temporary obstruction so that the water above it is slack and below it is turbulent. This will probably have cleared the bed of silt, but we were unable to take soundings to determine whether the bottom is indeed rock and a suitable foundation for barrage construction. There is a fairly sound Gneissic granite outcrop nearby, just above the hot springs, furnishing material considered by Dr. Kanthack as suitable for construction work.

Except as a possible site for a barrage the Liwonde Bar is of no great interest since the gradient here is too great to allow sediment and sudd to build a blockage.

A survey downstream from this point would show whether, in event of a barrage being built near Fort Johnston, it would not be advisable to blast the rock bottom at Liwonde to increase the gradient from Malombe down towards Matope, as recommended in Mr. Griffin's report.

The question of suitable sites for a barrage on the Upper Shire was naturally in our minds, and they are referred to in Mr. Griffin's report, where he also emphasises the advantage of being able to build a barrage or weir "in the dry", that is to say without first diverting the river.

The most promising site for such a method of construction is shown on the map at Ntundu, a small double village a mile or so south of Fort Johnston. The pronounced bend at this point lends itself particularly well to the purpose since it provides dry land for the construction work and a shortened course for the river, which on the lower side of the construction work at all events would itself do a good deal of the excavation.

In his report Mr. Griffin refers briefly to a choice of several types of regulating weirs or barrages and gives more detail about one of them, the Standing Wave Weir. For the benefit of those less acquainted with structures for regulating flow it may be useful to describe them more fully in a non-technical report such as this.

It must be realised that the conditions are not those of a normal river since the barrage will really be the outlet of the lake. There will therefore be no appreciable silt in the water nor will there be any other velocity than that caused by the "draw-in" of the flow through the regulating mechanism when open. On the other hand the velocity of flow below the barrage will depend amongst other things on the "head" or change of level above and below the works, and this again will depend on the amount of water allowed through the barrage which will vary with the requirements of lake level and flood control lower down the river.

The type of barrage recommended by Dr. Kanthack, though for a different site, is the standard one of a masonry low-level dam surmounted by a superstructure carrying sluice gates which would be operated by hand. The great advantage of a rock foundation such as exists at the Liwonde site is that there is no danger of scouring the bed below the structure, a risk which in alluvial ground such as that near Fort Johnston must be guarded against by building long concrete or stone "aprons" above and below the regulator.

In the standing wave weir the actual regulation of the discharge is done by some form of sluice suspended from a superstructure, including plain baulks of timber known as "needles".

There are two other ruling conditions for the regulator required which govern to some extent the type chosen. One is that the discharge need never be zero though the flow may have to be shut off to reduce it to as low as 2,000 cubic feet a second. This means that the sluice gates need not be watertight; they can be leaky, as indeed are "needles" of timber. Secondly there can never be a greater head of water at the weir than from 6 to 10 feet according to the height chosen at which to stabilize lake level, involving comparatively small uplift pressures for the foundation, since Lake Malombe will act as a sort of regulator itself for the height of water below the weir.

These are both conditions tending towards cheaper and simpler forms of construction, more suited to pioneer countries.

Accordingly when the requisite surveys have been made the engineers may be able to use designs, such as are in use in Australia and India for example, where effective though not highly finished structures have been made from rough timber and used railway material, including rails. The main item of cost remains in the foundations, core-walls and bank protection.

The chief embarrassment to the designers for a site here is the extremely small gradient between Fort Johnston and Lake Malombe and the only slightly greater gradient in the section beyond, down to the rock bar at Liwonde. It is on a reasonable gradient that the design depends for a natural clearance of obstacles in the channel below the barrage. To increase this gradient artificially the engineer has the choice of lowering the rock sill by blasting, or selecting a higher level for stabilization, or possibly a compromise between the two.

The nature of the problem is perhaps best illustrated by considering what would be the effect of laying an artificial rock barrier of stone or concrete, say three feet above the present bed of the river at Fort Johnston. This would then become the real lip of the outlet to the lake and would be non-erodable. The lake water would then set to work to establish an equilibrium according to this lip. Being at high level stage now, the lake would steadily fall until it reached that state of equilibrium, but, of course, at low stage there would be the risk of obstructions forming as before and at first sight the same cycle would be resumed.

If, however, the artificial barrier were constructed to such a height that the discharge never fell as low as it did in 1915, when the downstream gradient almost disappeared, there would be considerably less chance of the obstructions gaining mastery over the regular channel maintenance which would have to be established.

For instance, the present gauge height of the lake is about 23 feet for the minimum of the year, and its height in 1931, when the lake water was just beginning to overtop the stubborn obstructions of 15 years growth, was 15 feet, that is eight feet lower. The sounding just above the Ntundu Bend was 12 feet in 1946. Now if a barrier of sheet piling were driven in across the river at this point so that only eight feet of water were passing over it, this would hold the lake at the 1931 minimum in due course, and thereby maintain a gradient which in the past enabled the river to cope in some degree with the silt and sudd in the critical places downstream.

In fact if nothing more than stabilization of the lake level were the object, something of this kind would no doubt effect it, using some more permanent barrier than sheet piling and providing an apron of boulders above and below it and some protection for the banks.

There is even something to be said, but not a great deal, for running a full scale experiment in the river along such lines. An experiment must be cheap, it must do no damage and it must give an answer to the questions. How far such a trial would come within these conditions is for the engineers and local technical staff to say.

To refer once more to the Ntundu site, it is obvious that if it were used to build the barrage in the dry, the old bed would furnish the short canal leading to the lock which would be necessary for the river traffic.

In concluding these remarks on the Upper Shire it may be wise to refer to the fact that the whole area is part of the Great Rift Valley and is subject to the stresses which are still evident in many parts of the rift system.

The earth tremors which occur in this area, and the occurrences of hot springs, do of course mean that slight crustal movements are still in progress, but I do not think that significant movements have occurred in historic times or need be regarded as imminent in the future. It is necessary to state that opinion firmly because it appears that some people are opposed to any control measures in case they be nullified by a resumption of the rift valley movements.

The compass traverses of the upper and lower river, published on a reduced scale in this report, must be regarded as reconnaissance maps only. The total of about 90 miles of river was done in five working days and from a steel whaleboat or a river launch.

The detail of bends, widths and soundings is probably fairly correct, but as a whole the traverses will need considerable adjustment when the areas are finally triangulated.

Lower Shire Flood Plain

The general aim of development in the Lower Shire flood plain is to increase production of crops and absorb further population. There are two ways of effecting this, provided that the engineering work can be done.

One is to free the present flooded land from water sufficiently to permit the seasonal cultivation of cotton, as was practised in the early years of this century when the lake was low and there was only a small dry season discharge in the Shire. The other way is to provide water for partial irrigation, that is to say irrigation to supplement rainfall during part of the year.

To carry out either project the main requirement is that the flood plain should be higher and/or that the river should be lower. Of the two alternatives it is probably easier to effect a gradual rise in the level of the flood plain.

The immediate trouble is that the Shire itself, and the tributaries as well, all have beds which are too small for the discharges they have to deal with in time of flood. This may seem peculiar but it is common to most rivers flowing over their own flood plain for the following reasons. Not only is the plain due to the silt brought down and deposited, being the excess of what the water could carry off, but each flood goes through the same cycle of first digging out a deeper or wider channel and then, as the velocity decreases, dropping an almost equivalent amount of silt and filling up the bed again till it is too small to take the next flood. Consequently any flood may overflow the banks, break through and create a new channel. In course of time the river wanders across the flood plain lowering parts of it and leaving terraces of high ground in other parts. The high sandy bank on which the Chikwawa Boma and Hospital stand is just such an ancient terrace.

The first thing is to confine the main river, and the tributaries as well, to a permanent channel. This is usually done by excavating soil to create parallel "bunds" or embankments sufficient to accommodate the maximum flood. Apart from being a very costly undertaking this procedure leaves the swamp lands below flood level since there is no periodic addition of soil to them. In fact, since they naturally have a high percentage of peat or humus, they tend to shrink and become lower rather than higher, which means bad drainage or expensive pumping to fit the land for crops.

If it were possible it would therefore be a sounder principle to raise the flood plain by letting silt on to it while keeping the river within bounds and preventing it from wandering across the plain in its normal way.

There are means of doing these things by natural processes, and although they take a long time they are fairly sure and are certainly far less expensive than building an embankment.

Let us first see at what rate silt is being brought down to the lower river from the Shire Highlands. We will take the area of catchment of the escarpment rivers as one million acres and the mean annual rainfall as four feet. The run-off on these steep slopes is likely to be high, but we will adopt 10 per cent for the calculation. In the same way we can be conservative and take the average silt content of the water at 1/1,000 by volume, though in the major floods it is likely to be nearer 1/100. Now the worst swamps on the east side of the Shire below the escarpment total about 20,000 acres, and a short sum shows that if the silt brought down by these tributaries could be placed where most needed it would raise the depressed area by about one-quarter of an inch a year. Although this desirable end cannot be achieved, it is a useful figure to keep in mind, especially as it is a conservative one and neglects any contribution which might be captured from the Shire itself.

We therefore require some system of reclamation and river restriction which shall aim at extracting a proportion of the silt from the water and building up the plain with it.

There is such a system, discovered almost by chance by the officers of the Forestry Service in Burma, whose purpose was at first merely to improve the rivers for the floating of teak logs down to Rangoon. Just as in Nyasaland, there were short rapid rivers bringing large amounts of silt from highland areas on to an old flood plain. Indeed it is the similarity of topography which has directed my attention to the possible application of the same system to the Lower Shire.

The object of the system is to maintain a wide enough bed for the stream to keep a more or less permanent course and at the same time induce the flood water to part with a proportion of its silt on to the land, the coarser material to build a natural embankment or levee and the finer material to pass on to the flood plain beyond.

As practised in Burma from about 1915, a section of the river is selected where it overflows its banks every year. Here a strip from 100 to 200 feet wide on both sides is stripped of all vegetation so that the flood water is not checked in its flow and consequently does not deposit much silt. Towards the edge of this cleared strip a low fence of bamboo stakes about nine inches apart is built and the tops are fastened together by lashing other poles. The top of the fence is trimmed off so that it follows the general gradient of the river. Where the fence crosses lower parts of the land, such as old side channels, etc., the fence is naturally higher and in such places bamboo struts are lashed to take the higher pressures due to the deeper water.

When the silt-laden flood comes down it quickly overflows its undersized bed on to the cleared strips, cutting its channel wider as it passes. Brash, leaves and other rubbish are caught by the low fence as the water reaches it and the flow is checked. The check causes the water to drop its coarser silt, the heavier material on the stream side of the fence and the lighter material after the water has seeped through the clogged fence.

The result is the beginning of a broad low embankment. The lower parts, where the graded fence is higher than elsewhere, are raised at a greater rate than the higher parts because the water there being deeper has more silt to drop. Consequently the embankment grows to a regular gradient similar to that of the river, and at first quite rapidly, burying the fence in a few years. As the flood subsides the velocity of the water decreases and silt is dropped in the main bed of the stream in the usual way, but it now has a wider channel.

The maintenance involved is the clearing each year of any fresh vegetation which has grown on the lateral strips and the removal from the bed of the stream of any major obstructions such as trees. If that is not done the first flood may be checked so much that a break through of the new embankment may take place.

Each year the flood will raise and broaden the embankment still further, and the flooded plain beyond will receive a thin layer of finer silt, which will tend to fill up the lower portions at the most rapid rate.

The system is applied to the river in sections, that is to say it is begun where the river first overflows its banks on reaching the plain, and when that section, of say a mile or so, has built its embankment, the fences are continued further down the river and the process induced to begin there.

In Burma the results have been almost universally good, and in places spectacular, so it is worth discussing how the system might be applied to the Lower Shire, taking as an example the particular case of the Mwampanzi.

This stream debouches from the hills where the Chikwawa–Chiromo road crosses it by a drift. Here and for some distance further down it has a definite bed, but at a certain point there is evidence of where it overflows its banks in excessive floods. This is the point where the check fence should begin. The banks on both sides to a suitable distance—100 feet is suggested for the Mwampanzi—would be thoroughly cleared of all growth, mainly by fire where it is grass. At the edge of that clearing the grass would be left standing and could itself induce deposition. The fence would be constructed about twenty feet from this grass border. Stakes about four feet long would be driven in, about nine inches apart, to a depth of about two feet, and strengthened by lashing horizontal poles. The fence will thus be about two feet above the ground, and some care would be taken to see that its top, as marked by the horizontal poles, followed the general gradient of the river. Thus, where it crosses small depressions, the stakes would be more than two feet above ground level, and here they should be more substantial than elsewhere and be strutted to resist the extra force of the water in such a low place.

In Burma bamboo stakes are universally used, and it will be a matter for experiment to find a Nyasaland substitute for bamboo. It should certainly be ascertained whether treatment of the elephant grass would not be sufficient—something in the nature of binding a few stalks together for each "stake" and lashing to them more stalks laid horizontally. Such a fence might have to be reconstituted each year, whereas the stake fence, if preserved from fire, will last several years.

Naturally the rate of growth of the embankment, which will ultimately engulf the fence, will depend on the amount of silt brought down by the floods, but the effect on broadening and straightening the channel will be seen very soon, since the sweep of the current over the unobstructed ground will quickly induce erosion.

At the stake fence, for equal stillness the deeper the water the more silt it drops. The embankment, therefore, is so broad and regular that its growth will hardly be noticeable, even though for the first few floods it may well rise at the rate of six inches or more per year, as was the case in Burma.

The Mwampanzi flows over only a mile or so of lowland before joining the main river, and as it has a fairly large watershed and is notoriously silt-laden, it is a suitable stream for experiment.

An important feature of the system is that once the broad embankment has been formed it is comparatively easy to change the course of the river if desired. During the dry season a lead channel is dug through the embankment and obstructions of any kind are put into the former bed of the river below the breach. Stake fences are erected beyond the breach along the course the river is to take, and the process is begun again. Attention is directed to this possibility because there is some reason to believe that there is a belt of lower land between the present river and the escarpment, probably a former course of the Shire itself. If a survey shows that this is the case, there is some chance of gradually turning all the escarpment rivers into this low belt. This would not only relieve the main river of the silt from the escarpment, but would raise the flood plain just where it is most needed. Leaving that as a rather visionary possibility for the future, we may consider what might be done with the Shire itself.

In the years of a "low lake" the main river used to dwindle to a mere trickle in the dry season and rise up to fifteen feet during the floods, conditions which are very favourable for applying the system of natural banking. Now that the lake is high there is a fairly strong flow throughout the year and the flood rise is not much more than five feet.

A rapid traverse survey of the river in June 1946 showed that such a rise must regularly overtop the low banks somewhere between Nkate and Makwira. It is here that experiments with the main river would be begun.

The strip cleared should be some 300 feet or more on each side for so large a river, and the stake fence might require to be rather more substantial than for the smaller tributaries. It is worth noting that, if it is properly carried out, such an experiment cannot do any damage, for the flood will tend to be relieved rather than increased for the mile or so of the experiment. The worst that is likely to happen is that the river will take advantage of the clearer path to erode a wider channel between the fences, and the land is finally lost, as indeed would be the case in any system of river training. The material removed might clog the river further down and induce a temporary higher rise there, which could hardly be serious if the first experimental section were a short one.

It is natural to ask how such a system can, if required, be turned into a more ambitous scheme of training by artificial banks such as has been sketched by Mr. Griffin in his recent report.

The embankment raised by the river itself naturally cannot be any higher than the floods themselves, being built by them, but provided they have been planned at a sufficient distance from the river they will have done a great deal of the preliminary work. The channel of the river will have been broadened and the very broad embankments will furnish a safe foundation for the higher, artificial bank to be built upon them. The seepage through such broad natural levees will at least be less than through an artificial one, and, moreover, there can never be a wholesale break-through as in the case of high artificial banks.

There is, therefore, much to be said in favour of preliminary experiments with a view to a possible expansion of the system according to a plan so as to reclaim more land for flood cultivation, with the knowledge that it is all preparing the ground for larger schemes still.

In the absence of any contour levelling over the flood plain itself at present, the above recommendation can hardly be more than a suggestion, but experiment on a small scale need

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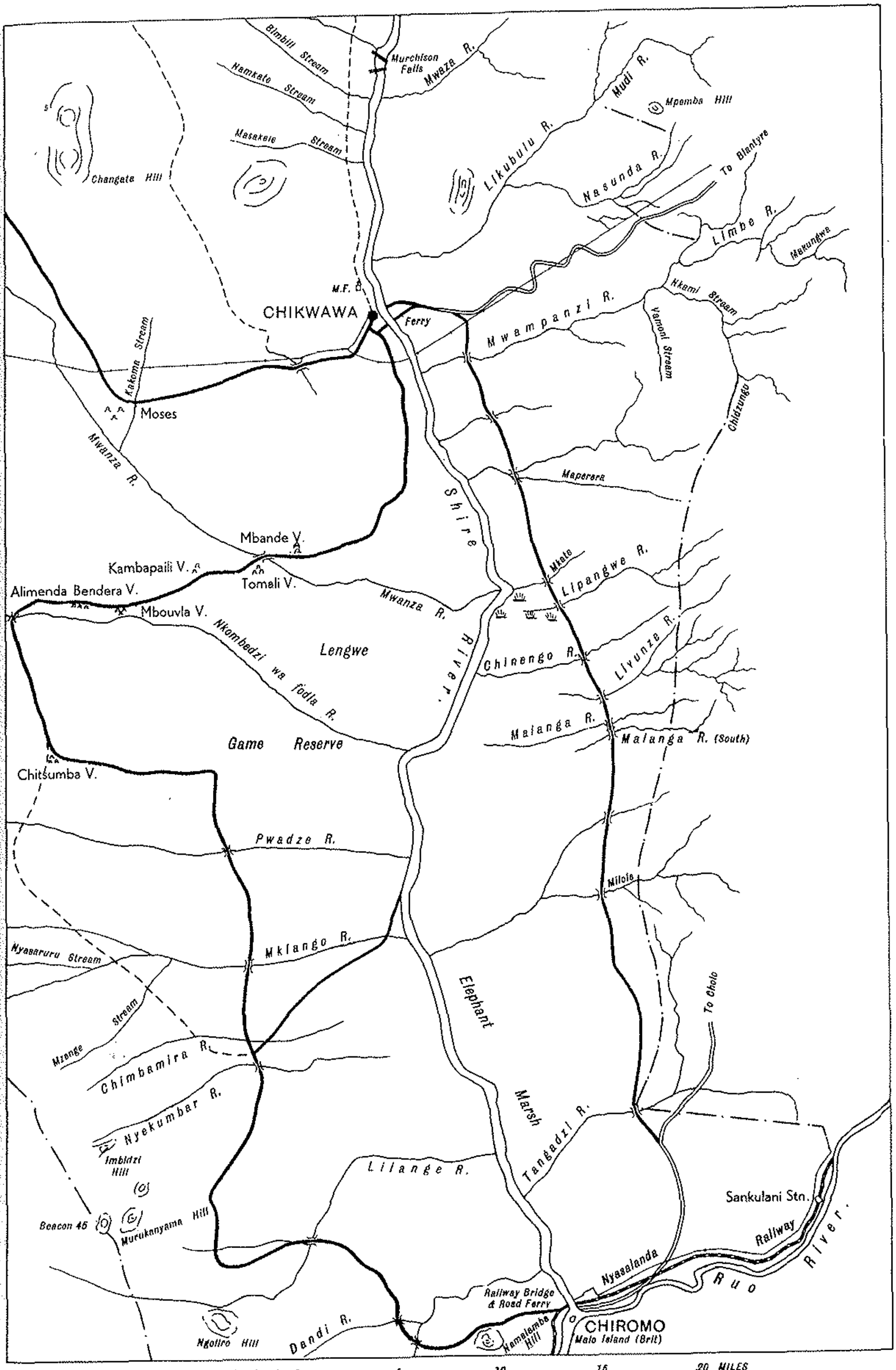

LOWER SHIRE RIVER, CHIKWAWA TO CHIROMO
(AFTER NYASALAND 8" MAP)

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not be delayed. A short section of one of the tributaries, such as the Mwampanzi, could be cleared and stake-fenced for very small cost and the results carefully observed.

An account of the system described above will be found in a book by the former Chief Conservator of Forests in Burma, Mr. F. A. Leete. The title is *Regulation of Rivers without Embankments*, and it was published by Crosby Lockwood and Son, London, in 1924.

The Settlement of Dry Areas

The term "dry" is not truly applicable to Nyasaland, whose rainfall as we have seen is usually above 30 inches for the year, but it is intended to refer to those areas which have no surface water available for the greater part of the dry season and are therefore unsuitable for villages.

In the past the Geological Department, in charge of well sinking and boring, has done a great deal to supply domestic water by these means. Its programme will be expanded a great deal now that the equipment and personnel are obtainable.

Wells have proved to be more expensive to sink than bores are to drill, and there is no doubt that where rock-fissure water can be reached by a bore that is the best source.

On the other hand, it may be that other methods of obtaining domestic water would repay trial. The waterless areas referred to are often due to the fact that the soil is so deep and porous that the water table (surface of free water) falls rapidly after the wet season beyond the reach of the native-made well and the area is abandoned, although it would grow seasonal crops. At the same time, a properly lined well in such material is expensive.

It would seem that these are the appropriate conditions for the jet-drilled wells referred to elsewhere. They are very rapidly sunk and the piping is much less costly than that required for tool drilling. The equipment for jet drilling is light and mobile, and there is no heavy superstructure to move from place to place. It is strongly recommended that such equipment should be obtained by the Geological Department.

The wells thus provided must, of course, be furnished with a pump, but because of the notorious precocity of the African woman in breaking such pumps a variation in the drilling method is recommended where the topography permits, namely to drill horizontally into the side of a slope instead of vertically. For jet drilling this means that the piping must be pushed into the hole created by the jet instead of merely following it by means of its own weight as in vertical sinking. With the lubrication provided by the issuing jet of water this pushing is not, under ordinary circumstances, a difficult matter and can be done by levers applied to the pump end of the piping.

The result is really a piped spring, and it would be fitted with a tap of a kind that cannot be left open. It is a practice which should certainly be followed wherever there is any indication, from dampness to an actual small spring, that there is a layer of less pervious soil holding up the water slightly on a slope.

The hilly nature and the deep soil of much of Nyasaland make the occurrence of what might be called "trickle" springs fairly common. They usually occur on a slope of deep soil as a slow trickle tending to become merely a damp patch later in the dry season. It is useless merely to open up the spring which is only the surface appearance of the general seepage of water through the surrounding soil. If this can be collected by any means the yield will be much increased, and this can be done by what the writer calls the wingwall spring or merely the winged-spring. The spring or seepage point is usually caused by a slightly more impervious layer of soil at that level combined with the slope of the ground. The exit point of the water is first opened up and a short pipe laid horizontally to deliver the water into tins or "debbies". From this pipe a trench is dug on either side back into the slope forming with the pipe a very broad Y. These wing trenches should go down to the layer which has held up the water and caused the spring, and their length depends upon the slope of the ground as well as the amount of seepage to be collected. The trenches are then filled in with ant-hill clay material, wetted just enough to be plastic and trodden in by the boys' feet. These impervious wings inclining towards the pipe then divert the general seepage to the centre and vastly increase the supply. In some cases such wing springs have ensured a flow throughout the dry season where before there was merely a wide damp patch. The clay wings, being buried, are quite permanent and they require no special skill in construction.

Any trickle spring will benefit from such treatment, but one would select one if possible which obviously had a large gathering ground and which was known to last, as a trickle, for the greater part of the dry season.

In several places in Central Africa the writer saw villages which were supplied for part of the dry season by such springs but where for the rest of the season the women had to walk several miles for their water. Little more than a day's work by the village on laying clay wings would, in the cases mentioned, have ensured the small supply required for the whole dry season, since there was ample seepage, but much dispersed. These villages were all situated near the head-waters of a stream.

Where there are rocky hills above the area another practice may be followed, which has solved the problem of domestic water in one or two localities in Uganda. Normally the rainfall, quite adequate in amount but seasonal in occurrence, runs off the rocky hill and sinks into the deep soil of the valley so that it cannot be reached except by deep wells.

Shallow channels are dug on the hillside leading the run-off so caught to a pit excavated in the rock which forms a rock reservoir. At first sight this seems to be an expensive way of conserving water, since it requires rock drilling and blasting. On the other hand, it is very permanent and, except for closing an occasional fissure in the rock, it requires little or no cement work. Moreover, rock treatment is not a strange technique to a large number of Nyasalanders who have worked in the Transvaal mines. For areas where the dry season is long and absolutely rainless the rock reservoir is not well suited, since it requires the excavation of about one cubic foot per person per day for the duration of the drought. For areas such as the Dedza highlands, where there are occasional local rains during the dry season, it would be useful.

Dams and Weirs

There seems to be a very good case for more surface conservation in Nyasaland. The comparatively dense population and the smooth functioning of native authority give point to the remarks in the general section of this report on the village dam scheme, its association with the village forest area and other benefits such as a piped supply.

It is true that some District Commissioners doubted whether the villagers would appreciate these benefits sufficiently to undertake the work themselves.

Nevertheless, it would appear, from analogy elsewhere in Africa, that if only one enlightened headman could be persuaded to put in such a scheme for his village the example would be heeded and followed by his envious neighbours. Especial care must be taken over advising as to the siting and design of such a "demonstration" example, since a failure will be heeded still more widely.

An area where experiment might be made with particular value is that centred round Balaka on the railway from Blantyre to Salima. Here there are reasonably fertile alluvial soils, but these are not fully used because there is too little water available during the dry season for domestic purposes, and villages cannot be established without a sure supply.

From three rapid traverses through this area it appeared that the most promising lines of attack on the problem would be

(*a*) Jet-drilled wells in the deep soils, particularly near the sharp slopes.

(*b*) Surface dams where there are narrower valleys, avoiding black cotton soil bottoms, which are difficult to deal with, since they are porous.

The arguments in favour of surface conservation are still stronger in the Lilongwe–Fort Manning area, where it is much needed for stock as well as for domestic use. The stronger relief produces more suitable sites, and a large number of streams run strongly in the rainy season, while ant-bed clay is usually available not far from any site. As is always the case in a wet-season country, the design of the spillway is the most important part of any dam, and the part most likely to be neglected by the African himself. Not only should the capacity of the spillway be made sufficient to carry the largest flood to be expected, but it is a sound practice to excavate it at least a foot lower than its final level as designed. For the first few years the capacity of the dam is lowered by this amount, but in that time the embankment is settling and consolidating itself. At the end of that time the spillway level is raised by filling with soil, with a small ant-bed core wall across it and topping it with stone work, using large enough boulders to resist erosion by the flow over them when the spillway is running.

This section would not be complete without some mention of the black cotton soils and their treatment in water conservation.

This type of soil, having a high percentage of colloidal material, is notoriously difficult material with which to make watertight dams. Yet so many of the otherwise promising sites for water storage consist of these soils that it is time measures were taken to discover the reasons for its porosity and some means of remedying it.

It is clear that its capacity for absorbing water and thereby swelling in volume is, in some way, the mechanical cause of its unsatisfactory performance as an embankment. Its rapid rate of absorption of water as compared to the slow rate in the case of true clays is in itself evidence of its porosity. Whether this is due to the established property of colloids to pass water through their substance or whether it has to do with the arrangement of the soil particles or the cracks formed in dry weather is perhaps a problem for the physical chemist. Yet something can be done in the way of experiment by the person on the spot, even without laboratory facilities, to search for a remedy against the seepage which evidently occurs in this type of soil. This is the more necessary since some black cotton soils will hold water and others will not, so there are local variations, which must be tested locally.

It is therefore suggested that before sinking capital into a dam on such soil a simple experiment should be made with it by means of four-gallon petrol tins (" debbies ") somewhat on the following lines.

Three tins, each with a similar nail-hole in the bottom, are taken and are half-filled with:

(i) The sample soil rammed dry.

(ii) The sample soil puddled, that is, kneaded with the least quantity of water necessary to permit kneading.

(iii) A true clay, e.g., material from a white-ant hill.

The tins are then filled to the brim with water and the comparative rate of loss noted. The experiment should be repeated after all the tins have dried out, simulating the effect of a dry season. The results of such a trial can hardly be conclusive, but should certainly suggest whether there is likely to be complete failure in a dam.

Nearly all soils have a proportion of true clay in them and if this can be separated so as to form a layer on the top of the soil it should be more watertight. This is the reason for the practice in many countries of driving stock round a newly-made reservoir when it has some water in it. It certainly consolidates the bottom material, but a more important action is that it muddies the water with the fine clayey fraction of the soil which later sinks slowly and forms a watertight skin to the soil itself. In all dams in alluvial material this sealing by fine material brought in during the rainy season gradually improves the holding capacity and the object is to hasten this action artificially by any means available.

In obstinate cases where the black cotton soil is so porous as to hold water only for a few hours, as seen near Salima, heroic measures may be required. These might include the following:

(i) Organised treading by natives or stock so as to muddy the water immediately it has gathered.

(ii) Spreading an inch or so of ant bed material over the bottom.

(iii) Laying a wash of impervious material over the dry bottom of the dam, selecting what may be available from:

- (*a*) used engine oil;
- (*b*) an emulsion of engine oil and clay or whitewash;
- (*c*) cement grouting, i.e., cement suspended in water;
- (*d*) waterglass (sodium silicate) in dilute solution sprayed on, followed a day later by a solution of calcium chloride. One pound to one gallon of water in each case;
- (*e*) one of the oil preparations, such as " Calos ", which are used for waterproofing roads.

None of these temporary sealings would be durable in themselves, but they should enable the dam to fill for a sufficiently long period to start the natural sealing with its own clay.

4. TANGANYIKA TERRITORY

MY VISIT WAS, unfortunately, confined to a traverse by bus and car from south to north, together with a train journey from Dodoma to Dar es Salaam and back again. I was thus able to have a brief glimpse of the following areas only:

(*a*) The Southern Highlands region with its good rainfall.
(*b*) The coastal region with its adequate rainfall.
(*c*) The central basin with its deficiency of rain.
(*d*) The minor areas of Oldeani, Arusha and Moshi with their good local rainfall.

The route therefore passed mainly through the pastoral districts; of the agricultural industries I was able to see only the sisal areas of the Eastern Province and the local coffee and pawpaw cultivations of Arusha and Moshi.

I had the benefit of many conversations with, and the company of, the newly-appointed Director of the Water Development Board, whose energy and wide knowledge of the country will be of the greatest value to the Territory as staff and equipment become available to him. The great advantage of having a more or less independent department dealing with water resources is very evident, and I have but few comments to make on the schemes of further development outlined to me.

Not the least important function of such a department must be to afford advice and occasional supervision to the administrative officers scattered over the Territory. These officers are generally well aware of what is required for their districts in the way of water development and for the many small-scale schemes which are overdue they merely require technical advice and encouragement. Such a peripatetic supervision of work and choice of schemes is already a part of the programme of the Director, and it is only mentioned here in order to underline its importance.

The psychological value of the co-operation of native authorities is naturally well understood by the District Commissioners, who in fact are the people best placed to introduce that mixture of persuasion and direction which is so badly needed by the African at the present stage when he cannot understand all the benefits which can come from water development.

The Dry Pastoral Belt

The belt of pastoral country running from Iringa to the Kenya Border, including the Masai country, suffers at present from two major difficulties apart from a small and variable rainfall, namely the inroads of the Tsetse fly, and a decided over-grazing of the fly-free country as a consequence.

The possibility of providing watering points for stock is therefore limited to a proportion only of the area which otherwise would support a much larger industry.

Speaking in general terms only, a rainfall of 20 to 25 inches, even though it is awkwardly spaced, should be ample for all stock purposes when suitable measures of conservation have been taken. These measures are, of course, inseparable from an active campaign against the soil erosion which has reached a disastrous stage in some places, notably near Kondoa. Such a campaign, involving storm water furrows, contour bunds and blockages in minor streams, will arrest some of the rapid run-off which is such a feature of the area.

Of other measures, most of which are already under consideration by the new Water Development Department, I was able to discuss with the Director the possibility of paying special attention to

(*a*) Sand river treatment for stock watering points,
(*b*) Small-scale dams and weirs on headwater streams.

The reason for emphasising this latter form of attack on the problem of water shortage is threefold.

In the first place, it tends to improve the water situation fundamentally by raising the water table and extending the period of flow of the streams concerned.

Secondly, the required small construction-works are relatively cheap.

Lastly, it permits a form of co-operation with the African himself which is both economically and psychologically sound in that the beneficial results are immediate locally, and the works, largely constructed by the local people, become a responsibility for them in a way which large and skilled schemes rarely do.

Such minor works would, of course, be supported by the boring-and-well-programmes already planned and awaiting staff and equipment for active prosecution.

With so little experience of the country I should not like to pronounce upon the projects, either in being or already planned, of constructing larger reservoirs with or without extensive piping downstream for water points. In certain localities, especially on those rivers which lose themselves in wide sandy basins, this must be the best remedy. On the other hand, they are expensive works, they are rather beyond the co-operation of the inhabitants, and, without strict control, they are liable to concentrate the stock population and induce soil erosion from excessive grazing and traffic.

An exception must be made for the case of those areas which are heavily infested with fly and whose rainfall is reasonable such as in the region between the Rift wall, by Lake Manyara, and Arusha. At present much of the surface water never reaches the dryer fly-free areas, and it should be possible to have large conservation dams in the hillier districts, the water from which could be piped long distances into what is mainly Masai country to provide water points.

For instance, the large massif of land above 5,000 feet which lies 60 miles to the south-east of Lake Manyara in fly country would repay a survey with this in view.

In the dry country to the south of Dodoma, on the other hand, I would favour the small-scale checks and an intensive use of the sand rivers rather than large reservoirs with their inevitable concentration of people and stock.

In the central Mbulu district the problem is a similar one as regards encroachment of the fly, but it has a much better rainfall than the lower pastoral country. Here in particular the multiple small-scale reservoirs or weirs should be effective, combined with control of pasturage and rotational grazing. Much of the work here could be carried out by the administrator in conjunction with the Native Authorities, if advice and a small amount of supervision could be got from the Water Development staff.

Irrigation Areas

It was impossible to give more than a glance at the present irrigation schemes in the Arusha–Moshi area, where a somewhat wasteful use of the available water is already being tackled by the Water Development authorities.

If and when large-scale irrigation is to be seriously considered in the Territory, I believe that a careful survey of the Great Ruaha and Njombe valleys will disclose areas eminently suitable for big schemes. Not only is the topography rather inviting, with its extensive plains, but a natural development of road and rail communications will in future lie along the general line of the upper Ruaha rather than on the high country at present followed by the road from Mbeya to Iringa and Dodoma. This is a comparatively uninhabited area at present and would be a natural outlet for the population surplus of the Southern Highlands near Mbeya and Tukuya, where indeed the people have a tradition for intensive agriculture already.

The same should be true of the lower Ruaha and Rufiji valleys judging from the topography, as indeed of much ot the coastal fringe where irrigated rice cultivation would seem to be a natural development.

The announcement, since my visit, of the plans for large-scale production of groundnuts has doubtless given a fillip to the development of the water resources in the areas concerned. Not the least of the benefits which will accrue from this scheme will be the importation of bulldozers and other mechanical aids to agriculture which can be diverted occasionally to water conservation projects to assist in food production by irrigation.

In this connection, one of the main difficulties in damming the medium-sized rivers may be mentioned here, though it applies also to many other parts of Africa. The perennial river which has a dry season flow of the order of a few cusecs is apt to discharge an extraordinary volume in flood time, up to several thousands of cusecs, which on the main river would entail provision of such a large spillway and revetment works that it might well double the cost of the dam.

Inspection of possible sites on that class of river for dams to conserve a few million cubic feet convinced me that in many cases there was a method of bypassing that particular difficulty. There is often a tributary valley, with a small catchment, running into the main river, which has a suitable site for that class of dam but insufficient water to fill it. If, then, the dam is built in such a side valley it can be filled, under control, by diverting water from the main river higher up. This means a canal with a sluice gate at the point of withdrawal which, under favourable circumstances, would be a very much cheaper proposition than a dam, or even a weir, on the main river itself. There are sundry other engineering advantages in such an indirect site, including the possibility of building " in the dry ", reducing the amount of silt led into the dam and even regulating the flood itself in some degree.

5. KENYA

The visit to Kenya was so brief that only a few rapid journeys to areas of water scarcity were possible. These included a trip over the Laikipia plateau to Maralal, then *via* Archers Post to the N.F.D. at Garba Tula, a trip to Machakos and Kitui, and finally a visit by road to Voi, the Teita Hills and Taveta. Consequently this report must be taken as recording impressions rather than as providing conclusions on the development of water resources.

Just as Kenya leads East Africa in its degree of general development so it also leads in the complexity of its social and economic problems. The physical background to most of these problems is the low rainfall, but there are other difficulties only slightly less fundamental, such as the prevalence of tsetse fly, which hinder development. Even when these are overcome, or at least modified, it is doubtful whether Kenya can be a food exporting country on the scale which the rest of East Africa might reach. Its rapidly increasing population will have enough to do to provide for its own subsistence and even that will only be possible with a more regulated form of native agriculture. Moreover, Kenya has recently undergone a succession of droughts which have intensified these problems to something approaching catastrophes, where in other territories they only remain as clouds gathering on the horizon.

A large part of Kenya must be regarded as marginal country, whether for arable or pastoral pursuits. In African terms that practically means country which cannot succeed under a peasant economy in very small units, but which may give a reasonable return under a collective economy, whether that be in the form of government schemes for the Africans or as some modification of the earlier large holding or plantation system. As far as soil erosion is concerned in pastoral districts it is a matter for management and grazing control more than anything else. There is no more striking sight in Kenya than the boundary between the ranch or large holding of a European and a native reserve, where on the one side there is good if sparse pasture, while on the other there is heavy sheet erosion due to over-grazing and lack of management.

General Picture of the Water Resources

That portion of Kenya which lies to the east of the Rift valley, that is to say more than two-thirds of its area, suffers under grave disabilities as to climate, rainfall and topography. Broadly speaking, the only regions in which surplus rainfall occurs are the volcanic districts of the Aberdare Mountains and Mount Kenya itself. Even here the areas of heavy rainfall, providing water which is to reach the three main rivers, the Uaso Nyiro, the Tana and the Athi, sum to under 1,000 square miles. Situated irregularly round these favoured districts there is a belt in which the rainfall is above 20 inches per annum amounting to some 10,000 square miles in area.

Elsewhere in Eastern Kenya, except for small areas such as at Marsabit and the Teita Hills, the rainfall is rarely adequate for the growing of crops until the coastal belt is reached. Subsistence crops are grown in favoured localities, but there is frequent failure and great uncertainty.

To this concentration of surplus rainfall in the Highland regions we have to add the unfortunate fact that many of the rocks of Kenya are porous, most of all those of Mt. Kenya itself, so that much of the surplus rainfall sinks below the lavas as soon as it falls. Such of it as appears again in springs where the lavas meet the older rocks then runs over decomposed layers, losing itself beneath the sands or to the sun's heat. The smaller rivers taper to nothing, while the two major ones, the Athi and the Tana, shrink steadily to a fraction of their upland discharge.

The question therefore arises as to whether these rivers should be used before they disappear into the sands or the air, or whether they should be left to furnish the underground sources which are undoubtedly there, if hard to find.

Nevertheless, as in other arid lands of the earth, there are significant compensations. The flatter lands, even on the older rocks, when visited by their scanty rainfall of six to ten inches, produce a good though thin pasturage. Of this an unduly large fraction is useless to stock, except after rain, for lack of watering points. A natural corollary is that with the increase of population and of stock the land within twenty miles of water has become badly over-grazed and much of it badly eroded.

The debate is not merely between the well watered highland and the dry lowland, but also between the agricultural and the pastoral peoples. None of the rivers, except the Tana, has sufficient discharge to support irrigation on any large scale. On the other hand, any withdrawals of water for small-scale irrigation increase the tapering of the rivers and reduce the supply available for the stock on the lowlands.

In a broad survey of what is to be done with these somewhat slender water resources one is drawn to the conclusion that in the long run it will be necessary to avoid the desperate losses from percolation and evaporation by piping the rivers to provide watering points, and by developing the principle of underground storage in sand rivers. Such measures, amplified by the large programme of boring recommended by Dr. Dixey, may suffice to keep the population and stock in the dry areas at its present level without permanent harm to the land. There can be little hope of accommodating increases of population and stock in these districts unless and until large and well-grassed areas can be freed from tsetse fly.

In recent years there appears to have been a falling off in the annual rainfall in Kenya east of the Rift valley. Lakes which were formerly full have sunk or dried up, rivers have become still more tapered and grasslands have become still more thinly covered. Some of these effects are so striking that people are beginning to talk of progressive dessication and to draw the gloomiest pictures of the future.

Whether this decrease will continue and is indeed part of a secular downward curve must remain at present a matter of opinion, not fully supported by actual figures. My own reason for allying myself with the optimists is that the "dessication" appears to be far too local to be a secular change.

In periods of drought the effects of a decreased rainfall are always more spectacular than the rainfall figures themselves, since the latter are only part of the story. Decreased rainfall means increased evaporation, less vegetation cover and a quicker run-off of rivers. The effects are in fact cumulative, and the arid conditions seem to be more permanent than they really are. Fortunately when rainfall increases again the reviving effects are equally spectacular.

Yet not all of these evidences of dessication can be accounted for by the reduced rainfall, some at least must be laid to the charge of human occupation, man's interference with an equilibrium which was never stable.

There is nothing new in this, and history records similar "dessications" in the past, especially in Mediterranean lands, which have been largely due to such activities of man as destroying forests for fuel, keeping an excessive number of goats and so on.

The removal of cover from the ground, even with the same rainfall, causes a quicker run-off, and earlier drying up of the rivers, removal of surface soil and therefore a fall in fertility. These and other effects produce the illusion of an encroaching desert. Further there is a considerable body of evidence, not wholly conclusive, to prove that the rainfall itself is affected by these surface changes.

It is therefore important to enquire how far man's treatment of the land may be contributory to this cycle of drier seasons, which of his many interferences with nature's distributions may be responsible, and how far they may be remedied.

If any single factor is to be selected as of prior importance it is the rate of run-off of the rainfall. The more quickly the water disappears from the surface of the land, into the sea, into subterranean reservoirs or into the air again, the more dessicated the land will be. This is of course much intensified when the rainfall comes in a definite rainy season. To delay the run-off is to hold the water in the surface soil longer, to render rivers more nearly perennial and to give a longer season of growth to vegetation cover.

Now the rate of the run-off depends on several things which are beyond man's control, such as intensity of rainfall, porosity, evaporation and so on. It also depends on a factor which is partially under control by man, namely vegetation cover, and, by corollary, depth of humic soil.

The most effective cover of all for arresting and delaying run-off is forest, preferably indigenous forest. Its action is of course closely related to its density and especially its undergrowth. We must not be led aside by the argument that the forest itself consumes a great deal of water. So it does, but without the forest that water and much more would quickly run away and be lost.

Continuous grass cover is next in its arresting effect on run-off; the denser the growth the greater its value. It must be noted, however, that a continuous dense grass cover is very difficult to induce in regions of small rainfall, especially when the rain falls over a limited period. In such regions we cannot remove forest and expect a dense mat of grass to take its place; moreover grass is far more easily destroyed by grazing or by fire.

There is another way of looking at the matter which is perhaps more illuminating. Before the white man came to Kenya the country had reached a stage of equilibrium between its rainfall and its vegetation. If we had desired to keep things just as they were in the matter of flow of rivers, volume of lakes, etc., we should have had to leave things alone. That being impossible, the somewhat delicate equilibrium had to be disturbed to benefit man, and it remains to discover how far it has been disturbed and in what directions. I suggest that the keypoint of such enquiry is the change in the rate of run-off.

It is for those who know the country far better than I, or any other temporary visitor, can be expected to know it, to establish which factors are the most important, and valuable contributions have already been made. Nevertheless in conversations and in certain reports on the subject there is often a certain narrowness of view, a piecemeal attack on the problem which is the reverse of useful. For instance there are those who wish to cause the rivers to run farther out into the dry areas, and advise the cutting down of forests to effect this. Others would abandon the dry area and use the water in the uplands, while others again would replace forest with grass for the sake of a larger grazing area.

Experience in other lands suggests that forests are the most important factor in arresting run-off, and I can see no reason why it should be otherwise in Kenya. I would therefore recommend the utmost caution in removing forest cover, and increased vigilance in its protection from fire, particularly on the tops and steep slopes of hills. I believe too that there can be no universal panacea, that each type of country and of rainfall needs its own special treatment. For instance to grass down land may be the best thing in one area yet quite disastrous in another. The diversity of opinions on what should be done is probably due not so much to any unwisdom on the part of the advisers as to their attempt to apply one treatment to all areas.

There is one other matter which calls for comment at at this point, even though it is not wholly concerned with water resources, and that is the method by which the Government effects its resettlement schemes. It seems to be almost too benevolent and is apt to carry out its projects without enlisting a due co-operation from those who will benefit most. A passing visitor must feel considerable diffidence in making such a comment since there may be paramount reasons for the method used.

In opening up fresh country for pastoral settlement it appears to be the practice for the Government to descend upon the area selected, clear it thoroughly, build dwellings and provide water, and then to remove population en bloc to the area. Where urgency is the spur no doubt this method is inevitable, but it is bad for the people and it is very expensive. The only work beyond the capacity of the Africans themselves is that of providing the water supply. Once this is completed, the clearing, the building and even the access might be left to the natives, under guidance, either with or without the spur of rewards, according to circumstances. The progress of resettlement may thereby be rendered much slower, but the psychological value of getting the people to help themselves may well outweigh this disadvantage.

There was considerable difference of opinion on this suggestion when it was put to administrative officers, many of whom, probably the majority, were of the opinion that it was better to provide everything for the new settlement, and move large numbers en bloc, even with a measure of compulsion. Others agreed that if by any means, either a miracle or the work of the Government engineers, a series of really permanent water points were to be established, there would be many pioneers amongst the Africans who would at once move in without persuasion or coercion and commence a new settlement by clearing the land, even in tsetse country.

It is hardly profitable to follow the argument further here, but it may be suggested that consideration be given to allocating rather more funds for the provision of ample water supplies in new areas, the fundamental need, and rather less for clearing and building.

The African is by nature and tradition a ready migrator, and his main spur in the past was an adequate water supply, with secondary ones such as security from raids, better soil and so on. It is therefore just possible that free-will and nothing but a water supply might accomplish more than coercion and a complete lay-out of roads, buildings and cleared land.

There is a minor but far more widespread instance of the same kind in the matter of weeds and low scrub invading pastures. The custom appears to be to leave such invasion until it has assumed dangerous proportions and then to organise an expensive campaign of eradication. As long as this is continued the people will naturally neglect their own duty in the matter, waiting upon Government action. But if the chiefs could be persuaded to take action themselves it would not only achieve the advantage of self-help but it would save great expense. For instance, if a headman could be prevailed upon to ordain that every "toto" in charge of a herd should every day bring in a bush or weed for every beast he looks after, solemnly counted before his seniors and added to the kindling pile, the menace of weeds would soon be removed and the pastures improved.

Isolated instances of too much Government help can never prove a case, and it would be dangerous to be dogmatic over what may merely be occasional or justified by expediency. It is a tendency which is almost inevitable when a territory advances beyond the stage when the District Commissioner has to carry out the improvements himself. A large technical staff cannot see the matter in the same light as the administrator nor be in close touch with the people concerned. The same applies to water development work; the technical staff driven by urgency, will usually prefer to do the work with their own staff and skilled methods rather than delay it by teaching the local people how and why the work is done.

For these reasons there is much to be said for a scheme of training classes in water conservation to which each district would send selected candidates for a few months' training in the elements of well-sinking and lining, surface dams, pumping or water-drawing appliances and so on, the majority of the trainees to return to their own district and not be allowed to join a general headquarters unit.

The Machakos and Kitui Districts

In a rapid traverse of both these districts I was able to see the results of the overstocking which have been the subject of many reports to Government. There is no need to describe in detail the state of much of the land of which a sorry picture was drawn as long ago as 1929 by the Hall Commission. The recommendations as to remedial measures put forward by this and later Commissions may have been sound but few of them seem to have been fully practicable. It has, I gather, been impossible to reduce the number of stock drastically, move large sections of the Wakamba, or to clear large areas of tsetse fly. Meanwhile the erosion seems to be spreading to an alarming degree, calling for still bolder measures.

This does not seem to be a water problem, the rainfall being fairly reasonable, but mainly an overstocking problem. In the brief enquiries I was able to make I was given to understand that a great part of the cattle population is not a vital food source, but is mainly a currency for the bride price system.

If this be so, then it would seem to be necessary to try to convert the people from a system so obstructive to their real welfare. A brief visitor cannot assess the difficulty or even the danger of such a fundamental change in their customs, but in discussions with various administrative officers, especially Mr. Thorp, the possibility of a change appeared to be very unlikely. Nevertheless, since desperate cases require desperate measures, one of the latter may at least be mentioned here. It would require the whole-time services of a senior officer well known to, and trusted by, the tribe.

It would be unprofitable to go into detail on the scheme by which this might be achieved, but the broad outlines would be to persuade the people to exchange their cattle currency, by sales, for a currency of bonds. Such bonds would have to bear interest equivalent to that of the natural increase of cattle, would have to be the treasured possessions of the sellers of cattle, and the "bride-bank" would have to be administered by the District Commissioner with some representative chiefs.

However fanciful and perhaps impossible such a scheme may be, the fact remains that the land cannot be saved without a tremendous reduction of the cattle of which a proportion merely represents currency for brides.

The Machakos district is now in the last stages of soil erosion in many places, with bare rock showing. Yet the powers of restoration of a hot climate together with a reasonable rainfall are such that it only needs a few years rest to recover a great part of its former fertility.

The run-off in the streams during the rainy season is naturally high, and it is recommended that some of this should be checked by the simplest and cheapest means available, by the villagers themselves if possible. Every small stream which floods should have a series of boulder weirs thrown across it, backed in the first place by some brushwood and earth on the upstream side to induce silting. The sand reservoirs thus formed would raise the water table and prolong the flow of the stream into the dry season.

Some of the sand rivers might be dealt with as recommended in an appendix to this report, the Thwaki River for instance would appear to be well suited for this treatment. There are also some narrow gorges providing suitable sites for dams from which piping could lead to watering points some distance from the river bed. These sites might repay further investigation since, though expensive in the first place, they would relieve the pastures near the river beds and would permit a degree of grazing control which is at present impossible. One likely site is at the back of the Kilimakimwe Hill, a few miles outside Machakos.

It is perhaps worth recording here that for slopes of 1 in 20 (easily obtained in the Machakos) a 1-inch pipe would water over 1,000 head of cattle, while a 2-inch pipe would water over 6,000 head.

Such supplies for a period of 100 days of dry season would require a storage of one million and six million gallons respectively. Given reasonable sites, dams to hold such volumes, allowing for seepage and evaporation, should not cost more than £1,000 to £3,000 even if built with masonry cores, and the piping costs should be not more than £300 and £600 per mile respectively. For a 10 mile run of 2-inch piping the total cost of installation should therefore not exceed £10,000.

It is true that such a sum would suffice for 20 or more bores, but their maintenance and pumping costs, as well as the uncertainty of striking water, must be reckoned to their disadvantage.

Whilst on the subject of water points provided by Government, it is recommended, for psychological reasons, that a close enquiry should be made into the possibility of payment, even on token terms, for the water. Nothing is so likely to induce care of the water equipment, taps, etc., and avoidance of waste as the realisation by the people that they are paying for it.

For the purpose of illustration we may take the above mentioned scheme of a dam and 2-inch supply line to serve up to 6,000 head of cattle.

A beast will drink from 2,000 to 3,000 gallons per year, or say 1,000 gallons of piped water in the dry season. If the value of the water were assessed at say 50*c*. per thousand gallons it would be appropriate to charge 50*c*. per beast per year to the owners, a very reasonable charge since goats and sheep would benefit without cost, and it is really a token payment.

Such a water rate would produce upwards of £1,000 p.a., possibly not more than the cost of collection, but the principle of participation would be established. A higher rate would account for the cost of maintenance and even a sinking fund for renewals.

It is not claimed, however, that a water rate would ever pay for capital expenditure, which remains a gift from the Government. It is the high psychological value of such a system which is recommended for consideration. It is therefore applicable in principle to all areas where Government expends money on facilities, whether to Europeans, Indians or Africans.

The Kitui district, on the other side of the Athi River, is less hard hit than Machakos, but appears to be heading in the same direction. Though it is lower in general altitude, its rainfall is fair, since it receives the first precipitations from air coming from the Indian Ocean as it is forced over the 3,000 foot contour. Such a situation calls for small weirs and headwater checks to floods, such as are described elsewhere in the report.

The Areas of Surplus Rainfall

These are situated mainly round the Aberdares and Mt. Kenya. I visited only the parts adjacent to Embu, Nyeri, Nanyuki and Thomson's Falls, but the undermentioned considerations probably apply to other centres as well.

The land is here under occupation by both Europeans and Africans, and the surplus water is used to some extent for irrigation. The method of using it is in many cases somewhat wasteful.

The arguments of these upland users of the water is no doubt that if it is allowed to run to the lowlands it will only be lost by evaporation and sinkage into the ground, and it must be admitted that at present such people have a strong case to that effect. This will not always be so, however, and as conservation schemes and piping are provided for the lowland users a due proportion of upland water will be needed and used.

It is notoriously difficult to control the use of water by ordinance, whether this works by penalty or not. Probably the only way to ensure the reasonable use of water is by the institution of some form of water rate. Such a system I believe is almost unknown in Kenya, but it is common usage in more settled countries and is by no means a new principle. At all events it merits consideration, and I suggest the following line of argument as the basis for such consideration.

The fundamental principle is that all water is the property of the Crown, and it is only rights of use which are granted to the people, such rights being divided into those which are indefeasible and those which are granted under application and, where necessary, for payment.

Thus the rights of use for domestic purposes, both human and animal, must be indefeasible, subject to no payment or restriction. This may be called the "primary" use of water, or, if preferred, the "subsistence" use.

The "secondary" or "profitable" use of water might include irrigation for cash crops and the watering of stock other than house stock, that is to say saleable stock. Such use may be the subject of application and, in certain circumstances, such as where it has entailed expense by the Crown, or where it affects supplies further down the stream, may be subject to payment.

What is sometimes called the "tertiary" use, that is for power, comes under a different category since the water is not expended. Nevertheless, since it involves making a profit out of the property of the Crown, namely the water itself together with the topography, it should again be subject to application and, where necessary, payment.

If these general principles are considered valid and just in Kenya, as they are in many other countries, then their application may be considered in outline.

The difficulty in instituting a water rate for secondary use is administrative rather than judicial, especially as the Government must hesitate before either adding to the responsibilities of District Commissioners or creating a large staff of water bailiffs.

This difficulty can be modified to some extent by undertaking, what should be done in any case, the measurement of all water used in furrows. This means the installation of meters, preferably automatic, at all main diversion points, the cost of which must be met by the users concerned together with the cost of the staff concerned in their observation and maintenance. A comparatively small water rate would pay for these measurements, without which no water authority can presume to allot water for secondary use. Moreover it is an entirely just charge to make, and one to which no fair-minded community can take exception. As one experienced District Commissioner said, "The farmers will always pay for a square deal".

The question of further increasing the water rate as payment for Crown property used is a separate matter and depends on considerations of a different type, including those of expediency and compensation for capital outlay by owners.

Provided that the water rate is related in some way to the amount of water used and not merely to the cost of the meter for the individual furrow, the need for the controlled usage of water will be largely met.

In any case I regard the installation of meters as essential, since no authority can go on allotting a limited supply of water without knowing the actual consumption per user. In the case of European users the method of installation is comparatively simple, each main furrow having a meter. For the native reserves the matter is more complex, but perhaps some communal meter and communal charge could be devised.

The respective volumes of surplus water to be allotted to upland and lowland owners must be a matter for discussion in each individual watershed. The present somewhat wasteful methods of use in the uplands, either by careless furrows or by irrigating crops which could be grown elsewhere under seasonal rain, will automatically be corrected when a water rate is charged, even when it merely meets the cost of measurement and administration.

The Uaso Nyiro Watershed

The comprehensive report by Dr. Dixey on the Hydrology of the Uaso Nyiro, submitted in 1944, makes it unnecessary to give a detailed description of this interesting river or to make more than passing reference to what has become known as the Uaso Nyiro controversy.

The recommendations of that report include an impressive programme of bore drilling and tank excavation to be carried out over a period of six years, which would meet most of the needs of the areas concerned. Unfortunately the cost is high in relation to the production of those areas at present and there is also an element of uncertainty as to the yield of the bores.

There may therefore be room for certain suggestions, to be considered as supplementary rather than alternative, relating to those sections of the watershed visited by me, which might receive attention and deserve some further reconnaissance surveys by the hydraulic engineers. They fall under three headings, namely,

(i) The provision of headwater checks.
(ii) The treatment of sand rivers.
(iii) The use of piped water supplies for stock areas.

The general regime of the river and its tributaries is now fairly well known, but there are certain tracts which are very inaccessible, and there is a great lack of figures for the discharge at various critical points. It is a typical "tapering" river, since its sources are in the regions of surplus rainfall of Mt. Kenya and the Aberdares, and it flows towards areas of deficient rainfall of under ten inches average and great variability from year to year. It is not surprising, therefore, that it rarely reaches the sea.

Further, while its sources are in the highlands which are capable of some further extensions in agriculture, it runs towards the purely pastoral districts of the lowlands which are marginal even for stock and are suffering severely from the evils of local over-grazing due to the bad distribution of water points.

There are, in fact, all the elements for sharp differences of opinion on the best or most just uses of the river water as between highland and lowland.

The flow in the rainy season usually, but not invariably, reaches the Lorian Swamps, providing "water meadow" pasturage for a large number of stock. Any large-scale interception of the flood flow would therefore prejudice the interests of the nomadic people who depend on this pasturage. This is a sort of natural irrigation, and in its present somewhat haphazard working is probably more wasteful than need be.

For other parts of the lower Uaso basin the pasturage depends on the seasonal rainfall, not on the river water. In the immediate vicinity (say a 15 or 20 miles distance) of the river there is no need for water points for cattle, and, as Dr. Dixey points out, the poor state of the pastures is due to over-grazing and increase of stock, so that a greater dispersal of stock is what is required. Dr. Dixey recommends measures for this dispersal which consist mainly of bores and tanks sited so as to give access to areas where there is reasonable pasturage, as yet but little used for lack of water points.

The Highlands

Something like 5,000 square miles of the upper basin of the Uaso Nyiro is above the 4,000-feet contour. In this section, in spite of the existence of many porous lavas there is some natural conservation in the form of marshes, particularly on the Uaso Narok, the best examples being near Thomson's Falls and Rumuruti. These have the effect of steadying the flow of the main river and extending the period of run-off of the rainy season. A considerable number of areas of " black cotton soil " on the Laikipia plateau would seem to indicate that these marshy areas were more widespread in the recent past than they are now. It is clear that a marsh of comparatively shallow water is a check to rapid run-off, but it is a somewhat wasteful one, both because it occupies land which might be producing crops and because it exposes an excessive surface to evaporation as compared with the volume of water so checked.

What is required, therefore, is to free some of the swamp land for use and at the same time to check flood water without undue loss by evaporation. On a small scale this is not difficult to do, as is described in an appendix on the treatment of damboes in Central Africa. But on an extensive plateau and with a very small resident population, as on much of the Laikipia, this treatment is not truly applicable.

Schemes of conservation and of drainage are already in operation or construction on the Uaso Narok, and provided they are properly balanced they must effect a general improvement in the regime of the whole river. Probably the ideal system would be to have a barrage above each swamp, which when drained for agricultural use would pass on the water, formerly left to evaporate, to a lower barrage. This has at least the merit of giving some immediate return for the cost of the barrages from the production on the drained swampland. The road to Maralal from Rumuruti passes several possible sites for such alternate damming and draining schemes, but they are in country which may at present be too sparsely settled for immediate development.

The geology of the Laikipia plateau seems to govern the distribution of surface water very closely. The lavas to the west and south are usually porous, while in the centre and north the older rocks of the " basement complex ", though decomposed to a considerable depth, are much more impervious. Consequently any large scale conservation schemes should be placed on the older rocks rather than the lavas unless there are local beds of clay which will seal the reservoir from leakage. The occurrence of many springs not far from the boundary of the lavas is merely another piece of evidence for the relative porosity of the lavas as compared with the underlying rocks. These springs would repay expert examination with a view to improvement, and the same remark applies to those much farther down the river beyond Archer's Post.

It is obvious that the porous lavas, while they are disappointing in themselves for lack of surface-held water, are fulfilling a useful function in conserving water underground and letting it out over the harder rocks slowly. It will be an early duty of the hydraulic engineers to measure the discharge of the major springs on the plateau, such as the Suguta Mugie and the Suguta Marmar.

It will be remembered that some of the most valuable irrigation schemes in California, such as the citrus plantations of the San Bernadino mountains, have their origin in just such underground water, in that case trapped and conserved in ancient scree talus from the mountain sides.

The old rocks are in general much fissured and therefore furnish excellent bore-water when the site happens to be a lucky one. Nevertheless they are costly to drill when the overall expenses, including those of the barren holes, are taken into account. Where there are neighbouring high mountains the prospects of dams might receive closer attention. The Maralal administrative station is in just such a situation with the Karissia Hills nearby rising to 8,000 feet. There should be suitable sites for reservoirs above Maralal which would not exceed the cost of two or three boreholes to build.

One would imagine too that in these hills the provision of headwater check weirs made chiefly of boulders would do much towards making the streams less intermittent or even permanent for some distance, not because they hold much water in themselves but because they raise the water table in the surrounding ground and the supply therefore escapes slowly by seepage instead of by rapid and destructive run-off. The Uaraguess and Matthews Ranges further east, rising to similar heights, are also likely situations for such schemes.

It is far too much to expect that the tribesmen of these areas would appreciate such an indirect method of improving water supplies. It will therefore be necessary for Government authority to provide demonstration schemes in such districts as that of Maralal, Kitui or Machakos before any persuasion of the native population can be expected.

The general principle of headwater checks has been explained in the General Section of this report. It may be repeated here that a small valley is selected which has an intermittent stream, its intermittent character being due more to rapid run-off than to a porous bed. The boulder weirs are sited towards the headwaters of the small tributaries in places where the gradient is less steep, the object being to raise the water table over as large an area as possible. The construction aims at producing what might be called a small swamp, not a watertight reservoir. It consists therefore of the largest boulders available backed by smaller boulders and then by soil and brushwood, and must not be so high as to invite destruction by floods which must run over it and leak through it. It is obvious that such a scheme must be accompanied by the preservation of the natural vegetation from fire or cutting, the function of both weir and vegetation being the same, that of holding the water temporarily in the soil.

The method is in fact a reversal of a process only too familiar in countries of low and seasonal rainfall, where streams which were once perennial have been made intermittent by the destruction of headwater vegetation and the draining of natural swamps.

As the Uaso Nyiro and its tributaries descend from the plateau, round about the 5,000 foot contour, they enter gorges in the old rocks which are pre-volcanic in age and most impressive in size. On the route followed from Maralal to Wamba there were only occasional glimpses of these mighty gorges and hardly any of the river itself. Nevertheless it is obvious that if ever a major scheme of conservation is to be undertaken these gorges will furnish sites similar in general character to those of the dryer Western States of America.

The Sand Rivers

In the rainy season most of the major water courses, lakes and longitudinal valleys collect water which in local storms even runs on the surface for a few hours. Much of this water is lost either by evaporation from shallow pools or by steady seepage down the sandy beds. Some of the latter is recovered for use by wells dug in the sand by the nomads and there seems every prospect of increasing both their number and their yield by constructing sub-sand barriers as outlined in the appendix to this report. The inherent advantages of such sub-surface reservoirs are of course that they can be ' stepped ' down a long valley, and that they protect the water from evaporation and pollution. If they can but be constructed cheaply they should be a valuable adjunct to Dr. Dixey's programme of bores and a useful step in prolonging the season for grazing in their vicinity.

The success of such sub-surface reservoirs depends on the nature of the rock or alluvium at the bottom of the sand. If it is porous itself the water will soak away under the artificial blockage. On the other hand the localities where the bedrock is impervious or comparatively so are well known to the inhabitants, both human and animal, who have dug water holes in the sand bed every season for centuries in such places, catching some of the seepage water as it passes down the bed. Their knowledge as to the depth of the water table in a sandy wadi or lake at any time is limited only by the fact that they could not dig holes in soft sand beyond a certain depth and so missed the lower levels of water in a deep sand river.

The modern methods of jet drilling through sand are particularly applicable to a deep sand river. Since such drills can be sunk at rates of up to one foot per minute, a jet-drilling outfit can be used quite cheaply for exploratory purposes, withdrawing the casing if useful supplies are not found and leaving it in place if they are.

It is just possible that before this report is in print some trials of this mode of treatment of sand rivers will have been made in Bechuanaland Protectorate, Uganda or Kenya, the results of which will be of the greatest importance.

The Case for Piping Water Supplies

Probably the only source of water in the watershed which can be considered for piping is the Uaso Nyiro itself, and the only areas which such piping could serve would be those to the north and south of that river below Chandler's Falls.

Possibly such a method of providing water points has already been investigated and discarded, though I can find no report on the matter. Nevertheless I consider that a special enquiry and reconnaissance survey would be well worth the expense since it offers three very valuable advantages. These are:

1. the most economic use of the slender dry season discharge of the river,
2. the optimum distribution of water points,
3. the small maintenance costs.

Against this is the somewhat formidable initial cost.

With so inadequate an inspection of the areas concerned I cannot do more than outline the nature of the scheme, leaving details of the reconnaissance and costings to the officers of the Water Development Department.

The Merti Plateau is a small area of high ground on the north side of the Uaso Nyiro about 25 miles below Chandler's Falls. Given a reservoir on its western side, piping could be laid to watering points situated on the rich grazing area in the direction of Arba Jahan which has so often been referred to.

According to the 'command' given by this reservoir, the area which could be supplied would range from half a million to one million acres. Allowing 30 acres to a beast, this would provide pasture for from 15,000 to 30,000 head of stock. Sufficient water for such numbers, with the fall available, could be provided by 5-inch piping, suitably decreased in diameter towards the fringe of the areas served. Moreover the take-off from the main river for the purpose would only be between one and three cubic feet per second.

To serve the Merti reservoir a main pipe would have to be laid from some point at or below Chandler's Falls according to the fall required. With a fairly low gradient this pipe would probably have to be of six inch diameter. For costing purposes we will put the length of this pipe at the outside figure of 30 miles. The length of the distributing pipes, from four inches in diameter down to one inch, would depend on the extent of country under command, but we may put it generously at 70 miles. It is difficult to arrive at the cost of purchasing and laying such lengths of piping, but a fair figure seems to range from £400 per mile for 1-inch pipe up to £2,000 per mile for 6-inch. The diversion works at the river would be comparatively cheap, and the reservoir at Merti need only hold about 300,000 gallons.

A rough estimate of the total cost of such a scheme is therefore

30 miles 6-inch pipe laid	£60,000
70 miles smaller piping at £1,000 mile	£70,000
Diversion works and Merti reservoir	£10,000
	£140,000

This is an outside estimate, and I would expect an engineers' survey to reduce it to the neighbourhood of £100,000 by various means, such as reducing the length of main pipe by pumping from a point nearer Merti, or by the use of hydraulic ram pumps. A figure of £3 to £5 per head of cattle for providing water during the life of the piping, say 20 years, is formidable but not excessive.

It is not easy to say what proportion of Dr. Dixey's programme of bores and tanks would be replaced over the area served, but it would probably be not more than £30,000. On the other hand the maintenance costs for pumping would be far greater were the same supply to be provided by spaced bores.

With such figures as a basis I submit that a reconnaissance survey by an engineer would be well worth while.

Should some such scheme be established it could not use more than two or three cusecs of the dry season flow of the Uaso, out of the 42½ cusecs which is supposed to be allowed to pass Archer's Post. Ultimately I should expect some of this balance to be used for small irrigations on rich lava soils above the south bank of the river. My acquaintance with the area does not justify outlining a scheme beyond saying that I noticed some very promising chocolate soils on the road from Isiolo to Garba Tula which would be under command of a take-off between Archer's Post and Chandler's Falls, or of some of the springs issuing above the river on the south side.

In Dr. Dixey's report there is a section on the "Uaso Nyiro Controversy" which seems to centre in the allotment, announced in 1941, of half the supposed low-water discharge at Archer's Post for the benefit of the lower river. It seems clear that the supposed low-water discharge of 85 cusecs at Archer's Post is not often attained, and Dr. Dixey and others have given reasons for this shortage.

In so far as this may be due to excessive use of the water on the higher plateaux this cause will tend to disappear if, as recommended above, meters are put in and a small water rate instituted.

Dr. Dixey has pointed out in his report that a good flood water discharge is required down the Uaso Nyiro in order to fill the Lorian Swamp for the benefit of the pastoralists there who use it as described above. He also gives evidence to show that of recent years the river has not run, above ground, as far as it used to do, but that this has nothing to do with the increased use of the water on the uplands. It seems clear that the variations in the distance downstream from Archer's Post at which permanent running water ceases are due to natural and not artificial causes. Speaking generally one may accept the fact that the river rarely runs, in the dry season, beyond the point where it leaves the old rocks and reaches the friable sediments known as the Merti Beds. This point is about 15 miles above Merti and therefore about 60 miles below Archer's Post.

From about the same point, namely the junction of the old rocks and the newer sediments, there is a marked increase in the density of trees along the river bed, showing that there is a sufficiency of underground water for their growth even during the dry season, and that this has been the case for a very long time.

It seems therefore that any endeavours to let more water pass Archer's Post in the dry season than at present would be wasted, and that the regulation which rules that nothing less than 42½ cusecs should pass that point is not only rather a dead letter in the present run of droughts but does not serve any markedly useful purpose.

The fact of the matter is that there are far too few data about the discharge either of the main river or of the springs nearby to make any hard and fast allotments of this type of much value beyond indicating an intention that down-river people should not be deprived of water. Moreover it is probable that the river receives considerable accessions from springs and seepage between Archer's Post and Chandler's Fall. There are no measurements of these accessions yet they must be important since the rainfall of the area between the river and the high Nyambeni Range is far from low. At Isiolo it is just over 20 inches, yearly average; on the river itself it appears to be of the order of 10 inches, while on the the Nyambeni hills it is likely to be 30 inches or more.

To obtain a rough idea of the water which has to be accounted for we may assume a mean of 20 inches for the area of drainage from these hills down to the Uaso Nyiro, which is about 1,000 square miles. The proportion of this rainfall which sinks into the porous lavas and escapes underground is quite unknown, but it may well be as much as 30 per cent. For the calculation however let us assume it is only 10 per cent. That would mean a quantity of 100,000 acre feet of water reaching the river by underground routes annually or about 4,000 million cubic feet. If that were spread evenly over the year, which of course is not the case, it would be equivalent to a rate of flow of 100 cusecs.

There is no way of assessing the dry season flow underground which is not frankly guesswork, yet since the rate of escape must be very much less than that of surface run-off, there is justification for thinking that this more or less invisible accession can rarely be less than 10 cusecs. The only significance which can be attached to this figure, or any other arrived at on such broad assumptions, is that the Uaso Nyiro below Archer's Post is not entirely dependent on the rainfall on and above the Laikipia plateau for its flow.

The question naturally arises as to whether there is any means of tapping this underground water, or of conserving some of the rainy season surface flow. The prospects are not hopeful, yet there are a few marshy areas some ten or fifteen miles from the main river where the lavas must be less porous than elsewhere, and it is just possible that in some of the water courses there are sites for dams or tanks on a small scale.

The country traversed on the road from Isiolo to Garba Tula is, in August, to all appearances rather hopeless, yet as we have seen, there is an ample supply of water underneath it, and that water if tapped has command.

It would be idle to suggest a careful investigation of the area at present, yet one cannot resist the conclusion that in the distant future means will be found for using this water, and that over small areas the rich chocolate lava soils may be made productive. What should be done when time and funds permit is a survey of the springs at the edge of the lava flows just south of the river itself. Some of these have command of the much drier country to the east and could be a source of a piped supply to areas where the grazing could be used if there were water points.

The Taveta Area

The main massif of Mount Kilimanjaro is in Tanganyika Territory, but some of the surplus rainfall of the mountain passes through what might be called the Tsavo-Taveta region of Kenya. This region therefore offers some possibilities for the resettlement of Africans from the overcrowded areas of the Kenya Highlands and is under investigation from that point of view.

The district was visited in the company of Colonel Brooke-Anderson, Chairman of the African Settlement Board, and the late Major Hughes. The latter knew the district well and was responsible for much of the survey work for irrigation schemes there. The route followed by car from Machakos down to Voi and thence to Taveta passes through wide areas of marginal pastoral country, mainly unoccupied because of tsetse fly. The rainfall is low, but with the help of bores, sub-sand reservoirs and some surface conservation it is probable that a sufficient number of water points could be found if the area, or parts of it, could be cleared of fly. Even then it could not accommodate more than a small proportion of the population which now requires resettlement.

The Tsavo River, crossed a few miles above its junction with the Athi River, and discharging in late August about 100 cusecs, was impressive in contrast with the country it passes through.

A detour was made into the Teita Hills, whose high local rainfall and verdure were in still further contrast to the fly-infested thorn-bush country which surrounds it. It seemed obvious that if the stream at Voi is to be improved as to average discharge it could be achieved at moderate cost by building a weir in the Bura Hills where there are many suitable sites.

The Teita Hills massif separates the run-off water coming from the eastern flank of Kilimanjaro into a proportion which runs north to join the Tsavo and another which runs south into Lake Jipe and thence to the Pangani River of Tanganyika Territory. It was this broad col or saddle between Kilimanjaro and the Teita Hills which was the area of our investigation, and it has some very interesting features from the point of view of water resources. Its average rainfall is round about 20 inches per year, but its real source of water is from the slopes of Kilimanjaro where the rainfall increases rapidly with altitude. It is not surprising therefore that from the beginning of white settlement in the district the idea of irrigation has been constantly in mind, and the sites of schemes, both existing and projected, were visited.

These schemes are very promising from the point of view of food production. It would, however, appear that for a district of such reasonable rainfall (18 to 20 inches) the water duty has been set too low. At present it appears to be reckoned on a basis of 70 or 80 acres per cubic foot per second, whereas except for rice it should be 100 or 120 acres, even for sugar cane which appears to grow very well there.

There are three local problems concerning water development which seem to deserve attention.

The encroachment of swampland at the Lumi delta

The Lumi River has its source on the foothills of Kilimanjaro but has a very small discharge until it receives the water of a group of springs near Taveta. Thence it runs into the large shallow Lake Jipe and out again by a channel, within a short distance of its present entry, as the Ruvu, which river here forms the territorial boundary.

The land of the Lumi delta is valuable either for irrigation or for seasonal crops, but it has recently been seriously encroached upon by the swamp growth to an extent of some thousands of acres, as shown by Major Hughes' surveys. The extent of 'brak' land has also probably increased though that cannot be proved by measurement. The cause of this encroachment is either some excessive flooding by the Lumi or undue growth of papyrus in the Ruvu, or a combination of the two. Such a decrease in the area of cultivable lands is especially serious where there are good prospects of establishing extensive cultivation and moving population from congested districts to take advantage of it.

In my opinion, and I believe Major Hughes agreed, the root cause is the choking of the Ruvu by papyrus growth. I would in fact be prepared to find that Lake Jipe itself owes its origin to blockage by vegetation. If that be the case the reduction of the swamp land would be easily and cheaply effected by drainage channels being cut, preferably in Tanganyika Territory, where the papyrus ends at the bridge near the Tanga Road. At this point effective control could also be best established.

That some such drainage should be done is obvious in order to reclaim such land as was quite recently available for cultivation. The question then arises as to whether a still further degree of draining would not be to the mutual advantage of both territories. At present Lake Jipe provides an uncontrolled reservoir for the steady discharge of the Ruvu and thence the Pangani. It is very shallow but it has an area of 16 square miles, with a volume of about 3,000 million cubic feet or 20,000 million gallons of water. If this could be controlled by comparatively cheap works at the Tanga Road bridge, it would simplify considerably the embarrassment of the Tanganyika Government over the power contract on the Pangani. Such drainage and control could on the other hand be arranged to release the recently swamped land and, by arrangement with Tanganyika, to reclaim further land by lowering Lake Jipe by a foot or two.

I would therefore strongly recommend that a survey be undertaken to establish these possibilities. Its object in the first place would be to ascertain that there is sufficient gradient between Lake Jipe and the point of control to ensure the drainage and, secondly, to find the area to be gained for cultivation by lowering the level of Lake Jipe. These primary facts could be obtained by a comparatively short-period survey instituted by the Kenya Government, but naturally the co-operation of the Tanganyika Government would be sought at an early date.

A great deal depends on the difference of level of the surface of Lake Jipe and that of the river at the Tanga bridge. If this difference is too slight to provide a strong current when the control gates were opened, the maintenance of the artificial channel through the papyrus might well be prohibitive in cost. Any control of the level of Lake Jipe would permit schemes of reclamation by embankment which under present conditions would be foolhardy.

The Crater Lake of Chala

This almost unique physiographic feature is situated about eight miles from Taveta at a height above sea level of about 3,000 feet. The lake lies in a crater or cauldron which it fills to within about 200 feet of the lowest part of the rim. It is perfectly fresh and its level changes very little, the changes ranging only over a few feet, as can be seen by water marks in the sheer sides of the basin. A gauge is now installed and this will measure exactly the range of level. It has been sounded by Mr. Scott, of the Water Development Dept., and has been shown to be more or less flat bottomed with a mean depth of about 250 feet. Its volume therefore is not far short of 15,000 million cubic feet.

The only explanation of its volume and constancy of level is that it represents the water table in the vicinity, exposed by the crater as a sort of giant inspection pit and varying only with the small changes in the flow of the Kilimanjaro springs which produce the water table.

Its value lies in the fact that it is perched well above the lower Lumi valley and commands some 40,000 acres of land of which nearly half is irrigable. More detailed levels may well show that it also commands part of the Tsavo valley. There is therefore a possibility of a major scheme of irrigation and water power here which most decidedly merits further investigation.

Such investigation must establish

(*a*) That the lake is indeed an exposure of the water table, or at least a natural reservoir fed by steady springs.

(*b*) How much water could be withdrawn without seriously affecting the level, or the springs already used near Taveta.

(*c*) The best means of withdrawal.

The trouble seems to be that investigation by borings to settle some of these questions might well be disastrous by establishing a leak or in some way affecting the present underground feed system. We must therefore first see how far the arguments of physical geography can meet these queries.

(*a*) There seems no reason whatever to doubt that the level is so constant that it reflects only the water table or at least the changes in volume of the springs feeding the lake. Moreover there is a series of springs issuing some eight miles to the north at a slightly higher level which are feeders of the Lumi, Njoro and Siante rivers.

It is therefore only natural to suppose that the crater of Mt. Chala has intercepted similar springs which accumulate in the lake to such a height as is in equilibrium with the seepage or flow out of it. That there is such a flow is proved by the freshness of the water.

Since no other explanation will fit the facts it may be accepted that Lake Chala is a perched reservoir with replenishment and outflow.

(*b*) The question as to how much water can be withdrawn without seriously affecting the level is obviously of prime importance, yet it is not easy to see how this can be ascertained without possible mischief being done to the system of feed and flow. Boring at the base or even into the side of the mountain might easily disturb those strata which are retaining the water and do serious damage to what is possibly a quite delicate balance between supply and outflow.

Large scale pumping over the rim of the crater to find the difference of level produced by withdrawal is clearly much too expensive a test. One is forced therefore to consider whether the final means of withdrawal may not itself be made the test. We may therefore pass to:

(*c*) The best means of drawing off the water for use.

The crater sides consist of what appear to be layers of lava and layers of ash, more or less consolidated, which in a general way lie along the inclination of the outer slopes. It is possibly through one or more of these layers that the overflow occurs and they are best left alone.

The most suitable way of tapping the supply would therefore seem to be to drive a tunnel from inside the crater beginning say 5 or 10 feet above the level of the lake in a sloping direction and with its exit below the lake level. The water would then be drawn off by syphons through the tunnel. The shortest distance for such a tunnel is at the north-east corner of the lake where, I am told, it would be only 1,000 feet in length.

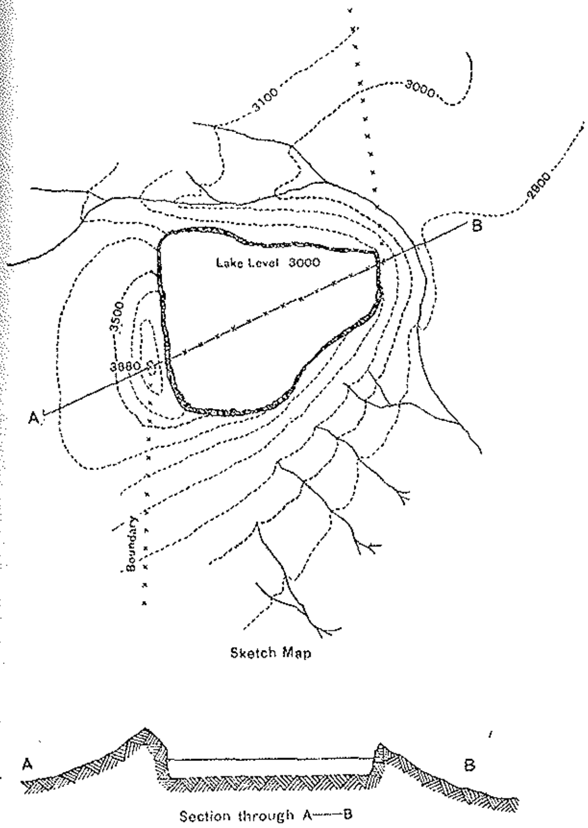
The excavation for a suitable tunnel, say 9 square feet in cross section, would amount to under 350 cubic yards, and even if the rock were to prove difficult it could hardly cost much more than £3 per cubic yard or £1,000.

The spoil on the crater side would be used to build a small platform (the sides are very steep) at the edge of the lake where the small syphoning pump or other necessary gear would be placed.

The test would then be made by erecting a centrifugal pump on this platform and pumping water into the sloping tunnel while at the same time recording the rate of lowering the lake level. A pump of about 12 horse power with a 10-inch discharge pipe would empty at the rate of about 10 cusecs, which would be a very fair test, since pumping continually for a fortnight at that rate should lower the level by 1½ inches if there were no replenishment.

I should not expect the lowering to be appreciable, since ordinary evaporation must account for several cusecs, and there appears to be no significant lowering during the dry season. In other words, I do not think the pumping test really vital, but should be inclined to proceed to the final piping for the syphonage.

With the available fall it would probably need a 36-inch pipe to deliver 100 cusecs, or careful lining of the tunnel might suffice. The cost of piping might be as much as £3,000, the cost of concrete lining considerably less. Once the syphon was working the actual safe quantity to extract would soon be known, and the syphon worked for the appropriate fraction of each 24 hours.



CHALA CRATER LAKE, KENYA

I have sketched this form of scheme, not because it is the best, since engineers will no doubt improve upon it, but to show that the all-in cost of tapping this supply is comparatively insignificant, probably under £10,000, without the distributing canals. Even with heavy canal costs this represents an exceedingly low capital cost per acre.

It is as well to point out that a proportion of the water could be used for hydro-electric power and still be available for irrigation at the lower levels. It there were a market for it, as much as 2,000 kilowats could be produced with the fall available, assuming that 50 cusecs could be used for it.

I feel that enough has been said on the prospects of using Lake Chala to justify a close examination by qualified engineers. Since the inter-territorial boundary crosses the lake there will have to be consultation with Tanganyika Territory, though none of the water could be used for irrigation on their side of the boundary. There is, indeed, a good deal to be said for a suggestion, which I believe is already in writing, for exchanging the Kenya half of Lake Jipe for the Tanganyika half of Lake Chala, since Jipe is of little or no value to Kenya and Chala of little or no value to Tanganyika.

A diversion of the flood waters of the Lumi River

The suggestion has been made by the late Major Hughes that the flood waters of the Lumi River, which in the past have done considerable damage, might be easily diverted into the watershed of the Tsavo River. He was good enough to show me the site for this diversion, where the Lumi and the Njoro approach to within 200 feet of each other.

To effect the diversion all that would be required is the cutting of a channel of that length, through alluvium with boulders distributed in it, and the placing of a plain boulder weir across the Lumi which would pass all the normal flow but deflect most of the flood flow into the Njoro. The cost of such diversion works, using bulldozers, would probably be under £2,000. Whether it is worth spending such a sum to reduce flood damage is a matter for discussion, but when water conservation on a large scale in the Tsavo valley is contemplated this flood water would be a valuable accession to that watershed.

That there are likely sites for a large-scale reservoir is obvious from the map, especially at a point about eight miles west of Tsavo Station. Here the Tsavo River has a steady discharge of about 100 cusecs and a flood discharge of up to 2,000 cusecs. As I have never viewed the site nor the land which would be served by such a reservoir, I can make no further comment. It would, however, appear to be one of the few places in Kenya where an irrigation project on a reasonable scale can be contemplated, especially as it is adjacent to road and rail communications.

One gained the impression on this brief visit that much more attention might be paid to the Taveta area, both as a food producing centre and as a settlement region for surplus population. The present small irrigation schemes have pointed the way for further development, which, while it can never be on a grand scale, might do much to alleviate Kenya's problems of food production and congested areas. It will call for a bold policy and considerable capital, but these are required in any case for any form of relief.

6. UGANDA

IN A VISIT of little more than one week it was impossible to obtain more than a general impression of the water resources of the Protectorate. On the other hand, since I had conversations on the subject with many people, from His Excellency the Governor downwards, and had as guide on my tour the Director of the Geological Survey, the study was intensive if brief. The impressions gained are therefore set down, together with tentative suggestions for further experiment or enquiry.

A visit to Uganda, after touring Tanganyika Territory and Kenya and seeing their extremes of rainfall, relief and types of people, produces a sense of contrast which is perhaps liable to be overestimated on a short visit, especially one which does not include Karamoja. One was apt to feel that, compared with the rest of East Africa, there were no very urgent problems as to water development nor any real lack of water.

It may appear to be a curious analogy, but the impression of being on a Scottish moor, magnified a thousand times, was strong throughout the first part of the visit. The encircling hills of a moor became the giant peaks of Elgon, Ruwenzovi and the Mufumbiro volcanoes, the shallow mountain tarn was Lake Victoria. There was the same indefinite drainage hither and yon of small streams in peat bogs magnified to the scale of large rivers such as the Katonga and the Kafu, flowing in two directions, and to the scale of extensive papyrus swamps from parish up to county size by Scottish standards.

This first and purely physiographic impression is not without its value, though it faded as one became acquainted with the people and began to appreciate their economic and social problems. In a broad way one may say that the ultimate development of land in Uganda, omitting its north-eastern section, will depend on the control or regulation of its drainage just as the crofter or gamekeeper improves his moor mainly by cutting ditches and draining bogs, while if the engineer takes a hand he will examine the prospect of his mountain tarn producing power or acting as a highland reservoir to water schemes at a lower level. So, at the Ripon Falls at Jinja, almost anyone with a touch of engineering imagination notes the mighty reservoir behind the useful head of water in that series of falls and rapids and wonders how long it will be before the increase of population will demand an industrial outlet for which the power is ready to hand. Large schemes such as these are the subject of other reports and find no place here, but reference may be made to very small power schemes for which, in the country as a whole, there are a myriad sites.

One has only to think what the Chinese or Japanese, or even the Javanese, would do with such a wealth of water running past their villages at such useful gradients. Those ingenious and industrious peoples would have harnessed these streams to their creaking water wheels for irrigation or for grinding meal or for rough workshop power, and would have terraced their hills for maximum production.

It is no criticism of the African that he has not done so, for hitherto he has not had the pressure of population, which was one of the urges to the Oriental peoples. Such pressure is inevitable in due course, and the time must be nearly ripe when European devices might be introduced to the African, such as the hydraulic ram, the small electric power unit, the mill wheel, even the giant water wheel on floats, of the Danube type.

Something of the sort is already being done by individual district officers who have that turn of mind, but it might be considered more fully as a policy of the Government to introduce such things on at least a demonstration scale. A visitor is quite unfitted to decide upon such matters or suggest how best such a policy should be carried out if approved. Nevertheless, one may be bold enough to ask whether the purchase and installation of such European devices is perhaps not the only or even the best way of beginning. What is needed most may well be appreciation of mechanical aids of that kind and the craftsmanship to construct them in the simplest forms, such as the overshot wheel or the use of bamboos (or banana sheaths) for leading water where it is required. If that is true then the Department of Education is just as much concerned as the P.W.D. or the Water Development authorities. It is perhaps not often realised in Africa that it may be better to sacrifice some degree of efficiency for the sake of a psychological advantage; that to give or sell to an African an intricate mechanism from Europe which works to perfection may not be such a real advance as persuading him to make for himself some "gadget" out of local materials which may be inefficient but is at least his own product and is fully understood by him.

If there is any truth in that suggestion, then what the African needs first from Europe is a supply of steel rods and bearings and perhaps a few gear wheels rather than the latest turbines or dynamos or roller mills.

In Uganda, more than elsewhere in East or Central Africa, one feels that the African has reached a stage where he can profit greatly by having his mind directed towards a fuller use for his abundant supply of water.

The Papyrus Swamps

To anyone concerned with water resources the most striking feature in Uganda is the prevalence of papyrus swamps of all shapes and sizes. These were to be expected in flat swampy places from a combination of a good rainfall and high temperatures, but they also occur in valleys of considerable gradient. This at once leads to the conclusion that in such a climate the papyrus, with other swamp plants, must be accepted as a really potent physiographic agent, capable of causing large-scale changes in the topography and one which may be regarded on the whole as an asset rather than a liability.

The swamps fall naturally into two categories, namely, valley swamps and what might be called basin swamps. Since these have a somewhat different function and value they will be treated separately.

Valley Swamps

The valley swamps are long narrow belts filling the valley bottoms, usually consisting of papyrus alone, but occasionally mixed with other swamp plants and even a shrubby tree of habit somewhat similar to the English alder.

They appear in their most striking form in the valleys of Kigezi. Here the high rainfall and the exceedingly high relief of the country would lead one to expect rapid rivers in sharply-cut V-shaped valleys. Instead one finds very steep-sided valleys with perfectly flat bottoms in cross-section yet with steep longitudinal gradients. All one can see without closer inspection is a sea of papyrus filling the valley bottoms like long green glaciers.

This most unusual topography seems to have been brought about entirely by the growth of papyrus under optimum conditions of rainfall and temperature. The process doubtless began by the occupation of the original V-shaped valley bottom by the papyrus, which thereby checked the flow of the rivers, induced the deposit of silt, and grew upwards on its silt and humus foundation till it formed a flat bottom to the valley, while maintaining its original slope longitudinally. The occurrence of these long peat-filled valleys has been recognised as of possible value, and recently a report on them was made by Mr. Griffin, formerly Director of Irrigation in the Sudan.

I have not seen this report, but I believe it contains recommendations for experimental drainage which are even now being carried into effect. The fear expressed by some people that a thorough drainage of these narrow valley swamps might adversely affect the climate in Kigezi need hardly be taken seriously. The mountains there usually rise to some thousand or more feet above the swamps and can only derive a very small fraction of their rainfall from the transpiration of the swamps, which occupy less than 10 per cent of the total area.

There are, however, other reasons for draining the swamps cautiously and in large blocks with virgin swamp between them, as I believe is recommended by Mr. Griffin. The pronounced gradient of these swamps invites variations in the type of drainage according to the crops to be grown, the slope of the sides, the incidence of tributary valleys and so on. Thus, where the valley swamp is very narrow—under 400 yards in width—a central drain is probably the most useful, draining the peat on either side for crops. Where the valley is broader, and especially where it dips towards the central line and has reasonably flat original soil at the sides, the treatment might be different.

From the centre of the swamps drains would be led to the sides of the valley, running along them like irrigation furrows, and so functioning for such crops as rice, draining away into a central ditch down the centre of the valley.

In such narrow swamps the ditches will be comparatively small and therefore very easily blocked should undue erosion appear to be taking place. Provided that the sections drained are not too long or steep, the flow should remain well under control.

I believe that Dr. Worthington has recommended that occasional tanks should be excavated for the cultivation of fish for food purposes. These would be best placed immediately above the blocks of original swamp, thus acting as a sump for the drained section above.

There is no need to go into further detail on schemes which are obviously in safe hands already, but I would like to express my firm opinion that the drainage of these valley swamps is not only easy and profitable but it is not likely to cause any disturbance either to the climate or to the hygiene of the country. They are so similar in most respects to the damboes and dimbas of Central Africa that the same general principles of development would seem to apply.

The Basin Swamps

These broad stretches of papyrus swamp are characteristic of the flatter country with a good rainfall, with special development in a wide belt from Lake Kyoga to the Kagera River. As a whole they may be taken as expansions of the valley swamps, but on a scale far wider and with much lower gradients.

Their very size renders them rather difficult to deal with, but they are essentially similar to the fenlands of England and the Netherlands, with the important advantage that they have a gradient and drainage can be by gravity instead of by pumping. They must have the same type of soil, possibly with a smaller silt fraction, as the valley swamps, and obviously experiment in their drainage is called for since so much potentially good land is at present occupied by them.

One might well regard these large swamps as valuable reserves for the future development of crop lands. It seems likely that when experiments have been made a long-term plan of development might be drawn up, to the ultimate benefit of this large tract of territory.

The Sand Rivers of Karamoja

I was unable to visit the north-eastern districts of Uganda, but their sand rivers were fully described to me by Dr. Davies and earlier by Dr. E. J. Wayland. I met similar features in other territories, especially in the Bechuanaland Protectorate.

With a higher rainfall than occurs in the northern districts of Kenya, the Karamoja sand rivers represent a source of water which calls for experiment. The treatment of sand rivers forms the subject of an appendix to this report.

The Porous Basin of Kisoro

In the extreme south-west of the Protectorate, this basin of volcanic lavas and tuffs, with a population of some 30,000 people, presents a peculiar local problem. The rainfall is good, from 20 to 40 inches, and fairly well distributed, but the land is so porous that the natives are almost entirely dependent on the lake for water. This means the transport of water for domestic purposes for distances up to 15 miles.

I was unable to meet the District Commissioner, who has already made some interesting experiments in small apron-catchments. These will, I feel sure, solve the problem when some modifications in design are made. As similar means of catching a domestic supply may be of value to other districts in Africa, I append a note on their construction, based on experience in other countries.

Apron Catchments

The use of artificial catchments for storing rainwater is restricted to somewhat unusual conditions. In the first place the ground must be so porous that no natural catchment area will serve, and secondly the rainfall must be fairly regular and not seasonal. The actual amount of rain falling is of less importance than its frequent occurrence. A few figures as to the quantity of water obtainable by artificial apron catchments will perhaps emphasise the latter point.

One inch of rain falling on one square chain—one-tenth of an acre—produces about 2,000 gallons, which on the African scale is sufficient for 40 persons for 10 days, allowing for some loss. If there is prospect of an inch or so of rain per month in the dryer part of the year a small apron catchment should be worth while. If there is liable to be drought for three or four months at a time the area for treatment must be so large that it could only be contemplated if very cheap means were employed.

The very large and costly aprons used at Gibraltar and in some parts of the United States need not be taken as normal examples of this method.

Site and Preliminary Preparation

Any natural depression in the ground can be utilised, and if it is half-saucer shaped, all the better. There is no advantage in having a marked gradient in the apron itself, but it will save excavation for the storage tank if the ground falls away more steeply below the depression. This is more important still if the storage is to be by circular galvanised tanks, which must be above ground.

The preparation of the site is the same for almost all the types suggested below. Vegetation and boulders must be removed, the ground must be smoothed off and firmly stamped and, if cement or plasters are to be used, the ground must have a surface of " murram " or gravel well rolled or stamped over it.

In all cases the actual apron must be fenced against both animals and persons.

Materials

Of all possible materials for making the apron a concrete made with portland cement is the best and most durable, but for Africa it is practically out of the question as quite prohibitive in cost. One square chain would require up to 3 tons of cement and, as we have seen, will not furnish a supply for many people.

Fortunately, a lime mortar mixture will serve nearly as well, provided the apron is made thicker, say 3 to 4 inches on a very well-rammed foundation of rubble or " murram " mixed with earth.

Both cement- and lime-concrete are porous and rough as to surface, and since full advantage must be taken of every passing shower, the apron must have a waterproof skin, for which there are several standard methods. A thin slurry of neat cement or of fine lime mortar into which oil has been thoroughly stirred to make an emulsion can be brushed over the finished surface. If the oil is linseed or cottonseed it will give a resinous and entirely waterproof skin when dry. Coal tar brushed over the surface is an excellent method of waterproofing, but may have to be renewed from time to time.

Probably the chief difficulty with concrete of any kind is the necessity for expansion joints of some kind over such wide expanses. The appropriate method is to sink a lath about ½ inch wide into the concrete when wet nearly through it and to fill the crack thus caused with pitch or asphalt, the joints being run in the direction the water will run over the finished surface. In default of caulking material like asphalt, it is suggested that weak ridges should be made as "joints" every ten feet or so, the low ridges being treated with a lath as before, so that the cracks will form along them, but being on ridges very little water will escape through them.

Bitumen or Asphalt Aprons

The principle is that of the tarred or tarmac road, but a much thinner application will do. If possible, gravel should be rolled into the surface first. If a proprietary surfacing is used, the instructions with it must be carefully followed. If plain tar is used, it must be applied hot.

Oiled Earth.

In places like California the ordinary dirt road is sprayed with crude oil and this makes a very good surface and sheds water. Used engine oil, strained and applied hot, should give similar results and is worthy of experiment. The oil companies at Suez surface all their dirt roads with a by-product of their refining, which should serve well if obtainable.

Clay Apron

Clay, or better still, ant-hill material, is an excellent shed-water. It should be laid either dry, well stamped and then slightly watered, or puddled first to a thick consistency. Cracks are less liable if it is laid dry and well rammed. A surface binder should improve its shedding and hold the clay against heavy showers. For this I would suggest used engine oil as above. In many places this would be the cheapest method, and if well laid should need only occasional repair.

General Notes

Whatever the material, it is essential to have an animal- and man-proof fence round the apron.

A small ditch or furrow should be dug round the apron to prevent excess water running under it which might cause bursts or warping.

The shape of the apron is of no great importance and depends mainly on the contour of the ground. On the side of a hill, for instance, it would have to be roughly V-shaped to lead the water to the tank and have a slight bank or ridge at the lower edge. The gentler the slope the less erosion of the material.

Since people will be moving round the tank it is better to build it separate from the apron and lead the water into it by a short pipe or channel.

The catch of water depends both on the area of the apron and on its degree of waterproofing. In general, it is better to cover a wide area with less impervious material than a small area perfectly waterproofed.

APPENDIX A

Notes on the Treatment of Swamps

THE EXTENT OF swampland in East and Central Africa is remarkable. In the tropical regions, as elsewhere, a swamp is the outward sign of arrested drainage, accompanied by a dense growth of a peculiar type of vegetation which grows in shallow water. The special characteristics of African swamps are that they often have a pronounced gradient, they rarely possess a visible barrier of rock or other obstruction, and they form very quickly. These peculiarities of tropical high level swamps are naturally all connected with the rapid growth of vegetation under the temperature conditions.

A variety of names is used for these swamps. In Southern Rhodesia and the Bechuanaland Protectorate the old Dutch word " vlei " is used to include swamps, but it appears to be a broader term than its African synonym. In Northern Rhodesia and Nyasaland the name " dambo " is universal. It seems to be specially applied to the longitudinal swamps which mark a large proportion of the upland valleys, though occasionally used for flat, treeless areas which are not true swamps. There are, therefore, damboes which are permanent swamps and others which could be used for pasturage, the real distinction being a matter of water supply and drainage. Very extensive flats which receive annual flooding, such as the Kafue flats and the Barotseland floodlands, are not usually given the name of dambo, which in any case is reserved in this report for the smaller areas of true swampland found along the minor valleys and at headstreams.

In Nyasaland, an additional word, " dimba ", is used to denote a variation in the dambo in a way which is at first somewhat confusing. The Director of Agriculture in that territory took some pains to find out its precise meaning to the natives by collecting the definitions given by his local officers. The word " dimba " appears to denote a well drained dambo, and may even be used, as in the Lower Shire flood plain, to describe the higher parts of a swamp which permit cotton growing. Once fully understood, the term is a useful one, expressing a functional distinction. Nor is it difficult to remember the distinction if one descends to a play upon the words and defines a dimba as an inadequately dammed dambo, or even a dim dambo, that is to say a less swampy dambo.

In Tanganyika Territory the word " mbuga " is used, somewhat generally, for swamps, while in Kenya and Uganda the English word is preferred and is applied to almost any area of marsh land, without any discrimination as to degree of drainage.

It should be clear that, except in the sub-arid parts of Kenya and Tanganyika, the swamp is a well-established feature of the African landscape and one which has a notable effect on health, agriculture, water supply, and other aspects of the African economy.

We need not go into detail as to the origin of these swamps, except to emphasise the importance of two factors. The first of these is the extraordinary rapid growth of water-loving plants in the temperatures ruling for most of the year, and the second is the frequent occurrence of heavy downpours during the rainy season.

The luxurious growth of swamp vegetation means that the arrest of drainage is often due almost entirely to the density of the plants themselves and hence the gradient of the swamp may be high. The heavy storms bring in a fairly large amount of silt so that the resultant soil has a free drainage yet has a modicum of clay particles, much of which indeed remains in suspension, so that dambo water is usually slightly milky in colour.

There is certainly room for research into the ecology of the swamp types of Africa, research which might well provide a useful guide to the use of swamp areas, or at least some correlations of " indicator " plants and their optimum conditions as to soil, extent of flooding, etc. At present there appears to be a good deal of confusion as to the significance of the occurrence of certain well-known plants, such as papyrus and phragmites, and there is at least as much uncertainty as to the appropriate habitat of others less well known. The ecologist should have a good deal to tell the agriculturalist as to the possibilities of dambo development for crops.

It will be realised that the African plateau swamp is nature's contribution towards the conservation of water derived from the rainy season, and as such it has, in the aggregate, a very vital effect on African life. In recognition of this fact it has been the general policy, in purely native reserves at all events, to refrain from using damboes to any large extent except as sources of water for village use. So keen is the appreciation of its conservation value, and so real the danger of wholesale interference, that in Uganda, the real home of the swamp, there have been enquiries ordered into the wisdom of draining swamps and using the land for cultivation. A report has been made by Mr. Griffin on the subject and consequently the suggestions made in this appendix are not intended to apply to the Uganda problems, which indeed were but cursorily seen by the present writer.

It is easy to see that the wholesale draining of swamps, supposing it could be done, might give rise to disastrous and unsuspected consequences. On the other hand, level and fertile land is rather rare on the African plateau, and if the swamp land is to be left completely virgin and untouched an important source of food production is ignored.

The object of these notes is to suggest certain means by which a middle course could be followed. It is admittedly a form of development which not only is beyond the powers of the African himself, but requires full control by authority, even under European management. South Africa itself is the awful warning against lack of control over drainage, but that does not mean that all drainage is harmful or even short-sighted.

Without going into excessive detail there are certain characteristics of damboes, as found in Central Africa, probably applicable also to East African examples, which must be mentioned since both their value and their treatment depend on those qualities.

Naturally the amount of water held by a dambo depends on its size and its gradient. Thus there are damboes which regularly run dry on the surface and others which, even in the most severe dry season, retain water at some level or other. In general, they must hold water for a long period to provide the conditions for the aquatic and marsh plants which grow on the dambo.

The relation between what one might for the moment call wet damboes and dry damboes is well shown by the larger swamps, such as the Kafue Flats and the Bangweulu Swamps. Here there is a fairly well defined zone of grassland round the wet swamp, the grass being eaten down by game as the flood waters recede, or grazed by cattle. These large-scale examples must be paralleled in some degree or another in the smaller swamps, that is to say there is, theoretically, a grass zone to each one of them, which is too wet for tree growth but too dry for aquatic growth. It is clearly possible to increase or decrease that grassy zone by drainage or by blockage, remembering that the grassy zone can also be a seasonal crop zone. Broadly speaking, one may require to increase the water in a dry dambo or decrease the water in a wet dambo, so that development is concerned both with drainage and with blockage, the former being, in general, much the cheaper.

Another characteristic feature is the soil, which according to circumstances may range from an almost true peat through many degrees of humus content to a dark loam. These dambo soils are often described by a term in general use, " black cotton soil ". The name may be convenient, but is not very exact, since it refers more to its consistency than to its agricultural value. Dambo soils may range from the highly cultivable types of limestone districts, such as Lusaka, to salt-impregnated soils as in parts of Barotseland, or to highly acid types in granitic country. Their depth will naturally vary according to the size and age of the dambo, while their sand content will depend upon the nature of the watershed supplying the stream and on its relief. A dambo soil should, however, always be better than the ridge soil above it, for its content of humus, its comparative freedom from termites, and its free draining properties.

The question of the actual amount of water conserved by damboes is clearly important, yet it is hardly measurable, particularly as there are so few reliable figures for evaporation. It may be taken that the loss by evaporation from a flooded dambo must be considerably in excess of that from an equivalent area of open water. Once the surface water has drained into the peaty soil the relative loss must be much lessened even though it may still be transpired in quantity by the leaves of the plants. One may at least say that a cultivated dambo soil will lose less by evaporation than under natural conditions and that as far as useful effect is concerned the gain by a measure of cultivation must be clear.

The argument concerning the judicious development of swamps therefore runs somewhat as follows. The natural swamp holds up water from rapid run-off, but loses a rather large amount to the atmosphere without giving any return. A completely drained swamp would render available considerable land for production of the seasonal type, but would tend to make the streams issuing more intermittent than ever. A middle course should permit both aims to be pursued in part, that is to say, a reasonable check to rapid run-off and the use of more production land of fairly high value.

It therefore remains to be considered what means of development should be followed, and for this question there is a certain amount of experience, successful and otherwise, already available. It must first be emphasised that such development should be initiated by authority and be preceded by experiment.

It will be noticed on the map on page 39 that the damboes towards the headwaters of streams are usually larger than those in the valleys proper. These headwater damboes need careful treatment since they are a safeguard against headwater erosion, but they also have more valuable land on account of their extent and position near lines of communication.

The dambo at Ndola is a good example and one which has acquired a certain notoriety for its effects on the town. Like all damboes, and unlike the typical fens of England and Holland, these headwater examples have a very definite gradient though it may be less than those in the valleys.

In both instances this gradient decrees that all development must be of a stepped type; a high level should never be allowed to drain freely into a lower level, nor should any ditch be dug at such a gradient as to invite erosion of its bed. The pattern of drainage will therefore depend very much on the general gradient of the dambo.

Thus, for one with a low gradient, the normal herring-bone pattern may serve, with a central drain. In this case it would generally be advisable to " step " the pattern by leaving a fairly broad belt of the original swamp across the dambo at suitable intervals, with a receiving tank or fish pond above it. Even so the ditches will tend to bring a certain amount of silt into the pond during rain storms.

This central drain pattern would on the other hand be useless for a dambo with a pronounced gradient, since the drain would rapidly erode the beds and end by completely draining the swamp, which is not the object of the development. The aim in such a case would be to lead the water away from the centre towards the sides by drains which practically follow the contours and have a very low gradient. These drains may terminate in one of two ways. They may empty into fishponds near the side of the dambo with a zone of virgin swamp growth below them, whence the water will seep back into the next section. If that be inconvenient the drains may be continued into the slope at the side of the dambo (as shown on the left side of the diagram), emptying into a furrow leading down the side of the valley, like a storm-water drain, and serving any required purpose, such as watering points for villages, or even small reservoirs for minor irrigation back into the dambo-land.

With this pattern the control of the water can be made almost absolute by constructing small sluices at the points where the drains reach the furrow. Under such a system the dambo will still tend to serve its original purpose of conserving water yet, being under control in sections, the land can be put to seasonal use, draining the water at the end of the rainy season and holding it up towards the end of the dry season.

A combination of the two patterns may be advisable in a very wide dambo, the sides being laterally drained and the excessively wet centre being centrally drained.

There is a third pattern of drainage which deserves some consideration and experiment, which may be called the Z or zig-zag pattern. The object of the whole scheme is to free the dambo soil of excess water yet to conserve as much as possible and at all costs to avoid erosion. This may be attained by running the drains in a zig-zag pattern back and forth across the dambo, always at a gradient too low to cause erosion.

Ponds could be left at the middle portion of each limb of the zig-zag and probably it would be as well to leave a belt of original growth on the downstream side of each limb. The reclaimed parts of the dambo would then be in the form of wedges pointing in alternate directions.

A point of practical importance is the setting out of the ditches for these patterns. It will usually be quite out of the question to arrange for, much less pay for, a thorough contour survey of a dambo by professional surveyors, and in most cases it is not necessary. In special circumstances, such as that of the Ndola dambo, where land values, urban amenities, etc., come into the matter, a detailed survey is no doubt desirable. In the more normal case no such expensive accuracy is really needed, and one or more of the tricks of field engineering practice may be followed.

These vary from the very sound if primitive principle of digging small trial ditches and seeing whether the water will flow, to any system of setting out boning rods based on the level line given by any standing water. A general preliminary in any case is to set up a few transverse lines of tall poles across the dambo wherever standing water gives a level and cutting them off at an equal height above that level. Each line of poles will be at a different level from the others but subsequent connection can be made if the actual gradient be required.

It follows that the best season for setting out by rough and ready methods would be just at the end of the wet season, when there is standing water and when trial ditches will show the direction and rate of flow. For setting out by purely instrumental means the end of the dry season would be best, when access is easy and much of the growth can be removed by burning or cutting.

The uppermost and the lowest sections of the dambo should be left in their original state, the upper zone to prevent undue washing in of silt from upstream and the lower to prevent scouring of the bed by the issuing stream, which in the rainy season will be receiving more water than it did before the development scheme began.

The value of the ponds is not confined to that of providing a source of protein food, and since they are likely to be the most expensive section of the work, more should be said about them. Their additional purposes are to localise the water, to provide water supplies for man and stock late in the dry season, and, as far as possible, to reduce the habitat of the malarial mosquito. They should therefore be fairly steep sided, be three feet deep or more, be kept clear of growth and yet be reasonably accessible. Of these desiderata probably the most difficult would be to keep phragmites, papyrus and other deep-water plants from establishing themselves; in other words maintenance is necessary. The spoil should be thrown out on the downstream side of the pond, both to increase its depth and to render that side more impervious by compressing the peaty soil. Trial holes would always be sunk to ascertain the depth of the dambo soil, and if the layer below it is porous the tank must not be so deep as to reach it.

Methods for developing the longitudinal or valley damboes are based on the same general principle. Experiments in the treatment of steep valley damboes, dimbas to be precise, have already been carried out in Nyasaland. In a typical case seen by the writer the swamp proper was only about 150 yards in width and the pattern was that of the central herring-bone. The result in crop production was excellent, but the impression given was that the gradient of the central ditch was too high and needed special safeguards against erosion. Belts of original swamp were being left at intervals down the valley and in every respect except that of flow-gradient the scheme seemed to be a model one.

It will be for the agricultural officers to decide upon the crops to be grown on the land freed for cultivation. Obviously rice is a possible crop under the circumstances, though there are two factors to be borne in mind. Dambo soil is really very porous and it will be difficult to ensure that the paddy can be kept flooded for the requisite length of time. Secondly, paddy fields give optimum conditions for the malarial mosquito.

Perhaps enough has been said to show that the extensive damboes, particularly of Northern Rhodesia, have not yet received adequate attention, and that their development need not be a costly venture. At the same time the suggestions made require experiment, based as they are on modifications of existing practice, in which the drainage has usually been made too wholesale and the ditches too steep as to gradient.

APPENDIX B

The Treatment of Sand Rivers

IN ALL ARID countries where the rainfall comes rarely but in heavy outbursts, the rivers run for a few days or even a few weeks on the surface bringing down sand with their flood, after which the water under the sand seeps gradually down the valley and finally disappears into whatever drainage basins are available.

In Africa these "sand rivers" are especially well developed in the Bechuanaland Protectorate, where the Kalahari sand fills the river beds often to the depths of from 20 to 40 feet. They occur too in certain districts in all the Territories I have visited, where the conditions are suitable for their formation.

They are naturally a standard source of water for the inhabitants, who know best where to dig holes in the sand to find the best supply. These places of course are where a rocky bar or other natural obstruction has prevented the seepage from going on too fast. The sub-surface dam or barrier is merely a method of providing such obstruction by artificial means. The following notes represent an attempt to collate evidence as to the nature of sand rivers and to suggest means by which sub-sand reservoirs may be constructed without undue expense.

The regime and structure of Sand Rivers

Since the methods advised are based upon the nature of the sand river and its origin a preliminary note is necessary.

To watch a flood coming down a sand river is an instructive sight, especially when the rain producing it has fallen upstream and the sand is dry. The flood usually appears as a small wall of water carrying at its front the light flotsam of twigs, leaves and rubbish which has accumulated on the sand bed during the dry season. For the first few minutes of its passage there is a strong appearance of boiling which is due to the escape of air from the dry sand as well as to the initial smoothing of rough places in the sand. The water is usually much too muddy to allow one to see what is happening to the sand itself, but from other evidence it can be deduced that it is in motion to a depth which is dependent on the velocity of the water and on the number of obstructions. Thus in a steep and perhaps rocky gorge possibly the whole of the sand is in motion, whereas in long stretches of even gradient it is rarely disturbed for more than a foot or so in depth. As the flood steadies and if the water runs clear, the rolling of the sand over its bed is easily seen to be only in the top inch or so except where eddies are formed by obstruction. Where these obstructions are of large size, such as a boulder or a causeway for a road, the water will scoop holes in the sand, and when the flood disappears these holes will contain water and are those which are first used by the natives.

The flood water is always muddy in its earlier stages and though most of this is in true suspension and passes down without settling, a certain amount is caught between the sand particles and each pool left after the flood has subsided has a small skin of mud drying on the sand. A pit dug in the sand will therefore disclose small lenticles of clay, but these are always limited in extent and never seal off the bottom layers of sand completely. This clay in the sand means that the water taken from a sub-sand reservoir will, at first, tend to be muddy, clearing by degrees.

The porosity of pure sand is about 30 per cent, and slightly less for a normal sand river. Consequently when fully charged the sand behind a sub-sand reservoir will hold up about one-quarter of its own volume of water.

As described above, the water left in the sand, after the surface water has run away, slowly seeps downstream and disappears. Its rate of seepage naturally depends on the gradient and on the resistance of the sand, which is largely a matter of the size of the particles. It follows therefore that if we can in any way decrease the gradient locally or increase the resistance of the sand to seepage, the water will escape more slowly and therefore be available for use over a longer period. This is the principle of sub-sand barriers.

Sub-sand Reservoirs

Provided that they can be constructed cheaply there are many advantages in this form of conservation.

The water is almost completely shielded from that bugbear of all surface dams in arid climes—evaporation. The degree of protection depends on the size of the sand grains. If it is coarse the escape of water by capillary action to the surface will not occur beyond a few inches. Even with fine sand there will rarely be any evaporation below 18 inches or two feet.

The water is well protected from contamination by animals or decaying vegetation. Moreover it is to some extent filtered as it passes slowly through the sand to the wellpoint.

The amount of water held by any one sub-sand reservoir can very easily be augmented by constructing cheaper semi-porous barriers upstream which will slowly feed the main reservoir.

The reservoir can make use of comparatively brief showers which run quickly into the sand and add to the supply below the evaporation level.

Choice of Site

The best conditions for a sub-sand reservoir are easily set out. They are a good depth of sand, a low gradient of valley and an impervious bottom. The broader the sand river the greater its capacity. In fact one searches for what in a full river would be long reaches of quiet deep water such as are sought for surface reservoirs.

It is not much use choosing a site with sand less than four or five feet in depth unless the gradient is very low. On the other hand a shallow depth of sand can sometimes be increased artificially by piling large boulders on the sand to form a sort of weir. At the first flood these will work down to the bottom by themselves and if high enough will hold up the sand to a greater depth than before.

A low gradient is important not only because it increases the capacity but because the floods will not disturb the sand bed so deeply in their passage. For the same reason one would avoid a stretch with many protruding boulders.

For the nature of the bottom and the sides of the sand rivers one must take what one finds, yet on account of their origin they are usually found either in rocky valleys or in material which is at least much less porous than the sand of the river. Likely sites are those used by the Africans for their temporary water holes, since by long experience they have selected places where some natural barrier below the surface has checked the seepage. In general, given a reasonable depth of sand, common sense will select a suitable site without much difficulty.

Construction Methods

There is a wide variety of modes of construction for sand river barriers available, some of them tried, some a proper subject for experiment. These will be described briefly from the elementary types suitable for native use with local materials up to the advanced types using the materials and the machinery of the engineer. Their efficiency and their cost will naturally rise in the same order.

Clay Barriers

The most natural method of placing a barrier across a sand river is to dig out a trench in the sand and replace it with impervious material.

There are two reasons why this, while possible, is not as simple as it sounds. One is that if the sand is absolutely dry a very large amount of sand must be thrown out to open a trench to the bottom. The second is that if the sand is wet there will be trouble with water in the trench. Both obstacles can be circumvented to a certain degree. To prevent excessive falling-in of the sand a double line of poles is driven in for a foot or so close together outlining the trench to be dug, about 2 or 2½ feet apart across the sand bed. As the sand is thrown out the poles are driven further, always a foot or so ahead of the digging and reinforced if necessary by struts from one side to the other. If water is reached the poles alone will not check the sand flowing into the trench and they may have to be reinforced with matting, palm leaves or other material.

If the trench is dry, or nearly so, to the bottom, as will usually be the case for sand less than 10 feet deep dug at the end of the dry season, the filling in with clay is easily done. Ant-bed material is easily the best material, but other types of clay or fine soil if well stamped and trodden will serve. The material is added in layers, each of them well trodden or rammed. The poles are withdrawn as the filling goes on as they would cause eddies in the first place and ultimately come to the top disturbing the clay barrier as they worked up. The filling is stopped at a level about two feet or less from the original surface, the remainder of the trench being filled in with the original sand and levelled off.

If the trench reaches water in any quantity beyond the scope of baling the barrier can only be a partial one but it can still be very effective as will be shown. In that case the sand will be removed to the limit imposed by the water, say two or three feet below the water surface, and the clay thrown in and well puddled with poles, finishing off as before.

The result will be a perched or hanging barrier which does not reach the bottom and does not really seal the subsurface dam. If such a hanging barrier were constructed in a normal river the effect would merely be to hold up the water slightly and produce a powerful scour under the barrier. The latter effect will not occur under the sand barrier because the sand is too tightly packed to transmit fluid pressure to any significant amount. In more scientific language the rate of seepage is dependent more on the cross-sectional area for escape than on the head of water. It will therefore act as a partial blockage of the seepage. Further there appears to be a progressive sealing of the sand under the barrier which may be due to the gradually working down of some of the clay.

In view of these difficulties with water it is obviously best to select the very dryest time of year for building barriers in this way.

For such simple, native-style, reservoirs, the water withdrawal point should be some yards above the barrier itself and can hardly be expected to be permanent, as the flood will fill it in each year. It can be made semi-permanent, however, by lining the first hole with heavy poles or tree trunks, not reaching quite to the surface. The hole will be cleared out each year with less difficulty than in virgin sand.

As doubts are often expressed as to the permanence of such a thin clay barrier we may consider the factors which threaten it. We can at once exclude pressures since it is supported on either side by the sand, and the water pressure under seepage conditions is negligible. We are left with disturbance as the only other likely cause of destruction. This may occur as the result of a monster flood which may disturb the sand to a depth reaching the clay barrier. Logs brought down and half submerged near the barrier may cause local eddies which may reach the clay. These and other somewhat fortuitous events may displace the upper portions of the barrier but cannot affect the lower part, which can be accepted as quite permanent.

It will be recognised that loose clay is not the only material which can be used for the barrier itself. Anything which will delay seepage will serve in some degree. Under certain circumstances closely driven stakes may be the only material available, while under others air-dried bricks ("Kimberley bricks") or even baked brick can be used to save material. These could be bonded with clay.

It will be noted that the main difficulty is nearly always the excavation, either with or without the hindrance of water seeping into the trench.

Metal Barriers

These represent a method of construction calling for imported material but using ordinary appliances. Corrugated iron sheets are an obvious form of sheeting to use, but anything heavy of sheet or slab type can be dealt with in the same way. The general procedure is to place the sheets vertically on the sand across the river, overlapping slightly. The sand is then dug from under the sheets which sink at first by their own weight and later by applying pressure.

For any depths below eight feet it is almost always necessary to provide a second line of poles, or temporary sheeting to provide against the sheets slipping forward into the trench, though there is no virtue in their being absolutely vertical.

The sinking of the sheets is very much simplified if a small force pump can be had, even a hand pump of the stirrup type used from a bucket. If the jet be directed at the sand at the bottom of the sheet which at the same time is tapped from above it will work down fairly easily for some inches. The damp sand is then removed nearly to the base of the sheet and the process is repeated.

The final development of such sinking of sheet metal is reached by using one of the various designs of steel "sheet-piling" used in the construction of coffer dams. These interlock and can be made watertight. They can be driven by hand hammer or by pile driving machinery. In sand their rate of driving can be much improved by using a force pump directing a jet at the driving point.

Such a development however belongs rather to the next section and in any case is an expensive form of barrier, hardly to be considered except in the unusual case of conserving water for a town supply.

Grouting Methods

These methods will normally be found the most satisfactory, and though they entail the use of engineering appliances these are practically limited to force pumps of small power and in mobile units.

The method of grouting under pressure, usually with cement slurry, is a standard practice in civil engineering and the only problem is to apply it in the simplest way to sand rivers.

The appropriate method is to sink the pressure pipe through the sand to the bottom and then to pump the grouting mixture down it, slowly withdrawing the pipe at the same time. The grouting penetrates the sand round the pipe leaving, when set, a watertight pillar from bottom to top. The sand barrier is completed across the river by a series of such 'pillars' abutting against each other.

The best method of sinking the pipe in the first instance is to use a force pump to give a hydraulic jet. The lower end of the pipe is slightly bell mouthed so as to give a jet rather wider than the pipe. The upper end is connected to the pump by flexible piping, the pump drawing water from any source available. The pipe is then set upright in a hole in the sand about two feet deep and the pump turned on. The pressure of the jet disturbs the sand below the pipe and drives it with the expelled water up the outside of the pipe into the hole. With a little hand pressure the pipe will sink into the sand at rates up to a foot per minute, according to the pressure behind the jet.

The pressure required for the grouting mixture to permeate the sand round the pipe is small. The specific gravity of a grouting mixture of clay or lime or cement fluid enough to pour easily from a bucket is from 1.5 to nearly 2.0. It is therefore heavy enough to push the water already in the sand from between the interstices provided the head is at least the same as in the sand. In the case of cement grouting in particular the process would be too slow without some extra pressure as the cement begins to be 'killed' in from twenty minutes to one hour.

The rate of penetration and the pressure required for a reasonable rate depend on the grain size of the sand, and a certain amount of trial would have to be made with the sand of the river being treated in order to find the appropriate pressure. Normally this would be applied by pouring the grout into a pipe extended above ground level, but no doubt in fine sand it might be necessary to pump the grouting in. The amount required for a given thickness of the grouted column is easily calculated. For a column one foot in diameter it is about one-quarter cubic foot of grouting per foot depth, or about 10 per cent of the volume permeated, in terms of dry clay, lime or cement. If we apply these proportions to a sand river 100 feet wide and average depth of 10 feet it means about five tons of dry material for a 'wall' of columns, one foot in thickness, and reaching to within one foot of the surface. It is of interest to note that in such a sand river, if it had a gradient of five feet per mile, a sub-sand reservoir would impound about five million gallons. Of this theoretical volume at least two million gallons should be available, allowing a wastage of 60 per cent by leakage.

The right pressure as well as the best mixture of the grouting material is largely a matter for experiment, as also is the rate at which the pipe should be withdrawn so as to permeate the sand with the grout to a suitable diameter. The grouting is stopped within a foot or eighteen inches of the surface.

The process is thus exceedingly simple, more or less continuous and comparatively cheap. Variations in the general method will readily occur to any engineer to suit different circumstances. Thus for depths of sand of the order of six feet an ordinary double-stirrup hand-pump worked by two 'boys' would probably provide sufficient pressure to sink the pipe, which should have small perforations in its walls for a foot or two above the jet orifice to allow the grouting access to the sand.

We may now consider the materials to be used for the grouting. Cement grout is not necessarily the best though it probably gives the most durable barrier. It use is well understood and it is hardly necessary to add that it must be used freshly made and at a consistency which will penetrate the particles between the sand grains to a suitable radius. The resulting barrier will not at first be absolutely impervious though it should be sufficiently so for practical purposes.

Comparatively small quantities of cement are used in the process, but it is expensive and has to be transported to the site, so we turn to materials which are cheaper and closer to hand or easier to transport.

An obvious alternative is a slurry of slaked lime. It will of course take a longer time to set than cement, and it will not be as impervious to begin with. On the other hand as it is cheaper more can be used or a double row of 'pillars' could be set. Though it is slightly soluble in water, its durability would not differ greatly from that of cement since there would be little movement of water near it.

The cheapest material of all, and one which may well prove the most satisfactory, is clay. There is nothing new in clay grouting which has been used for sealing foundations for reservoirs or in mines, but it has not been used for sub-sand reservoirs so far as I know. To that extent it is an experimental material. It is usually used in a slurry, from 80 to 120 per cent of water to weight of clay, and with suitable pressures can be made to penetrate sand many feet from the point of delivery. It should be as fine as possible and if the original clay contains any sand it must be elutriated, that is to say puddled in water and the overflow in suspension allowed to settle. Ant-bed would again be the most useful source, but since this contains some larger particles it would have to be sieved and possibly elutriated. The deposit of fine clay to be found in pans is another promising source.

The clay particles, though penetrating the sand intimately, will not set as does cement or lime. This may affect the durability of the barrier to some extent but not its impervious properties. Nothing but large scale experiments will settle these points.

From these better-known materials we now turn to two unusual substances for which I have no data in this connection and which call for experiment. The first is tar or any other liquid form of pitch or bitumen such as is used in binding road surfaces. Grouting with such material would hardly need any pressure since it is a fluid with no particles in suspension. In dry sand its penetration and sealing would undoubtedly be excellent, as in the surface grouting of roads, especially if it can be applied hot. My doubt is as to its performance in wet sand—the usual case. Theoretically it should, under steady pressure, drive the water between the sand particles in front of it, but in practice it may leave gaps in the sealing.

The final suggestion is that of a chemical sealing which, though it has been tried in various situations, notably in Germany, is as yet in the experimental stage. The principle behind the method is the formation of silicates between the grains of sand which will form a matrix. Such a matrix would not be very strong but it should be watertight. Water glass (sodium silicate) would almost certainly produce the desired effect, and it is not unduly expensive in the dilutions which would be used. A more fruitful line of experiment is in the use of two separate solutions, impregnating the sand first with one and then with the other, the chemical change to form a silicate then taking place in situ. Sodium silicate followed by calcium chloride would be one such combination.

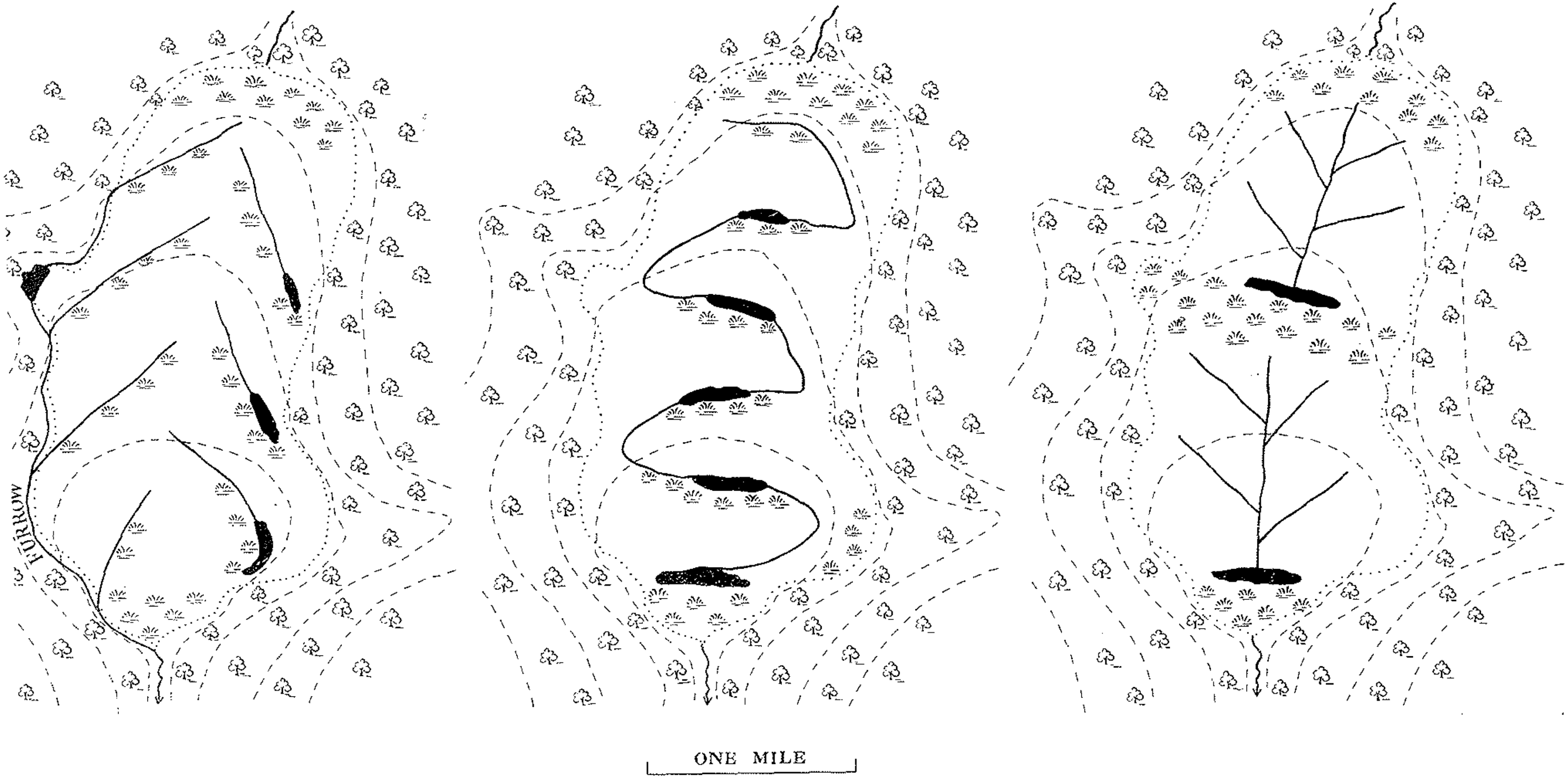
The only advantage in such chemical methods might be a very real one in that they would require no pumping or piping. Twin troughs would be dug across the sand and the appropriate solutions poured into them to be allowed to impregnate the sand to the bottom, the chemical interaction taking place slowly where the impregnations meet each other.

The Stepping of Sub-sand Rivers

The amount of water held in such reservoirs, being about one-quarter of the sand held back by the barrier and below its top, is liable to be slender unless the sand is deep and wide. There is a very simple way of adding to the supply which is perhaps worth mentioning.

If, at distances governed by the gradient, a series of more porous barriers is placed above the lowest one, these will each hold up its quota of water to begin with and release it slowly to augment the final reservoir. This is most necessary in small sand rivers of the order of six feet depth of sand and 20 feet wide. In such cases the upper steps would be made in the cheapest way possible merely by shovelling a trench across, putting in clay and puddling it as far down into the sand as poles would take it. The slight obstructions to seepage thus formed would produce a delay in the rate and continue to reinforce the lowest reservoir for an appreciable period.

Lest it be thought that the amount of water conserved



ONTOUR PATTERN   ZIG ZAG PATTERN   HERRINGBONE PATTERN

:) 11 (R)   SKETCH MAPS OF DAMBO DRAINAGE in sand rivers is insignificant, we will conclude by working out the storage for a moderate size of sand river.

Let us suppose that the river is 30 feet wide with a 10 feet mean depth of sand, and a gradient of 1 in 500.

The effective height of the barrier would be eight feet and the throw back would be 4,000 feet. The volume of water-bearing sand would then be 480,000 cubic feet, of which one-quarter—120,000 cubic feet or 750,000 gallons—would be water. This is actually a conservative figure because the hydraulic gradient of water in sand is not a level line, that is to say the surface of the water-bearing sand will, for some time, be nearly parallel to the actual surface of dry sand.

The corresponding capacity for a small sand river, 4 feet deep, 15 feet wide, and with the same gradient, would be little short of 60,000 gallons, an amount which would water 100 head of cattle for three months.

Methods of constructing sumps, settling tanks and even siphons for use with sub-sand reservoirs have been studied by Dr. E. J. Wayland, formerly Director of the Geological Survey of Uganda. Designs by him will be found in the geological reports of that Protectorate.

It will be seen therefore that, while the general principle of conserving water in a sub-sand reservoir is well understood, there is much to learn as to the best practical method in the circumstances obtaining in Africa.

It is strongly recommended that trials should be made, at first on a small scale, by the authorities responsible for water development in the various territories. These trials should be accompanied by such experiment as the conditions permit. For instance it is of some importance to find the rate of natural seepage for a given grade of sand, gradient of river, etc. This would best be carried out by digging two holes down to water level, one of them a few yards upstream from the other. Fluorescein or eosin dye poured into the upper one will make its appearance in the lower one in due course, giving some data on the rate of seepage. Similarly the depth of the water table in sand beyond which there is no capillary rise to the surface and consequently no loss by evaporation is a figure of fundamental value in siting sub-sand reservoirs elsewhere.

The efficiency of any sub-sand barrier should also be proved either by some record of the amount of water withdrawn or perhaps equally well by sinking an open pipe into the sand below the barrier and comparing the depths of the water table above and below during a dry season.

Possibly the best procedure would be to select a likely small sand river for experiment and to get an engineer to make trials of different methods at different points along the river. His report would then become the basis for large scale development of the methods he found most suitable for the conditions in that territory.

ACKNOWLEDGMENTS

It is impossible for me to express my thanks adequately for all the help and hospitality which I received during those active ten months. All I can do is to record with gratitude the reception I was given by everyone from Their Excellencies the Governors of the different Territories down to the most junior members of their staffs.

Naturally I am particularly indebted to the Secretariats, who arranged the details of my journeys, and to the Heads of Departments who gave me interviews and access to information with the utmost willingness. I would like to make special reference to the kindness of a great many administrative officers at their 'bush' stations, whose routine I must have grievously disturbed, but whose hospitality was instant and whole-hearted.

I hope that the technical officers who accompanied me on individual journeys will regard this report as partly theirs, since a great deal of it is due to their guidance and to their intimate local knowledge. It was indeed a great honour to be shown round the Kalahari desert by the eminent geologist, Dr. Wayland, to thread the channels of the Bangweulu Swamps with the man who had cut several of them, Mr. Brelsford, and to survey the Lower Shire with the oldest pilot of the river, Mr. Boby.

It was, further, a great privilege to be taken for a week's drive round Uganda by the Director of the Geological Survey, Dr. Davies, to penetrate into the N.F.D. of Kenya with Mr. Scott of the P.W.D. of Nairobi, and to be shown parts of the vast area of Tanganyika Territory by Mr. Buckland, the Head of the Water Development Section of the Secretariat. One could go on mentioning names for many pages, but I must content myself with one more. I owe a very special debt to my indefatigable Secretary, Miss Wanklyn, who found herself called upon to work in many queer situations and at many unusual duties.

A
B
C
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E
YANGALA
SOUTH END
LAKE MALOMBE
Reeds
Phragmites
Dense Palms
MWERA
MWERA PT.
Conspicuous Fever Tree
DIMU
TYAKA
Large Tree
Dead Tree
NKAZI R.
Tall Tree
Presumably Mouths of the NKAZI
Hippos
NAMPUTU
Papyrus
Lone Palm
NAMBINDA R.
Many Fever Trees
Mainly Phragmites
Many Large Fever Trees
2 Huts
Lone Palm
NAMKONDA R.
Reeds & Phragmites
Black Dead Tree
MKAWEYA
3 Palms 1 Dead
Dead Tree
Phragmites & patches of Papyrus
Many Baobabs
Single Thorn
Reeds Phragmites & some Papyrus
MKAWEYA (II)
MITOLI R.
WIDE FLOOD PLAIN
Papyrus
Telegraph Pole
Concrete Beacon 5.9' above W.L. June 27/46
Ferry Gauge 12.5'
Old Bridge
LIWONDE
COMPASS TRAVERSE
OF THE
UPPER
SHIRE RIVER
NYASALAND
MADE BY PROF. F. DEBENHAM
FROM
A LAUNCH, JUNE 1946.
SCALE 1:50,000 APPROX.


LEGEND
Villages
Plantations
Banana Gardens
Palms
Trees
Whirlpools & Eddies
Height of Bank above river level in June 1946
Sounding in feet
LAKE NYASA
Presumed Direction of Bar
Reeds & some Papyrus
Reeds with very small patches of Papyrus
Dense Palms
Reeds
Sandy Boat Landing
Palms
Dead Palms
Marsh
Low Reeds in Water
MPONDA'S MISSION
MPONDA
Dead Palms
Reeds Islands
Palms on low Dambo Land
FORT JOHNSTON
Ferry
A
FORT JOHNSTON
YANGALA
Dense Palms
Palms
NTUNDU
NTUNDU
DIMU
Continuous Reeds
LAKE MALOMBE
B
B
SOUTH END LAKE MALOMBE
Phragmites
MWERA
MWERA PT.
Conspicuous Fever Tree
TYAKA
Large Tree
Dead Tree
C
C
& Phragmites
NKAZI R.
Tall Trees
Presumably Mouths of the NKAZI
Hippo
NAMPUTU
Tall Tree
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D
Lone Palm
NAMBINDA R.
Phragmites
Many Fever Trees
Reeds Mainly Phragmites
Many Large Fever Trees
2 Huts
Lone Palm
Phragmites
MANKONDA R.
MKAWEYA
Reeds & Phragmites
Black Dead Tree
Dead Tree
3 Palms 1 Dead
Phragmites & patches of Papyrus
Reeds Lone Palm
E
Concrete Beacon 5.9' above W.L. June 27/46
Ferry Gauge 12.5'
Old Bridge

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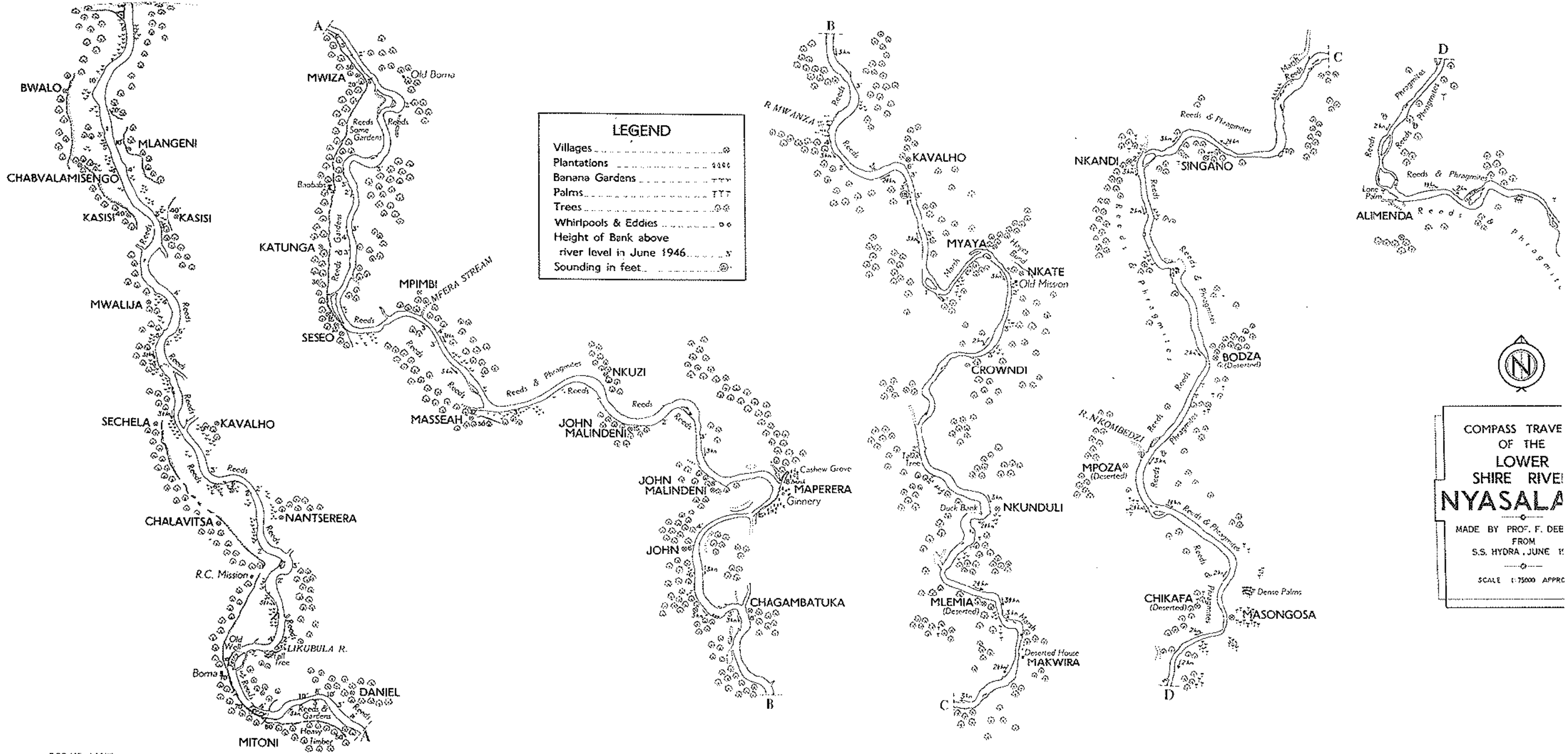
COMPASS TRAVE
OF THE
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LEGEND
Villages
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Whirlpools & Eddies
Height of Bank above river level in June 1946
Sounding in feet
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MWALIJA
SECHELA
KAVALHO
NANTSERERA
CHALAVITSA
R.C. Mission
Old Well
Tall Tree
LIKUBULA R.
Boma
DANIEL
MITONI
Reeds & Gardens
Heavy Timber
A
MWIZA
Old Boma
Reeds Some Gardens
Baobabs
KATUNGA
MPIMBI
MFERA STREAM
SESEO
MASSEAH
Reeds & Phragmites
NKUZI
JOHN MALINDENI
JOHN MALINDENI
Cashew Grove
MAPERERA
Ginnery
JOHN
CHAGAMBATUKA
B
R. MWANZA
KAVALHO
MYAYA
NKATE
Old Mission
CROWNDI
Tall Tree
Duck Bank
NKUNDULI
MLEMIA (Deserted)
Deserted House
MAKWIRA
C
NKANDI
SINGANO
Reeds & Phragmites
BODZA (Deserted)
R. NKOMBEDZI
MPOZA (Deserted)
CHIKAFA (Deserted)
Dense Palms
MASONGOSA
D
Lone Palm
ALIMENDA

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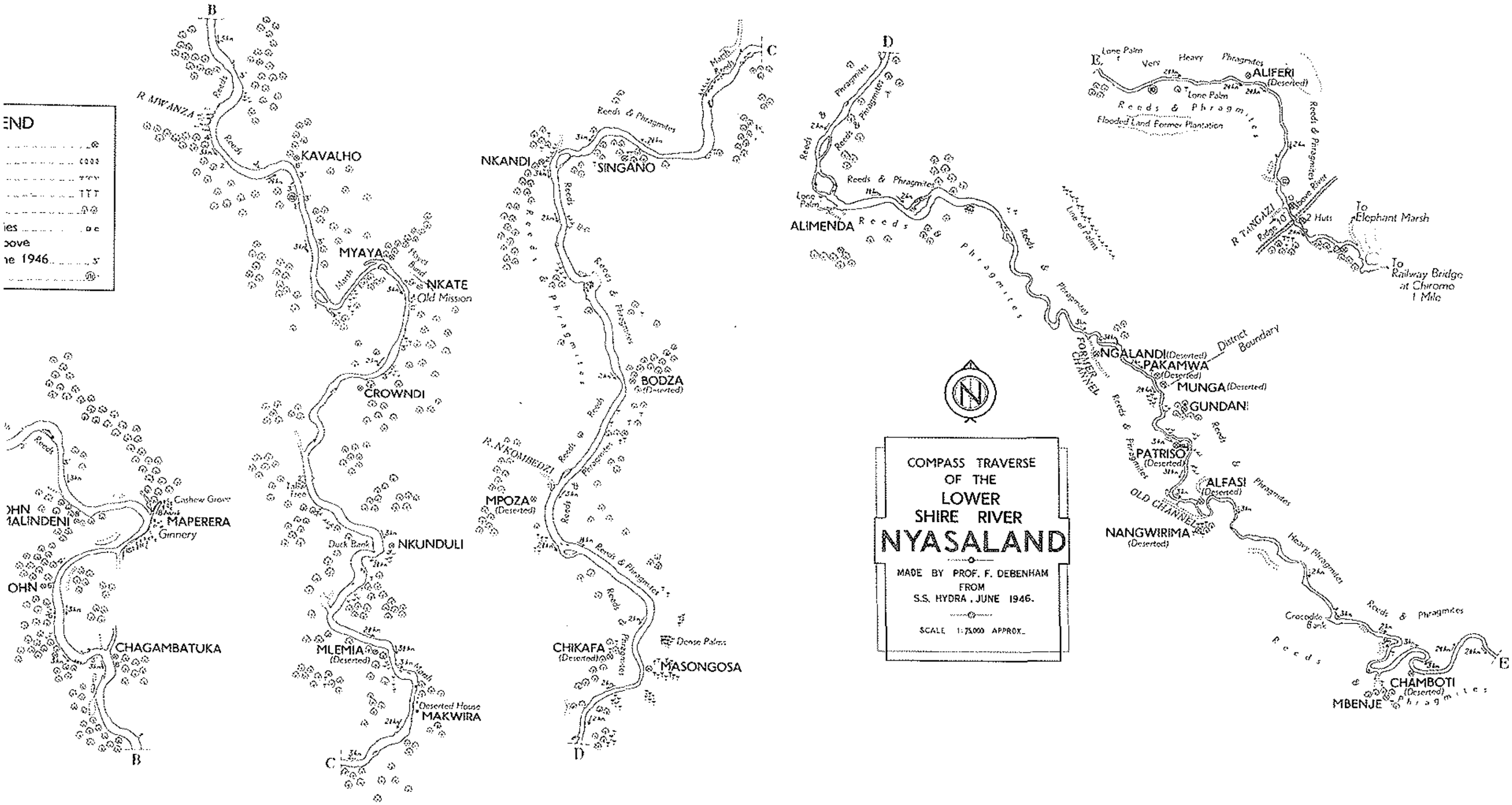

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KAVALHO
MYAYA
NKATE
Old Mission
CROWNDI
NKUNDULI
Duck Bank
MLEMIA
(Deserted)
Deserted House
MAKWIRA
C
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MALINDENI
Cashew Grove
MAPERERA
Ginnery
OHN
CHAGAMBATUKA
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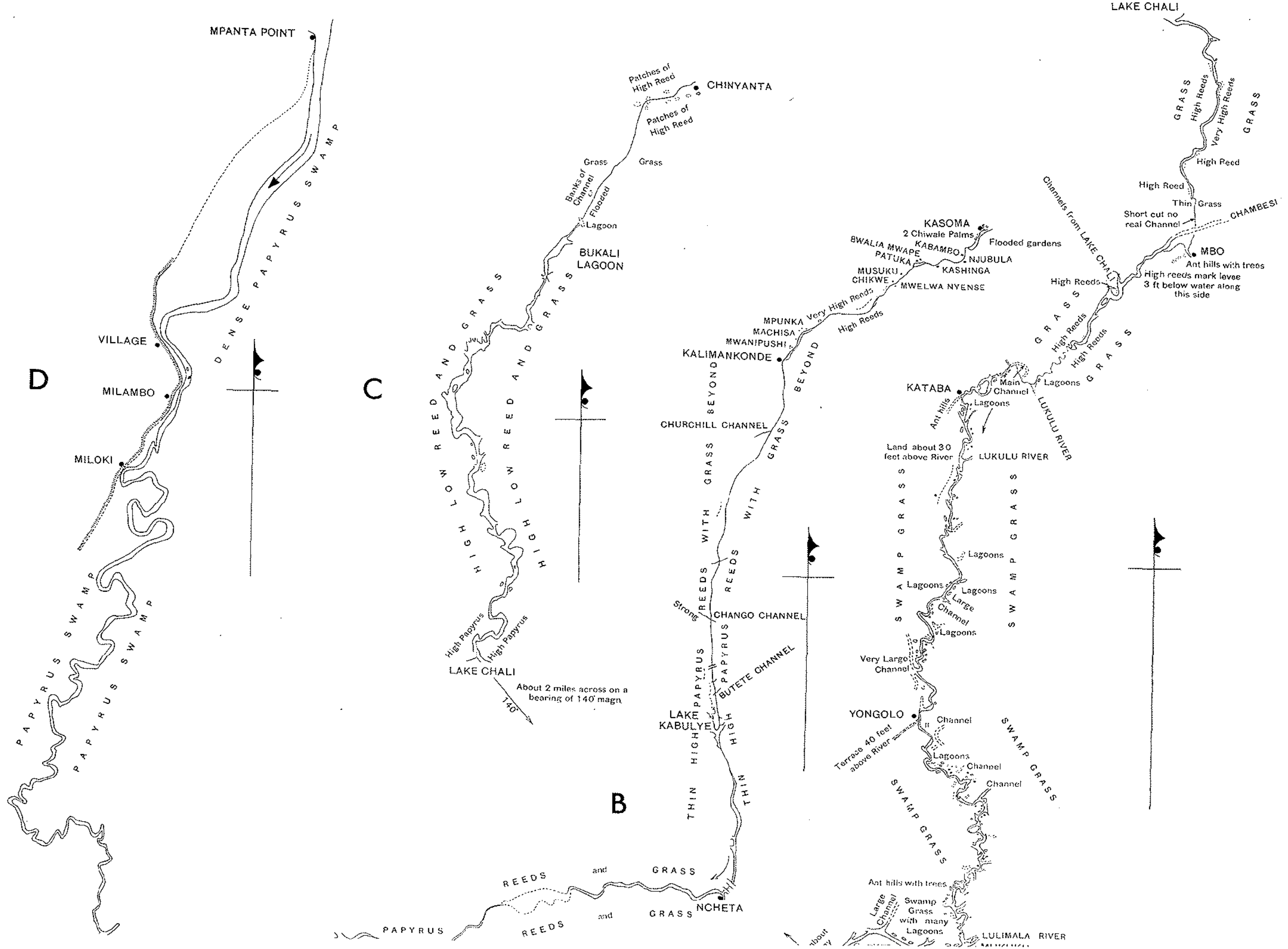
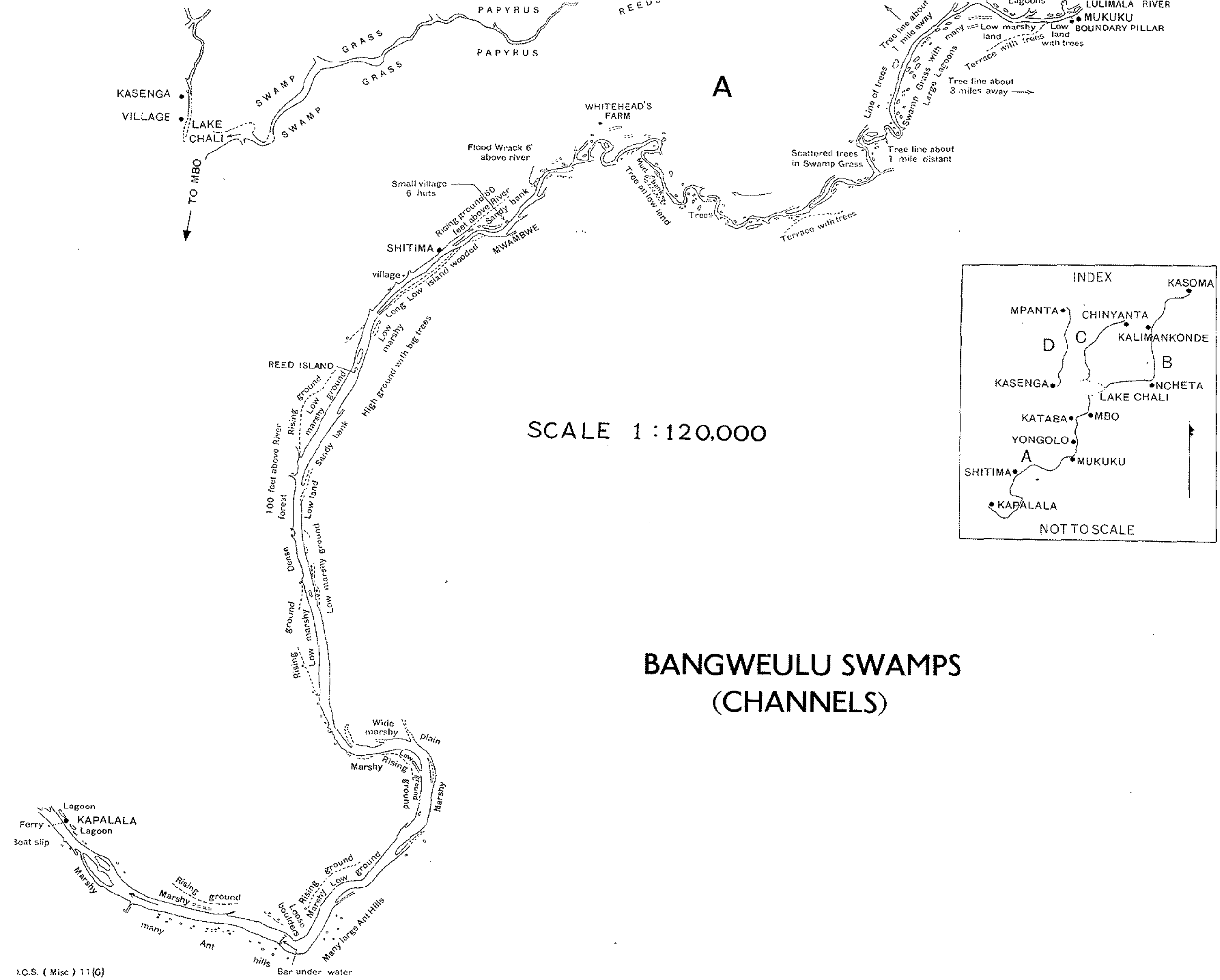
NKANDI
SINGANO
Reeds & Phragmites
BODZA
(Deserted)
R. N'KOMBEDZI
MPOZA
(Deserted)
CHIKAFA
(Deserted)
Dense Palms
MASONGOSA
D
C
D
Lone Palm
ALIMENDA
Reeds & Phragmites
Line of Palms
FORMER CHANNEL
NGALANDI (Deserted)
PAKAMWA
(Deserted)
MUNGA (Deserted)
GUNDANI
District Boundary
PATRISO
(Deserted)
ALFASI
(Deserted)
OLD CHANNEL
NANGWIRIMA
(Deserted)
Heavy Phragmites
Crocodile Bank
Reeds & Phragmites
CHAMBOTI
(Deserted)
MBENJE
E
E
Lone Palm
Very Heavy Phragmites
ALIFERI
(Deserted)
Lone Palm
Reeds & Phragmites
Flooded Land Former Plantation
R TANGAZI
2 Huts
To Elephant Marsh
To Railway Bridge at Chiromo 1 Mile
N
COMPASS TRAVERSE
OF THE
LOWER
SHIRE RIVER
NYASALAND
MADE BY PROF. F. DEBENHAM
FROM
S.S. HYDRA, JUNE 1946.
SCALE 1:75,000 APPROX.



D
MPANTA POINT
DENSE PAPYRUS SWAMP
VILLAGE
MILAMBO
MILOKI
PAPYRUS SWAMP
PAPYRUS SWAMP
PAPYRUS SWAMP
C
CHINYANTA
Patches of High Reed
Patches of High Reed
Grass
Grass
Banks of Channel Flooded
Lagoon
BUKALI LAGOON
HIGH LOW REED AND GRASS
HIGH LOW REED AND GRASS
High Papyrus
High Papyrus
LAKE CHALI
About 2 miles across on a bearing of 140° magn.
140°
B
KASOMA
2 Chiwale Palms
Flooded gardens
KABAMBO
BWALIA MWAPE
PATUKA
NJUBULA
KASHINGA
MUSUKU
CHIKWE
MWELWA NYENSE
Very High Reeds
High Reeds
MPUNKA
MACHISA
MWANIPUSHI
KALIMANKONDE
BEYOND
GRASS WITH
CHURCHILL CHANNEL
REEDS
Strong
CHANGO CHANNEL
PAPYRUS
BUTETE CHANNEL
LAKE KABULYE
HIGH
THIN
REEDS and GRASS
NCHETA
PAPYRUS
REEDS and GRASS
LAKE CHALI
GRASS
High Reeds
Very High Reeds
GRASS
High Reed
High Reed
Thin Grass
Short cut no real Channel
CHAMBESI
Channels from LAKE CHALI
MBO
Ant hills with trees
High Reeds
High reeds mark levee 3 ft below water along this side
High Reeds
High Reeds
GRASS
Lagoons
Main Channel
KATABA
Ant hills
Lagoons
LUKULU RIVER
Land about 30 feet above River
LUKULU RIVER
SWAMP GRASS
SWAMP GRASS
Lagoons
Lagoons
Lagoons
Large Channel
Lagoons
Very Large Channel
YONGOLO
Channel
Terrace 40 feet above River
Lagoons
Channel
Channel
SWAMP GRASS
SWAMP GRASS
Ant hills with trees
Large Channel
Swamp Grass with many Lagoons
LULIMALA RIVER



BANGWEULU SWAMPS (CHANNELS)

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