AMER ASSOCIATES FOR MIDDLE EAST RESEARCH, INC.
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December 19, 1986

Mr. C. Gordon Smith
235 Woodstock Road
Oxford OX2 7AO
ENGLAND

Dear Mr. Smith:

As agreed in our recent telephone conversation, I am sending herewith the materials on the Nile Rivber system for your examination.

I have tried to make clear what is needed so as to enable you to make an early decision. We are under a time constraint, but I understand your commitment until January 15. I hope you will, however, be able to read these materials in the meantime.

We are enclosing the following items:

1. An outline, based on the work statement for the project, detailing the types of data and analysis that should be included in the report. This is a "wish list," not a straightjacket. We should cover the subject as completely as possible, given the available data, rationalizing conflicting data where possible, exercising professional judgment in extrapolating from known data to that which is not available, and discussing the limitations of our data and analysis. We have a strong interest in judicious projections.

2. Drafts of what our people did here before they had to drop out. These are in two parts, not yet integrated: (a) one is a description primarily of the "natural regime" of the river; (b) the other begins to discuss the issues surrounding man's use of the river, demands past and future, and modifications of the system.

3. Data sets obtained from Cairo: The printed aggregate data (see the caveats entered by the author of 2a) from the Ministry of Irrigation; and hand-copied data for 1965-1984 from the large-format archives of the Ministry of Irrigation.

4. A print-out of the classified bibliography on the Nile that we have collected here in Philadelphia during the course of the research. The first section "Instructions for Use" tells how to interpret the classifications. As you will see, the bibliography is in six sections, dictated by the need to make information available at frequent intervals to those working on the project. As indicated, you can request copies of materials from us simply by telephoning with a list of reference numbers. The "Nile 7" bibliography is in final stages of editing, so there is at least some new material in our files that does not appear yet in the bibliography. If in doubt, ask us for something -- we may have it.

I hope you will be able to undertake this task. It is part of a three-year project, this being the last item to be completed in the first phase (the "technical phase"). We hope to commence the second phase in February.

I will telephone you again in the first week of January to see if you require anything further or to answer any questions.

Best wishes for the holiday season and New Year.

Sincerely,

Thomas Naff

AMER ASSOCIATES FOR MIDDLE EAST RESEARCH, INC.

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6 May 1987

Mr. Raymond L. Jenison
2139 Statute Lane
Vienna, VA 22180

Dear Mr. Jenison:

Enclosed for mark-up is a rough first draft of an analysis on the Nile River. We have elected in the case of the Nile to go for pure analysis, for two reasons:

1) The literature on the subject is so extensive that to attempt anything descriptive would be an act of supererogation;

2) The Nile was actually an unfunded add-on to the project which we undertook at sponsor's request in the light of the new problems that made it more interesting than we had originally anticipated.

The present analysis takes us up to this spring's first-time public acknowledgement by Egyptian officials (especially Boutros Ghali) that they do have a scarcity problem due to the African drought; up through last summer they were pooh-poohing the whole notion.

Please let us know your evaluation of this analysis.

Sincerely,

Thomas Naff
Chief Research
Consultant

THE NILE

INTRODUCTION

The Nile is among the most remarkable of the world's major river systems. It is the longest river in the world, 6694 km. from its most distant source to its outfall in the Mediterranean, yet it receives no permanent tributary for the last 2,700 km. as it flows through the Sahara, the world's largest hot desert. Other large rivers, such as the Amazon, the Zaire and the Mississipi have larger basin areas and a greater annual flow. To the ancient Greeks and the Romans, who only knew the Egyptian valley of the Nile, there was something particularly mysterious about a river which rose in flood at the hottest time of the year in late summer when Mediterranean rivers were either completely dry or at their lowest flow. The source of the Nile remained a matter of controversy and speculation to the Greeks and Romans, and later to the Arabs when, in their turn, they came to dominate the Middle East and North Africa. The Blue Nile sources in Ethiopia were only discovered in the 17th and 18th Centuries by European explorers pushing inland from the Red Sea while the White Nile sources were discovered even later, in the second half of the 19th Century, by other Europeans during the exploration of central Africa which preceded the 'Grab for Africa' by European colonialpowers. On his last great African journey David Livingstone had become obsessed with the problem of the 'Nile sources'. ~~and~~ It was his rescuer, H.M. Stanley [illegible] American journalist, who on a later journey finally resolved most of the outstanding problems of the Nile sources in the Lake Region of East Africa.

From Pharaonic times until the present Egypt has been utterly dependent on the waters of the Nile so that the comment of the Greek historian Herodotus in the 5th Century B.C. that "Egypt is the gift of the Nile" remains equally valid today. Following the Egyptian conquest of the Sudan in the 19th

Century and the political partition of Africa by European colonial powers in the latter part of the century the greater part of the Nile basin came under joint Egyptian and British control; this was all the more effective and obvious after the British occupation of Egypt in 1882. This occupation lasted until 1954 and was quickly followed by the grant of independence to the Sudan, Kenya, Tanzania and Uganda. The sources of the Blue Nile in Ethiopia, and a small part of the White Nile headwaters in Zaire and Burundi, never came directly under British or Egyptian control, save for a brief period from 1941 until the end of the Second World War when there was some direct British involvement in Ethiopia following the expulsion of the Italian administration. The Nile is today an international river which includes within its basin parts of eight states. Two of these, Egypt and the Sudan, are major users of Nile water but contribute little to its flow; the remaining six countries contribute to its flow while making very little use of it themselves. These states, Ethiopia in particular, may in the future make reasonable and legitimate demands for a share of Nile waters both for irrigation and power. Reconciling such demands with the existing use of the Nile water by Egypt and the Sudan will not be an easy task without further engineering projects to improve and control the flow of the various sources and tributaries, and this will require political negotiation and new agreements between the states concerned. There is already a precedent for this in the agreement between the British colonial administration in Kenya and Uganda and the Egyptian government at the time of the construction of the Owen Falls Dam on the White Nile at the outfall from Lake Victoria. Normally the use of a river for hydro-electric power can be reconciled with irrigation demands since it involves no permanent loss of water which may be used several times over for power generation further downstream. However, the optimum timing of withdrawals of water for power generation and irrigation use do not necessarily coincide; this can be demonstrated within Egypt by some of the problems which have arisen at the Aswan High Dam.

Since the completion of the Aswan High Dam in 1970 the Nile within Egypt is for the first time under complete human control. From Aswan to the Mediterranean the river has become a huge irrigation canal with an almost constant flow but regulated in such a way as to meet the irrigation requirements of the country at all seasons. Only a series of years of very low flow or very high flow should pose serious problems and the consequences of such an eventuality can be mitigated in ways impossible before the construction of the High Dam. The High Dam has inaugurated what might be called the third stage of Nile control. During the first stage, from Pharaonic times until about 1820, irrigation in Egypt and the entire life and economy of the country were dependent on the height of the annual flood under the system of basin irrigation by which almost all the agricultural land received one watering per year. Year round or perennial irrigation was only possible close to the river bank where water could be raised by animal or man powered hoists and in a few favoured places where underground water was near the surface. After 1820 there was a gradual increase in the area under perennial irrigation as large irrigation canals and a series of low dams or barrages were constructed. The barrages raised the water level in the river and the canals conducted the water to areas in the valley where water thus became available for irrigation round the year. This second stage of Nile control was made possible by the introduction of western engineering technology; the need arose firstly to meet the food demands of a rapidly increasing population and later to provide for the cultivation of two important crops: cotton and sugar cane with their large water demands. By the time of the Second World War it had become obvious that no further extension of the cultivated area was possible without major irrigation works which would store water from year to year and thus overcome the danger of an abnormally low flood. The series of dams, barrages and canals constructed between 1820 and 1939 enabled perennial irrigation to be extended to some 85 percent of the agricultural area of Egypt and brought nearly a million acres of land under irrigation in the Sudan. However both countries remained vulnerable to the consequences of low or high Nile floods while in a normal or average year about a third of the flow of the Nile passed to the Mediterranean during the flood season from August to October. The construction of the Aswan High Dam has inaugurated the third stage of Nile control. Water can now be stored from year to year in lake Nasser, the reservoir behind the dam, thus guaranteeing a fixed and regular supply of water to both Egypt and the Sudan. Normally little water will flow to the Mediterranean to waste and the irrigated area in both countries has been considerably increased. However many problems remain, not least the possibility of a succession of years of very low flow or very high flow beyond the capacity of the reservoir to cope. It is the purpose of this short analysis to indicate the nature of these problem and what further measures of Nile control may be possible. Their success is dependent on the behaviour and nature of the river itself and this is very variable over time. Although hydrological data on the Nile is more complete than that available for some other large rivers there is unfortunately some indication that it has become less comprehensive and reliable recently. This makes it more difficult to monitor and assess the working of the High Dam and comes at a time when there has been a succession of years of low NILE FLOW. l.c.

THE NATURE OF THE NILE BASIN

With a total area of some 2,900,000 sq.km the Nile basin consists of five distinct and contrasting topographical units, and in its course of about 6,700 km the river flows through five very different climatic regions (Fig. 1). The headwaters of the White Nile in East Africa drain a region of equatorial highland climate while the headwaters of the Blue Nile in Ethiopia lie in rugged and mountainous country with a typical tropical monsoon climate and thus with distinct dry and wet seasons. From these two upland source regions the rivers descend abruptly, in the case of the Blue Nile in a spectacular and deep gorge, to the level plains of the southern and central Sudan, where climate grades northwards from tropical savanna with a single rainy season to extremely hot, dry desert in the eastern Sahara. North of Khartoum and Atbara the combined stream of the main Nile flows firstly in a shallow valley with a gentle gradient interrupted by a series of rapids or cataracts and then, north of Aswan, in a broad alluvial floored valley the limits of which are clearly marked by the steep cliff like desert edge. This section of the Nile valley forms the historic land of Egypt and is today the most densely populated part of the Nile basin. At Cairo the valleys broadens out into a flat and fertile delta region with its seaward margin stretching along the Mediterranean coast between Alexandria and Port Said. Here the climate is transitional between Mediterranean and Saharan conditions with some scanty winter rainfall. Fig. 2 shows the longitudinal profile of the White Nile and the main Nile from Lake Albert (Mobutu) in Uganda to the Mediterranean. Fig. 3 is a generalised map of the mean annual rainfall of the Nile basin.

The most distant sources of the Nile are situated between latitude 2 and 4 degrees south of the Equator in northern Tanzania and Burundi but the rainfall and runoff from Uganda and western Kenya make the largest contribution to the flow of the white Nile. The various sources of the White Nile drain a plateau region of moderate elevation lying athwart the Equator. Over much of this region annual precipitation is only moderate for equatorial latitudes, and it is highly variable; but there are some mountain regions in western Uganda and on the borders of Zaire and Burundi where rainfall is heavier. Although rainfall occurs around the year there are two wetter seasons in most of the region: from March to May and from October to December. Earth movements in recent geological times have resulted in a complicated relief with mountain and rift valley structures so that the drainage of the area has been largely channeled into a single system, that of the White Nile. These earth movements have contributed to the presence of several lakes, five of which: Lakes Victoria, Kioga, George, Edward and Albert (Mobutu in Zaire) form part of the White Nile system and serve to act as natural storage reservoirs, or regulators, of the flow of the White Nile where, as the Bahr el Jebel, it leaves Uganda to enter the Sudan. Very large quantities of water are stored in the extensive but relatively shallow Lake Victoria and in the smaller but deeper Lake Albert. Evaporation from the surface of these lakes is approximately balanced by rainfall over the lake so that, with control and regulation by dams at their outfall, they have a considerable future potential for long-term or over-year water storage. To some extent this already occurs at the Owen Falls dam in Uganda, where the Victoria Nile flows out of Lake Victoria, but further works will require international agreements which may not be so easy to obtain. The annual flow of the White Nile at its exit from Lake Albert amounts to almost one-third of the total Nile flow in Egypt, but approximately half this amount is lost by evaporation and transpiration where the river enters the swampy plains of the southern Sudan known as the Sudd. Thus at the entry of the Nile into Lake Nasser only some 14% of the natural flow is contributed by the East African lake region.

The major and most important sources of the Nile lie in Ethiopia. This rugged and mountainous country lies between latitude 4 and 18 degrees North and experiences a single rainy season during the period of "high sun" from June to September. In the southwest of the country the rains last rather longer, from April until October. This Ethiopian Monsoon brings a heavy rainfall of between 1000 and 1600 mm per year and perhaps even more on the highest mountains. The rainfall is, however, notoriously variable from year to year and it is this unreliability that accounts for the considerable interannual variation in the flow of the Nile. Much of central and northern Ethiopia is drained by three rivers, the Sobat, the Blue Nile and the Atbara. Together these rivers contribute some 85% of the average annual flow of the Nile and some two-thirds of this is from the Blue Nile, or Abbai, as it is called in Ethiopia. With the exception of the relatively small and shallow Lake Tana in the headwater region of the Blue Nile there is limited natural storage to regulate the large and rapid seasonal runoff of these rivers. Lake Tana is a potential site for over-year storage if the level of the lake could be raised, and there are possible sites for large storage dams in the gorge section of the Blue Nile valley in Ethiopia.

Fig. 4 is taken from a work by HURST (1952) and illustrates the annual regime of the four major rivers contributing to the total Nile flow. It shows clearly the very regular regime of the White Nile at Mongalla and Malakal (after the loss of 50% of the flow in the Sudd region) as compared with the marked seasonal peaks in the flow of the Blue Nile and Atbara; the latter river is virtually dry from January to June. The Sobat, with its more southerly catchment area, shows a smaller seasonal variation of flow although there is a period of minimum flow between January and June.

The total flow and régime of the main Nile within northern Sudan and Egypt is thus a combination of the rainfall and runoff in the lake region of East Africa and that from Ethiopia. On the White Nile, from the outfall of Lake Albert to its confluence with the Sobat, losses by evaporation exceed the small gains from other sources. These small gains are from a series of minor tributaries, usually termed "the torrents", in the section of the river downstream to Juba; and from an extensive drainage system in the southwestern Sudan collectively termed the Bahr el Ghazal tributaries. This water enters the main river upstream of Malakal. From Juba to Malakal the White Nile has an extremely low gradient and, in the wet season local runoff causes the river and tributaries to overflow in the swampy Sudd region. It is in this section of its course that the White Nile loses about half its flow through evaporation and transpiration. At the same period the area east of the river suffers similar flooding where the tributaries of the Sobat and other small streams flowing from the Ethiopian highlands debouch onto the plains; here much water is lost in marshes and swamps in the same manner.

The southern Sudan is a region of tropical Savanna climate with a single rainy season at the time of "high sun". Rainfall varies from an annual average of 1000 mm at Juba to 780 mm at Malakal and it is surprising that so little of this rainfall finds its way into the Nile but evaporation and transpiration at this season are high. The central Sudan, north of Malakal, is a region of tropical steppe, or semi desert, grading northwards into desert as the length of the wet season decreases and rainfall becomes scantier and less reliable. At Kosti mean annual rainfall is 400 mm with a standard deviation of 80 mm and at Khartoum it has fallen to a mere 160 mm with a standard deviation of 80 mm. From Malakal to Khartoum no permanent stream enters the White Nile and there is a further small loss of flow by direct evaporation from the river surface.

Downstream from Khartoum the régime of the main Nile is now dominated by the large seasonal flood brought by the Blue Nile and emphasised still further by the even more marked seasonal flood of the Atbara. From its confluence with the Atbara until it enters the Mediterranean the Nile receives no tributaries except for occasional and insignificant contributions from the storm flow of small wadis which may only carry water for a few hours in a period of several years. From Dongola to Beni Suef, 60 km south of Cairo, the mean annual rainfall is less than 25 mm and several years may pass without significant rain. Thus the almost rainless land of Egypt, both in the Nile Delta and in the long valley extending south to Aswan, has for millennia been utterly dependent on the rainfall of regions lying far to the south. The timing and extent of the annual flood is determined by the arrival and the amount of the summer rains over Ethiopia which, as the most recent years have demonstrated very starkly, are highly variable, and, as yet, unpredictable. From around the middle of the last century engineering works have increased man's control of the Nile in both Egypt and the Sudan so as to mitigate some of the seasonal variations in the flow of the river and thus extend the area under irrigation. However, until the construction of the Aswan High Dam Egypt remained vulnerable to two very different effects of the variability of annual flow; a low flood which could cause famine or a high flood which might burst the river's banks at the wrong time and thus destroy both crops and life. A succession of such abnormal years was an even worse disaster.

WATER BALANCE OF THE NATURAL RIVER

Table 1 below is an attempt to illustrate the broad features of the water balance of the whole Nile system on the basis of the average or mean annual flow, ignoring abstractions for irrigation above Aswan. It shows the contributions from the various components of the system and the major losses from evaporation and other natural causes. Reservations must be made about any such attempt for the following reasons:

1. The concept of a mean in hydrology, whether for rainfall or runoff, is highly misleading since the mean may rarely occur; it is a very artificial figure. There are wide variations from year to year and the incidence of extreme years is not necessarily distributed in a random manner even assuming there is no periodic change of climate. This problem is briefly referred to in a later section. Climate is not necessarily stable or constant.

2. The data itself may not be reliable and may vary in quality over time and from one part of the system to another. The quality of the data may improve with time as methods are refined and more data is collected but it may also deteriorate with time. If the country,or the government department concerned, suffers from the effects of political instability, civil war or the loss of competent expatriate officials and engineers data may become less readily available and less reliable. This seems to have occurred recently in Uganda, the Sudan and perhaps in Ethiopia, a country from which data has always been sparse.

3. All hydrological data is to some extent an approximation. Most rain gauges are probably at best 95% accurate; while measuring the flow of a large river at the time of peak flood is by no means easy. Most hydrologists are satisfied if their measurements are accurate to within 5% or even 10%. The measurement of evaporation and evapotranspiration is particularly difficult and there are very wide variations between area estimates of these elements despite the problem having received much attention by eminent scientists.

Of the numerous published measurements of Nile flow for various parts of the river system those given in the publications of the Egyptian government's Physical Department, and later the Nile Control Department, are the most comprehensive and probably the most reliable. They are the basis of those given in most other published work (HURST 1952, ABUL ATTA 1978 and SHAHIN 1985). the figures given below are those of ABUL ATTA, formerly Minister of Irrigation in Egypt, as being the most up-to-date and likely to include the best corrections to earlier data.

TABLE 1

WATER BALANCE OF THE NILE SYSTEM

Flow of the natural river

	Mean Annual Flow Flow in billion cu.m.
(1) LAKE VICTORIA	
Inflow from catchment area of the lake	18 x 10^9 m^3
Rainfall over the lake	+100
Evaporation from lake surface	- 94.5
Outflow by 'Victoria' Nile	23.5
(2) LAKE KIOGA	
Inflow from Victoria Nile	23.5
Inflow from other streams	+3
Rainfall over the lake	+8
Evporation from lake surface	-12
Outflow by Victoria Nile	22.5
(3) LAKE ALBERT (MOBUTU)	
Inflow from Victoria Nile	22.5
Inflow from Semliki River (via Lakes George and Edward)	+4.0
Inflow from other streams in the lake catchment area	+2.5
Rainfall over the lake	+3.8
Evaporation from lake surface	-6.3
Outflow to White Nile (Bahr el Gebel)	26.5

	Mean annual Flow Flow in billion cu.m.
(4) THE WHITE NILE in the "Bahr el Gebel" section from Lake Albert to Mongalla	
Inflow from small tributaries (the torrents)	+4.8
Evaporation from swamps and river vegetation	-1.3
Flow of the white Nile at Mongalla	30
(5) THE WHITE NILE between Mongalla and Malakal.	
Losses by evaporation and transpiration in the swamps of the Sudd region	-15
Net gains from Bahr el Ghazal tributaries (estimated total flow of this system 15.5 bcm, evaporation 15 bcm!)	~~-15~~ + 0.5
Inflow from the River Sobat	+13.5
Flow of White Nile at Malakal	29
(6) THE WHITE NILE at Khartoum	
Estimated evaporation losses between Malakal and Khartoum	-2
Flow of the Blue Nile at Khartoum	+50
Flow of the Main Nile below Khartoum	77
(7) THE NILE between Khartoum and Aswan	
Inflow from the River Atbara	+12
Losses by evaporation and seepage Khartoum to Aswan	-5.5
Mean annual flow of the Nile at Aswan	83.5×10^9 m^3
	or 84 bcm

This value of 84 billion (or milliard) cubic metres at Aswan is the long term average annual flow which was adopted for planning purposes and for the operation of the Aswan High Dam. It was also the value adopted in the Nile Waters Agreement beteen Egypt and the Sudan in 1959; this agreement allocated 18.5 bcm to the Sudan and 55.5 bcm to Egypt. The difference between the sum of these allocations and the total flow of 84 billion was an allowance made for the estimated annual evaporation and seepage losses from Lake Nasser. This was assumed to be 10 bcm on average and there has been much controversy and discussion over this figure; the problem is discussed more fully in a later section.

As has been remarked above this figure of 84 billion (or milliard) cubic metres flow per year is both an average and to some extent an approximation. However it has been the basis of most modern planning for the better control of the Nile within Egypt and the Sudan. The contribution made by the major components of the Nile system to the flow arriving at Aswan can be summarised approximately as follows by treating the whole flow of the Nile as divided into seven roughly equal parts in which case:-

4/7 of the flow comes from Ethiopia <u>via</u> the Blue Nile

1/7 of the flow comes from Ethiopia <u>via</u> the Atbara

1/7 of the flow comes from Ethiopia <u>via</u> the Sobat

1/7 of the flow comes from the East African lake region <u>via</u> the White Nile but this is <u>only half</u> the total flow arriving in the Sudan from Lake Albert

THE VARIABILITY OF NILE FLOW

The vagaries and variability in the annual flow of the Nile, and the hazards to life by flood and famine as a consequence, have been a persistent theme in the long history of Egypt. No doubt they are the basis of the story related in Genesis, Ch.41, where Joseph advised the Pharaoh that grain should be stored during the seven fat years (years of high Nile) against the food shortages which would occur during the succeeding seven lean years (years of low Nile).

Within the period of modern record there have been significant variations in the annual flow of the Nile and the height of the flood; not only from year to year but from one period to another. Data, which is thought to be reliable, exist for the monthly and annual flow of the river at Aswan since 1870. There was a change in the mewthod of measurement in 1902 when more refined methods were adopted, but HURST et al. 1966 (p.95) do not believe that the earlier measurements are necessarily less accurate or representative than later ones. TABLE 2 below gives the mean annual flow and the standard deviation for four different periods.

TABLE 2

MEAN ANNUAL FLOW OF THE NILE BY HYDROLOGICAL YEAR:

(AUGUST - JULY)

Period	Mean Billion cu.m. (10^9 m^3)	Standard Deviation 6
1870/1 to 1981/2	90.3	19.0
1870/1 to 1899/1900	109.0	18.8
1900/1 to 1964/5	85.6	13.9
1900/1 to 1981/2	83.5	14.0

During the whole period the lowest annual flow was recorded in 1913/4 with a mere 42 billion cu. ms. The highest annual flow was recorded in 1978/9 with 150 billion cu. ms. Years as extreme as these two have not been recorded recently but there have been large periodic variations as the figures in Table 3 indicate. These recent periods give both the highest and lowest ten and five year mean values recorded this century. It might be noted that the highest five and ten year period means occurred during the planning and construction of the Aswan High Dam while the lowest five and ten year means came while the reservoir of Lake Nasser was actually in process of filling. This will be discussed in more detail later but the reservoir did fill despite the dire predictions of some critics of the High Dam!

TABLE 3

NILE FLOW. PERIOD MEANS

Period	Mean annual flow by hydrological year (August - July)
1956/7 to 1965/6	98.3 billion cu. ms.
1967/8 to 1976/7	71.5
1960/1 to 1964/5	97.8
1968/9 to 1972/3	67.0

Since the near average annual flow of the years 1977 to 1981 there have been five consecutive years with very low flow consequent upon drought in Ethiopia. As yet this author has not been able to obtain adequate or reliable data to compare these very recent years with the earlier periods. The effect of these years upon the volume of water stored in lake Nasser is, however, discussed later in this paper.

The variation of annual flow over time is illustrated in Fig. 5 and Fig. 6, which show respectively the flow by ten year moving averages and by the method of accumulated departure from the period mean. Both these graphsare for the long period 1870 to 1982. The accumulated departure graph, or mass curve as it is also described, needs a little care and thought in interpretation. A continuous rise signifies a su~~oc~~cession of years with above average flow and, conversely, a continuous fall a succession of years with below average flow. Thus the years of high flood before 1895 are clearly shown as is the shorter period of high flow between 1960 and 1965. The recent years of low flow come out very clearly.

The shape of such a graph of accumulated departures will depend very much on the period chosen and the mean for the period. Thus Fig. 7 is a graph of accumulated departures from the lower mean for the period since 1960 (84 bcm). On this graph the years up to 1955 show minor oscillations about the mean while the years of higher flow from 1955 to 1965, and the subsequent years of low flow, are given much greater emphasis than in the graph for the longer period illustrated in Fig. 6.

The fact that the mean flow of the river varies considerably from one period to another is highly significant for the planning of major water storage schemes and the calculation of water available in the future. On the basis of the evidence from the past century it would be dangerous to assume that the mean for the long period, or the mean for the most recent period, will be relevant to the next ten, twenty or thirty years. This is a problem that has received much attention by the officials of the Nile Control Department in Egypt and has been fully investigated by HURST <u>et al.</u> 1966. The theory behind it and a possible solution to the problem are set out in HURST et al 1965. The matter is discussed later in this paper in relation to Century Storage and the Aswan High Dam.

THE HISTORY OF RIVER CONTROL AND ENGINEERING WORKS ON THE NILE

Between 1861 and 1939 a series of low dams or barrages was constructed on the Egyptian section of the Nile and these enabled perennial irrigation to be gradually extended to about 85% of the cultivated area of the Nile valley and the delta. Perennial irrigation allowed two or more crops to be grown on the same area of land during the year and also extended the area on which maize, rice, cotton and sugar cane could be grown. These crops have a higher water demand and need a longer period of watering than the traditional winter crops grown under the system of basin irrigation:- wheat, barley, clover, flax and winter vegetables. These irrigation developments were also necessary to keep pace with the rapid growth of population and to increase the area sown to cotton which, after the American Civil War, became Egypt's major export.

Barrages on the Nile were built to raise the water level upstream and thus to maintain a head of water round the year in the major irrigation canals. The first of these barrages was the Delta Barrage completed in 1861 just downstream from Cairo and at the head of the delta. The original barrage was replaced in 1939 by two new structures on the Damietta and Rosetta distributaries; the old barrage having become unsafe. Three barrages were built in the Nile valley: at Assiut in 1902, at Esna in 1908 and at Nag Hammadi in 1930, in conjunction with new or improved lateral valley canals. However the largest and most important work was the original Aswan Dam completed in 1902, heightened in 1912 and again in 1934. In its final form the reservoir behind this dam had a capacity of 5 billion cu. ms. and raised the upstream water level by as much as 20 metres. The object of this dam was to store some of the water at the tail of the annual flood in October and to release it downstream between February and July when the natural flow of the river is lowest and irrigation demands are rising. In the early stages of the annual flood the waters of the Nile are very silt-laden and it was necessary to let this flow downstream to the sea to avoid siltation behind the dam. The location and functions of the Aswan Dam and the various barrages and canals in the pre-High Dam era are shown diagrammatically in Fig. 8. By 1939 the only significant area of land still under basin irrigation was in Upper Egypt between Aswan and Esna but there remained some land under this old system as far downstream as Assiut. This land was all converted to perennial irrigation after 1964 when the first stage of the Aswan High Dam completely blocked the river and the reservoir of Lake Nasser began to fill.

Two dams were built in the Sudan before the Second World War: the Sennar Dam on the Blue Nile in 1925 and the Gebel Auiliya Dam on the White Nile was completed in 1937. The Sennar Dam allowed irrigation to be extended to some 800,000 Feddans in the land between the Blue and White Niles south of Khartoum, this area is known as the Gezira, and it became a major productor of cotton. The Gebel Auliya Dam was built to hold back some of the waters of the White Nile at the peak of the Blue Nile flood, so that it could be released for the benefit of Egypt after the Blue Nile flood had passed; it was thus a supplement to the storage of the first Aswan Dam.

Despite these impressive achievements in irrigation and intensive year round cultivation in Egypt it had become obvious as early as the 1930's that the limits of perennial irrigation under this system had been reached. Any further increase in the irrigated area could only be achieved by storing more water in a series of new reservoirs which could contain some of the 32 billion cu.ms. of Nile water which, in an average year, flowed into the Mediterranean during the flood season from August to October. Also, to obviate the danger of years of low flow and high flood some means of storing water from year to year was required. Egypt's phenomenal rate of population growth was an important factor in the chain of water, irrigation methods, agriculture and food. The population rose from 2.5 million in 1821, to 7 million in 1882, to 14 million in 1927, and to 19 million in 1947, by which time the country was barely able to feed itself. Since then population growth has been even more rapid; 30 million in 1966, 37 million in 1976 and an estimated 48 million in 1985.

The 1929 Nile Waters Agreement allotted 48 billion cu.ms. of the annual flow of the Nile to Egypt and only 4 billion to the Sudan. This agreement was between an independent Egyptian government and the government of the Sudan which was, at that time, in effect a British colonial administration. However, the agreement was not quite so one-sided as these proportions might suggest since Egypt was utterly dependent on Nile water while the Sudan has extensive rain fed areas in the south of the country. The only large area in the Sudan depending on Nile water at that time was the newly completed Gezira irrigation scheme. Egypt had always been very sensitive of the threat posed to the country by the possibility of large abstractions of waters upstream. These fears had been given additional force as recently as 1924 during a dispute with Britain over the issue of independence and the continued British occupation. One sentence in a British diplomatic note to Egypt appeared to threaten to give greater priority to the Sudan's irrigation needs. Despite a hasty British clarification of the matter the incident was long remembered in Egypt.

CENTURY STORAGE AND THE ASWAN HIGH DAM

The two problems of finding a means of storing sufficient Nile water to increase the area under irrigation in Egypt, and of calculating how much water would need to be stored to guard against the worst probable sequence of dry years and the possibility of dangerous flood flows, were thoroughly investigated by the Nile Control Department for many years. This, and much other fundamental work on the Nile basin, is set out in the sequence of volumes under the general title The Nile Basin published between 1931 and 1966 for each of which the late Dr. H.E. Hurst was a major contributor. In Vol. VII, HURST, BLACK and SIMAIKA, (1946), a solution was proposed for both of these problems in a scheme which has generally been termed 'Century Storage' or the East African Lakes Scheme. The broad outline of the plan is illustrated in Figure 9. They argued that for maximum efficiency the Nile Basin should be treated as a whole and that the main water storage reservoirs should be in the East African Lakes, Albert and Victoria, with further storage in Lake Tana in the headwater region of the Blue Nile. They proposed a diversion canal, the Jonglei cut, around the Sudd region of the Sudan to avoid the large losses of White Nile water through evaporation in the swamps. Evaporation in the whole system would be minimised by storage in the highland lakes where temperatures are lower and rainfall nearly equals evaporation. The outlets from the lakes would be controlled by dams and regulators and hydroelectric power could be generated at a number of these sites. A dam was proposed on the main Nile at the Fourth Cataract in the Sudan for the seasonal storage of water for summer irrigation in Egypt; and protection against high floods in Egypt would be provided by a flood relief reservoir at Wadi Rayan south of the Fayoum. The obvious drawback of this scheme was a political one: Egypt and the Sudan would be dependent on agreements with the upstream states and on their continuing goodwill and cooperation. This might be assumed while much of the area was still under British administration, as it was in 1946 when the plan was published. The plan was also criticised as being more expensive and taking longer to complete than one single large storage dam. One positive result of this plan was the construction of the Owen Falls Dam at the outlet from Lake Victoria, completed in 1950, which had the immediate advantage for Uganda of providing a large amount of hydroelectric power.

The Egyptian government at first seemed to approve the Century Storage plan prepared by the Nile Control Department, a government agency in which the most senior official, Dr. Hurst, was a Briton who had served Egyptian governments for nearly forty years and who was still in their employ as a consultant as late as 1965. However, two events were to change everything. In 1948 Adrian Daninos, a Greek resident of Egypt, suggested in a paper that a suitable site for a large dam and storage reservoir, which would meet all Egypt's irrigation needs, existed about four miles upstream of the original Aswan Dam. In 1952 a military coup d'etat brought to power a group of officers who were intent on breaking with the past and promised rapid economic and social reforms. They quickly took up the Daninos scheme and proceeded to advocate it as the solution to many of Egypt's problems. After the plan had been submitted to the Nile Control Department and to a number of respected international experts, who all reported favourably, work on the Aswan High Dam, or Sadd el Ali, commenced in 1960 with Soviet technical and financial support. In the intervening years the High Dam was not only the subject of much criticism and controversy but the whole project became involved in great power politics; it led indirectly to Egypt's nationalisation of the Suez Canal in 1956 and the subsequent Anglo-French attack on the Canal Zone.

Before Egypt could proceed with construction of the High Dam it was necessary to reach a new agreement with the Sudan on sharing the Nile waters. This was achieved in 1959 but the newly independent Sudan proved extremely obdurate with the result that, of the expected 22 billion cu.ms. of water to be made available for irrigation after the completion of the High Dam, Egypt agreed that 14.5 billion should go to the Sudan thus leaving Egypt with a mere 7.5 additional billion. The Sudanese case was a strong one, since Lake Nasser, the reservoir behind the High Dam, would at its maximum capacity flood much land in the Sudan and part of the town of Wadi Halfa. Egypt would be the main beneficiary of the large hydroelectric potential of the dam, and the major work of Nile control would be in Egyptian hands.

A description of the High Dam, and an account of its operation, follows in the next section; but at this point it is appropriate to make a brief comment on the theory behind over-year storage or 'Century Storage' by which is meant having a sufficient volume of water stored to mitigate the effects of the worst probable sequence of river flow events that might occur within a period of a hundred years. The problem is fully discussed in an important work by HURST et al (1965) and at greater length in Vol X of the Nile Basin (1966) with particular reference to the Nile and the working of the High Dam. Having studied all the long period records of Nile flow, including the hundreds of years of flood height at Cairo recorded by the famous Roda Nilometer, together with some hundreds of records of other natural phenomena such as rainfall and river gaugings, Hurst concluded that many natural phenomena are not distributed according to the laws of chance. In other words extreme events are not randomly distributed but they are clustered in time. This obviously has important consequences for long term storage if a guaranteed annual draft from a reservoir, or series of reservoirs, is to be maintained at all times. Hurst concluded that a single equation gave the best approximation in the case of river flow and this closely matched the actual behaviour of the Nile over many years. The equation is:

$$R = \sigma \times 0.61 \times N^{0.72}$$

where R. is the storage required to ensure a draft equal to the mean.

σ is the standard deviation of the annual flow over the longest period available.

N is the number of years.

The value of R, or the storage required, is thus larger as the standard deviation increases and larger if the period of years increases. This can be illustrated by the following two examples from Nile flow records:

(1) For the period 1900/01 to 1981/2 the mean flow was 83.5 billion cu.ms., and the standard deviation 14 billion.

therefore $R = 14 \text{ X } 0.61 \text{ X } 82^{0.72}$

or 235 billion.

(2) For the period 1870/1 to 1981/2 the mean flow was 90 billion cu.ms., and the standard deviation 19 billion.

therefore $R = 19 \text{ X } 0.61 \text{ X } 112^{0.72}$

or 346 billion

The operational storage capacity of the reservoir behind the Aswan High Dam is 90 billion cu.ms. Therefore it cannot provide complete protection against such sequences of Nile flow as have occurred this century still less against the worst sequence known to have occurred since 1870. However, by planning for an annual draft rather lower than the mean the volume of storage required becomes progressively less as the draft is reduced.

THE ASWAN HIGH DAM: ITS NATURE AND OPERATION

The Aswan High Dam, or Sadd el Ali, is one of the largest and most impressive structures of its kind in the world. Lake Nasser, the reservoir behind the dam, is the second largest man-made lake in the world and, at its maximum extent, is over 500 km in length with an average width of 10 km. The dam is a rockfill type of structure with a width at the base of 980 m. and a top width of 40 m. The top of the dam is 111 m. above the downstream river level. The total length of the dam at its crest is 3,600 m. of which 520 m. spans the river; the remainder of the dam consists of extensions on either bank to retain the upstream water level in the reservoir. The reservoir, at a maximum level of 185 m. above the Mediterranean would have a capacity of 183 billion cu.ms. and a surface area of 7174 sq. km. However, it is unlikely that the lake will be allowed to fill above level 182m., at which the capacity is 162 billion cu. ms.

The dam was built in two stages between 1960 and 1968. Between 1960 and 1964 a coffer dam of locally excavated material was placed across the river on the upstream side of the dam site and a large diversion channel was cut in the hard Aswan granite on the eastern bank of the river. The diversion channel has a total length of 1950 m. and in this a portion of the country rock was retained through which six large tunnels were bored. These tunnels were lined with concrete and provide both the outflow downstream for release of water and the site for the 12 turbines of the hydro-electric station incorporated into the structure of the dam. In 1964, the flow of the river was diverted through the new channel and construction of the main dam began. Between the upstream coffer dam and a new downstream coffer dam construction of the main dam was able to proceed; this was completed in 1968 and the two coffer dams were incorporated in the main structure. From 1964 the reservoir behind the dam began to fill and the river flow was now under human control.

The rate of filling of the reservoir is illustrated in Figure 10 and Table IV. The dam was fully operational as a regulator of the downstream flow of the Nile by 1968. The power station, with its twelve turbines capable of generating 10 billion kwh per year, was completed in 1972. This has made a very large contribution to Egypt's generating capacity; the power is transmitted to Cairo and the delta region by a high voltage grid system.

The effect of the dam on the downstream flow of the Nile and on the water level of Lake Nasser is illustrated in Fig 10. The water level rose to the maximum operational capacity in 1976; storage capacity above this level is intended to be used only in the event of a very high flood or sequence of such years. Water will be released from the reservoir so that it does not exceed this level before the arrival of the annual flood. The two lower curves of the graph in figure 10 show the inflow and outflow (thick line) from the reservoir while the annual amounts are given above. The upper part of the graph shows the reservoir contents in terms of the water level in the lake (expressed in metres above Mediterraneansea level) and the contents in billion cu.ms. (thin line). These graphs show clearly the annual regime of the natural river with high flood flow from July to October and low flow from January to June. Release of water from the reservoir follows an annual cycle related to the seasonal irrigation needs of Egypt. It can be seen that even during the period 1964 to 1968, while the dam was under construction, some control over the annual flow was possible as the reservoir began to fill. By 1968 the lake level had risen to 156 m. and the storage to nearly 53 bcm. After 1968 the annual flow of the river was under complete control and the annual outflow remained virtually constant at between 54 and 56 bcm which is Egypt's share of the Nile waters under the 1959 agreement with the Sudan. The slightly higher release in 1977 was because the lake had, for the first time, reached its maximum operational storage level. The figures on which these graphs are based have been supplied by the High Dam Authority and by the Nile Control Department.

The graphs show that the High Dam has already served a useful function. The high floods in 1964 and 1975 would have caused problems downstream before the building of the dam; even the limited storage available in 1964 relieved some of the dangers. The years 1972 and 1973 were years of low flood and, without the storage available in Lake Nasser, there would have been serious water shortages in Egypt; the quantity of water released in 1972 was greater than the inflow. Fig. 11 brings the graph of water storage in the reservoir up to 1984 from figures supplied by AMER. It has not been possible to obtain detailed and reliable figures for the period since 1977 to bring such a graph as Fig. 10 up to date. There is, however, a rough agreement between the figures for the content of the lake and those for the flow of the Nile at Dongola but this depends both on an estimate for the amount of water withdrawn in the Sudan and estimates of the losses by evaporation, absorption and seepage from Lake Nasser. It has already been noted that the flow of the Nile has been below the long term average since 1976 and this was illustrated in Figs. 5,6 and 7. Since 1981 the flow has been very much below average. From figures for the inflow and storage in the lake during 1985 and 1986, quoted in The Financial Times, for 3rd March 1987, this trend has continued until the present. The paper quoted an Egyptian official as stating that in early 1987 the reservoir level was as low as 161 m., which implies a storage of 63 bcm, and this might be reduced to as little as 45 to 50 bcm. before the arrival of the 1987 flood. This is the lowest level reached in the reservoir since it filled in 1976 and it may necessitate a reduction in the annual release downstream and serious problems for the operation of the power station. The 30 bcm allowed for 'dead storage', and shown on the graph of Fig. 11, is intended to provide for the gradual siltation of the bed of the lake which it is estimated will occur over about 500 years.

THE PROBLEM OF SEEPAGE AND EVAPORATION LOSSES FROM LAKE NASSER

One of the most controversial aspects of the High Dam, and one which caused much criticism and discussion during its construction, is the large water loss which might occur through evaporation, seepage and absorption. The most widely quoted estimate of the average annual evaporation loss from the lake is an annual average value of 10 billion cu.ms. and this figure was officially adopted in planning the operation of the dam (HURST et al 1966). This figure would vary from year to year depending on the surface area of the lake. This is a high proportion of the annual flow of the river and is actually greater than Egypt's gain of additional water! Some critics argued that evaporation would be even larger because the surface wind speed over a large body of water would be greater than over a land surface. However, few critics seem to take account of the possibility that evaporation might be less because of the higher moisture content of the air immediately above the water surface. Direct measurements of evaporation from the lake surface have been attempted by the Egyptian Meteorological Service with conflicting results (personal discussions). Any attempt to estimate evaporation, by taking a water balance of the lake inflow and outflow over several years, runs up against the even more difficult problem of estimating the losses from the lake by ~~evaporation~~ absorbtion and seepage which are even more difficult to measure. Abul Atta (1978) has provided figures for the combined losses for the first twelve years of the operation of the dam and has concluded that evaporation, seepage and absorption losses have been less than those estimated at the planning stage. Some confirmation of the fact that the total losses have been less than were first feared is the fact that the reservoir filled to its operational level during a period when, in every year but one, the natural flow of the river was below the long period average. Losses by seepage and absorption would inevitably be large as the lake filled, and each year a fresh area of virgin land was submerged, but this initial seepage and absorption should decrease fairly soon as the bed and sides of the reservoir become saturated. After a few years the deposit of silt on the bed of the lake should provide an impervious layer and also seal any fissures and cracks in the bedrock.

Fig. 12 is a simple histogram to show the observed losses from the lake for each year from 1964 to 1977 by taking the difference between the inflow and the outflow. Total losses were large in some years, particularly those in which the area of the lake increased by a large amount. It is, however, important to note that in 1972 and 1973, years when the lake shrank, and in 1976 and 1977, when the lake had filled, losses were much less than in preceding years. Fig. 12 also shows how much of this loss would be attributable to evaporation on the assumption, (a very conservative one) that mean daily evaporation was only 5mm. as compared with the figure adopted for planning purposes of 7.3mm a day or 2.7 m. per year. The difference between the total loss and the evaporation loss as shown in Fig. 12 would therefore be attributable to seepage and absorption. Even on this assumption about evaporation, the seepage losses in 1972 were small. Fig. 13 is a similar histogram but constructed on the assumption that evaporation averaged 7.3 mm per day. This shows that the annual evaporation would, in some years, have been greater than the actual loss and therefore that seepage and absorption were not occurring even during the filling of the reservoir. This is most unlikely at a time when initial seepage must have occurred and the conclusion must be that the actual evaporation has been less than the initial estimates.

A tentative attempt has been made to estimate the actual losses by evaporation in each year on the basis of the figures given by Abul Atta (1978) and the monthly and annual figures for the lake contents supplied by AMER. For years when more reliable data is available the calculations suggested that mean annual evaporation from the lake was 2.1 m. or 5.8 mm per day. This varies from about 2.9 mm in January to 8.2 mm per day in July, a direct link with the annual temperature range. On this basis Table 4 has been compiled to show the relationship between the evaporation loss each year and the size and contents of the reservoir. For the years 1964 to 1977 it is possible to give a figure for the total losses from the reservoir and the difference between this and the estimated evaporation loss gives some indication of the probable losses by seepage and evaporation. For the years since 1977 it has only been possible to suggest a figure for evaporation loss based on the area of the lake. Reliable figures for inflow into the lake are not available. The figures supplied by AMER for the contents of Lake Nasser and those for the 'flow of the natural river' are difficult to reconcile with data for the river flow at Dongola in the Sudan. Without direct knowledge of the water removed for irrigation in the Sudan it becomes virtually impossible to calculate a flow of the natural river by adding together the flow of the White Nile, Blue Nile and Atbara. Table 4 suggests that the losses from absorbtion and seepage were large as the reservoir filled but became much less in years when the area of the lake did not increase. This is what would be expected on theoretical grounds and confirms the initial assumptions at the planning stage that seepage and absorbtion losses would rapidly decline once the reservoir was full. It would also appear that annual evaporation losses are less than the average figure of 7.3 mm per day. They are probably in the range 5.8 to 6.3 mm per day on average, or 2.1 to 2.3 m. per year. At the higher figure of 2.3 m. per year almost the entire annual losses in 1976 and 1977 would be accounted for by evaporation; this suggests that the actual evaporation loss was rather less as some seepage and absorption losses would still be likely. The relationship between the annual evaporation from the lake and its contents is illustrated in Fig. 14 which is a graph of annual evaporation loss against the water level in the lake on the assumption that daily evaporation ranges between 3 and 7 mm over the year with an annual mean of 5 mm per day. In fact the evaporation is likely to be higher than this on the basis of the calculations above but the shape of the curve would be similar.

TABLE 4

LAKE NASSER AREA, CONTENTS AND WATER LOSS

Year	Max Contents (bcm)	Max Water Level (m. above msl)	Max Lake Area (sq.km.)	Observed Water Loss (bcm)	Estimated Evaporation (bcm)
1964	9	127	668	1.0	0.8
1965	14	133	900	1.8	1.1
1966	23	141	1310	4.3	* 1.7
1967	40	151	2052	5.6	3.0
1968	53	156	2580	7.3	4.4
1969	65	161	3076	8.7	5.4
1970	78	165	3500	10.7	* 6.3
1971	89	167	3950	11.1	6.7
1972	80	165	3530	7.0	6.7
1973	84	166	3726	8.1	7.2
1974	100	170	4350	13.7	* 9.0
1975	125	176	5250	18.5	10.1
1976	128	176	5420	13.0	*10.9
1977	133	177	5650	12.8	10.9
1978	134	177	5680	(No Reliable Data)	*11.1
1979	126	176	5300		10.2
1980	127	176	5380		10.3
1981	126	176	5400		10.4
1982	111	173	4800		9.2
1983	97	170	4270		8.2
1984	76	164	3540		6.8
1985	(54)	(157)	(2660)		(5.1)
1986	(56)	(158)	(2750)		(5.3)

Values in Brackets Provisional Estimates

* Evaporation Values Calculated Monthly and Therefore More Reliable

Other Years Calculated on Annual Average Contents

THE ASWAN HIGH DAM: CREDIT AND DEBIT

The benefits to Egypt of the High Dam can be briefly stated: a controlled and guaranteed annual flow of 55.5 b.c.m. of Nile water in all but the worst sequence of years and the removal of the historic threat of a disastrous flood. HURST et al (1966) suggested that a sliding scale of reductions in the draft from Lake Nasser be adopted so that if the reservoir contents fell below 60 b.c.m. the annual draft should be reduced by 5% and that if the contents fell below 50 b.c.m. this should be reduced by 20%. They calculated that the reservoir contents might fall below 60 b.c.m. seven times in a hundred years and below 50 b.c.m. twice in a hundred years with the possibility that the contents might fall below 30 b.c.m. once in five hundred years.

Egypt has been able to convert all the remaining areas of land under basin irrigation, about 800,000 feddans, to perennial irrigation and to undertake the reclamation of some 1,250,000 feddans of new land, mostly on the eastern and western fringes of the delta and to irrigate this with Nile water. Work on land reclamation has been proceeding for over twenty years but progress has been slow and the results disappointing both in terms of the very high costs and the poor yields obtained on some of the more marginal land. Locally there have been examples of increased soil salinity, both in the newly reclaimed areas and on some previously irrigated land; this is probably a result of hasty over-watering and neglect of soil drainage.

The prospects of a high Nile flood now raise a rather different kind of danger. The capacity of Lake Nasser, if operated according to plan, could contain the water of a flood as high as that of the year 1916/7 (119 b.c.m.), and mitigate to some extent the effects of a flow as high as that of 1878/9 (150 b.c.m.), but a flow as high as 150 b.c.m. would cause serious problems. If large releases of water have to be made from Lake Nasser erosion downstream will be much increased as this water will be clear and largely silt free. Previously the heavily silt laden flood waters were less likely to erode the foundations of barrages and bridges downstream and degrade the river bed. Much attention has now been given to this problem which was realised even before the High Dam was built. In order to keep the direct spill of water from Lake Nasser to a safe level an emergency spillway and canal has been constructed some 250 km.upstream of the dam so that water from Lake Nasser can be conveyed into the Toshka depression in the Western Desert to the south of Kharga oasis. This water would do no harm and might, in the long term, even have some beneficial effect in that it would replenish in a small way the underground water whcih is drawn up by wells in the Kharga land reclamation area. This forms part of the so-called "New Valley" scheme on which greatly exaggerated hopes were placed some twenty years ago.

Many criticisms of the High Dam were made during the planning and construction stage. Some of these were made by Egyptian engineers but the majority came from foreign journalists anxious to criticise the policies of the Egyptian government. These latter often took the form of sensational and exaggerated newspaper and magazine articles: where there was some element of truth in the criticisms they also aroused concern in Egypt. For example it was claimed that the High Dam would increase the incidence of Bilharzia, a debilitating disease spread by a water snail and which was largely absent in the areas under basin irrigation. It was also claimed that the High Dam would prevent the annual deposit of a layer of fine fertilising silt which for millennia had been spread evenly over the agricultural area. Both these criticisms completely ignored the fact that these were consequences of perennial irrigation and were at least a hundred years old. Before the construction of the High Dam the greater part of the silt was carried into the Mediterranean by the annual flood and the remainder was deposited in the main irrigation canals from where it was dug by the fellahin during the annual canal cleaning. Bilharzia had been rife amongst the peasants in the perennially irrigated lands for at least a hundred years and can only be checked by better health standards which involve persuading the population not to wash and bathe in the canals, or the Nile itself, and to wear stout footwear when working the land! Concern has also been expressed that the new régime of the Nile, with little water flowing into the Mediterranean, will increase coastal erosion in the delta and that the offshore fisheries, particularly those for sardine, will suffer from the changed composition of Nile water and the reduced flow. Both these criticisms have validity and the consequences are being continuously monitored. It will also be necessary to observe closely the quality, thermal stratification, and aquatic life in the water of Lake Nasser. This has become an important source of fish, particularly the Nile perch which here grow to a very large size. The probable value of this fishery may exceed that off the coast of the delta. On balance it is probably fair to conclude that the benefits of the dam, which include a very large output of electric power, are more than enough to balance these harmful side effects. A special report on the effects of the High Dam was prepared for the Egyptian government by the Commission for Agricultural Production and published in 1976 (The High Dam and its Effects published by Al Ahram and Al Iktissadi in English and Arabic). This examines the criticisms mentioned above and other side-effects; its conclusions are generally optimistic but suggest continuous close observation of all aspects of the effects.

THE CONSEQUENCES OF THE HIGH DAM FOR THE SUDAN

The 1959 Nile Waters Agreement allows the Sudan to take a much larger share of the Nile waters; 18.5 b.c.m. as compared with its previous share of 4 b.c.m. The evidence available suggests that the Sudan has rapidly increased the area under irrigation since the agreement was concluded. Most of this increase has been in three areas: two on the Blue Nile in the Managil extension to the Gezira and at Rohad; and another area on the Atbara river around New Halfa fed by the Khasm el Girba dam, completed in 1964. A large new dam on the Blue Nile at Roseires was finished in 1966. Both these dams store water at the tail of the flood season on the Atbara and Blue Nile when the silt content of the river is lowest; water is then released from the reservoirs behind the dams during the low water season when the Atbara is virtually dry. The area irrigated from the Khasm el Girba dam amounts to some 400,000 feddans and that on the Blue Nile from the Sennur and Roseires dams is as large as 3,125,000 feddans. Some of the irrigated land at New Halfa was used to resettle those displaced by the flooding of Nile valley land around Wadi Halfa as it was submerged by the rising waters of Lake Nasser. Some valley side land on the main Nile north of Khartoum, and on the White Nile south of the Gebel Auliya dam, is irrigated directly by pumps and up to 2 b.c.m. of Nile water is used in this way to irrigate another 950,000 feddan. It seems that this water withdrawn by pumps from the main Nile and White Nile was excluded from the Nile Waters Agreement on the grounds that it was a traditional right so that the Sudan may draw a total of 20.5 b.c.m. of Nile water *in toto*. Use of Nile water by the Sudan has increased from 6 b.c.m. in 1964 to between 15 and 16 b.c.m. in 1982 (ABUL ATTA 1978 and ROBBINS and HENNESSY 1982). Further prospects for large scale irrigation developments exist in the southern Sudan in the Mongalla to Malakal section of the White Nile and in the Machar Marshes region of the Sobat basin. Much of this work would involve draining the Sudd marshes and controlling the network of streams forming the

Bahr el Ghazal system. Such work could well be long delayed by the political instability and virtual civil war prevailing in this region of the Sudan and the work will be prolonged and costly. Work on the first stage of the Jonglei Canal in the Sudd region was started in the late 1970s but it has now been halted by the unrest in the south. This canal would increase the flow of the White Nile by 3.8 b.c.m. a year. Under the 1959 agreement Egypt and the Sudan agreed to share any future increases of Nile water flow on a 50/50 basis with Egypt meeting its share of the costs. The agreement also allowed Egypt to take any unused share of the Sudan's water quota in the form of a water loan but the evidence of the inflow and outflow from Lake Nasser does not indicate that Egypt has taken up this option.

FUTURE USES OF THE NILE WATERS

At present the area irrigated in Egypt amounts to some 7.5 million feddans and its water use for all purposes to 55.5 b.c.m. This compares with an irrigated area of about 4.5 million feddans and a water use of 20 b.c.m. in the Sudan. This difference can be explained by the fact Egyptian irrigated agriculture is much more intensive than that in the Sudan. In Egypt much of the land grows two and sometimes three crops a year and the total crop area exceeds 11 million feddans. On much of the Sudan's irrigated land only one crop per year is grown and in some areas the land is left in fallow every second or third year. An undetermined amount of water is used in Egypt for domestic and industrial purposes in the large cities and estimates of this range from as little as one billion cu. ms. to as much as eight b.c.m. Since much of this water may be returned to the river as effluent and sewage it may not be totally lost to agriculture. Virtually all Egyptian agriculture is irrigated apart from very tiny areas along the Mediterranean coast where, in a year with good winter rain, some scanty yields of barley or wheat may be obtained by dry farming methods. Small areas in the Western Desert oases of Siwa, Kharga and Dakhla are irrigated with water from wells, both shallow traditional wells and the new deep artesian wells in Kharga and Dakhla. Some underground water and flash flood water from Wadis is used for irrigation in Sinai. However, in spite of all the efforts over the last twenty years to reclaim desert land using underground water in the New Valley scheme the total area irrigated in this way in Egypt is probably no more than 100,000 feddans.

The High Dam has provided Egypt with a breathing space in which to relieve some of the effects of a desperate shortage of both land and water; and it has removed some of the dangers of a variable and uncertain Nile flow. The High Dam has also provided an additional bonus in the form of plentiful and cheap electric power, but this may be limited from time to time by the need to reconcile demands for power with those for irrigation and water storage. The Sudan has gained rather more in terms of irrigation development and there is great future potential for the expansion of both irrigated and rain fed agriculture in the south of the country.

Future development and control of the waters of the Nile basin must depend on the gradual implementation of those aspects of the 1946 "Century Storage" scheme which can be carried out; dams on lakes Kioga and Albert in Uganda and on Lake Tana in Ethiopia; and swamp drainage and river control in the southern Sudan. In carrying out such work there is the opportunity for a greatly increased power generation, particularly in the Blue Nile gorge in Ethiopia and on the Bahr el Gebel section of the White Nile in the Sudan. However, the raising of lake levels in the upstream countries for the benefit of Egypt and the Sudan, even if these countries are unlikely to make large demands on Nile water, will require much political negotiation and compromise. In particular, Egypt is likely to continue to take a great political interest in developments in the upstream countries and her policy towards them will continue to be determined by the overriding importance of the Nile waters.

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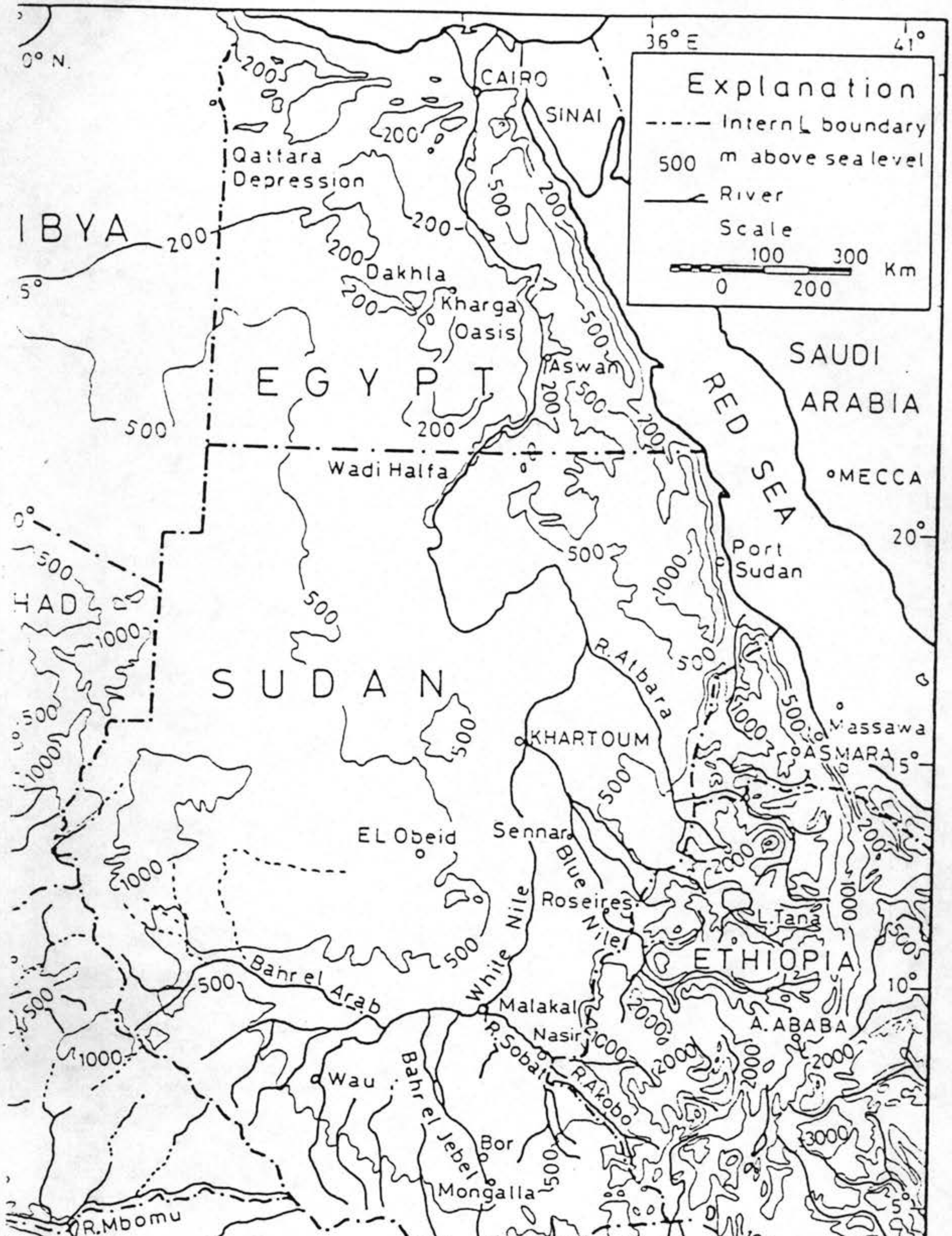
ROBSON, J.F. and HENNESSY, J.R.	1982	"The development of the Nile waters and its tributaries in the Sudan", Paper read at a meeting of the British section of the International Committee on Irrigation and Drainage, London.
SHAHIN, M.	1985	Hydrology of the Nile Basin, Amsterdam, Oxford and New York.
(HURST, H.E.	1952.	The Nile, London.)

Only references which have been directly quoted in the text have been included above. There is a voluminous literature on the Nile and much of this has been used to provide background information. However much of the literature is merely repetitive and to quote any one source might well involve adding many others. The statistical data supplied by Amer has been widely used in the calculations but in recent years much of this is contradictory and it does not always agree with data quoted in some of the references above.

SOURCE: SHAHIN



2.2. Topographic map of the Nile Basin

FIGURE 1.

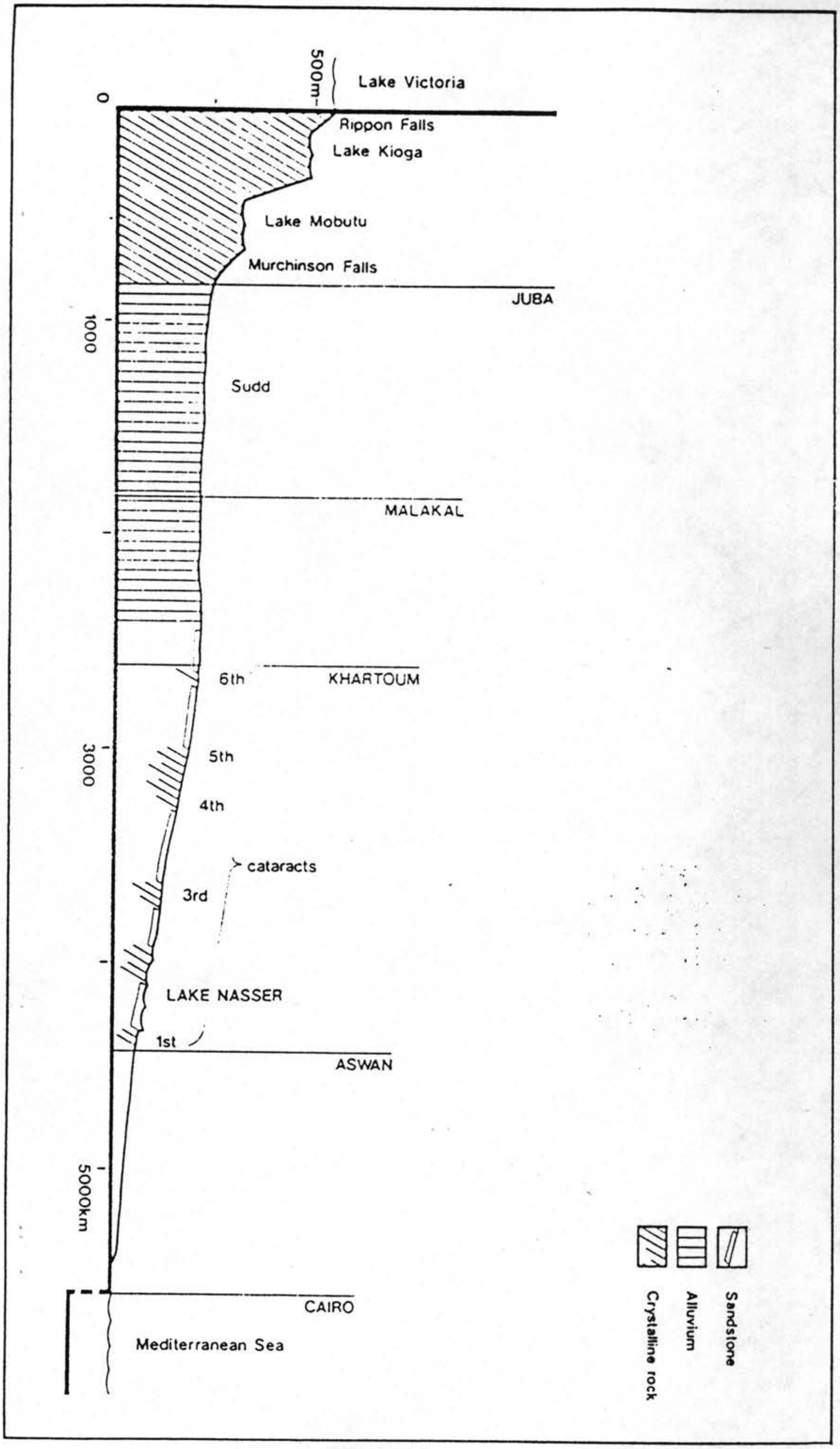
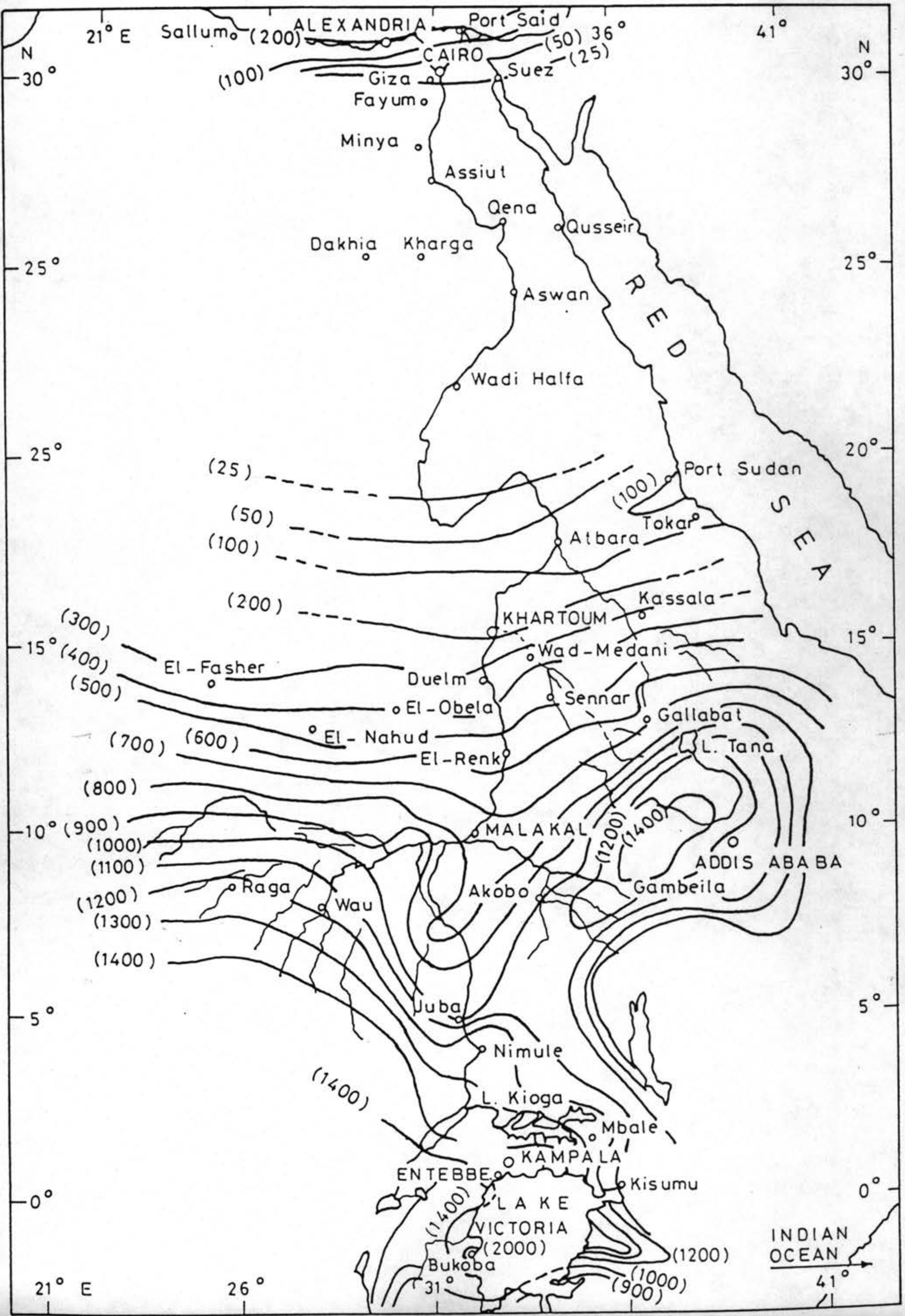


Figure 2 Longitudinal Profile of the Nile River
Source: Middle East Research Institute

FIGURE 3 (SOURCE: SHAHIN)



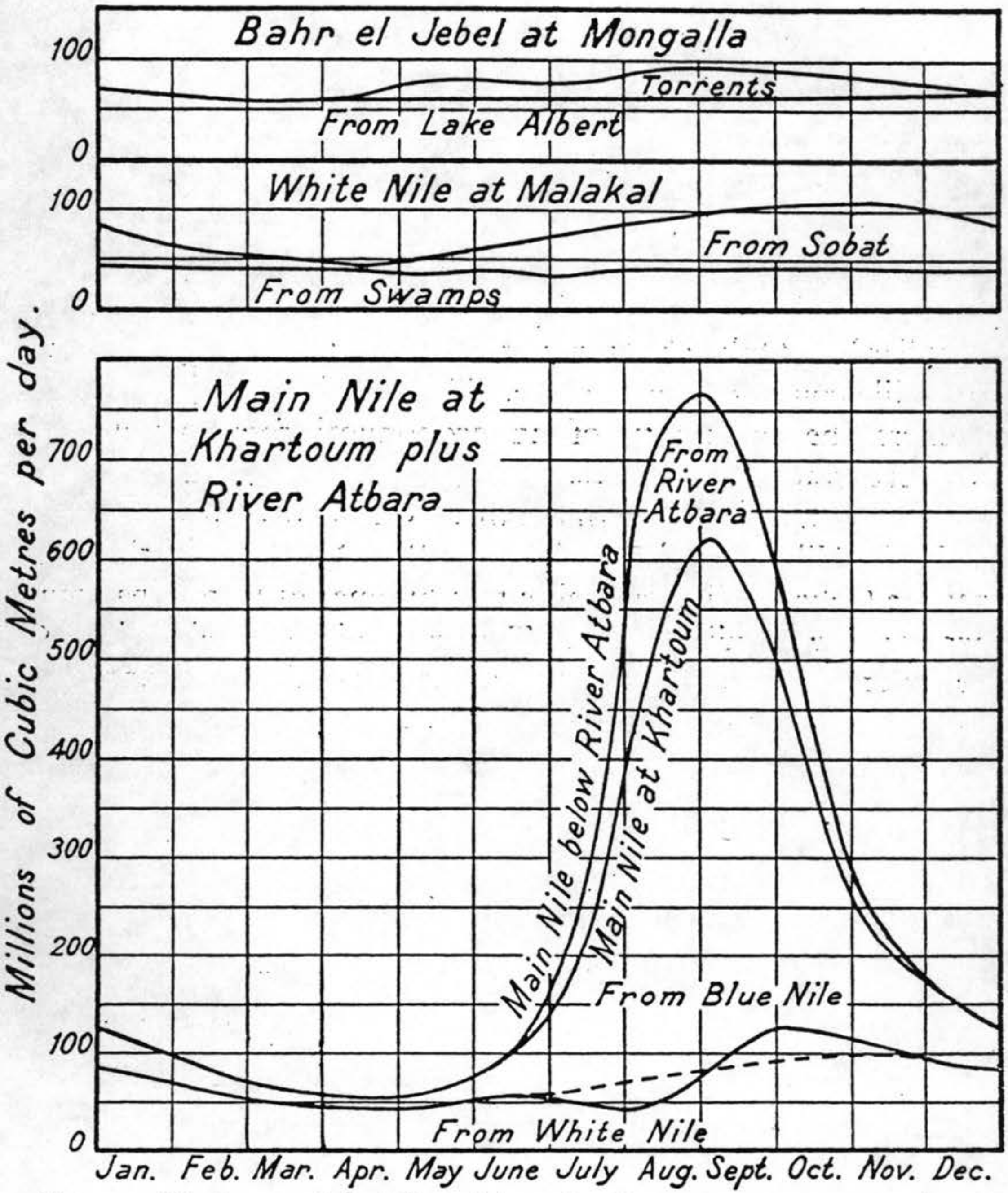


FIG. 17. Discharges of the Nile and its main tributaries. Average 1912–36.

FIGURE 4.
SOURCE HURST

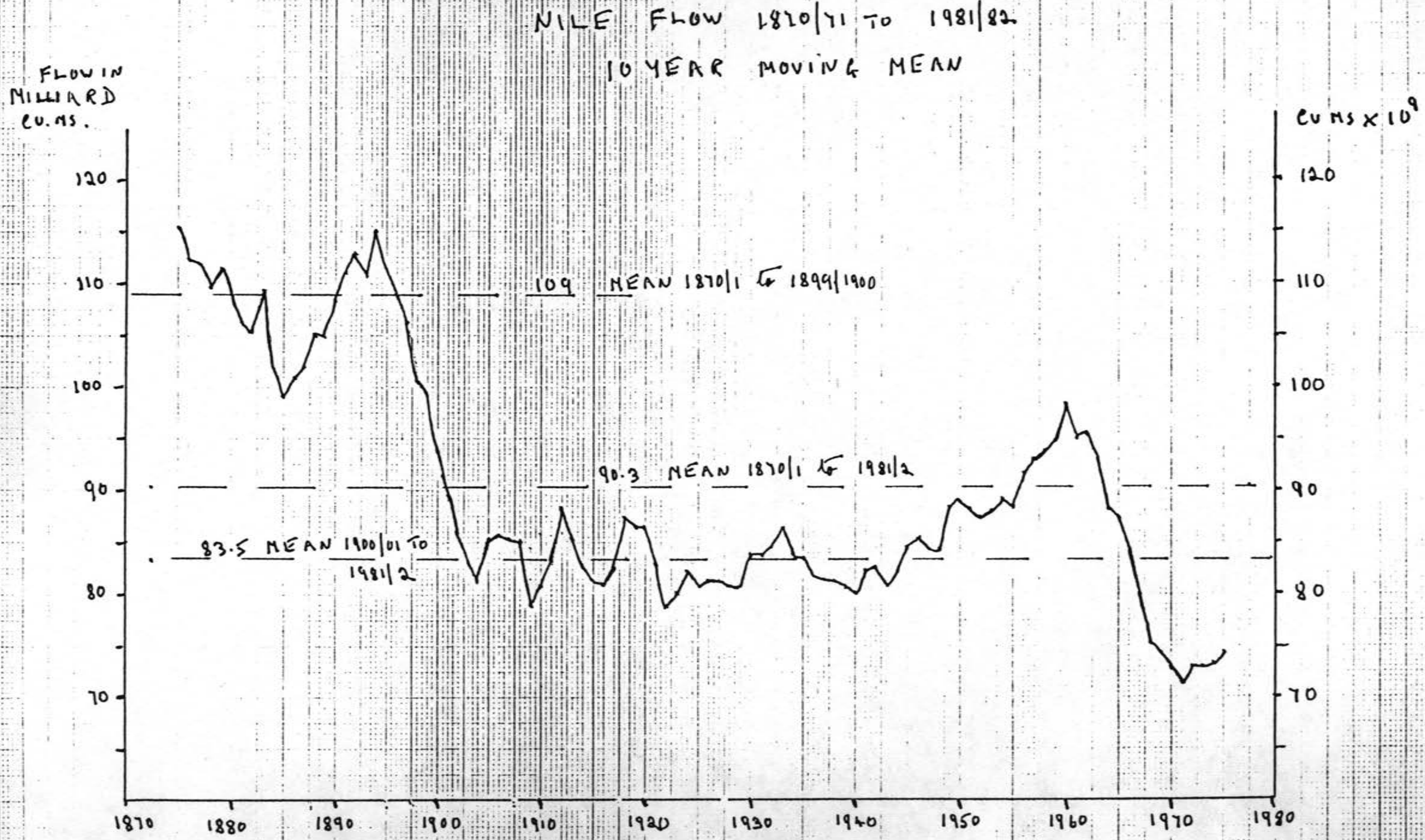

NILE FLOW 1870/71 TO 1981/82
10 YEAR MOVING MEAN
FLOW IN MILLIARD CU.MS.
CU MS X 10^9
120
110
100
90
80
70
109 MEAN 1870/1 to 1899/1900
90.3 MEAN 1870/1 to 1981/2
83.5 MEAN 1900/01 TO 1981/2
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980

FIGURE 5 (ELS)

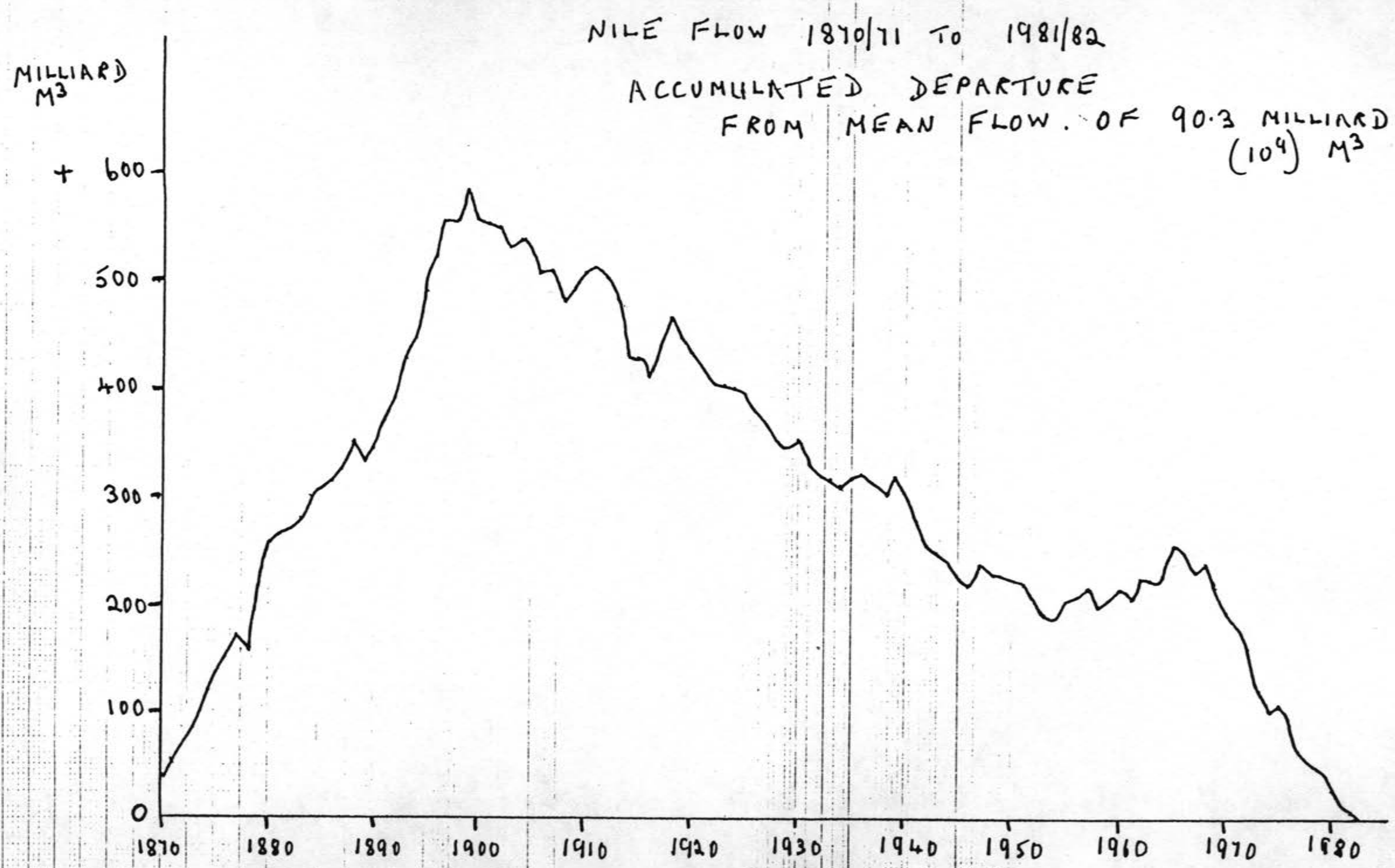

NILE FLOW 1870/71 TO 1981/82
ACCUMULATED DEPARTURE FROM MEAN FLOW. OF 90·3 MILLIARD (10^9) M³
MILLIARD M³
+ 600
500
400
300
200
100
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980

FIGURE 6 (e.e.s).

NILE FLOW NATURAL RIVER AT ASWAN ACCUMULATED DEPARTURE FROM MEAN OF FLOW 1900/01 TO 1981/82 (AUG-JULY)

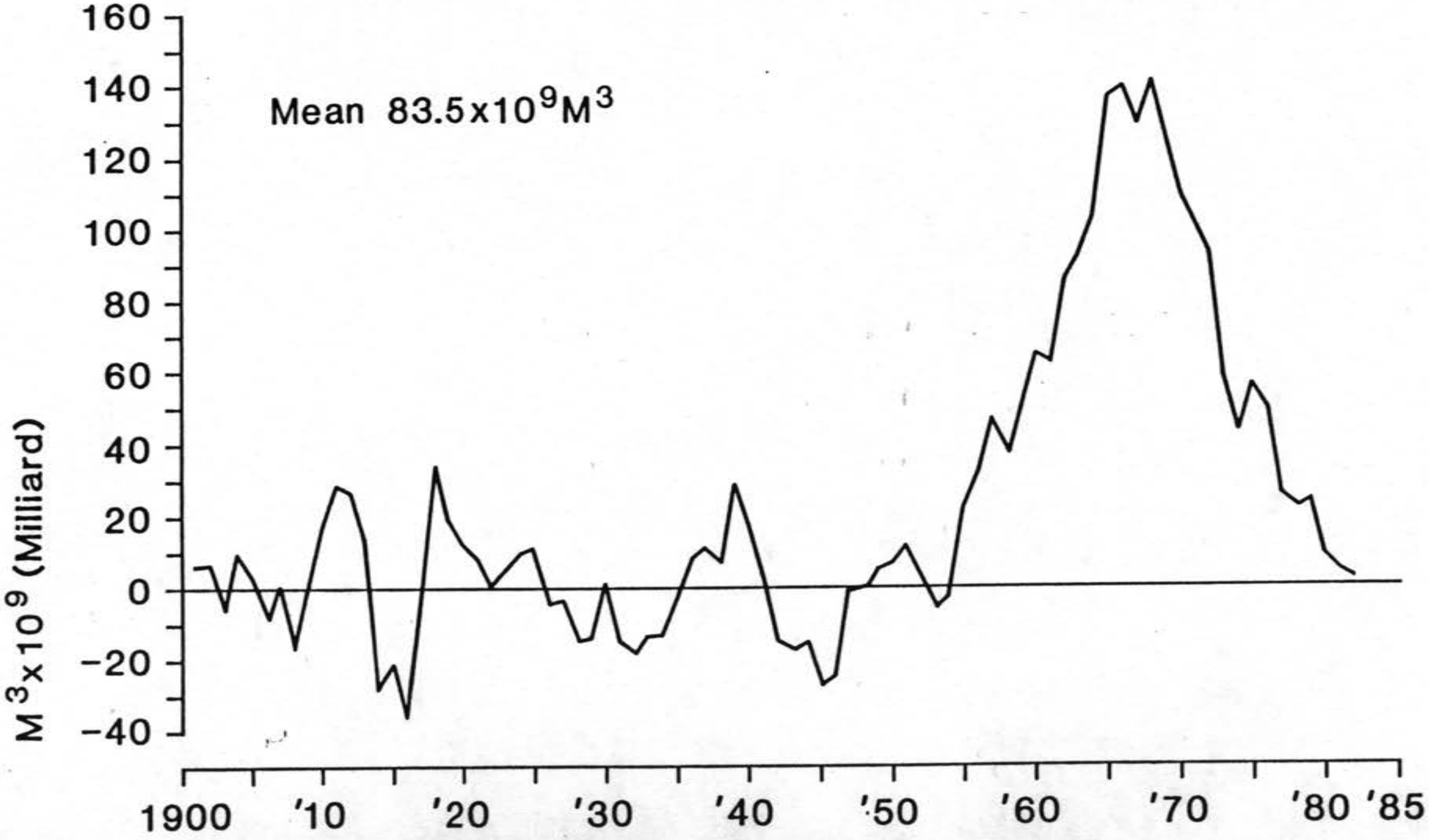
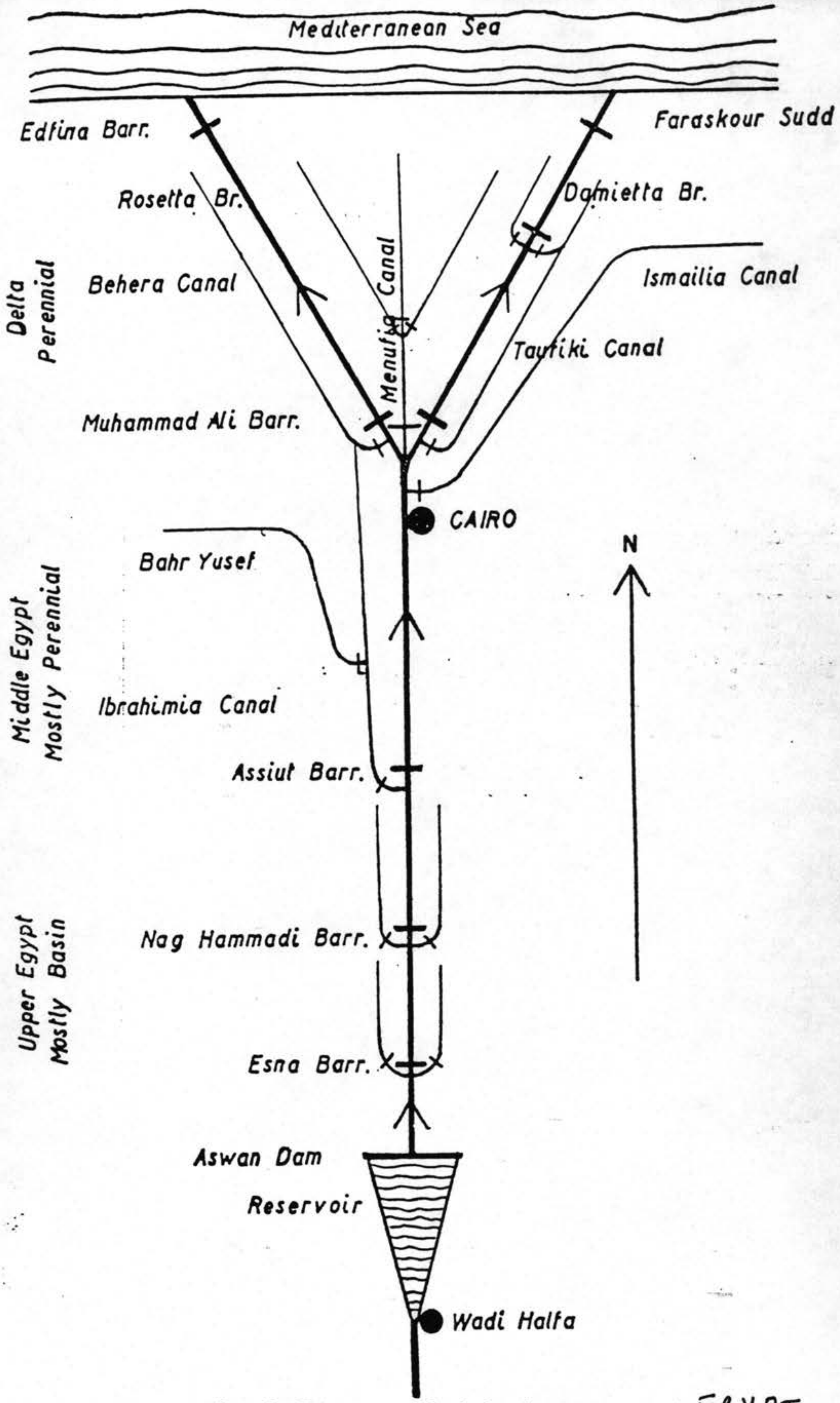


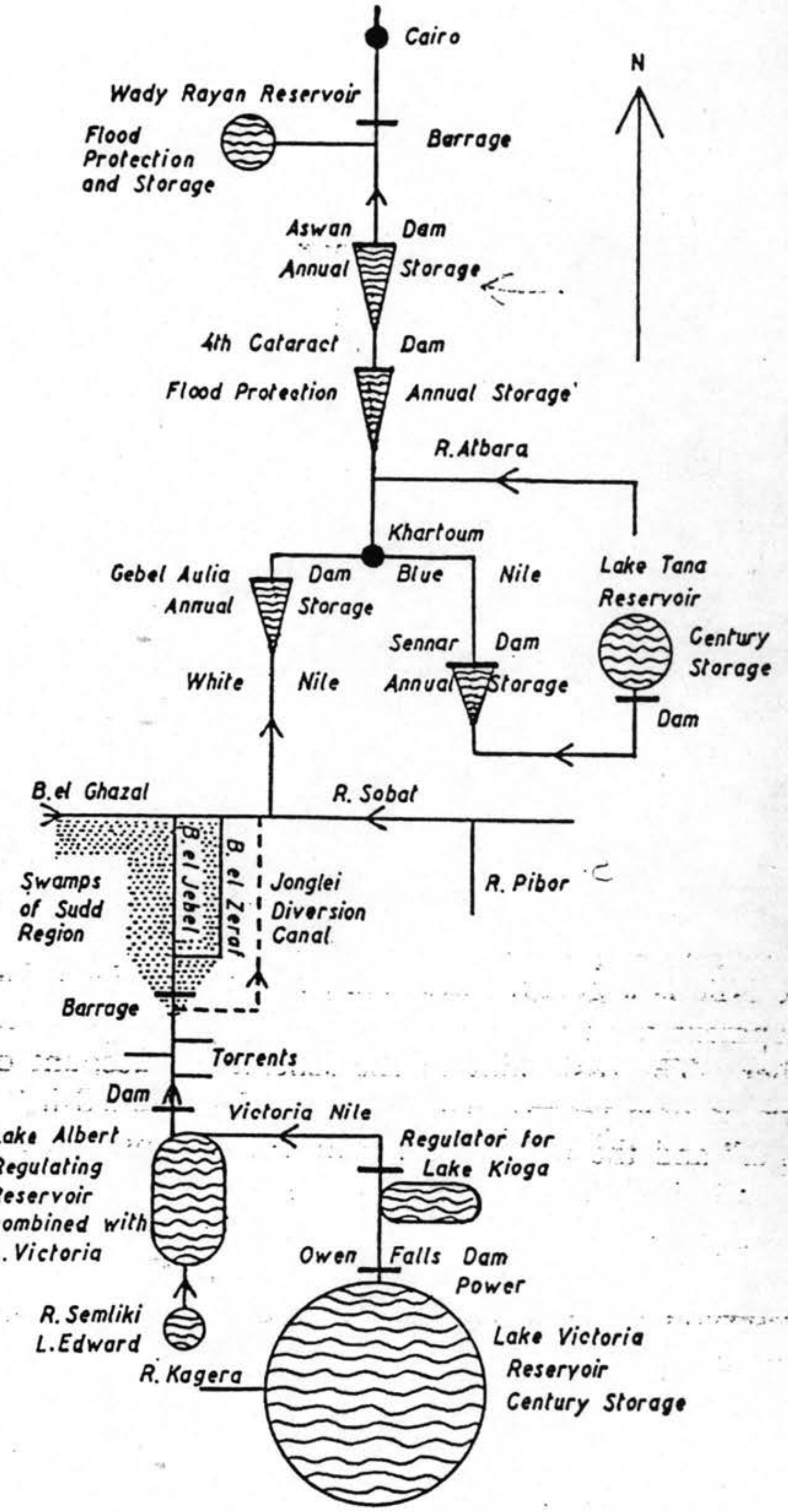
FIGURE 7 (e.g.s.)



~~Fig. 6.~~ Diagram of the irrigation system. IN EGYPT

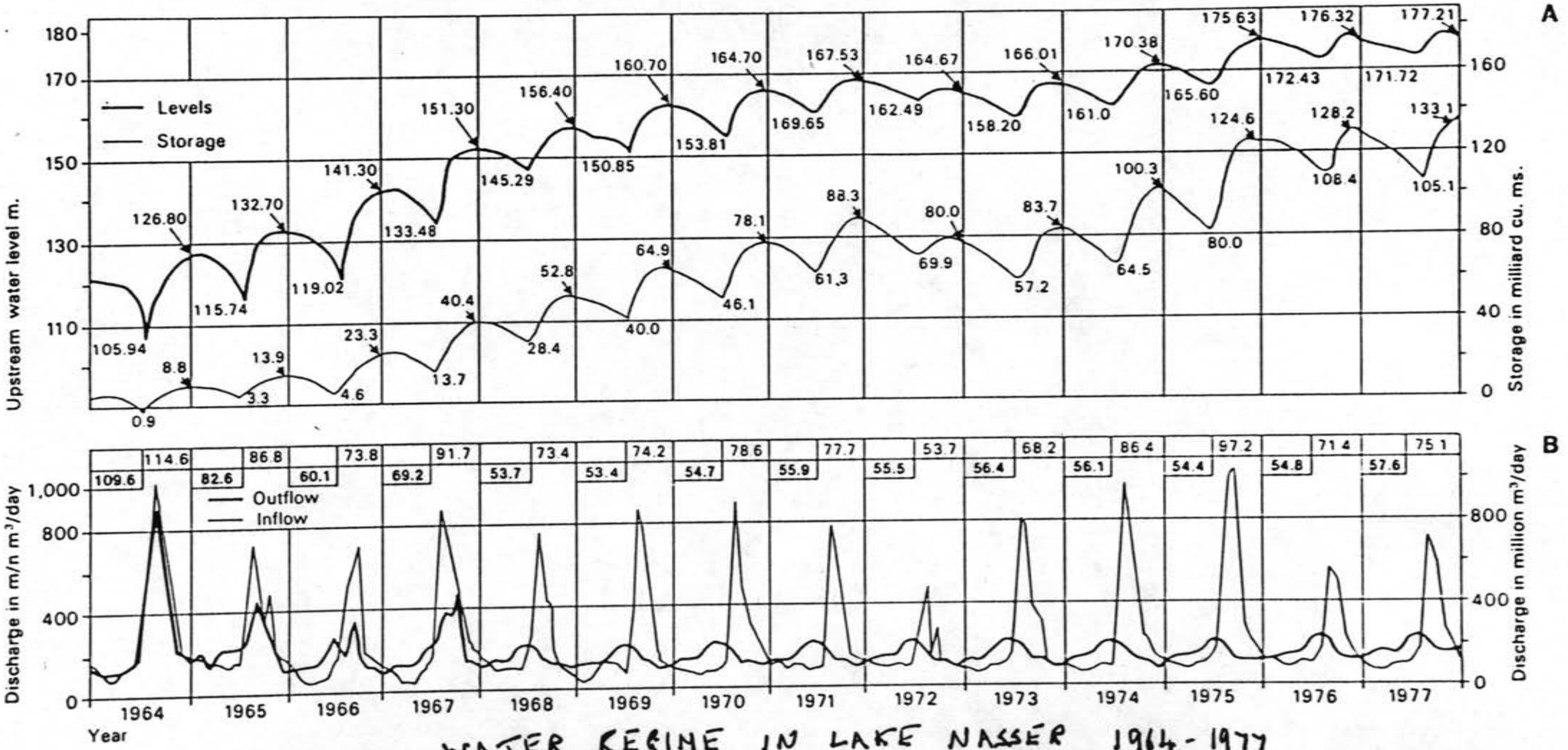
FIGURE 8 (SOURCE: HURST)

THE NILE



CENTURY STORAGE
PROPOSALS
(SOURCE: HURST)

FIGURE 9



WATER REGIME IN LAKE NASSER 1964 - 1977

FIGURE 10. (C.E.S)

WATER STORAGE IN LAKE NASSER

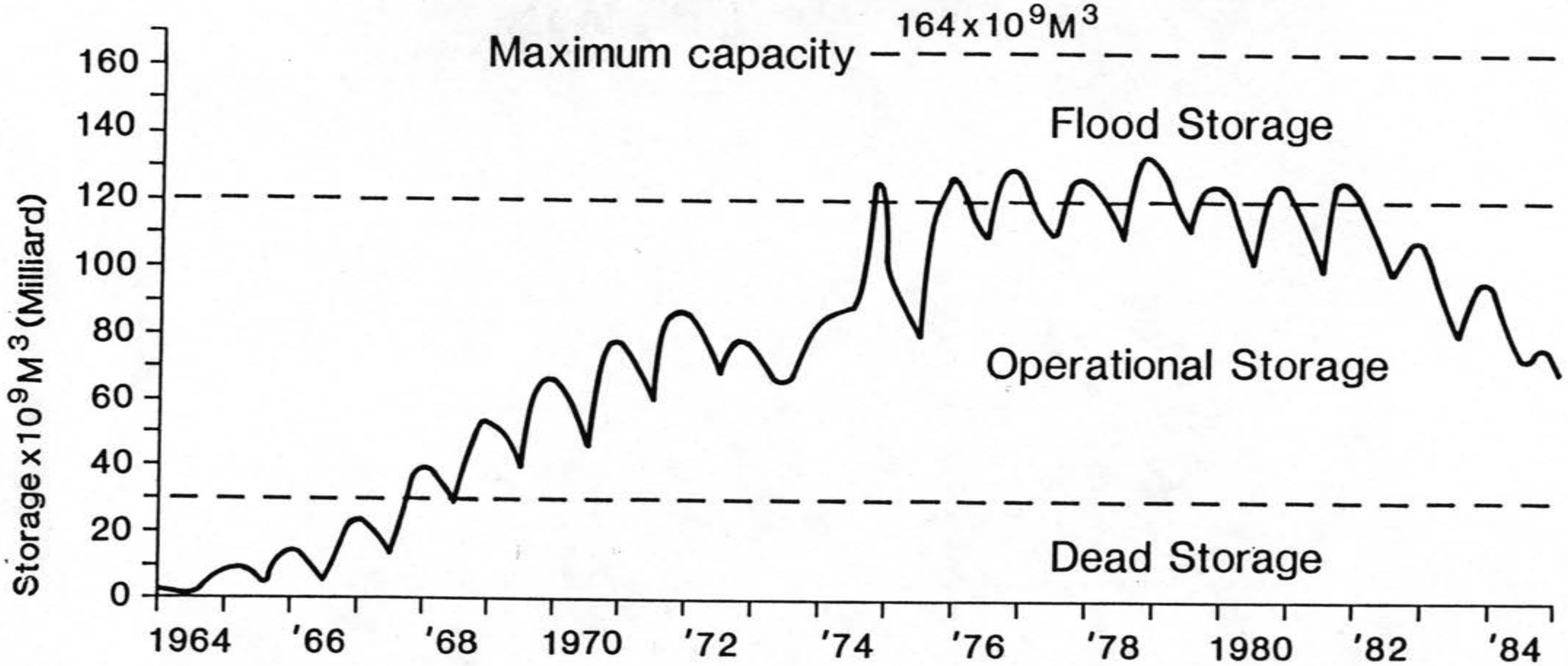


FIGURE 11 (ERS.)

LAKE NASSER: OBSERVED ANNUAL WATER LOSS 1964-77

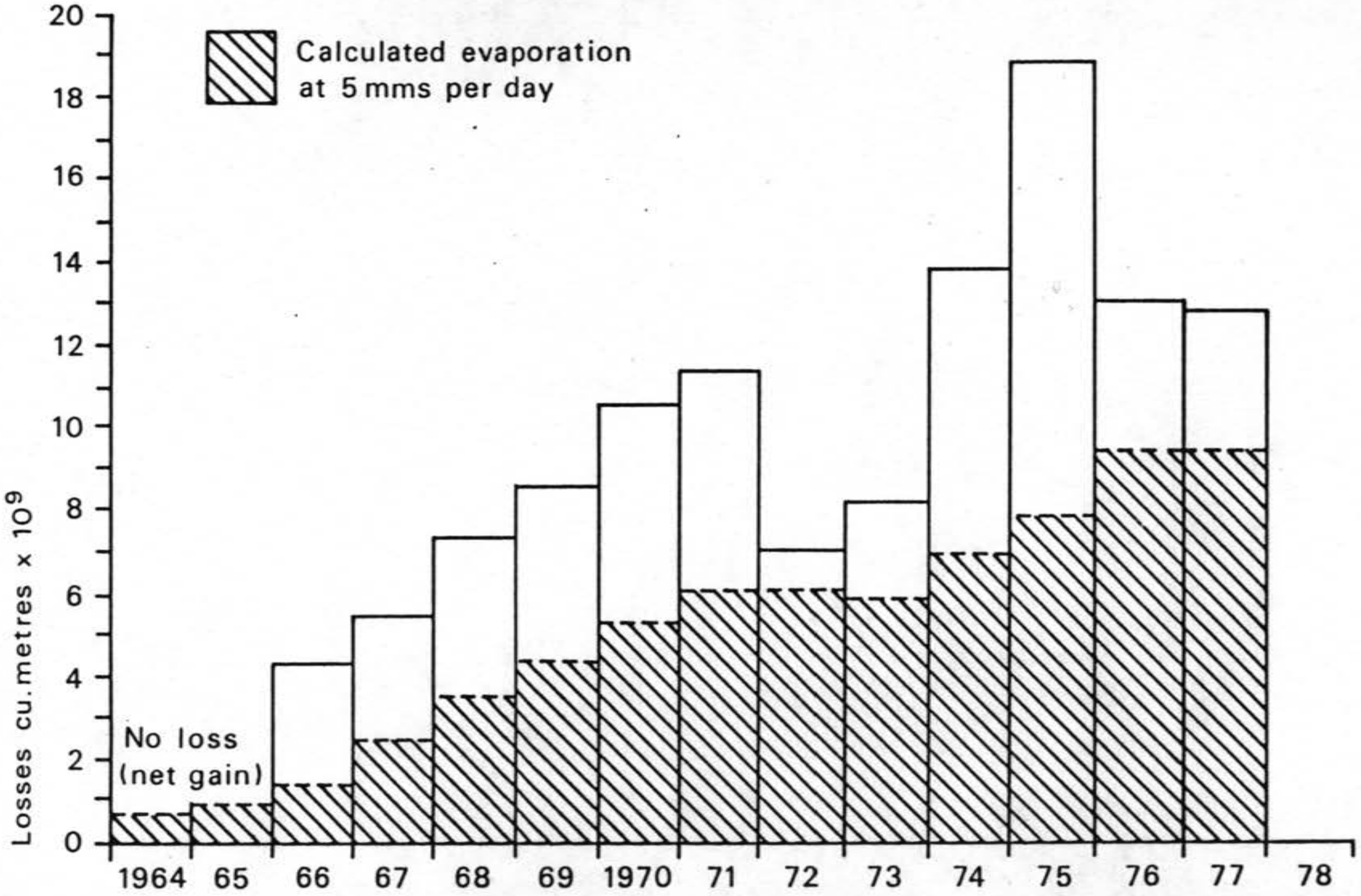
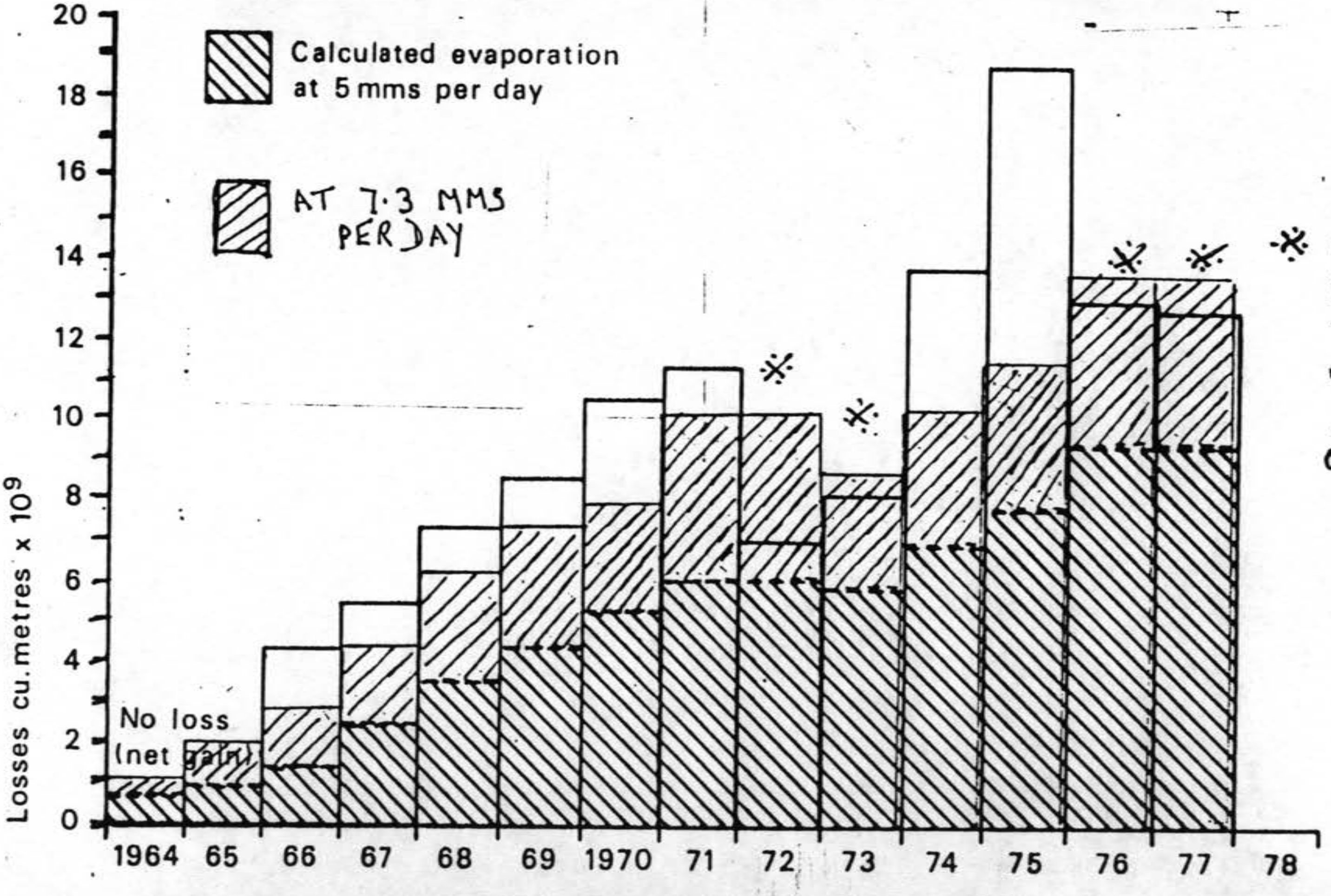


FIGURE 12 (C.G.S.)

LAKE NASSER: OBSERVED ANNUAL WATER LOSS 1964-1977



※ IN THESE YEARS EVAPORATION AT 7.3 MM A DAY WOULD HAVE EXCEEDED THE OBSERVED LOSSES

ANNUAL EVAPORATION: LAKE NASSER (ESTIMATED)

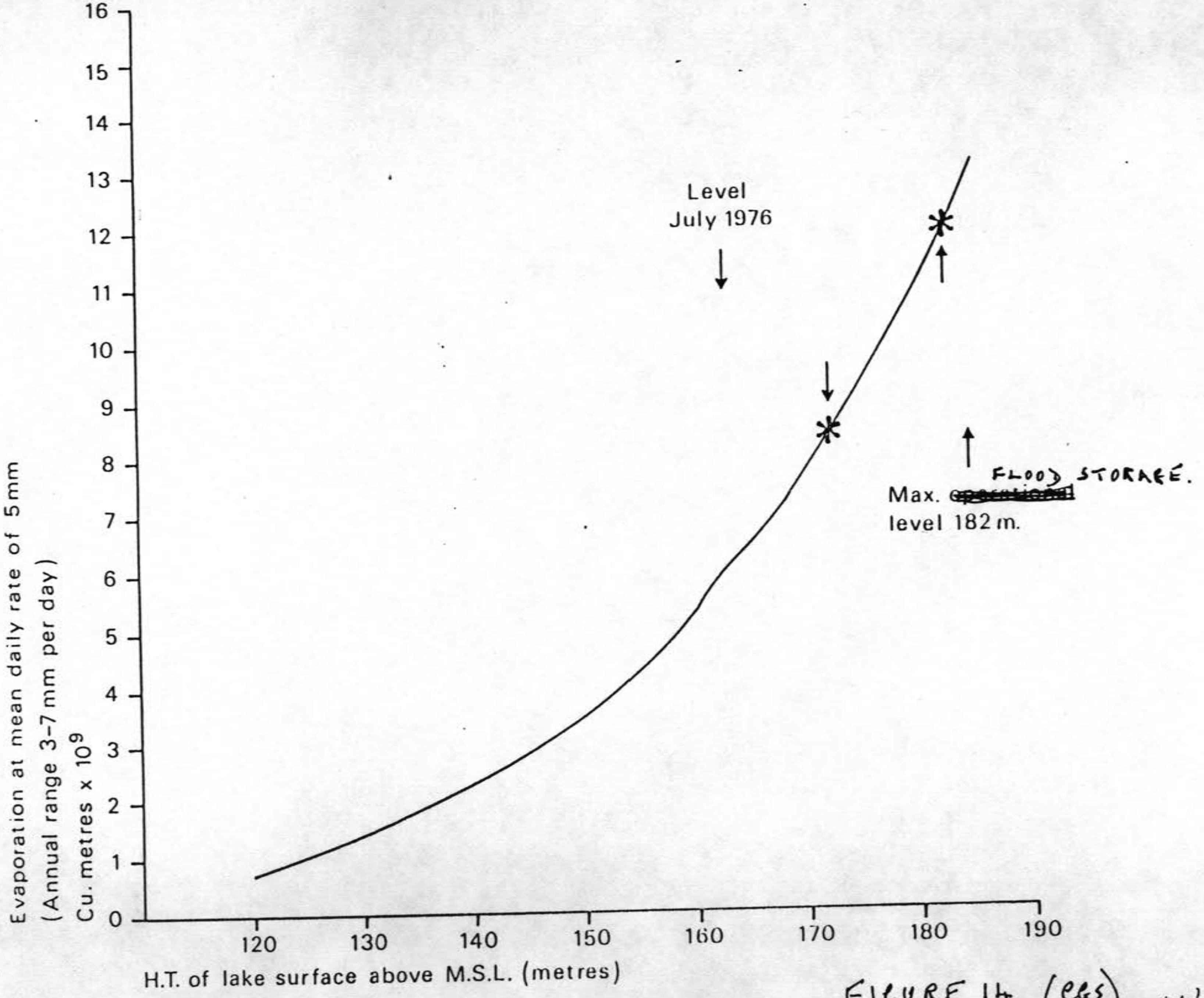


FIGURE 14 (ELS)