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The Nile Catchment
Technological Change and Aquatic Ecology

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THE NILE AS AN INTERNATIONAL DEVELOPMENT PROBLEM

By the Nile Catchment in the title of this paper I mean the whole catchment, including the river itself with its barrages, dams and reservoirs, all its tributaries, the great and small lakes and swamps, and mountain streams from which its water ultimately derives. Studies of the aquatic ecosystems of this great complex show examples of development without due regard to the possible benefits and malpractices of modern technology, and also cases in which ecological considerations have been successfully applied. One reason for chosing this ambitious case study is to emphasise the importance of treating freshwater environments in terms of catchment areas as a whole rather than individual water bodies such as particular lakes, rivers or reservoirs; and also the importance of linking developments which affect the aquatic ecosystems with other ecosystems on the land or even in the sea, for the influences of large-scale modern developments on a great river are rarely limited to the particular purpose for which development was designed.

That development of the Nile catchment presents a truly international problem is vouched by the fact that it is shared by no less than 8 countries. One thinks first of Egypt as the main receiving country, wholly dependent for its economy and the safety of its people on the controlled flow of the river. Next the Sudan which is both a receiver and giver in that the Northern Sudan depends largely on the river but the Southern Sudan ~~includes~~ provides all the tributaries of the Bahr-el-Ghazal and some of those which flow to the Sobat and Blue Nile; it ~~provides~~ gives passage moreover for the waters of the Bahr-el-Jebel and the Atbara. Ethiopia is the principal provider of water for the Atbara, Blue Nile and Sobat and in doing so it has, on account of its massive soil erosion, provided the Delta and the fertile soil of Middle and Upper Egypt - that is, until the High Dam was constructed at Aswan. The waters of the White Nile, on the other hand, are provided by no less than five countries - Kenya, Uganda, Tanzania, Congo (Kinshasa) and Rwanda, the first three sharing Lake Victoria and its tributaries, the last two sharing with Uganda the Semliki system. ~~which joins the Victoria Nile in Lake Albert.~~

The technological changes which have influenced the Nile's ecosystems during the past century are, first and foremost, the series of barrages designed to lift the water level at particular points, and of dams designed to store water or to produce hydroelectric power. Their influences have been manifold and have included, in certain cases, barriers to the distribution of flora and fauna up and down the river and, more important, the creation of large-sized man-made lakes. Coupled with the barrages and dams has been, in certain cases, the drainage of swamps to ensure more rapid run-off and the creation of intricate systems of canals and, in some cases, drains, in the irrigated lands commanded by the barrages.

Other technological influences of wide effect have come with the development of fisheries. These, in almost the whole Nile catchment, are of great importance owing to the distance from the sea and consequent lack of animal protein food in country much of which has but a meagre animal industry as a result of trypanosomiasis and other disease.

The development of transport is another technological influence which, followed by massive human travelling, has had influence both for the good and for the bad, the latter particularly noticeable in the spread of bilharziasis which is now probably the most important human disease in the catchment area as a whole. The technology of transport has also allowed, indirectly, the importation and escape of certain alien species, including aquatic plants, which have caused great trouble and expense.

But perhaps even more important than these changes (dare we say it) has been the technology of Pax Britannica. Gradually, during the last century and a half, until the independence of all countries of the Nile during the present generation, Britannia crept up the Nile in the wake of men like Baker, Kitchener, Lugard, the 'bog barons' of the Southern Sudan, and the political and technical officials of colonial government. She has provided the background for all other change.

My own qualifications for writing on this subject are that the mysteries of the Nile, and particularly of the countries and lakes at its head waters, have proved irresistible since university days. I regret, however, that owing to the time factor, this paper has had to be prepared "off the cuff".

THE EVOLUTION OF AFRICAN AQUATIC ECOSYSTEMS

~~To understand the ecosystems as they are today one must delve into the geological past.~~ In terrestrial biology one can recognise a number of biogeographical regions, each of which has a characteristic facies in its flora and fauna, and the two principal ones in Africa are the Ethiopian region to the south of the Sahara and the Mediterranean region to the north. There are, of course, subdivisions such as the extreme south of Africa with its unique Cape Flora; but broadly speaking the mechanisms for distribution of terrestrial organisms is such that Africa south of the Sahara is one, north of it is another. For many millennia the desert has been the principal barrier to distribution. Not so, however, with aquatic organisms, for the Nile itself provides a main route between the Ethiopian and Mediterranean regions. For all fresh waters in Africa we have to recognise a number of separate regions, or sub-regions. Among them the most clear-cut are the Nilotic, Congoan, Zambesian, Victorian and Tanganyikan. Judged from its indigenous fishes, and some other groups, each has its own distinctive fauna but their similarities are such that all must at some time or other have been in contact. This must have been when the original land mass of Africa had eroded to a great peneplain and there was probably a divide between east and west in the neighbourhood of the present eastern short of Lake Victoria. Then came Tectonic movements - the eastern and western Rift Valleys were created and the saucer-like depression of Lake Victoria and Kioga between them. The original drainage pattern of consequent rivers was drastically altered and was further diverted and dammed by volcanic activities associated with the rift faulting. On top of such changes came the series of pluvial and interpluvial periods which caused some isolated basins to spill over - Lake Rudolph for instance into the Nile - and others to dry up, or nearly so - for instance, Lake Victoria, thereby exterminating most of its former Nilotic fauna.

During all this time evolutionary change, especially of the fishes, was proceeding wherever the gene flow within uniform populations was impeded by geographical or ecological isolation. So today nearly every lake or river of Africa has its own list of unique forms which are found nowhere else in the world. Organic diversity is very great - some 2,000 species of African fresh water fish have been described, compared with ~~the 50 or so~~ less than 100 to be found in Europe.

An illuminating example of these changes in drainage system is the first great dam on the Nile system which was created some 10,000 or 20,000 years ago when the Mufumbiro volcanoes sprung from the floor of the western Rift Valley and ponded the Rutchuru River, an upper tributary of the Semliki system. The result was the drowned valley of Lake Kivu which, having formerly drained northwards to the Nile, spilled over to the south and so into Lake Tanganyika. This surprising change in drainage is well documented, not only by the geological evidence but, also, by the distribution of fauna. For example, a well-known sporting fish, Barbus altianilis, which many an angling visitor has caught at the source of the Nile from Lake Victoria, was cut off and still persists in Lake Kivu and the River Ruzizi which now drains it southward.

The natural productivity of these waters is sometimes great, sometimes small, dictated by a combination of physical and biological factors which are dependent on this geological history. In general the deep lakes have a much lower productivity than shallow ones, because in the tropics a permanent thermoclyne is generally formed at about 100 metres below surface, and this locks up the nutritive salts in the depths beneath. For this reason Lakes Tanganyika, Malawi and Edward have a much lower productivity per unit area than, say, Lakes Kioga or George which are so shallow that the nutritive salts are continually in recirculation.

FAUNA AND FLORA OF THE NILE

The Nile catchment today includes two quite distinct aquatic regions, the Nilotic and the Victorian. The former extends from the Delta the whole way upstream to the Murchison Falls, above Lake Albert on the Victoria Nile, and the Semliki Rapids on the branch which drains from Lake Edward. Below these barriers the fauna of fishes is very rich in families and genera and includes important large predators such as the Nile perch (Lates) and tiger fish (Hydrocynus). Above the barriers, i.e. in Lakes Kioga and Victoria and their tributaries, and in Lakes Edward and George, there is a fish fauna greatly impoverished in families and genera but with wealth of closely related species, most of them unique to this part of the world, having come into existence through local speciation in recent geological times. The reasons for this great distinction between Nilotic and Victorian fauna is a long story but fossil evidence shows that once the whole Nile was one from the faunistic point of view. Disaster overcame the lakes at the head waters, probably through drought during an interpluvial period, though some would say through the heat and toxic chemicals of volcanic activity. At all events most of the original fauna was destroyed and the present fauna of the Victorian region, poor as it is in familes and genera, but rich in species, has come into being largely through very recent evolution.

Associated with this difference in fauna is another factor of importance, namely the length of the food chains. In the Nilotic region, with abundant and varied predators, a typical food chain may consist of six links from microflora, through microfauna, insect larvae, small, intermediate, and large fish, before man and crocodile are equated against each other at the top. At each link theoretical productivity is reduced to about one-sixth, so that one cannot expect very heavy fish crops from such waters - between 20 or 30 kilogrammes per hectare would be good. By comparison the principal food chain of Lake George is Algae - Tilapia - Man, and this vast, natural fishpond has one of the highest natural productivity rates known anywhere in the world - over 100 kilogrammes of fish per hectare.

In all such matters there is much scope for research and for argument. For instance, specialists are by no means agreed whether the presence of crocodiles is good or bad for fish production. Apart from damage they cause to nets, some conclude that, by eating more piscivorous than herbivorous fishes, they allow a larger crop to be available to man (Cott, 1961). However, a quirk of geological history which obliterated the original fauna of Lakes Edward and George, also obliterated the crocodiles which, as shown by fossils, formerly inhabited these lakes. Thus a natural experiment was started and the ecologists can now draw the results. Without going into details the fisheries of Lakes Edward and George, in the absence of crocodiles, run at a consistently higher level of productivity than those of the bays of Lake Victoria, in their presence.

This, however, is no good argument for the persistent dessimation of the crocodile populations which has been going on throughout Africa during the past 20 years. The crocodile has proved to be an important natural resource in its own right with a high value in the skin trade. Moreover, in certain national parks, notably that surrounding the Murchison Falls in Uganda, the crocodile, though even here sadly reduced in numbers by poachers, is a major attraction to tourists. Indeed, so important is the crocodile in certain conditions, that I am sure we shall see crocodile farms being established before many years are out, and from these it should be possible to re-stock certain waters where this reptile could, or should, be a resource of major importance.

Another interesting problem in productivity, obvious to those who have visited national parks within the Nile system, relates to the hippopotamus. To what extent do these animals benefit fish production by eating vegetation from the land by night and dumping it as faeces into the water by day? Like the crocodile, the hippopotamus was exceedingly abundant through all the upper Nile catchment area until about 30 years ago, since when it has been drastically dessimated. However, protection in certain national parks and reserves has shown how rapidly this great animal, which has few enemies, can multiply in favourable conditions. The result is that, to avoid gross overpopulation by hippos, some thousands are now cropped each year from the reserved areas and contribute significantly to local meat supplies. By consuming great quantities of swamp and grass vegetation which would otherwise be wasted, the hippo is a most useful creature, so here again I hope we shall see hippo rearing encouraged and a policy adopted of re-stocking many of the swampy coastlines around Lake Victoria and Lake Kioga, for example, in the double interest of providing meat supplies and improving fisheries.

THE NATURAL NILE FROM SOURCES TO MOUTH (Figure 1)

Every natural ecosystem is so complex that the science of ecology is apt to get wrapped up in endless description. This gives it a bad name compared, say, with the more experimental branches of biology, because, in drawing conclusions from descriptive ecology, an element of subjective thinking is almost inevitable. ~~and this is anathema to the experimentalist with his concentration on pure objectivity.~~ Good ecological conclusions come generally from comparison of one situation with another, and the more diverse the situations the more clear cut are the conclusions. Here in the Nile catchment we have not only markedly diverse ecological situations, such as the contrast in the fauna between the Nilotic and Victorian sub-regions, and the presence or absence of crocodiles; but also we have a number of major ecological experiments which have drastically changed the natural systems as a result of Nile control. In order to clarify these situations it is necessary to trace the Nile in its natural state from sources to mouth and then to follow the sequence of its control. The latter is most conveniently done from mouth to source since most of the economic initiatives arose from the interests of Egypt.

The Victoria Catchment

Starting then from the ultimate sources of the Nile - the tributaries of the Kagera River in Rwanda which make the Nile the longest river in the world - the first major feature is a great series of papyrus swamps through which the Kagera meanders before the more rapid reaches as it approaches Lake Victoria about half way down its western shoreline. The papyrus swamps, which cover vast areas in most parts of the upper Nile catchments and again in the Sudd area of the White Nile in Sudan, indicate a considerable alkalinity of the water, caused more by soda than by lime. Although many attempts have been made to utilise these great reserves of vegetation for paper-making, fibre for sacks and ropes, none can, I think, be deemed an unqualified success. As sponge-like water reservoirs these swamps have undoubted importance, but this is counterbalanced by the enormous loss of water through the transpiration stream, probably substantially more from a papyrus swamp than from an equal area of free water surface. As a medium for aquatic and terrestrial animal life they have severe limitations owing to complete deoxygenation of the water below the surface film which enables only those invertebrate animals and fishes to survive which have air-breathing adaptations. The vegetation of a papyrus swamp, though by no means limited to the papyrus plant itself, is not particularly attractive to terrestrial mammals, although it provides good cover and a modicum of sustenance to such animals as buffalo and elephant during the dry seasons when resources of truly terrestrial vegetation tend to be exhausted. When drained the deep, peaty soil of these swamps will grow good crops for a few years, but their rapid exhaustion when oxygenated at tropical temperatures, coupled with the accumulation of certain toxic agents, presents a tricky problem to agriculturalists.

Lake Victoria itself, 67,000 square km. in extent, is nowhere more than 90 metres deep and so has a higher biological productivity than the deep Rift Valley lakes. It acts as a magnet to human populations and many African tribes have accumulated round its shores. But the fishery, though it employs very many people, is even today limited to the inshore waters, a fact which is connected more with fish ecology than with the capacity of boats to operate in the open water.

The exit of the Nile on the northern shore of Lake Victoria over the Ripon and then Owen Falls, which in its former natural state was one of the great shrines of explorers, presented a partial barrier to the movement of aquatic fauna, but was surmounted, even in the upward direction, by certain of the more active species. The early torrential reaches of the Victoria Nile and the great, swampy and lily-clad waters of Lake Kioga into which they debouch, thus have an aquatic ecology similar to, though in some respects differing from, that of Lake Victoria. Lake Kioga is nowhere more than some 6 metres deep and large parts are less than 3 metres and are covered by a continuous growth of water-lilies. The shoreline is fringed with papyrus swamp which in some parts forms a belt several miles wide between land and water. Such a situation tends to very high biological productivity but somewhat specialised methods of fishing are needed if this is to be used for the benefit of mankind.

Lake Kioga takes additional drainage from the eastern part of Uganda. The exit from its western end, passing Atura, soon tumbles over the 150 vertical feet of the Murchison Falls, an absolute barrier to most aquatic organisms as already mentioned.

A close look at the boiling waters below the falls immediately bring out the contrast in the whole facies of the fish fauna. Up above there were *Tilapia* and *Haplochromis* of many species, nothing more than 1 lb. or so in weight except the cat-fishes (*Clarias* and *Bagrus*), Lung-fish, and *Barbus*. Below are great Nile perch up to 100 lbs. or more, active tiger-fish up to 5 or 10 lbs., silvery *Citherinus*, the shape of angel-fish but very much larger, Distichodus, which feeds on aquatic weeds, and a dozen more which are completely unknown above the falls. There are also great leathery water tortoises (Trionix), which from time to time stick up their narrow, pointed snouts for a breath of air. Like most of the fishes, Trionix is unknown from Lake Victoria and adjacent waters, except in the fossilised state. This Nilotic aquatic fauna continues from Murchison Falls right down the Nile though it has been thinned out in Egypt through human agency.

The Semliki Catchment

Turning to ~~the~~ other sources of the White Nile, Lakes Edward and George lie in a branch of the eastern Rift Valley just south of the Ruwenzori. The former is relatively deep (117 metres) and so its lower waters are stagnant, very rich in nutrient salts but deoxygenated and stinking of H_2S. The latter is very shallow, mostly no more than 3 metres, in constant circulation, and turbid, rather like green pea soup. Both have fauna showing certain affinities with Lake Victoria but some speciation of their own, and the shallow waters of both have high productivity, though Lake George much more so than Lake Edward.

The Semliki River, which drains Lake Edward to ~~the south end of~~ Lake Albert, is broken by a series of rapids, and it remains something of a mystery why the Nilotic fauna below, including even crocodiles, have never succeeded in reinvading Lakes Edward and George. That they were there before the event which destroyed the former Lake Edward fauna is proved by fossils.

The White Nile

Lake Albert, which collects the waters from both Victoria Nile and Semliki, is a big lake by any standards, although not so vast as shown in Sir Samuel Baker's original sketch map. It lies in the western Rift Valley between impressive escarpments, and when I of its water deeper than 48 metres. This implies that the water is frequently mixed from surface to bottom. The fishery is important to both the Congo and Uganda.

Below Lake Albert, proceeding northwards, the Albert Nile has a long slow-flowing swampy reach to Nimuli on the Sudan border, around which it receives several torrential rivers from the east. Then after the Fola Rapids the river, now called Bahr-el-Jebel, soon enters the Sudd which continues for some 300 miles or so to Lake No. This vast area of papyrus and reed swamp, includes that around the lower waters of the Bahr-el-Ghazal, which here enters the river from numerous western tributaries.

The Sudd region, which provides a unique biome, is of enormous importance to Nile hydrology. The transpiration stream through its swamp vegetation accounts for no less than half the total flow of the White Nile and this huge amount of water entering the atmosphere undoubtedly affects the ecoclimate locally, if not the precipitation. Important also, in relation to the subsequent use of the White Nile's water, is the fact that the Sudd removes chemical salts from the water with the result that the Nile below this area, though half as much in quantity, has a significantly smaller chemical load per unit volume than in the Bahr-el-Jebel above. This is important to the use of this water in irrigation. Much of the current knowledge about this part of the Nile catchment was gleaned by the Jonglei investigation team (1955) which studied the area from 1948-1953. A considerable number of trained scientists were concerned with hydrology, ecology, the human inhabitants, animal and grass husbandry, crop husbandry and fisheries.

A little further downstream, near Malakal, enters the Sobat River which drains a good portion of south-east Sudan and south-west Ethiopia and once, also, served as the overflow from Lake Rudolph. This great lake, though now in a closed drainage basin, its water highly enriched with soda, must be classed with the Nile from the biological viewpoint. Its fish fauna is purely Nilotic, proving the former connection although the time of isolation since connection with the Nile during the pluvial periods, has been such that speciation, ~~having taken place in isolation,~~ in certain cases warrants sub-specific and even separate specific rank.

The Blue Nile and Atbara

We must now look at the Blue Nile which, though much smaller than the White Nile on the map, ~~contributed~~ contributes, on average, more than twice the amount of water. Compared with the White Nile system, whose flow is retarded by the tremendous series of natural lakes and swamps, the Blue Nile is a flash flood stream, the great bulk of its flow arriving in August to November following the summer rainfall of the Ethiopian highlands. Lake Tana, at its source, is isolated from the lower river by the high Tsitsisit Falls in much the same way as the Victorian region is isolated from the Nilotic by the Murchison Falls. In isolation Lake Tana, like Lake Victoria, has produced some remarkable unique kinds of fish and other fauna, although, oddly enough, different groups of fishes are involved.

Associated with the flood period the main characteristic of the Blue Nile is the enormous quantity of silt carried down from the plateaux and mountains of Ethiopia, which are heavily cultivated right up to 12,000 and 13,000 feet with almost no forest left. ~~even at the summits~~. The "Brown Nile" would be a better title, for it is blue only during the period of low flow when, before control ~~under the natural conditions~~, the soil of Ethiopia had been swept down to the Mediterranean, forming the Nile Delta on the way.

Well below the junction of the two Niles at Khartoum the joint river receives the Atbara, also from the east. Like the Blue Nile, the Atbara drains a substantial part of the Ethiopian highlands, and behaves like the Blue Nile with big, late-summer floods. But it is completely dry in most years from about November till June.

The crude outline of the hydrological regime is that, in September, the average discharge of the total Nile is around 700 million cubic metres per day, of which about 20% comes from Atbara, 70% from Blue Nile and only 10% from White Nile. At the opposite time of year in April, when the total flow is no more than 50 million cubic metres per day, more than 80% is from the White Nile, less than 20% from the Blue, none at all from the Atbara. (Figure 2) The difference in behaviour of these major tributaries provides the basis for control which we can now consider.

THE CONTROLLED NILE FROM MOUTH TO SOURCE (Figure 3)

Hydrology and Population

From the hydrological point of view the Nile is the best-known of all big rivers, at least in its lower reaches. The ancient Egyptians recorded river levels on nilometers four or five millennia ago and some of these nilometers can be seen today. For the river at Cairo there is in more recent times a fairly complete series of maximum and minimum annual levels from 641 AD to 1450 AD and onwards with interruptions, on the Roda Island gauge. At Aswan levels have been recorded since 1870. But it was only during the present century, especially since the 1914/18 war, that the study of the Nile and its tributaries was greatly intensified. This has been the great work of Dr. H.E. Hurst who, having handed over to his Egyptian colleages many years ago, still, at the age of 88, is retained as hydrological

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In the ancient past, and until the present century, control of the Nile was the concern of only one country - Egypt. We are accustomed to think of overpopulation problems as a modern trouble, but Egypt, which has been since time immemorial one of the richest and at the same time one of the smallest countries - the inhabited area even today is only the size of a large English county - has been through it before. Indeed, the history of ancient Egypt shows cycles of prosperity followed by disaster, and there is not much doubt that they were accompanied by, and perhaps caused by, big increases of population. One of the first of these cycles, dating back some 5,000 years, preceded the construction of the pyramids of Giza after one of the many invasions of Egypt and the introduction of new blood. A period of prosperity and population increase followed. Then it seems that the population became excessive and, in order to find work for the surplus people, the powers-that-be ordered the construction of the pyramids. The population was still there, however, and still went on breeding. There followed a blank of 400 years in the records of Egypt (W.L. Balls, 1944).

Coming to modern times, the population of Egypt at the beginning of the 19th century is estimated at about $2\frac{1}{2}$ million, but by 1850 it had doubled to 5 million. The first modern census of 1897 gave a figure of $9\frac{3}{4}$ million, and by 1950 it was put at 19 million. The latest census, of 1960, gave a total of almost 26 million. Thus the population seems to have doubled each half century, with a tendency now for the rate to accelerate. The density on the arable land is now about 730 per square kilometre.

The Barrages

Early in the 19th Century that far-sighted man, Mohammed Ali Pasha, became Governor of Egypt He started the great series of barrages which function, not to store water, but to lift the level of the river in order to command a system of canals at all times of the year. This allowed the changeover to start from the old basin or annual "slosh" irrigation to perennial irrigation, so that instead of one crop being grown a year, two, three or even more crops could be grown on the same land. Mohammed Ali built the Delta Barrage just below Cairo to control the Rosetta and Damietta branches of the Nile. Its architecture was reminiscent of a mediaeval castle, but it served well, and was not replaced by modern work until 1940. Since then the Mohammed Ali Barrage has commanded the whole Delta, aided by the Zita Barrage on the Damietta branch.

The next barrage, at Asiut, was not constructed till 1902, enlarged in 1938; it provides for perennial irrigation in middle Egypt with one of its canals running as far as the Fayum. Next to be constructed, in 1908, was the Isna Barrage, and the latest at Nag-Hamadi in 1930. Both these are in upper Egypt and were designed to improve the water supply for basin irrigation. That is now changing since the High Dam at Aswan enables the whole of Egypt to change over to perennial irrigation.

The Dams

We must now consider the great dams which have a function entirely different from the barrages. The need for storing Nile water when the river is at high stage, that is, when the Blue Nile and Atbara are in flood, so that more could be available at low stage was appreciated well before the end of last century. And that mighty granite edifice, the first Aswan Dam, was completed in 1902. The capacity of its reservoir was more than doubled at the first heightening in 1912 and multiplied five-fold in 1934. The final dam contained a little more than half as much masonry as does the great pyramid of Giza.

The old Aswan Dam, when at full storage, held up the flow of water as far upstream as Wadi Halfa and after the end of each storage period the sluices were opened to drain most of the lake and wash the accumulated silt downstream, much of it into the basins where agriculture benefitted from this annual contribution of fertile topsoil.

The new High Dam, impounding behind it the vast Lake Nasser of some 5,000 square kilometres, which will never be drained, must cause a revolution in Egyptian irrigation. Practically all the fertile silt from Ethiopia will be deposited in the lake, not on the agricultural land below the dam. While this has certain obvious disadvantages, the extra water in store, and the reduction of the silting factor in the irrigation canals, allows a total changeover from basin to perennial irrigation as well as a significant increase in the irrigated area.

Although the great engineering works on the Nile are thought of primarily as providers of water for irrigation, they have another function in flood control, and this can be of supreme importance in a flat country which lies at an altitude below that of its waterways. The great disaster of ~~1885~~ the 1880s when the banks burst in lower Egypt and a very large, but unknown, number of people were drowned, is no longer fresh in people's minds, but there have been several touch-and-go occasions since then. In the autumn of 1946 when the Blue Nile and Atbara were having their second-highest flood on record, I happened to be, for an hour or two, in the Physical Department in Cairo. Few of the engineers had slept for several nights because they were lining the banks with sandbags. All available water storage was at full capacity and yet the Nile kept rising. Telegrams and telephone calls poured in from minute to minute. On that occasion the upstream pressure was relieved by the river flooding over its banks below Khartoum and little damage was occasioned, but it brought home the need for strict working of every control point on the best hydrological advice. Now the Aswan High Dam provides storage against flood control as well as for irrigation, and for that reason is never allowed to fill up. But woebetide Egypt if ever its storage capacity should be over-stretched before a season of exceptional Blue Nile and Atbara flow.

Effects on Aquatic Life

In this paper I am concerned primarily not with the effect of control on agriculture, nor on flood risk, but on aquatic ecosystems, and we can divide this clearly into the influences on the waters of the irrigated lands on the one hand, and of the impounded lakes on the other. In the past one of the biological problems of the canals has been the growth of water weeds, nurtured no doubt by the deposition of fertile silt, thereby providing an ecosystem highly favourable to those kinds of water snail which are the intermediate hosts of Schistosoma. Schistosomiasis, in its urinary and rectal forms has been, and still is, the bane of Egypt and of most other irrigated lands in warm climates. Vast tonnages of copper sulphate and other herbicides and moluscides have been dissolved in the canals of Egypt to create partial control of the disease. This has killed or starved out most of the snails, fish and other aquatic life. Let us hope that the changes offered by the water from Lake Nasser will help toward a new approach to schistosomiasis control.

The great basins of upper and formerly also of middle and lower Egypt were important as temporary sites for aquatic life. Submerged for a period under a foot or two of water, they produced quantities of algae, a rich insect fauna, and rapidly-growing fish crops from the fry washed in with the irrigation water. The algae may well have contributed to fertility through the fixation of atmospheric nitrogen, the insects were mostly eaten by fish which, in their turn, were collected and consumed by the people as the waters drained away. From a health point of view, although the basins may have contributed in the past to ~~serious~~ epedemics of malaria in upper Egypt from population explosions of *Anopheles gambiae*, the aquatic habitats of the basins did not last long enough to be a major hazzard. Perennial irrigation, however, provides permanent aquatic ecosystems and certainly encourages the debilitating, though not usually killing, diseases of schistosomiasis and hookworm.

Interest in the aquatic ecosystems of Lake Nasser itself centre around the potential fishery and here, as in all other large man-made lakes, there are great opportunities for the ecologists to predict and take advantage of the changes involved by impoundment. Lake Nasser is unique among the great man-made lakes in that, being formed largely on desert, there are no problems of submerged trees. The lake provides new opportunity for the Nilotic fauna which in Lake Albert and Lake No is already well adapted to lake conditions. However, the interests of fishery development and of the irrigation engineers may sometimes come into conflict. When I was at the High Dam during its construction, the engineers were talking about the possibility of saving a huge amount of water, which would otherwise be evaporated from the surface of Lake Nasser, by attempting to keep it covered with a film of ethyl alcohol. I doubt if this will be practical, but if it is, to break the gaseous exchange between hydrosphere and atmosphere will have a considerable influence on biological productivity and fisheries.

Equatoria

The rather attractive little town of Wadi Halfa is now under water and Abu Simbel is perched upon its new emminence. We have to go far upstream, past Khartoum to Jebel Aulia on the White Nile, to find the next dam, which was completed in 1937. Its function is to hold back part of the White Nile while thb Blue Nile is in flood; but since the valley above Jebel Aulia is very flat and open (at maximum capacity the reservoir extends 300 miles upstream), a great deal of water is lost by evaporation and seepage. This is a man-made lake of no mean proportion, though hardly comparing in size to Lakes Nasser, Volta or Kariba. Fortunately, through the excellent scientists available in the Sudan, the Jebel Aulia lake has been studied rather thoroughly from the viewpoints of medical entomology, and the other fauna and flora. The fisheries have proved to be highly productive and profitable, and, once the lake had settled down to its annual regime, the health risk was less than had been feared.

The whole complex of the White Nile upstream of Jebel Aulia has great possibilities of control, wide implications on agriculture, fisheries, hydroelectric power, as well as in delivering water in the right quantities and at the right time to the lower Sudan and Egypt. Before the High Dam became practical politics lthe hydrology of this region was studied in detail by H.E. Hurst (Vol. 7 of the Nile Basin and elsewhere) in connection with his theory of century storage, so that major works of control could be planned toguard against the variations of precipitation and evaporation and consequent variation in the flow of the river. The needs for such control works have been reduced by the huge storage in Lake Nasser, but there is no doubt that proposals ;will be made again in the future, though perhaps with rather more emphasis on the advantages to the countries of the upper Nile and rather less to Egypt.

Proceeding southwards the first project which has been worked out in detail was the Jonglei Canal, intended to by-pass the Sudd area from a little north of Juba to the main river south of Malakal, a distance of some 300 miles. It would take about half the flow past the Sudd with minimum evaporation loss, leaving the other half in the natural channel. Thereby the 50% loss under the natural regime would be reduced to about 25%. Above Nimuli there was planned for the Albert Nile, though never brought down to a specific project, a storage dam ~~up to 30 metres high~~ which would have greatly increased the size of Lake Albert and provided the main controllable storage of White Nile water. Between the Murchison Falls and Lake Kioga it was thought that a barrage would be needed at Atura in order to let out from Lake Kioga as much water as enters it from Lake Victoria and thereby avoid major loss through backing up in the papyrus swamps.

Owen Falls

At the outfall of Lake Victoria itself, an event took place in April 1954 which made the dream of a great British Colonial Secretary come true:- "What fun to make the immemorial Nile begin its journey by diving through a turbine!" (Winston Churchill, 1908).

The Owen Falls Dam, the first control work on the upper Nile which is in the interest of the local countries as well as of Egypt, has hydroelectric power as its primary function but, at the same time, it controls the outflow of Lake Victoria which it thereby converts into the largest reservoir in the world. This project was put forward in 1946 in connection with the first 10 year UGANDA development plan (Worthington 1947), and was designed to bring the requirements of Uganda into line with those of Egypt. It was worked out at the technical level during 1947/48 at meetings between Uganda, Egypt and the Sudan, and also with Kenya and Tanganyika which are affected by the level of Lake Victoria. In order to help rectify the serious lack of data about the hydrology of Lake Victoria, the Uganda hydrological survey was inaugurated at the same time. The stage of dimlomacy, leading to formal agreement, followed soon afterwards.. The Uganda Electricity Board was created to take general charge and to arrange the finance: Uganda was to pay for the main dam and installations and Egypt for the extra few metres on the dam to provide for water storage in Lake Victoria, as well as compensation around the lake shore consequent on the change of level. Engineering consultants on the civil and electric sides soon worked out the details; contracts for the construction and supply of equipment were let. When Her Majesty Queen Elizabeth pressed the button to start up the generators, less than 8 years had elapsed from writing the original proposal, which for a work of this magnitude and international complexity, is perhaps a record.

Recognising that the provision of relatively cheap electricity would lead to a rapidly increasing demand, including industrial demand, the Owen Falls scheme was considered from the beginning as one of several which could be created on the Victoria Nile, taking advantage of the considerable drop in elevation from Lake Victoria to Lake Kioga. However, rather than proceed with the second of these the Uganda Government now proposes to go to the Murchison Falls, one of the wildest and most beautiful places left in Africa, and to exploit the hydroelectric potential there instead. The Murchison Falls, lying at the heart of the National Park of that name, have become a point of pilgrimage for tourists throughout the world. It is not surprising, therefore, that on scientific and aesthetic, as well as on economic grounds, this new project is a matter of international as well as national controversy.

All these river control works, existing or projected, have considerable influence on the aquatic systems. The Jebel Aulia Dam, in addition to creating a new and important fishery, undoubtedly impedes the movement of migratory fish up and down river. A fish ladder was installed as part of the barrage, but it is not in a good situation and almost certainly stops the passage of most of the Nile perch which tend to accumulate in large numbers below. The question of installing a fish ladder at the Owen Falls Dam was carefully considered, but knowledge of the fish ecology of Lakes Victoria and Kioga was such that a decision could be taken against it. The grounds were that only a few species of minor ecological and economic importance were capable of surmounting the former Ripon Falls in the natural state.

The Blue Nile

Turning now to the Blue Nile, the Sennar Dam, which was commenced in 1914 and completed in 1925, serves the needs of the Sudan more than those of Egypt. Its main function is to provide water for the Gezira irrigation scheme which still provides the basis for the Sudan's economy. It does this in two ways: by raising the water level to command the Gezira Canal during the time of high Nile, and by storing water in the period of falling flood for use in the season of low water. When first built a fish ladder was provided but this was soon destroyed and has never been rebuilt.

~~Much~~ Further upstream, near the Sudan-Ethiopian border, is the Roseires Dam and reservoir. This was completed in 1966 and has the primary purpose of greatly increasing the Blue Nile storage, previously available only at Sennar, and also has a hydroelectric installation. The reservoir is over 50 miles long with a maximum depth of about 50 metres and is under study by the hydrobiological research unit of the University of Khartoum. The water stratified soon after filling with complete deoxygenation of the lower layers and, in 1967 there was a heavy fish mortality when deoxygenation affected all the water temporarily. An interesting biological event here has been the elimination of large beds of the Nile oyster (Etheria eliptica) which have been smothered by enormous quantities of silt deposited in the upper reaches of the lake.

Far above Roseires, past the Blue Nile Gorge, which is still very little known, Lake Tana has been an attraction for many years to those concerned with Nile control. At one time it appeared a good place for a storage reservoir to hold back a proportion of the Blue Nile flood, but Ethiopian interests around the lake, including historic and religious sites on the islands, made this impossible. The most that might be done is a regulating weir at the lake's outfall. This project, like those on the upper White Nile, has been deferred owing to the High Dam at Aswan. If a barrage is ever made it would have little effect on hydrobiology because, as already remarked, the Tsisisit Falls already provide a major barrier to the movement of aquatic life into and out of Lake Tana.

From the viewpoint of biological productivity and food production, in spite of temporary setbacks such as the fish kill at Roseires through deoxygenation, there can be no question that, in the Nile basin at least, the flooding of land for water storage leads to a far higher useable production of the area concerned. Desert, savannah and swamp, which are the three kinds of land used for this purpose, are not nearly so productive in terms of human needs as water with its fisheries and opportunities for transport and agriculture around the shoreline. The only exception to this is the drowning of Wadi Halfa and its agricultural settlement under the waters of Lake Nasser.

FISHERIES

Fisheries in the whole Nile system have always been important in providing protein food. The entire human population in the catchment area, with the exception of those in the Nile delta, are far from the sea and the communications thereto are poor so the amount of sea fish brought to them is small. Even the dense population of the delta ~~derive~~ get ~~but little sustenance from the Mediterranean, for~~ a large proportion of their fish ~~comes~~ from the delta lakes: which, in terms of production per unit area, are among the most productive fisheries in the world. Deriving their water from irrigations drainage these delta lakes are also part of the Nile's catchment.

Introduced and Indigenous Methods

European methods of fishery technology and fishery management began to penetrate Egypt in the latter part of the 19th century though it wasn't till well into this one that fisheries research got started there. Once upstream of Khartoum, however, the fisheries, though they had undoubtedly existed in almost every lake, river and swamp since time immemorial, relied entirely on indigenous methods until this century and, in most of the waters, until after about 1930. Many of these indigenous fishing methods, based as they were on local materials, were efficient. The combination of many varieties of basket-trap, fished alone or in association with seines made of papyrus stems or banana leaves, of fish weirs across the rivers, and even something comparable with the trawl, reveal~~ed~~ a surprising knowledge of fish ecology. One fishing tribe, the Luo of Lake Victoria, had separate names for many kinds of fish and in one case the distinction of native name gave the clue to scientific distinction between closely related species. The technology of boat building throughout the Nile system was likewise locally adapted to available materials: the papyrus-bundle craft of ancient Egypt, for instance, had its counterpart in the papyrus-bundle fishing canoe of the Luo, although there is every reason to believe that this came from independent invention, not from culture contact.

When to the upper Nile and the lakes modern fishing nets of imported material were introduced the results were often dramatic. Some of the indigenous methods survived. (One was even exported, for during the war I started a food fishery for perch in English and Scottish lakes based on a design of non-return traps borrowed from the Luo and this still persists as a means of controlling perch in many British waters). Of the imported methods, the gill net of hemp or cotton twine, about five inches mesh stretched which is used mainly for *Tilapia*, was the most important. Sometimes it has led to serious over fishing.

In 1905 a Dutchman introduced this type of net to the north-east corner of Lake Victoria and it was quickly taken up by the native fishermen. To begin with the new fishery was very productive, each net during one night in the water caught an average of about 30 fish. By the 1920's, however, this fishing index had dropped alarmingly to 10 or even less, and a fishery survey of Lake Victoria was organised in 1927 (Graham, 1929). By then the index in the Kavirondo Gulf had dropped as low as 5, and our recommendations were designed to conserve the stock and maintain a permanently productive fishery. The recommendations were acted on only in part, and about 1940 the fishing index had dropped further, to 2. It is now running at a little more than 1 per net per night in spite of the boost which has come in recent years from the replacement of hemp and cotton by nylon.

Research

This classic example of gross over fishing resulting from the introduction of modern technology is fortunately not typical of all the Nile waters. For many of them the ecology was studied and recommendations for fishery management were made before the introduction of modern techniques. A major recommendation of the Lake Victoria fishery survey was that a permanent hydrobiological and fishery research institute should be established on Lake Victoria. After a respectable gestation period of 20 years, such an institute was opened at Jinja in 1947, and the era of intensive team research was inaugurated. Meanwhile, however, fishery surveys had been conducted on most of the other great lakes (Worthington 1929 and 1931) and based on their recommendations, fisheries using modern techniques were developed and supervised by a growing cadre of fishery officers.

In the Sudan also there were developments. The Game Department took a particular interest in fisheries, and in 1953 a hydrobiological research unit was established at the University of Khartoum. Egypt, meanwhile, had built up a network of fishery research, first under the direction of British scientists, who later handed over to their Egyptian colleagues. The mullet and Tilapia fisheries of the delta lakes were developed on sound conservation lines to very high productivity; the fish production of Lake Qarun and in many other Egyptian fresh waters was stimulated by stocking with mullet fry and elvers.

Now ~~we are in the era of~~ there is opportunity for more sophisticated research and in this connection I would like to refer to one of the research projects under the International Biological Programme, which is currently operating on Lake George. Here, as a joint project between Uganda and the United Kingdom a group of young scientists, financed through the Royal Society, are devoting a number of years to a comprehensive study of biological productivity. Lake George has been chosen because it of its very high fish production (see above). ~~is one of the most productive natural lakes known. About 100 square miles in extent it produces an average crop of Tilapia of about 100 kilogrammes per hectare per annum.~~ This is not the only IBP project on fisheries on the Nile catchment. For instance, by arrangements with FAO, it is intended to include within the programme the research components of several UNDP schemes of which one is now devoted to the productivity and fishery potential of the open waters of Lake Victoria, basing itself on the Research Institute at Jinja.

Introductions

The contrast between the fish fauna of Lake Victoria and Kioga, with no large predators which could be caught on a rod, and the Nilotic fauna below the Murchison Falls, where such were abundant, stimulated repeated suggestions that the Nile perch should be introduced up above. These were resisted by most biologists on the grounds that damage might be done to the economic fisheries, but in the end the introduction took place, first to Lake Kioga about 1957 and to Lake Victoria a year or two later. The result to date in Lake Kioga has been somewhat unexpected. A flourishing fishery with gill nets and long lines had been developed there and the annual catch had crept up to about 11,000 tons. As the voracious Nile perch, each capable of growing to 50 or 100 pounds, rapidly colonized the lake, the prospect looked poor for the other fishes; but not a bit of it! During the past 7 years the total catch of other fish has continued to increase, and on top of that a catch of Nile perch has risen rapidly to 7,000 tons a year. If this remarkable production is maintained it will confound the Jeremiahs, and the numerous fishermen of Lake Victoria, where the Nile perch is taking longer to get established, will look forward with some optimism. What this predator will do to the species flocks of endemic Cichlidae is another question!

A more gloomy story must be told about the introduction of the water hyacinth (<u>Eichornia crassipides</u>). A native of South America, this ornamental plant is assumed to have escaped in Africa from garden pools or aquaria. It spread with rapidity in southern Africa and caused extensive damage to fisheries and water transport. During the 1950's it invaded the Congo system where it flourished exceedingly and millions of dollars were expended in attempts at control. There were grim forebodings as to what this pest would do if it got across the watershed into Lake Victoria. In fact it has not yet reached Lake Victoria, but it appeared in the Nile below the Sudd region about 1958 and vast quantities soon accumulated in the Jebel Aulia Lake where it caused great trouble to the water engineers. Fortunately it has proved possible to get the pest under some form of control with hormone weed-killers, but it involves continuous, expensive and troublesome operations.

Eichornia will be one of the problems to be discussed at a technical meeting on the hydrological influences of aquatic vegetation, which is arranged by the IHD and IBP in December 1968.

The Mediterranean

There is one other matter in which Nile control has an important bearing on fisheries but in this case on fisheries in the Mediterranean Sea. In the old days of the natural Nile, large quantities of water, well-laden with silt and nutrient salts, poured across the delta into the Eastern Mediterranean which, except for this annual fertilization, is a sea of low biological productivity. There was a sizeable fishery, particularly in the inshore waters near the delta and up the Levant coast. Nile control reduced steadily the supply of nutrients and the position was complicated by the Suez Canal which allowed the passage of some Red Sea water and some Red Sea fauna into the Mediterranean. Now the Aswan High Dam has cut off the supply of water and nutrients almost completely, and to replace it more Red Sea water is running through the Canal. The Levant fishery is at a low ebb.

This is a complex of man-made change which is scientifically of deep interest and economically of importance to a number of countries which are concerned in the Eastern Mediterranean fishery. The IBP is planning an international meeting in October 1969 to discuss all aspects of the problem and to recommend a course of action.

CONCLUSIONS

What are the main lessons to be learned from this multiple case history?

The first conclusion is that, by limiting this paper to aquatic ecosystems, and not at the same time taking full account of the interactions between the control of the Nile and terrestrial ecology, we have seen only one side of the crystal. The terrestrial ecology which also needs to be considered includes the wild lands and tame lands. It includes animal industry, plant industry and irrigated agriculture, and it includes human ecology, that is, the activity and inactivity of the human being in health and disease.

We cannot go into all these matters here, but there is one broad obvious conclusion, namely that every project in Nile control has had to be undertaken with a strictly limited background of knowledge. As a scientist who has participated in development I have sometimes found it positively frightening to take decisions which will affect the lives of millions of people when the basic facts were unknown. ~~Sometimes~~ It felt a bit like writing the conclusions of a scientific paper before settling down to do the research!

A second conclusion is concerned with prediction. Here we have a rather marked difference between the approach of the engineer and that of the ecologist, for engineers <u>must</u> predict the future of the works they create, otherwise they could not start the designs.

Ecologists are rather apt to say that prediction is hardly worth the paper it is written on because there will always be so many unknown factors.

Each of the projects of Nile control, from Mohammed Ali's barrage onwards, involved many kinds of prediction, not only the future of the engineering works, but their effects on land and water use, agriculture, health and social change. ~~Recognising that,~~ In developing countries at least, there will never be enough funds or enough scientists to cover all aspects of information needed for thorough prediction, so it seems to me that the art of the ecologist is to pin-point those features of the total ecosystem where the limited effort can most effectively be applied. We need more ecologists with the courage of their convictions.

A third conclusion derives from every major work of Nile control and is similar to that brought out by Dr. Scudder in his analysis of the Lake Kariba situation, namely that in the original design and working out of projects the viewpoint has been unduly narrow. Usually there is but one, sometimes two, primary objectives, irrigation and hydroelectric power, and obviously the designers, financers and executors must keep these to the fore. However, every project influences a great many other subjects which may be of general importance to the country concerned or of over-riding importance to small groups of people: they are often to do with food-producing activities such as fisheries and agriculture, or with health. Each project, moreover, brings up new opportunities such as cultivation on the draw-down margins of a reservoir. The existing system, however well-intentioned, is not generally equipped to give all such matters due weight.

When all is said and done, however, the progressive steps in the control of the Nile during the 70 years or so since Sir William Willcox presented his ~~original~~ plan for the first Aswan Dam, provide an outstanding example of how the scientific and technical approach can open the door for international collaboration. This history presents a sequence, from the collection of basic knowledge about the river's hydrology, chemistry and biology (albeit sometimes meagre), the working out of projects, international agreement, financing, construction and finally adaptation to the new regime. It is surely not too much to hope that, under the independent countries which now own the catchment, the future may hold opportunities for ecology and international development no less than those demonstrated by the past.

Indeed, the opportunities should be greater, for the financial resources available through the United Nations and bi-lateral aid are larger than in the colonial era. I hope that Professor Gilbert White, who has been concerned with current developments in the Nile catchment, may have something to say about this at the Symposium.

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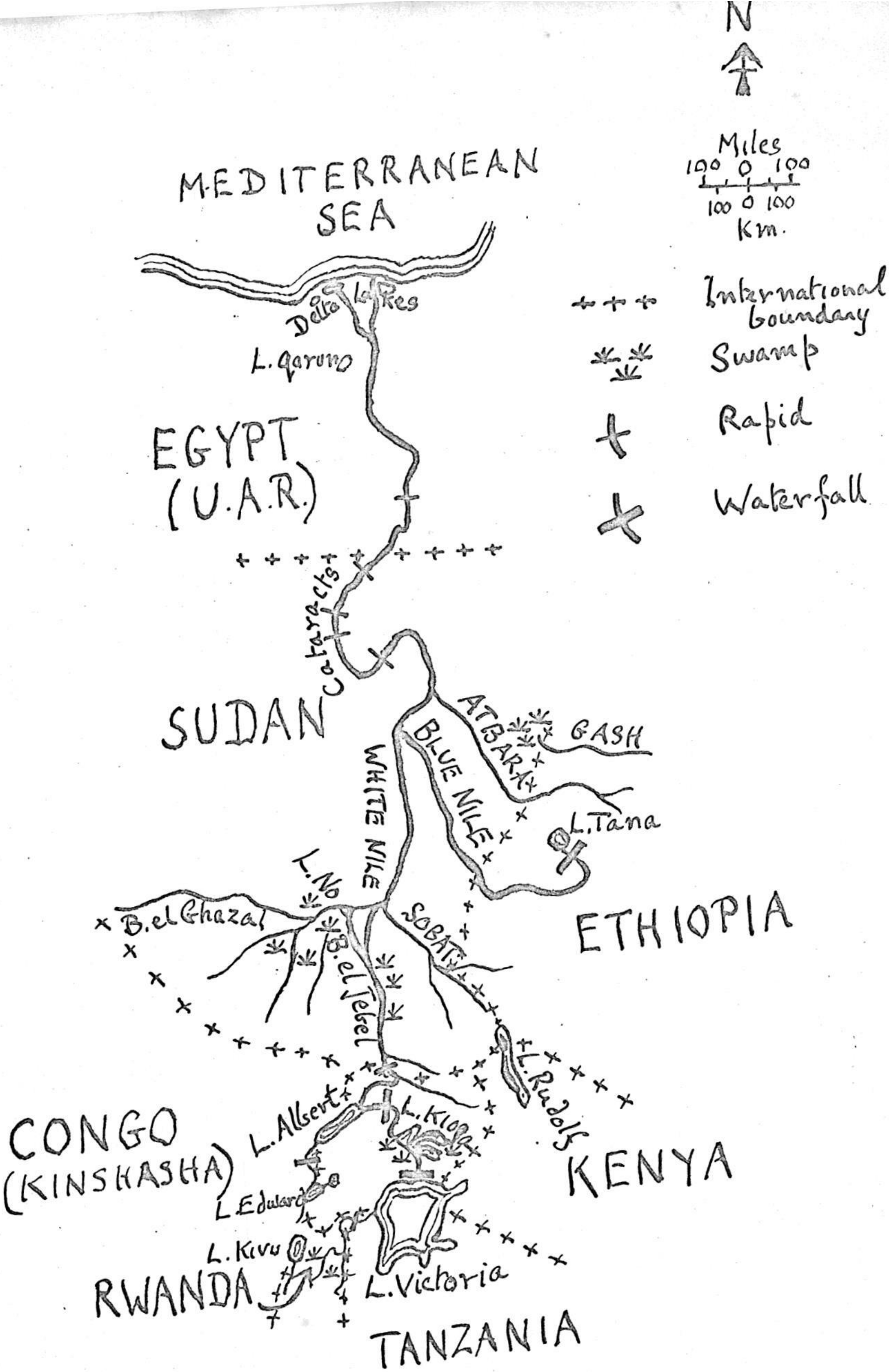

Figure 1 - The Natural Nile

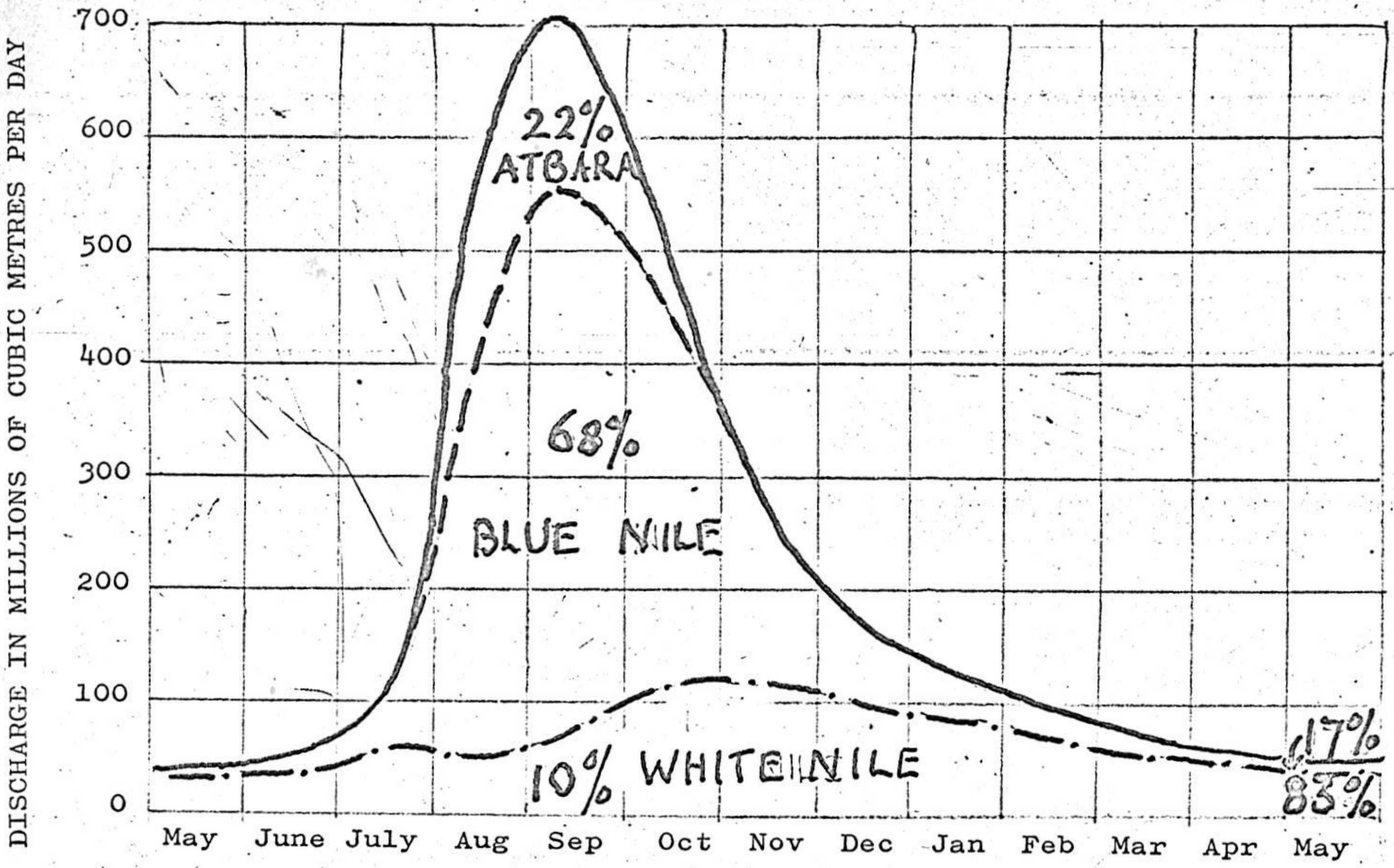

Figure 2 - Average flow of the Atbara, Blue Nile and White Nile.
The % relate to peak flow and minimum flow (from H.E. HURST)

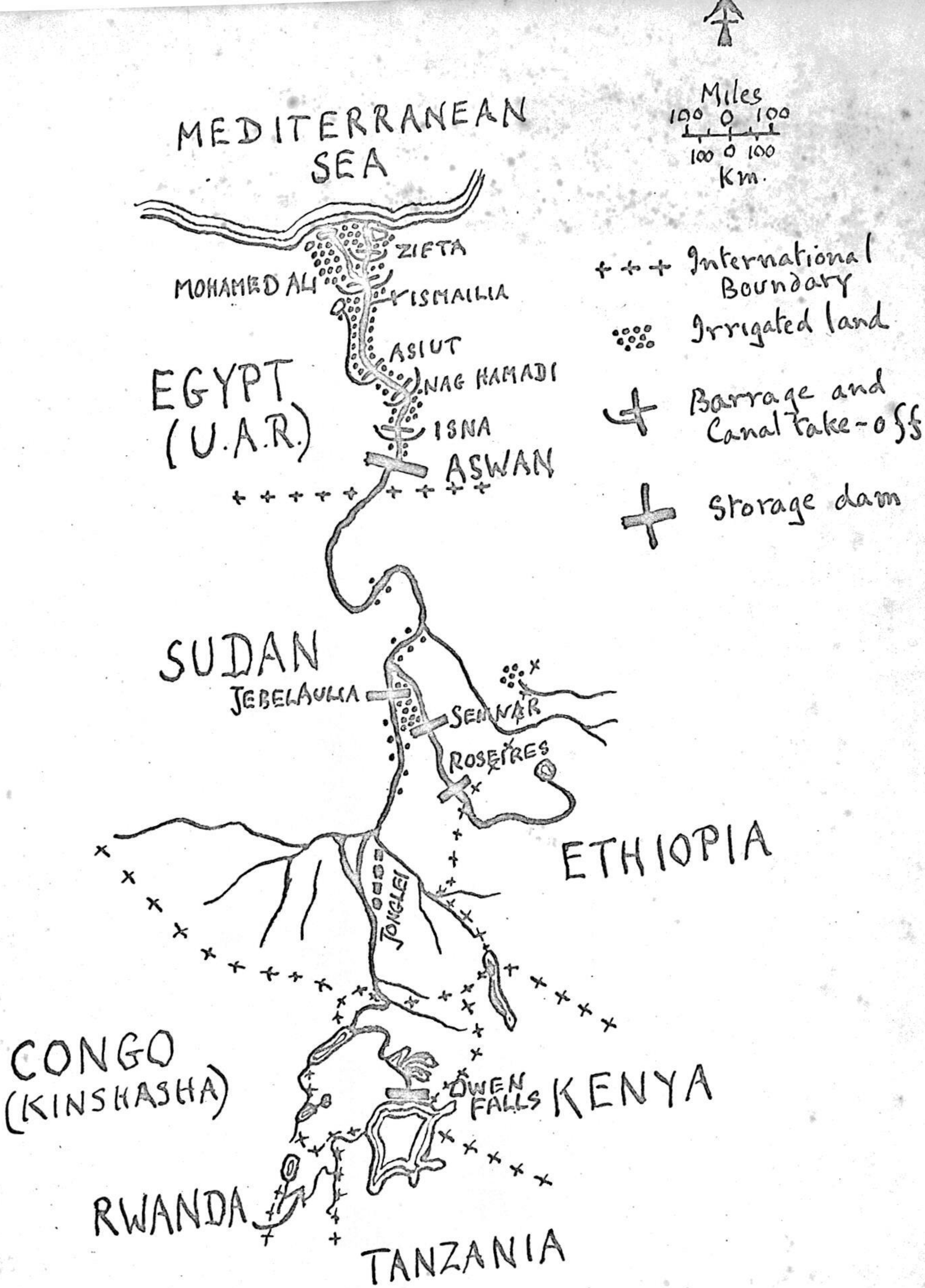

Figure 3 - The Controlled Nile