SUDAN GOVERNMENT

ROSEIRES DAM

PROJECT REPORT

BY

SIR ALEXANDER GIBB & PARTNERS

FEBRUARY 1954

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CONSULTING ENGINEERS
QUEEN ANNE'S LODGE,
WESTMINSTER, LONDON, S.W.1.

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28th February, 1954

THE PERMANENT UNDER-SECRETARY,
MINISTRY OF FINANCE,
SUDAN GOVERNMENT,
KHARTOUM,
SUDAN.

SIR,

ROSEIRES DAM PROJECT

In accordance with the instructions conveyed to us in the Financial Secretary's letter reference FDK/345-18 of the 15th February, 1952, we now have pleasure in submitting our Report on the Roseires Dam Project.

Our Terms of Reference are attached hereto.

Our Conclusions and Recommendations, which are dealt with under appropriate headings in the body of the Report, may be summarised as follows :—

(1) The Damazin Rapids provide a suitable site for the construction of a dam. Sound rock is exposed in the river channel, but is covered on both flanks by unconsolidated sedimentary deposits of varying depth and permeability.

(2) Storage capacity of 1,000 million cubic metres can be obtained by means of a reservoir having a top water level of R.L. 471.5 metres.

(3) The recommended design of dam includes a concrete central section of the heavy buttress type across the trough of the river, with earth embankments on either flank. The central section is provided with gates for passing floods up to 15,000 cubic metres per second and for regulating the discharge of the river. Provision has been made for a public road across the dam, the normal operation of the control gates being carried out from an independent lower deck from which the public would be excluded.

No provision has been made for a rail crossing.

With a reservoir top water level of R.L. 471.5 metres the overall length of the dam would be 3,900 metres and the maximum height from river bed to road level would be 47 metres.

(4) Suitable construction materials, both for the concrete section and for the earth embankments, are available in the locality. The possibility of manufacturing cement at the site has been considered and rejected on economic grounds.

(5) The estimated cost of a dam to store 1,000 million cubic metres of water is £E15,050,000. Further details of the make up of this figure are contained in Chapter 5.

(6) The estimated time for completion from the commencement of preparation of contract documents and drawings is eight years. For about four months in each year no work will be possible in the river bed owing to the floods and during the same period construction of the earth embankments will also be brought to a standstill owing to the saturated condition of the ground. The working season will, therefore, be about eight months in each year.

When it is decided to proceed with the construction of the dam one of the first steps to be taken must be the provision of living accommodation at the site together with improved access facilities.

(7) Provided the existing Roseires gauge is replaced by a new measuring point higher up the river, a suitable operating regime can be established with the reservoir acting either as the head pond of an irrigation system drawing its water direct from the reservoir, or as a supplementary supply to Sennar.

In considering these alternatives due regard has been paid to the recommendations contained in our Report on the " Estimation of Irrigable Areas ".

Other factors which have been taken into account are :—

(i) The effect of the Roseires regime on Sennar including pump irrigation around its fringes and cultivation of " Gerf " lands within the reservoir area.

(ii) The effect of a storage project at Lake Tana.

(8) The operating regime has been based on the impounding of silt-laden flood water, the reservoir being filled to its top water level by the end of September each year. Although this will mean that the tendency towards siltation will be increased as compared with Sennar, it is not anticipated that this will have any appreciable effect on the storage capacity of the reservoir even after a long term of years. Means have been provided in the design of the dam to permit the reservoir basin being flushed by the rising flood.

(9) Provision has been made in the design of the dam for the passing of driftwood, including trees, during the flood period.

Proposals are also included in the Report for a debris trap at the head of the reservoir. If constructed this might avoid the passing of driftwood on to Sennar and could be combined with a road and rail crossing of the river.

(10) The Damazin Rapids is the only site available on the Blue Nile where a dam might be constructed to store water on a large scale within Sudan territory. Our surveys have shown that it is possible to increase the reservoir capacity to at least 3,000 million cubic metres and, should the additional water be required, there are considerable economic advantages in so doing. These advantages are examined in Chapter 7, where it will be seen for instance that storage could be doubled at an incremental cost estimated at £E3,750,000.

We strongly recommend that should it be possible to arrive at a definite conclusion as to the ultimate storage required at Roseires the dam should be constructed to its full height at the outset.

(11) We recommend that allowance should be made in the design and construction of the Roseires Dam for a future hydro-electric power plant. Taking into account the possible effect of storage in Lake Tana we propose that, with a reservoir having a top water level of R.L. 471.5 metres, provision should be made for a future installation of up to 112,500 kilowatts depending on the operating regime adopted. With higher top water levels this could be increased.

We would like to place on record our deep appreciation of the assistance and co-operation which we have received throughout our investigations from officials in many departments of the Sudan Government.

We are particularly grateful to all officials of the Sudan Irrigation Department who have made the records of the Department so freely available to us.

We have the honour to be, Sir,

Your obedient servants,

SIR ALEXANDER GIBB & PARTNERS

(Signed) J. GUTHRIE BROWN

(Signed) R. L. FITT

ANNEXURE

ROSEIRES DAM PROJECT

TERMS OF REFERENCE

As sent to Sir Alexander Gibb & Partners by the Sudan Government under cover of their letter of 15th February, 1952, Reference FDK/345-18

The suggestion of a storage reservoir on the Blue Nile south of Roseires, with the dam located in the region of the Damazin rapids, was made by Sir William Garstin in 1904. It was not pursued, and the Sennar Dam was built to serve the Gezira area. Preliminary studies by the Sudan Irrigation Department in 1938 indicated a possible reservoir capacity of 1 milliard (1,000 million) cubic metres. It is now intended that the Consulting Engineers, Sir Alexander Gibb & Partners, shall be responsible for the development of preliminary proposals for the construction and operation of a dam and reservoir near Roseires.

The immediate object is to secure a storage reservoir with a capacity in the order of 1 milliard cubic metres, or greater if reasonably practicable. It will be necessary to fill the reservoir from the Blue Nile in the later stages of the flood, while the water is still silt-laden. Used in this way, the project will supplement the Sudan's resources in advance of the development of the Lake Tana scheme. As and when Lake Tana is developed, the Roseires Reservoir would become a complement thereto : it would most probably be used to store water released for power but untimely for irrigation.

There may also be local potentialities, in connection with the survey of irrigable areas now in hand in the area. These are secondary to the immediate object.

In accordance with the foregoing the Consulting Engineers will :—

(1) Examine all existing hydrological data.

(2) Inspect and carry out preliminary surveys of possible sites for a dam, in the area of the Damazin Rapids just south of Roseires, to provide storage capacity of approximately 1,000 million cubic metres, or greater if reasonably practicable.

(3) Carry out a preliminary survey of the storage reservoir area.

(4) Consider the geological information available at the possible dam sites and to make arrangements for such further geological investigations as may be required.

(5) Arrange for such borings as may be required at the dam sites.

(6) Consider the availability of local construction materials.

(7) Consider the top water level of the dam, and operation of the reservoir, in the light of the downstream investigations already in hand, if it becomes clear that the dam could be used for the headworks of a major irrigation system downstream.

(8) On the basis of these considerations, submit a Report giving recommendations as to the location and type of construction of the dam. (The design to be such as to permit the passage of considerable quantities of driftwood (including logs and trees) in flood and to impound flood water while still silt-laden).

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by

Dr. Francis Jones, T.D., M.Sc., F.G.S.

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CHAPTER 1

INTRODUCTION

For a distance of 1,000 kilometres from its source beyond Lake Tana to a point 113 kilometres above Roseires, the Blue Nile lies wholly within Ethiopian territory, and with its numerous tributaries drains a sparsely inhabited mountainous and plateau area some 210,000 square kilometres in extent.

It is from this catchment and as a result of the heavy rains that fall upon it during the monsoon period from March to September that the Blue Nile collects the run-off which is of such importance to the people of Egypt and the Sudan. Heavy soil erosion in Ethiopia produces the silt and floating debris brought down by the river during the flood period.

Just before crossing the frontier the Blue Nile enters the clay plain through which it flows to Khartoum. Between the frontier and Roseires there are numerous outcrops of rock in the river bed including those at Famaka Gorge. Rock outcrops are visible throughout the length of the Damazin Rapids, which extend for a distance of 4 kilometres and terminate 6 kilometres above the town of Roseires.

The course of the Blue Nile from its source to Khartoum is shown on Fig. No. 1.

CHAPTER 2

HYDROLOGY

1 River Discharge

The occurrence of rainfall on the Ethiopian highlands has a well defined pattern, but the amount falling each year varies erratically. The result is that the annual discharges of rivers collecting the run-off of this area, including the Blue Nile, vary over a wide range as also do the peak discharges during flood periods. Apart from Lake Tana, the overall effect of which is small, there are no natural balancing reservoirs on the Blue Nile to even out the river discharge. The undeveloped state of the upper catchment area and the absence of reliable records of rainfall and river flow have, in the past, made it impossible to provide any forecast of the flood discharge of the river before it enters Sudan territory.

Past flow records are based on readings taken at two gauging stations, one at Roseires and the other at Wad el Ais about 7 kilometres upstream of Singa.

The present Roseires gauge was erected in May 1905, but gauge readings exist from 1903 onwards. River discharges at low stages have been measured regularly at Roseires since February 1918. Since 1922 flood discharges have been measured at Wad el Ais, a gauge having been established in that year.

No attempt has been made in this Report to reproduce the gauge readings and discharges which are readily available in " The Nile Basin " Vols. III & IV and Supplements. Typical hydrographs are shown on Fig. No. 2.

Table 1 is a summary of data derived from a study of the 10-day mean figures for the period 1912-1952. Figures for the years up to 1942 are published in " The Nile Basin " Vol. IV, and its three Supplements ; those for subsequent years have been supplied by the Sudan Irrigation Department.

TABLE 1

SUMMARY OF BLUE NILE DISCHARGES

Description	Date	Gauge Level at Roseires*	Discharge	
			Cumecs†	Milliards‡
1. Maximum level and discharge	1946 (August)	21.61	10,078	—
2. Minimum level and discharge	1914 (May)	10.59	38	—
3. Maximum annual discharge	1917—1918	—	2,236 (av.)	70.58
4. Maximum but one annual discharge ..	1929—1930	—	2,120 (av.)	66.80
5. Minimum annual discharge (abnormal) ..	1913—1914	—	637 (av.)	20.10
6. Minimum but one annual discharge ..	1912—1913	—	1,180 (av.)	37.21
7. Mean annual discharge	1912—1952	—	1,572	49.62

* Zero gauge reading at Roseires taken as R.L. 426.21 metres referred to Khartoum datum assumed as R.L. 360.00 metres.
† 1 cumec = 1 cubic metre per second.
‡ 1 milliard = 1,000 million cubic metres.

2 Maximum Floods

The highest recorded peak discharge of approximately 10,800 cumecs occurred on August 24th, 1946, when a level of 22.68 metres was reached on the Roseires gauge.

If the maximum annual floods over the period since 1912 are plotted as a probability curve the indications are that the maximum 10-day mean discharge at Roseires is not likely to exceed 11,500 cumecs. This suggests that the maximum discharge of 15,000 cumecs allowed for at Sennar provides a very ample margin of safety, and that a flood of even 12,000 cumecs will only be exceeded in the most exceptional circumstances. Bearing in mind, however, the known vagaries of the Blue Nile as evidenced by the 1913 flood, which was far below what could have been anticipated from a study of subsequent records, we are of the opinion that it would be prudent to apply to Roseires the same assumptions as were made in the case of Sennar. Accordingly, we have based our preliminary design of the dam on a maximum discharge of 15,000 cumecs.

3 Silt

Based on data derived from measurements made at Wadi Halfa and published by the Egyptian Government in Physical Department Paper No. 40 by Simaika, it is estimated that in an average year some 70 million cubic metres of silt are carried in suspension by the Blue Nile between the beginning of July and the end of November. During the rest of the year the river carries very little silt, and it may, therefore, be said without serious error that the total annual suspended silt load averages approximately 70 million cubic metres.

In addition to the suspended silt there is, however, a continuous movement of rolling bed material. While the magnitude of this bed load has never been determined it is not generally considered to be of great significance in comparison with the suspended load.

At Sennar the operating regime of the reservoir is such that after raising the water level to canal command level (R.L. 417.2 metres) the sluice gates in the dam are gradually opened to allow the rising Nile flood to pass without causing any further raising of the reservoir level.

It is not until the height of the flood has passed and the silt content has fallen to a relatively low value that the gates in the dam are gradually closed and the water level brought up to full reservoir level (R.L. 421.7 metres).

This regime ensures that over the period of heavy silt concentration the Nile waters are allowed to flow past the dam with the minimum obstruction and ponding. Experience indicates that this method of operation, which has been in force since 1926, has been successful in preventing serious siltation of the Sennar reservoir.

Conditions at Roseires will differ somewhat from those at Sennar, mainly in the following respects :—

(*a*) It will be necessary to commence storing water above any canal command level at Roseires at the beginning of September, just after the peak of the flood has passed and whilst the silt concentration is still very high.

(*b*) The physical characteristics of the Roseires reservoir are factors which, in contrast with Sennar, will tend to reduce the rate of silt deposition.

Since the filling of the Roseires reservoir must take place at a time when the river is carrying a heavy suspended load, some siltation is inevitable, and the amount deposited is likely to be appreciably greater than that which occurs at Sennar under the present operating regime. It is to be anticipated, however, that the greater part of the silt deposited during the early part of the falling flood will be removed the following year by the scouring action of the rising flood.

It is not possible to express any firm opinion as to the rate at which the useful storage of the Roseires reservoir will be reduced by the cumulative effect of siltation. Nevertheless, the evidence available leads us to the conclusion that, provided the design of the dam permits the reservoir basin to be flushed by the rising Nile flood, the permanent loss of capacity will not be such as to detract seriously from the value of the reservoir, even after a long term of years.

4 Evaporation and Seepage Losses

After taking into account the changing climatic conditions and varying water surface area throughout the year, it is estimated that the total loss by evaporation from a reservoir providing a gross content of 1.2 milliards would be 0.16 milliards. This quantity is equivalent to an annual loss of 1.92 metres from the exposed water surface.

Of this total loss 0.04 milliards is attributable to evaporation from the natural river surface, so that the additional loss of water resulting from the construction of the Roseires dam may be estimated at 0.12 milliards or 10 per cent. of the gross contents of the reservoir.

As regards seepage from the floor of the reservoir it is not possible to make any reliable estimate. Having regard, however, to the generally impervious character of the plain over which the Blue Nile flows, and to the fact that a covering of fine silt will in the course of time be deposited over the reservoir basin, we believe that for practical purposes the seepage losses can be ignored.

NOTE : In this report the term " contents " is used to mean the total volume of water in the reservoir less the volume of water which would be contained within the limit of the reservoir if the river were flowing at a rate represented by a reading of 12.0 metres on the Roseires gauge.

" Effective contents " means the gross contents less the amounts debited to allow for eventual silting and for the increased losses by evaporation due to the creation of the reservoir.

CHAPTER 3

DESIGN OF DAM

1 Selection of Site

From a geological examination of the area in the vicinity of the Damazin Rapids the dam has been located on the line BB shown on Fig. No. 3.

The reasons which lead to this choice are set out in the Geological Report by Dr. Francis Jones, which is attached as Appendix II. Apart from offering the most favourable foundation conditions the selected site possesses a further important constructional advantage. A well defined rock channel which forms a loop on the western side of the main river can be utilised to divert the river during the construction of the dam and can subsequently be used as a permanent flood channel.

2 General Features

The general design of the dam is shown on Fig. No. 7 and 8. The structure is composed of three principal elements, the east and west flank dams and the central river section respectively. The flank dams are earth embankments founded on a variable depth of mixed deposits the permeability of which may vary widely. The central section across the trough of the Nile is a heavy buttress concrete dam provided with gates for passing flood water and regulating the discharge from the reservoir.

In relation to the annual discharge of the river the reservoir is small and its operation is entirely seasonal. In addition the presence of established large scale irrigation in the Gezira and elsewhere in the Nile basin will have a preponderant effect on the manner in which the stored water is to be used. The resulting method of operation of the reservoir, which is discussed in detail in Chapter 6, is comparatively inflexible and involves filling the reservoir soon after the peak of the Nile flood, when the silt load is heavy. It is this feature which distinguishes the Roseires reservoir from that at Sennar, to which it may be compared in other respects.

3 Top Water Level

Since our Terms of Reference specifically refer to a reservoir with a storage capacity of 1 milliard, the designs which accompany this Report have been drawn up to meet this requirement and they are based upon a top water level of R.L. 471.5 metres, corresponding to a gross estimated contents of 1.2 milliards.

In estimating the gross contents of the reservoir necessary to ensure a useful storage of approximately 1 milliard we have considered it prudent to assume that all the contents below R.L. 457.0 metres may eventually be lost through silting of the reservoir, an ultimate loss of 0.1 milliards. From the residual volume of 1.1 milliards a further deduction has to be made to allow for the additional evaporation, arising from the creation of the reservoir. This additional loss has been estimated in Chapter 2 at 0.12 milliards leaving an effective content of 0.98 milliards.

The operating levels proposed will be suitable for the installation of hydro-electric generators and this aspect has been dealt with in Chapter 8.

The Damazin Rapids is the only site available on the Blue Nile where a dam might be constructed to store water on a large scale within Sudan territory. Because of the difficulties inherent in the subsequent raising of an existing dam it is most desirable that very careful consideration should be given to the amount of storage which should be provided. To assist in reaching a decision we have, therefore, prepared estimates of cost for constructing the Roseires Dam to impound water to higher levels. These are recorded in Chapter 7.

4 Central Sluice Dam

The central portion of the dam, which occupies the river channel, is founded on rock. A heavy buttress type of dam is recommended, for this enables a clean design to be developed, integrating various sections of the work with due economy in the use of concrete. This section of the dam is 704 metres long, and the maximum height from the bed of the dry season channel of the river to road level is 47 metres.

We have suggested a total freeboard of 2.0 metres above top water level, 1 metre of which is provided between top water level and road level, and the remainder by the heavy parapet beam which carries a travelling gantry.

This central dam incorporates four deep sluice gates discharging into the dry season channel of the river. The size of these gates is 6 metres wide by 10 metres high, and their sills are at R.L. 434.0 metres. They serve three purposes, firstly, to provide a low level waterway during the construction of the dam, secondly, to provide fine regulation of the discharge of the dam during its operation, and finally, to enable the river to be contained within its natural channel during the rising flood, so that silt left by the previous flood can be carried away by a strong current.

Fourteen crest gates are provided in the western half of this section. They are sector gates, 10 metres square, with a breast wall above them, with their sills at a uniform level of R.L. 457.0 metres. These gates control the full retention level but discharge as a free crest when the gates are lifted. They provide capacity for discharging floods up to 15,000 cumecs in conjunction with the low level sluices.

The protection works downstream of all sluices indicated on Fig. No. 7 and 8 are tentative only, and should be the subject of model investigations before they are finalised.

A small hydro-electric installation is accommodated between two buttresses on the east bank of the river. Two sets of 500 kW. each are proposed. These sets would supply power for operation of the gates, and for use in the offices, workshops and living quarters associated with the dam.

The construction of the Roseires Dam would afford the opportunity for the generation of power on a considerable scale and this aspect of the project is discussed in Chapter 8. Although the building and equipping of the power station could be deferred it would nevertheless be essential that not only should the design of the dam make provision for the future turbine intakes, but it would also be necessary to carry out certain foundation work simultaneously with the construction of the main dam. While these works are not shown on the accompanying drawings the estimates include a sum to cover this essential expenditure.

The dam is topped by a 7 metre wide road to serve as a public highway across the river.

The road is spanned by a service gantry which is used for handling an emergency gate for the deep sluices and for general maintenance on the upstream side of the dam. It will also serve for handling the stoplogs and for the removal of the deep sluice gates for repair.

As will be seen from Fig. No. 8 a separate service level is provided below the public road which would give through access over the central concrete dam. This level accommodates the winches and operating gear for the sluice gates and such services as water and electricity which may be required either for the dam or for the local township. Access is provided at four points in its length.

The normal operation of the dam is thus completely independent of the public road, which can be kept clear of any obstruction except at those times when the gantry is required for major maintenance operations, or for handling the emergency gate at the deep sluices.

5 Embankment Dams

As will be seen from Fig. No. 7 the rolled earth embankments which form the flanks of the dam are set at an angle to the central concrete section in order to utilise to the best advantage the natural configuration of the ground.

The gently sloping land on each side of the main river channel is formed of varied beds of sand, gravel and clayey silt, overlying an irregular rock surface at depths of up to 60 metres below ground level.

The construction of a conventional cut-off wall carried down to sound rock would, in such conditions, be very costly. However, the unconsolidated deposits overlying the rock, although containing much permeable material, are overlain by a more or less continuous blanket of silt and clay which should make it possible to provide a leakage path of sufficient length in relation to the head to reduce percolation to acceptable values and ensure the safety of the embankments.

To meet the site conditions it is proposed to construct a zoned embankment of carefully compacted sand and clay, the upstream side of which would be protected against wave action by stone pitching. The natural ground blanket would be reinforced as may be necessary to control leakage through the foundations.

The detailed design of the embankment dams is subject to the results of the extended field investigations which are now in hand.

It is proposed that the top of the embankments should be 1 metre above the top water level of the reservoir, while a solid parapet wall standing 1 metre high above the roadway would provide additional protection against wave action.

The eastern and western embankments have lengths of 2,100 metres and 1,100 metres respectively, their maximum height above ground level being 19 metres. As seen in Fig. No. 7 they will terminate against the concrete dam in a curve of 300 metres radius.

The embankments, which are quite low over a large proportion of their length, can carry a roadway 7 metres wide. Any canal headworks which may be required for irrigation would be incorporated with the embankment dam.

6 Rail and Road Crossings

We consider that from a practical point of view it would be most unsuitable to use the Roseires dam as a combined rail and road crossing. While the top of the dam can readily be adapted to carry road traffic the use of the structure to support the rail crossing would involve additional expenditure, which would be comparable with the cost of an entirely independent structure.

The design is based on the assumption that road, but not rail, traffic will be taken over the top of the dam.

7 Alternative Designs of Dam

The broad principles of the proposed design with a concrete dam across the river bed and earth embankments on either side are dictated by site conditions. It is necessary to provide a strong and durable structure to pass the high floods within the river bed, and equally necessary to impound water safely beyond its confines.

Over the central portion, where sound rock is found at or near the surface, a gravity dam, either of masonry or concrete, is the most suitable form of construction. Our reasons for adopting concrete are recorded in Chapter 4, paragraph 7(*a*).

A massive buttress dam is more economical than a solid dam on foundations such as are available at this site, for the adoption of the former results in a reduction in the total quantity of concrete. Higher stresses can be attained in the concrete due to its more advantageous disposition. Uplift caused by hydraulic pressure under the dam is reduced since the natural river level below the dam is reached without traversing a great thickness of concrete. There are other features of particular advantage in the Sudan. Overheating of the concrete during setting is reduced since the cooling surfaces are larger, shrinkage effects can be dealt with more efficiently, and there is better access to the concrete for inspection. A heavy buttress design is also readily adaptable for the provision and operation of both deep sluices and crest gates.

The arrangement of gates is unusual for Nile dams. It is essential that some deep sluices should be provided in order to draw down the reservoir and keep it as clean as possible. But the discharges required for those purposes are not large when compared with the extreme flood flow which must pass the dam in exceptional years. We have consequently limited the deep sluices to four in number, each 10 metres high by 6 metres wide, set in the dry season channel of the natural river. In this location they best fulfil their essential purposes and also serve to pass the river during construction.

The other sluices must be considerably higher to avoid very heavy costs in increased excavation and concrete quantities. The choice remains between submerged sluices and crest gates. The main factors affecting the decision are as follows :—

(1) Crest gates can give large unobstructed openings for the passage of trees reaching the dam. Submerged sluices should be screened to prevent large debris jamming them.

(2) Crest gates do not require emergency gates since they are more readily serviced. Such emergency gates are essential with submerged sluices.

(3) For similar hydraulic conditions, crest gates must have a larger area than submerged sluices, but their construction is lighter. The difference of size has been reduced by providing a breast wall which does not affect free discharge over the crest.

(4) Operation of crest gates should be less frequent than the corresponding submerged sluices, and by correct manipulation of the four deep sluices it should be possible to avoid using the crest gates at partial opening.

(5) Erosion problems will be much the same for either type of gate. The rock bed of the river will provide considerable natural protection.

(6) If hydro-electric power on a large scale is developed in the future, and it proves possible to maintain a minimum level of R.L. 456.5 metres during the flood season, the high sills of the crest gates will be of great advantage in minimising gate operations to maintain this level.

There are thus many advantages in adopting crest gates instead of submerged sluices, for economy in both cost and operation.

The use of earth embankments beyond the confines of the river bed is dictated by economy. Site conditions are such that any other solution would be far more costly, and would achieve nothing more than a reduction of the small initial seepage which will pass the earth banks. Since the design of the embankments will ensure that seepage will not endanger the structures and will gradually reduce, there is no reason to contemplate a more expensive type of construction.

In our design we have located the embankments so that their downstream slopes are clear of the influence of floods and always available for inspection. The concrete portion of the dam is, therefore, longer than is necessary merely to accommodate the flood gates. If, however, provision is made for future power development the intakes must be installed in the concrete section. As the embankments are founded on material whose permeability is not yet fully investigated it would be unwise at this stage to reduce the concrete portion and extend the banks.

CHAPTER 4

CONSTRUCTION

1 The Working Season

The river works would be the most important and difficult part of the project ; they would represent a high proportion of the cost and determine the overall construction period.

The annual flood produces flows of such magnitude that inundation would take place and work in the river channel would be stopped for a period. The time during which the inundation would persist is dependent on the capacity of the diversion works and the height of the cofferdams.

Our investigations show that the length of the working season in the river bed would average just under eight months. This season could only be lengthened slightly at greatly increased cost, because of the rapid rise and fall of the river.

Progress of the works would also be affected by the rains, which close the existing roads to Roseires from June to November, and sometimes for a longer period. Although a steamer service is operated at present between Es Suki and Roseires during the flood, the dam site would not be directly accessible by water through the lower reaches of the Damazin rapids. Goods handled by this route would require much trans-shipment.

It has been assumed that the railway will be extended to Roseires before the commencement of major construction works on the dam, but movements by rail are also affected by the rains. It may be said, therefore, that large scale movement of men and materials would be greatly reduced during the rainy season, with a consequent lack of continuity.

In addition, work at site would be difficult during the months of heavy rainfall and the construction of the earth embankments would be brought to a standstill owing to the saturated condition of the ground.

In spite of these difficulties it would be essential for work to proceed as far into the rainy season as possible, and for all available means of communication to be employed to a maximum degree to ensure a rapid return to full scale operations as soon as site conditions permit.

Another factor controlling the length of the working season may be the maintenance of an adequate labour force. Men employed on the works may wish to return to their homes during the rainy season, when food crops are sown, and there would be no advantage in seeking to change this custom. Labour remaining at the site would be largely required for repair and maintenance operations, preparing for the next working season and for general watching and security duties.

Imported personnel would also require a break from the arduous site conditions especially as their services would be required over a number of seasons.

Plant would be operating at maximum capacity throughout the working season, and it would be necessary to make good the wear and tear during the rainy period when it would be largely out of commission.

The above considerations lead to the conclusion that full scale constructional work must be considered as confined to a limited period each year. The Construction Programme has been drawn up on this basis.

2 Initial Stages

Before tenders can be invited for the construction of the dam, time is required for the preparation of designs and contract documents. A preliminary document should be made available during this period in order to give prospective tenderers the fullest opportunity to study the nature of the works in relation to site conditions. Its issue should, therefore, be timed, as far as is possible, to coincide with the reopening of the roads to Roseires after the rains. Such an arrangement allows of tenders being received and considered and a contract placed before the following working season commences.

3 Housing and Labour Camps

Living accommodation for the labour force and supervisory staff would have to be specially constructed. It would be advantageous if this accommodation were to include permanent housing which will ultimately be required in the neighbourhood of Roseires.

Some housing should be provided ahead of the commencement of the main civil engineering works. It should be ready for occupation as soon as possible after a decision has been reached to construct the dam, and if possible during the tendering period.

The Sudan Government will, no doubt, wish to consider without delay the planning of any new township which may be required to serve the needs of the future community in order to ensure that such permanent houses as may be built will conform to local standards and fit in with the overall plan.

The construction of the temporary camps for a labour force which may amount to 3,000 men should preferably be left to the contractor appointed to build the dam, although consideration of their siting and the general standards to be imposed should receive early attention.

4 Plan of Construction

In planning the work and preparing the estimates we have assumed that the method and programme of construction would be as follows :—

(*a*) During the first dry season the diversion channel will be excavated (see Fig. No. 7) and it is likely that this work will occupy the whole of the working season. This gives time for the ordering up and delivery to site of the plant and materials required for the cofferdams, the production of concrete, and the construction of the permanent work. Furthermore, the material excavated from the diversion channel will form an initial stock pile to be crushed for concrete aggregate.

(*b*) During the second season two cofferdams will be constructed across the main river channel to enclose the working area to be occupied by the deep portion of the main dam. The water will thus be diverted into the channel formed during the previous season. It will be impracticable to construct the cofferdams to such a height as to ensure that the whole of the river flow is diverted during the flood season, and it will be necessary, therefore, to make them sufficiently substantial to withstand overtopping by normal floods without excessive damage. Since it will be impracticable to construct both the cofferdams and the permanent work in the main river channel in a single working season the practical problems involved are considerable. There appears, however, to be no alternative solution.

(*c*) In the third season excavation and construction proceeds within the cofferdam and it is anticipated that during this period the permanent work would be brought up to the level of the top of the cofferdam. Openings will be left in the permanent work to take the normal dry weather flow and it is proposed that these same openings will later be fitted with screens and gates to form the principal control sluiceways.

(*d*) The fourth season's work will consist of the re-diversion of the river to the original dry weather channel by means of smaller cofferdams across the temporary diversion channel. Excavation and permanent construction will then proceed across the diversion channel simultaneously with the remainder of the concrete dam.

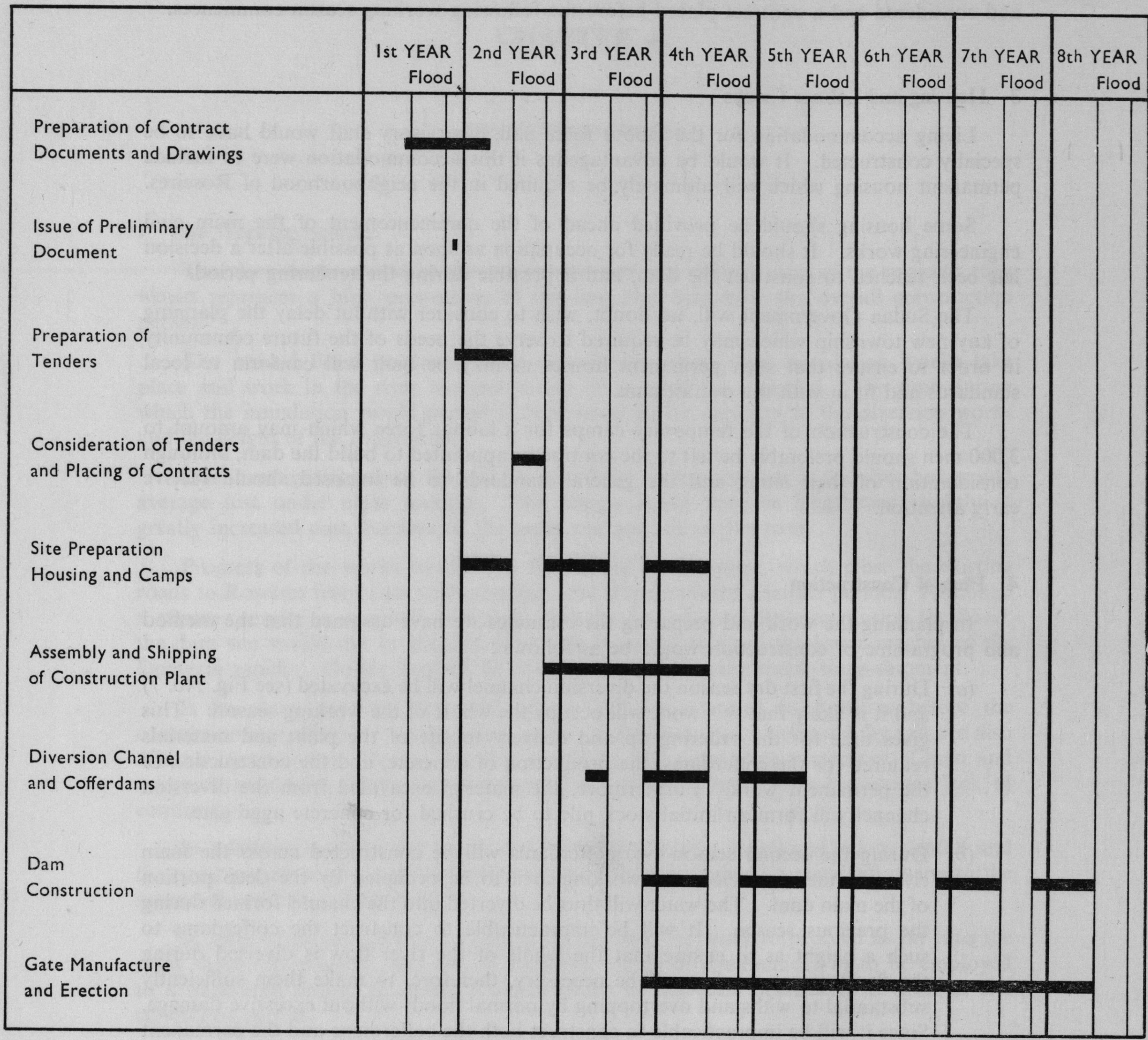
(*e*) Construction of the embankment dams will proceed while the major river works are in progress. It is anticipated that the whole construction work would occupy not less than six seasons after a contract has been placed, assuming that no abnormal circumstances arise.

5 Construction Programme

The tentative Programme is summarised in Table 2.

TABLE 2

CONSTRUCTION PROGRAMME



The proposals outlined above are subject to reconsideration when a Contractor is appointed. It will be necessary to employ a Contractor experienced in this type of work, in particular in the control of water.

6 Communications

In addition to the essential provision of road and rail access to the site, the advantages of providing air transport facilities between Khartoum and Roseires should not be overlooked. It would be desirable to provide an all-weather landing strip suitable for light passenger and freight aircraft clear of but accessible to the new works.

It should be noted that the east embankment dam will encroach upon the existing unpaved landing strip and it is recommended that consideration be given to the provision of a more permanent runway which will last at least as long as the construction period of the dam.

It is assumed that adequate telephone and radio communication with Khartoum would be available at an early stage.

7 Materials of Construction

(*a*) *Local Materials*

In considering the design of the dam due allowance has been made for the utilisation of local materials to the best advantage.

There are many sources of stone in the Roseires area which are suitable for concrete aggregates and we anticipate that there would be no difficulty in selecting local deposits of material suitable for the construction of the embankment dams. Investigations to prove this are at present in hand.

Local materials suitable for masonry work also exist, and consideration has been given to the use of masonry as an alternative to concrete in the construction of the dam. The conclusion was reached that, at a site as remote as Roseires, it is essential to keep down labour costs, for not only are labour rates high but, there being no local supply of skilled masons, all such labour would have to be imported into the area. This would incur very heavy charges in respect of recruiting, travelling and site accommodation. Modern techniques can be applied to a concrete structure, which will enable the labour force to be kept to a minimum.

(*b*) *Cement*

We estimate that about 80,000 tons of Portland cement would be required for the construction of the Roseires Dam to a top water level of R.L. 471.5 metres, and that over a period of some months the demand might rise to a peak equivalent to an annual rate of some 40,000 tons.

There are three possible sources of supply :—

(i) Purchase of cement manufactured in the Sudan from the existing works at Atbara or from any future works which may be set up.

(ii) Cement produced locally from a new works set up at Roseires for the purpose.

(iii) Purchase of imported cement.

The output of the Atbara Works in mid 1953 was between 50,000 and 60,000 tons per year and was fully taken up by existing demands. It may be presumed, therefore, that these works would not be in a position to make an important contribution to the needs of the Roseires project unless they were extended. It is understood that such extensions are contemplated by the owners of the works.

We have examined the economics of setting up near Roseires a cement works for the specific purpose of meeting the requirements of the dam. Even assuming that satisfactory local sources of the necessary raw materials could be found, and this is by no means certain, and even if a permanent local market for the output of the works could be assured after the completion of the dam, we consider it unlikely that the cost of cement from such a local works would compare favourably with supplies obtained from other sources.

Our investigations have led us to the conclusion that the cost of imported cement delivered to Roseires would not differ greatly from the cost of obtaining supplies from the Atbara works. Such imported supplies could, therefore, be considered as a means of supplementing those which might be obtained from local sources.

There is a further possibility which should not be overlooked. It might be possible to arrange for the owners of the Atbara works to set up a grinding plant at Roseires to process cement clinker. Such an arrangement would have certain advantages since it would ease the storage problem and would allow the transportation of clinker over the Sudan Government Railways to be adjusted to suit the convenience of general traffic requirements. This proposal has not been discussed with the cement manufacturers but should be examined before a final decision is taken.

CHAPTER 5

ESTIMATED COST

The following table summarises the estimated cost of the main sections of the work. The estimate relates to a reservoir with a top water level of R.L. 471.5 metres affording an effective storage of approximately 1 milliard, and includes appropriate allowances to cover the cost of :—

(*a*) Contingent works, details of which cannot at this stage be foreseen.

(*b*) Preliminary expenses and the cost of site investigations.

(*c*) The preparation of contract drawings and documents, detailed engineering design, the administration of contracts and the supervision of construction.

(*d*) Laboratory investigations and tests.

The estimate does *not* include :—

(*e*) Any general administrative costs which would be charged against the works by the Sudan Government.

(*f*) Interest on capital during construction and the cost of raising monies required for carrying out the construction of the works.

(*g*) Cost of land and compensation.

(*h*) Customs dues on imported plant.

(*i*) Cost of extending the Sudan Government Railways to Roseires.

(*j*) Cost of an all-weather airstrip at Roseires.

In preparing the estimate it has been assumed that it will be possible to deliver Portland cement to the site at a cost of £E13 per ton.

SUMMARY OF ESTIMATED COST

	£E
1. Earth embankments and associated works	790,000
2. Concrete dam, cofferdams, diversion channel etc. ..	12,230,000
3. Flood gates, sluices and mechanical and electrical equipment	980,000
4. Provision of access roads, temporary camps and housing	1,050,000
	£E15,050,000

CHAPTER 6

OPERATION OF RESERVOIR

1 General Assumptions

In approaching the possible operating regime of the Roseires reservoir it has been necessary to make a number of assumptions none of which have any material effect on the design of the dam, but all of which affect the water levels at various times of the year. We have assumed for instance,

(i) that the water requirements of existing irrigated areas have priority over any new projects.

(ii) that the regime established by the Nile Waters Agreement in respect of Sennar will have a similar application to Roseires and that a " Water Account " will be operated over the period from January to July.

(iii) that the regime at Roseires should be designed specifically to meet irrigation needs and that hydro-electric development is a matter of secondary importance.

(iv) that, in view of its proximity to the Ethiopian frontier, the regime must be so arranged as to make it possible to operate with little or no warning of the rising and falling discharges of the river. It will be necessary to replace the Roseires gauge as the criterion of natural flow in the Blue Nile. With a reservoir top water level of R.L. 471.5 metres, the temporary gauge at Famaka could be made into a permanent one, unless a better site could be found in a readily accessible location higher up the river. This would in any case be necessary if the top water level at Roseires is raised to a level which affects natural flow conditions at Famaka.

Within the above limitations there are two principal alternatives. Alternative I assumes a main canal with headworks at Roseires dam and with a gravity irrigation scheme drawing its water directly from the new reservoir. Alternative II assumes that there will be no gravity irrigation from Roseires and that the new reservoir will be used to supply water to Sennar reservoir, from which it will be distributed.

It is possible to combine these two alternatives should there be any advantage in so doing, but we have confined our attention to the two cases only and have shown them diagrammatically in Fig. No. 10.

2 Alternative I—Main Canal with headworks at Roseires

The reservoir is assumed to have a top water level of R.L. 471.5 metres with gross contents of 1.2 milliards. The reservoir level required to give full canal command has been taken as R.L. 463.0 metres, at which level the reservoir has a gross content of 0.3 milliards.

At Point A on Fig. No. 10 the reservoir is shown to be full on January 1st, after which date it is gradually drawn down to meet irrigation requirements and to provide storage above canal command level up to the date of the last watering on 31st March. Point B on the curve, therefore, represents a level of R.L. 463.0 metres reached on 31st March, or possibly a day or so earlier. The residual contents of the reservoir are then available to meet outstanding items in the " Water Account " and the reservoir is shown as being drawn down at a uniform rate until a minimum level is reached at Point D on 15th May, by which time the river will have begun to rise in a normal year.

During the period immediately after the end of March the reservoir level will remain above sill level of the main canal headworks until at Point C, on or about 22nd April, there will be approximately 50 centimetres of head at the main canal offtake. In other words domestic water requirements in the irrigated area can be provided for at least 22 days in April, without resort to pumping.

On the 15th May all gates on the dam would be fully open and the levels would follow the normal flood curve until Point E is reached on the 10th July. This gives a period of about six weeks during which annual maintenance of the dam can be carried out. As the flood rises, silt deposited during the previous filling would be removed from the bed of the reservoir through the four deep sluices. If a longer period proved to be necessary for maintenance, Point D could be brought back to an earlier date than the

15th May, for a rapid draw down during the final stages would not affect the stability of the earth embankments. While these embankments are retaining water it is important that changes in reservoir level should be as gradual and as uniform as possible, during both filling and emptying. This applies to any regime which might be operated at Roseires.

On the 10th July the raising of the reservoir level would commence until by the 20th July canal command level of R.L. 463.0 metres is reached at Point F. The raising of level would be achieved, first by a gradual closing of the deep sluices, and, once the reservoir level had reached sill level of the crest gates at R.L. 457.0 metres, by operating the crest gates in conjunction with the deep sluices. From the 20th July filling of canals would commence to permit of irrigation five days later. The canal command level would be held until Point G is reached on the 1st September, after which date crest gates would be closed one by one and the top level of the reservoir raised to R.L. 471.5 metres at Point H on the 30th September. This level would then be held until the 1st January.

Operations at Sennar would not be adversely affected by such a regime. The quantity of water passing Roseires would be recorded more accurately than at present, and during the period from the end of March to the middle of May the normal discharge of the river would be increased by about 6.7 million cubic metres per day. This additional quantity of water would enable Sennar to hold a reduced canal command level for a little longer than at present, and, therefore, shorten the period of time during which it is necessary to pump domestic water into the Gezira canal system. Other than this the existing regime at Sennar would continue. Pumping stations around the fringe of the reservoir would be unaffected and cultivation of " gerf " land in the bed of the reservoir would go on as at present as the water level falls. Such cultivation could also be carried on around the perimeter of the Roseires reservoir.

3 Alternative II—Roseires Reservoir used as supplementary storage to Sennar

In this alternative it is assumed that major irrigation development in the Sudan will take place with headworks at Sennar and that the whole of the storage at Roseires would be necessary to meet the needs of this additional area.

If the operating regime is considered in relation to evaporation losses at both Roseires and Sennar there would be a slight advantage in drawing down the Sennar reservoir initially and meeting the whole demand from Roseires storage during the later stages of the irrigation season. Such a regime would, however, increase pumping heads on existing irrigation schemes at Busata, Kassab and elsewhere and also on such additional pump schemes, deriving their water from the Sennar reservoir, as are included in our " Estimation of Irrigable Areas ".

On the other hand it might be considered desirable to draw down Roseires first and thus to reduce these pumping heads with a consequent saving in fuel costs. Against this it could be argued that local cultivators now making use of the " gerf " land around the reservoir would be denied this facility. On balance, therefore, we recommend that the present regime at Sennar should be maintained. Thus from 1st January Roseires would be drawn down to meet the new irrigation demand from Sennar until Point J on Fig. No. 10 is reached on or about 25th March when the irrigation season ends. Sufficient water would then remain in the Roseires reservoir to meet outstanding commitments under the " Water Account " in respect of all additional irrigable areas which have been brought into commission as a result of the Roseires storage.

In plotting Point J we have had to estimate this residual quantity of water. Evaporation from Roseires reservoir during the period January to July amounts to approximately 50 million cubic metres, to which has been added domestic water requirements during the May to July period of 30 million cubic metres, and compensation water for additional pump schemes of 60 million cubic metres. This gives a total amount of 140 million cubic metres requiring a reservoir level of R.L. 459.0 metres at the end of the irrigation season. It will be noted that with this arrangement just over 1 milliard is available for irrigation between 1st January and the end of March.

After irrigation ceases, the Roseires reservoir level should be lowered at a steady rate in order to safeguard the earth embankments. The lowering could be arranged at the same rate as in Alternative I which would mean that the reservoir would empty by 17th April, indicated by Point K on Fig. No. 10. It would not be essential for Sennar to pass on the residual water at this stage and Sennar canal command levels could be held for the supply of domestic water for a considerably longer period than at present, again with resulting saving in pumping costs. Pump schemes would also be assisted in this respect.

It will be noted that, as compared with Alternative I, Alternative II provides a longer period during which the reservoir is drawn down and flow confined to the natural river bed.

All gates would be kept open until the 1st September. The floods would first be discharged through the deep sluices until the sill level of the crest gates was reached, after which these openings would come into service and the flood would discharge naturally through them as well as through the deep sluices until Point L is reached on the 1st September. After this date sector gates would be closed one by one, fine adjustment of reservoir level being effected by means of the deep sluices.

The level would be raised at a controlled rate until Point H is reached on the 30th September and the top water level thereafter held at R.L. 471.5 metres.

4 Other Possibilities

Between these two alternatives there would be no difficulty in arranging other regimes which might, for instance, permit part of the water to be used for an irrigation scheme with headworks at Roseires and the balance for further irrigation from Sennar.

The effect of possible development of hydro-electric power on the operating regime is referred to in Chapter 8.

5 Effect of Regulated Water from Lake Tana

In the absence of any definite information other than that contained in our Terms of Reference, we have assumed that Lake Tana may, at some future date, be fully developed either as a power scheme or for the storage of irrigation water or even a combination of both.

A power project would mean that the stored water in the lake would be released in such a manner as to represent a reasonably uniform discharge throughout the year at Roseires. Insufficient information is available to evaluate the effect of this additional regulation but the total quantity of water is comparatively small when compared with the uncontrolled discharge of the Blue Nile at Roseires. There would be an increase in the dry weather flow, and it might be possible to delay the final filling of the Roseires Reservoir to its top water level and therefore to reduce the extent to which it would be necessary to store silt laden water.

If a proportion of the increase in flow in the timely season were allocated to the Sudan it could be used to irrigate more land with little effect on the operating regime of the Roseires Reservoir.

These effects would be even more beneficial if Lake Tana were developed to store irrigation water for release during the timely season. The peak of the annual flood discharge at Roseires would be reduced by the amount held back in Lake Tana, whereas there would be a marked increase in flow from January to June.

Future developments at Lake Tana, so far as we can foresee, should neither affect the design of the Roseires Dam nor complicate its operating regime.

CHAPTER 7

SELECTION OF RESERVOIR CAPACITY

The effects of raising the reservoir top water level above R.L. 471.5 metres have been investigated and the results summarised in the following Table.

TABLE 3

VARIATION OF COST AND CONTENTS WITH TOP WATER LEVEL

Top Water Level R.L. metres 1	Estimated cost £E millions 2	Gross Contents Milliards 3	Average cost of gross contents Milliemes per cu. m. 4	Effective contents Milliards 5	Average cost of effective contents Milliemes per. cu. m. 6	Incremental cost of effective contents Milliemes per. cu. m. 7
470.0	14.25	1.000	14.25	0.815	17.5	
						4.46
472.0	15.30	1.285	11.9	1.050	14.6	
						3.71
474.0	16.45	1.610	10.2	1.360	12.1	
						3.80
476.0	17.80	1.985	9.0	1.715	10.4	
						3.78
478.0	19.35	2.420	8.0	2.125	9.1	
						3.83
480.0	21.15	2.915	7.25	2.595	8.15	

The economic advantage of increasing the storage capacity of the reservoir is brought out clearly in column 6 of the above Table. It will also be seen from column 7 that within the range of top water levels considered the incremental cost of increasing the effective contents of the reservoir is almost constant.

The relatively high unit cost of water at the lower levels arises from the natural characteristics of the river and its valley which make it necessary to incur heavy expenditure before any benefit is secured.

We are not required by our Terms of Reference, nor would it be possible for us, to make a definite recommendation as to the ultimate storage capacity which should be provided at Roseires, but certain conclusions can be reached from the above estimates.

The provision of a reservoir having effective contents of 1 milliard calls for an estimated expenditure of £E15,050,000. At an incremental cost estimated at £E3,750,000 this capacity could be doubled. Although it would be possible to increase the height of the dam at some later date, the cost of doing this would not only be very much greater, but a proportion of the additional expenditure would have to be incurred in the initial construction stage in order to make suitable provision for the increased height, particularly in the deeper sections of the river bed.

Should it be possible to arrive at a definite conclusion as to the ultimate storage capacity at Roseires we recommend that the dam should be constructed to its final height at the outset. Full utilisation of the stored water by the Sudan must plainly depend upon future irrigation development, but if temporary use is made of it while irrigation potential is being developed it would avoid the need for subsequent heightening and provide an immediate financial return for the capital expenditure incurred.

CHAPTER 8

HYDRO-ELECTRIC POWER

1 Introduction

The possible development of hydro-electric power has been examined within the limitations imposed by the reservoir operating regimes described as Alternatives I and II in Chapter 6.

The effect on power potential of holding a minimum reservoir level of R.L. 456.5 metres has also been considered, and the resulting modified regimes are referred to in the paragraphs which follow as Alternatives IA and IIA. This level, which is 50 centimetres below the sill level of the crest gates, is convenient both for operation and for maintenance of the gates and gate openings. The river within the reservoir area would not extend beyond its original flood channel and, with the provision of low level sluices to maintain a strong flow, siltation should not be aggravated.

In order to provide a basis for preliminary estimation of power potential the average ten-day mean discharge curve of the Blue Nile at Roseires, as shown on Fig. No. 2, has been used.

In an average year the river flow varies from 116 to 6,025 cubic metres per second, and with a top water level of R.L. 471.5 metres the maximum available head would be 29.4 metres.

2 Power Potential for Average Discharge

The four alternatives referred to above provide the basis for Fig. No. 11, which demonstrates the advantage to be gained in April and May by retaining the reservoir at a level of 456.5 metres instead of emptying it completely. The wide variation of power potential through the year is shown, and this is further explained in Table 4 which shows the continuous power always available for given percentages of an average year.

TABLE 4

CONTINUOUS POWER AVAILABLE IN MEGAWATTS FOR VARYING PERCENTAGES OF AVERAGE YEAR

	100%	95%	90%	80%	70%	60%	50%	40%	30%	20%
Alternative I ..	0	0	5	26	31	41	64	104	250	540
Alternative IA ..	16.2	24	27	33	42	60	78	125	250	540
Alternative II ..	0	0	0	9	35	66	98	132	252	510
Alternative IIA ..	15.0	20	26	41	60	82	108	155	260	510

NOTE: 1 Megawatt (MW) = 1,000 Kilowatts = 1341 H.P.

It will be seen that in Alternatives I and II there is a period during which no power is obtainable. Alternatives IA and IIA provide 16.2 MW and 15.0 MW respectively, which could be sustained continuously throughout an average year.

During the irrigation season, from 25th July to 31st March, the minimum continuous power increases to 23 MW in Alternatives I and IA, to 25 MW in Alternative II, and to 30 MW in Alternative IIA.

3 Effect of Low River Discharge

Over the period when critical conditions apply the natural flow of the river may fall to half its average value. Based on past records the continuous power available may be reduced to 8 MW in Alternative IA and to 6.5 MW in Alternative IIA.

There is insufficient storage below R.L. 456.5 metres to make good the deficiency by drawing extra water, but if the date of final release of compensation water is deferred by a week or two in years when a low flow is anticipated it may be possible to avoid any restriction on power use. It should be noted that this expedient would reduce the period during which maintenance of the crest gates is possible.

4 Effect of Increasing Reservoir Storage

Raising the top water level of the reservoir would serve to increase the head during part of the year, and would, therefore, increase power potential. It would not, however, have any marked effect during the critical period during which the reservoir is drawn down. Important advantages could, however, be obtained by holding a level higher than R.L. 456.5 metres during the critical stages. This would also mean raising the sill level of the crest gate openings.

5 Effect of Lake Tana

In the event of controlled discharge being available from Lake Tana this would have a most important bearing on the power potential at Roseires. On the assumption that the minimum rate of river flow at Roseires would be increased to 220 cubic metres per second, it would become possible to increase the continuous output throughout the year by 13 MW.

6 Possible use of Power

The possible markets for power may be summarised as follows :—

(i) Domestic and general industrial consumers.

(ii) Pump irrigation.

(iii) Special industries working on a seasonal basis

Domestic and general industrial load

Power available all the year round might be developed to supply centres of population such as Roseires, Singa, Sennar, Wad Medani and Khartoum, if its transmission proved technically sound and financially advantageous. Taking into account an annual load factor of about 45 per cent. and the availability of diesel plant to deal with peak demands, an ultimate installed capacity of 65 MW at Roseires would appear to be a reasonable proposition. Full development up to this figure would not be possible until controlled discharge from Lake Tana became available.

Pump irrigation load

Based upon our assessment of potential pump schemes in the Blue Nile Region between Roseires and Sennar, as described in " Estimation of Irrigable Areas " Chapters 10 and 13, a continuous output of about 5.3 MW would meet possible future irrigation demands during the critical period at the end of March. During October the comparable figure is 6.7 MW.

If pumps are operated for 18 hours per day during the peak period an installed capacity of 10 MW would meet this potential demand.

Special industrial load

Further power could only be absorbed in industries which do not give rise to a continuous load all the year round. An electro-chemical industry might provide a suitable outlet and we understand that Brigadier Cox has already reported to the Sudan Government on this matter, with particular reference to the manufacture of fertilizers.

We have assumed that, due to the absence of suitable raw materials other than air and water, the only chemical fertilizer which could be considered is ammonium nitrate and that a plant capable of producing 3 tons per hour of this chemical would be the minimum economic size of installation. Such a plant would provide a continuous demand of approximately 22.5 MW or, say, 25.0 MW at the power station. The period during which the plant could be kept running would depend upon the reservoir operating regime adopted.

Stand-by Plant

Alternatives I and II represent a hydro-electric plant which is not connected by power transmission lines to any existing sources of supply such as Wad Medani and Khartoum.

Stand-by hydro-electric plant is, therefore, essential together with a diesel plant to meet essential local requirements when no water power is available. Such a diesel plant will be necessary during the construction period, and should be made part of the permanent installation.

Alternatives IA and IIA are assumed to be linked to existing diesel power plants whose main duty would be taken over by the Roseires plant but which would remain available to meet peak demands, and possibly to come into service during periods of abnormally low river discharge.

7 **Summary**

Considering the four alternatives the following possibilities emerge of ultimate installed hydro-electric capacity at Roseires.

TABLE 5

ULTIMATE INSTALLED CAPACITY OF POWER PLANT

	Alternative I		Alternative II		Alternative IA		Alternative IIA	
	MW	Months available	MW	Months available	MW	Months available	MW	Months available
*Domestic and general industrial load	—	—	—	—	65.0	12	65.0	12
Pump irrigation	10.0	8½	10.0	8½	10.0	8½	10.0	8½
Special industry	25.0	7½	25.0	8	25.0	8	25.0	9
Net Total	35.0		35.0		100.0		100.0	
Allow for standby hydro. plant	15.0		15.0		12.5		12.5	
Gross Total	50.0		50.0		112.5		112.5	

*Includes provision for regulated discharge from Lake Tana.

Although the possible development of hydro-electric power at Roseires calls for a thorough preliminary study before any positive steps are taken to install plant, we recommend that provision should be made in the design and construction of the dam for future installations as follows :—

(i) If the reservoir is to be drawn right down at the end of the irrigation season (Alternatives I and II)—50 MW.

(ii) If a minimum reservoir level of R.L. 456.5 metres is to be held (Alternatives IA and IIA)—112.5 MW.

An increase in the top water level above R.L. 471.5 metres would permit of an increased provision under (ii) above.

CHAPTER 9

FLOATING DEBRIS

Attention has been drawn in the Terms of Reference to the need for special consideration of the problem of floating debris. Our proposals for the dam incorporate large crest gates which are capable of passing whole trees at high flood and floating debris should, therefore, cause little trouble. Any such material lodging against the dam beyond the influence of the gates can be dealt with at a suitable time with the assistance of the deck gantry.

We have considered the possibility of intercepting the debris near the head of the Roseires reservoir, so that its removal could be effected without imposing the onerous duty of dealing with it in its entirety at Roseires dam, and subsequently at Sennar. We have no information on the relative quantities of debris crossing the frontier from Ethiopia and arriving at Sennar, but we assume that interception near the head of Roseires reservoir would relieve both Roseires and Sennar dams of a considerable proportion of their debris problem.

Our proposal is shown on Fig. No. 9 and the location of the structure on Fig. No. 5. Since the Roseires Dam is unsuitable for a rail crossing the latter must be an independent structure. It could conveniently be incorporated with the debris trap.

The suggestion is that a flexible net, made of wire ropes, should be slung across the river near the head of the reservoir at a point where the river appears to be narrow but deep. This net would be suspended from an overhead structure but the ends of the horizontal ropes would be firmly anchored to heavy piers on the banks which would thus take most of the horizontal load resulting from trapped trees.

Fig. No. 9 shows the proposal in diagrammatic form. It has been assumed that there would be no large trees floating down the river when the water surface was below R.L. 470 metres, which would be the bottom level of the net. The top level of the net would coincide with the extreme flood level of R.L. 475 metres, and it would appear appropriate to adopt a mesh of approximately 2.5 metres square.

During the flood period trees would be trapped by the net, but on account of the depth of water below this would not greatly affect the flow. When the peak of the flood has passed, the level of the reservoir will have risen so that the water in this area will be relatively calm. Under these conditions it should be a comparatively simple matter to remove the trees, access to which could readily be obtained from the structure above.

The proportions of the structure supporting the net would be such that, at comparatively small extra cost, it could be adapted for use as a road or rail bridge. With the arrangement shown the upper deck of the bridge would carry the traffic, whilst the lower deck, in addition to supporting the net, could be arranged with platforms and fittings for cradles or other devices for lowering men down to the net and trapped trees.

The dimensions shown on Fig. No. 9 are very approximate as no detailed survey has yet been made. In consequence we are not in a position to give a reliable estimate of the cost of the combined structure, but should the dimensions prove to be reasonably accurate we anticipate it would be of the order of £E250,000-£E300,000.

The erection of the structure could be deferred until its usefulness, both as a debris trap and as a rail crossing, were established. Experience in dealing with debris at the dam could be obtained without undue hazard during the early life of the reservoir and whilst gaining this experience an assessment of the probable relief at both Roseires and Sennar could be made.

APPENDIX I

SUMMARY OF FIELD INVESTIGATIONS

First Season

1. Following a preliminary reconnaissance, a field party was established at Roseires on 5th February, 1952, and spent four months on the site. The Damazin Rapids were traversed throughout their length, and two sections, which appeared superficially to offer suitable conditions for a dam site, were selected for survey. These sections are designated as A.A. and B.B. on Fig. No. 3. Cross sections of the river bed and flanks to the general plain level were surveyed. The river valley was inspected up to Famaka and the temporary river gauges at Damazin and Famaka were restored to their original condition. The Sudan Irrigation Department made arrangements for these gauges to be read continuously through the following flood season.

2. The Sudan Survey Department arranged for aerial photographs of the Rapids to be taken from low altitude and from these photographs an approximate map of the area was built up. This, coupled with records of cross sections carried out by the Sudan Irrigation Department some years previously, was of considerable value during the subsequent investigations. This map has now been superseded by more complete information obtained during the Second Season.

3. In addition to the engineering studies, our Geological Adviser, Dr. Francis Jones, spent several weeks in the Sudan, first studying the information made available by the Geological Survey in Khartoum, and subsequently investigating conditions in the Rapids. At his suggestion a third section designated C.C. on Fig. No. 3 was included as a possible alternative and our survey work was extended to cover this. Bench marks were established at intervals on the right bank of the river from Roseires to Abu-Zagholi. A number of level traverses were run to establish the topography of the ground between the river channel and the general plain in the vicinity of the Rapids. The low flow channel of the river was sounded at several locations on and adjacent to the selected sections.

4. The field party was withdrawn at the onset of the rains in June and returned to London to prepare a further season's work. During this period the results of the surveys were assessed, a drilling programme drawn up, and arrangements made for aerial and ground survey of the reservoir area.

Second Season

5. On 1st November, 1952, the party again assembled at Roseires and carried out a programme of field investigations during the following six months, finally returning to London early in June 1953.

6. This second season's field work was largely concerned with drilling and reservoir survey. The drilling programme was carried out by the Drilling Section of the Public Works Department with assistance from Messrs. George Wimpey & Co., Ltd., of London, during the latter part of the season. The object was to determine the profile and nature of the rock along the three selected cross sections.

7. In all, 124 holes were drilled with a total depth of 4,551 metres, 3,234 metres being in overburden and 1,317 metres in rock. The samples and cores were inspected and described by the staff of the Sudan Geological Survey and selected samples were sent to Dr. Francis Jones in London for detailed examination. At the end of the season the cores from these borings were transferred to Sennar for future reference.

8. Aerial photography of the reservoir area was undertaken in December, 1952, by Messrs. Hunting Aerosurveys Ltd. The Sudan Survey Department extended their triangulation system to cover the area and produced the co-ordinate values of a number of points from which the mapping of the reservoir was controlled.

9. In addition, the Survey Department extended their series of bench marks up both banks of the river and these bench marks were used to establish the heights of a large number of control points required for the plotting of contoured maps from the aerial photographs. A member of Messrs. Hunting's staff spent the season in the field with the survey team and identified suitable control points on the ground and on the photographs.

10. In addition to the field work on the reservoir area, the surveys of the three possible dam alignments were amplified and extended as necessary.

APPENDIX II

THE GEOLOGY OF THE DAMAZIN AREA

by

Dr. FRANCIS JONES, T.D., M.Sc., F.G.S.

CONTENTS

APPENDIX II

THE GEOLOGY OF THE DAMAZIN AREA

by

Dr. FRANCIS JONES, T.D., M.Sc., F.G.S.

STRUCTURE

1. The succession of rocks is as follows :—

(iii) Soil with vegetation.

(ii) Unconsolidated sediments.

(i) Basement rocks.

A geological map of the surface of the Basement rocks is included in this Report (See Fig. No. 3).

The Basement Rocks

2. These, commonly termed the Basement Complex, consist of a mixture of granite-gneiss, pegmatite and fine grained granite overlain to the north and south by marble.

Basic gneiss grading into amphibolite is closely associated with the marble, and may be derived in part from it. Its true position is uncertain but since with one definite exception (Fig. No. 3) and several suspected occurrences it does not occur in the boreholes, I place it above the granite-gneiss series. It has little import as regards the dam site proper other than being usable as structural material. I include in the Basement Complex, its fractured and weathered surface and also relics of a limestone bed which has been reported in one borehole and which also outcrops on the East Bank near the Roseires road about 3 kilometres south of the town. This limestone is probably much younger than the gneiss and marble. Olivine dolerite (wrongly termed pelite) occurs in one boring : this too is classed in the Complex.

3. Since the predominant member of the Basement Rocks is a gneiss of granitic composition penetrated by pegmatite veins and granite sills, all composed of much the same minerals, it will simplify description to refer to this member of the Complex as " Acid Gneiss ".

The surface of this Acid Gneiss reaches its highest altitudes in or near the river channel : East and west of this the sedimentary cover thickens. Broadly speaking the surface forms a low dome with its summit near the centre of the B.B. line, the location of which is shown on Fig. No. 3.

Observation of jointing and foliation show an axial line just south of B.B. The axis trends N.E.-S.W., north of this line the foliated rocks and the granite sills and marble dip N.W. : south of it there is a less pronounced slope S.E. Foliation within the Complex, however, shows deviation from this—in the central area I recorded north-south lineation as prominent. The mixture of gneiss, granite and pegmatite (Fig. No. 4) seen at the surface in the neighbourhood of boreholes Y2 and Y3, the location of which is shown on Fig. No. 3 presents no directional features. Whatever the details, the " Acid Gneiss " constitutes a good foundation : it is regrettable that it falls away on the flanks.

4. The fact that the Blue Nile has cut a channel through the summit of the dome needs explanation. The most likely one is that it is a case of superimposed drainage, i.e., that the river has cut through sedimentary cover down to these resistant rocks and has cut a passage through them. Erosion has produced deep pot holes and joint channels and the Blue Nile is trapped by the Basement Complex. A less likely explanation is that the river formerly cut through where the Acid Gneiss lies deeper, but that it choked such channels with its own debris. These problems are discussed later in relation to the Geological History of the area.

Unconsolidated Sediments

5. Clays, silts, sands, gravels, boulder beds attaining a maximum depth of up to 60 metres hide most of the Basement Complex. Since these will form a considerable portion of the dam foundations it is important to probe their nature and discuss their origin.

For the most part they are unconsolidated. Their surface, except near the Blue Nile channel or where the khors have eroded them, is almost flat. This surface extends for miles in every direction broken only by isolated jebels and hill districts like the Ingessana. It has an almost imperceptible downward tilt to the north—a tilt which is responsible for the direction of the river flow and for the tendency of such tributaries as the Dinder to be roughly parallel to the main stream.

6. There is little doubt that much of this sedimentary cover was there before the Blue Nile existed and that the Basement Complex is largely a buried landscape. As the river cut through it removed some of this loose cover, it disturbed a great deal of it, and has now added some of its own. This accounts for the confusion which obtains when correlation of boreholes is attempted. Speaking generally there is a tendency for these deposits to become coarser downwards, and there is a very welcome " clay " at or near the top. Whether this is always true clay-grade material is unlikely, but the presence of this bed indicates local impermeability.

7. Clay is deposited in almost still water and its occurrence, largely at altitudes ranging from 470-480 metres, suggests either lacustrine origin or flood water resting on a plain at a time before the Nile had commenced to erode vertically. Whereas the former seems more likely, there might well have been a combination of both.

The coarser deposits below the clay contain clues which are of interest ; sharp sand, angular gravel, quartz pebbles, basalt pebbles, kankar, sandy clay with boulders, ill-sorted sand and gravel. Some of these can be matched in the river channel today, especially at the mouth of khors where rounded pebbles, chiefly quartz or granite of small size, are embedded in silt. Angular sand suggests water-deposition as opposed to aeolian sand. The basalt pebbles, may, like those in the river channel today, have been brought downstream from the Ethiopian borders, but since " dolerite " is present in the complex they may be local (basalt and dolerite are often indistinguishable in the field and under the microscope). There is much ineffective sorting, suggesting fluctuation in the rate of movement and quantity of water. Kankar occurs at every level from 427 metres to 470. (The bottom of the deepest channel along the B.B. river section is approximately 427 metres.) The term, as generally used, means concretionary limestone produced in semi-arid regions where evaporation is nearly equal to rainfall. There is no discoverable distribution except its greater abundance in the holes which show great thickness of sediment. Some of the limestone nodules may be residual from the limestone recorded with the basement rocks. It is interesting to point out that none of the pebbles or rock fragments described consists of marble, i.e., at the time of this deposition of these loose sediments the acid gneiss had no marble cover.

8. A further point of interest is the absence of fossils : even allowing for the difficulty of noticing these during drilling operations, if any were present, they should have obtruded themselves in one or other of the many holes.

Soils with Vegetation

9. The top layer of soil with its Baobab, Acacia and grass vegetation as seen near the river consists predominantly of silt rather than clay or sand. There seems to be an increase of clay soils towards the Ingessana Hills.

SELECTION OF THE DAM SITE

10. The three lines investigated can be reduced to one, namely B.B., for the following reasons :—

Line A.A.

The rock exposed in the river channel is largely pegmatite and consequently brittle. Marble occurs immediately to the south of it, and although it is not impracticable it would be undesirable to impound the water close to such a junction. The acid gneiss floor is very low down on the East Bank. In the immediate neighbourhood of the present channel the rock is rotted to nearly 20 metres below water level.

Line C.C.

11. The surface of the acid gneiss averages lower than on B.B. While the rock in the river channel mainly consists of good fine grained granite there are depressions close to the channel containing weathered rock lower than the base of the river. The East Bank while better than that of A.A. is inferior as a foundation to that of B.B.

Line B.B.

12. The rock visible in the river bed is of good quality. Samples of granite and gneiss collected near boreholes Y2 and Y3 showed high crushing strength. Although the rock

exposed is of mixed character (gneiss granite and pegmatite) it is largely unweathered. The high central ridge just west of the main river channel is aligned south-north. The granite sills are almost horizontal.

On the East Bank down to low water level the rock is mainly granite and its jointing is almost vertical and horizontal. Away from the river, continuing in an easterly direction for about 1½ kilometres, the drilling record shows that the surface of the basement complex is not too deep down. Some of this surface it is true, consists of weathered rock but by comparison with A.A. and C.C. the site on this bank is vastly superior.

The rock under the West Bank is, however, less satisfactory—from boreholes Z2 to Z23 the surface of the Basement Complex either consists of highly weathered and fissured rock at moderate depth, or sound rock under thick cover. To some extent this defect is compensated by an almost continous bed of clay of adequate thickness lying at about the 470 metre contour, but a study of the sections shows places where there is no impervious cover and where the underlying rock may allow leakage. It should be pointed out that the West Bank conditions along A.A. and C.C. have similar defects, though A.A. is perhaps slightly better.

13. Within the limits of the Damazin Rapids B.B. is the best selection. About half a kilometre north of this line the rocks in the river channel lose height—become more foliated and schistose and dip downstream and eventually disappear under marble.

Diagrammatic sections in the vicinity of line B.B. will be found on Fig. No. 4.

STRUCTURAL MATERIALS (PETROLOGICAL INVESTIGATIONS)

14. The search for the following classes of material was not confined to the Damazin area, but included a riverside area along the East Bank north of Roseires, the area on the north and east flanks of the Ingessana Hills and intervening country near the road between these hills and Roseires. The location of these areas is shown on Fig. No. 1.

(*a*) Building Stone.

(*b*) Rock for infilling and road making.

(*c*) Sand and aggregates for concrete.

(*d*) Materials for cement.

(*e*) Impervious materials.

Building Stone

15. The Basement Complex can supply granite, gneiss (acid and basic) and marble. Many sections of these rocks have been cut : a brief summary of their availability and specific characters is now given :—

Granite

16. Nearly all the granite samples are fine grained—north of Roseires in contact with marble they are more correctly termed microgranite. In the hand specimen they are commonly grey or cream coloured. Under the microscope they seem to consist of felspar (microcline and oligoclase), quartz, biotite mica with subordinate muscovite and the usual accessory minerals magnetite, apatite, sphene and zircon. The latter are very subordinate. The quartz frequently shows strain shadows and the felspars distortion. Despite this evidence of strain the rock is very strong and, if care is taken in selection, it is scarcely weathered. Some specimens show considerable pyrite.

17. In the river channel area granite occurs only as thin sills—I estimate the maximum thickness of these sills to be 15 metres. If B.B. is used as the Dam site, rock from C.C. may be available and also from high ground in the vicinity of B.B. provided quarrying does not weaken the key structure. Further afield there is ample granite at Jebel Bagis and somewhat nearer at a location marked " Boulders " on the accompanying map. This granite is a little coarser than that of the Blue Nile channel. It is also less micaceous and contains more sphene, but is equally sturdy. That from the " Boulders ", which is in reality a small jebel, is intimately mixed with biotite rich gneiss—the mixture is just as tough as the granite. Bearing in mind the depressions in the surface of the Basement Complex at Damazin, I advise the use of granites derived from external sources, such as those described above.

Gneiss

18. The acid gneiss is a greyish rock, the depth of colour varying with the proportion of biotite mica. White or buff coloured bands of felspar and of colourless quartz ramify through the rock which sometimes displays contortion. As long as the mica is subordinate

in quantity the rock is strong and can be used instead of granite for construction, but with increase of mica the rock becomes schistose and weak. This passage from tough gneiss into weak schist is obvious and material should be quarried with judgment.

Just north of the B.B. line almost in the centre of the channel there is sound gneiss associated with sound granite. Under the microscope the average section shows parallel bands of felspar, quartz and greenish brown mica. The individual grains of the two first named are small and there is much interlocking making for strength. The felspar as in the granite is largely microcline and is very free from kaolinisation.

As already noticed, similar gneiss is available from the Jebel Bagis area.

As will be seen from the drilling record, acid gneiss is the principal rock of the Basement Complex.

19. In some of the holes garnetiferous gneiss is encountered—in the river channel area fragments of garnet are of rare occurrence in the rock. The garnet bearing gneiss is probably marginal and contaminated and not so strong.

Basic Gneiss

20. This dark coloured rock outcrops in small patches in the Damazin locality and also north of Roseires. It looks like a gabbro in the hand specimen but is a metamorphic rock consisting of dark green or black minerals mixed with whitish felspar. Sometimes it is highly banded, deserving the term gneiss. It passes imperceptibly into amphibolite. Amphibolite was found intimately associated with marble south of the A.A. line. Under the microscope this Basic Gneiss shows much mineral variation—when it most resembles gabbro it consists of plagioclase felspar (andesine), pyroxene (hedenbergite), green-hornblende and scapolite together with magnetite, but where it fingers into the marble hornblende, scapolite and epidote are associated with calcite. A remarkable feature about all the rocks I have classified as Basic Gneiss is their extreme freshness—none of the minerals are altered. If accidentally exposed in quarrying operations most of this rock is good building material.

Marble

21. Marble varying from pure white to greenish grey in colour is very abundant and accessible near to the river on both banks north and south of the rapids. Much of it is too coarse in grain to be of constructional value but the pure white fine grained rock is strong and has the virtues of being easily worked and shaped. Localities are indicated in Fig. No. 3.

In thin sections the pure white marble consists mainly of calcite : the darker coloured varieties contain besides calcite, dolomite, phlogopite, mica, tremolite, serpentine and occasionally scapolite.

Rock for Infilling and Road Making

22. Besides those previously described as building stone, the ubiquitous pegmatite can be used for these purposes. It mainly consists of quartz and microcline. The latter mineral often shows crystal boundaries causing the rock to break in angular fragments. Quartz cannot decay and microcline is very resistant.

Sand and Aggregates for Concrete

23. Search for sharp coarse sand in the river bed provided no specific localities. Much of the sand occurring there resembles dune sand—it is very fine grained and not angular. This fine sand no doubt conceals coarser material. Much of the river sand is very micaceous and not suitable. Profitable localities may be found near the boreholes W3, W4, W6, W7, on line C.C., and Y1 on B.B.

24. Coarser aggregates provided much the same difficulty. The pebbles of the river bed, derived from basalt, are discoidal in shape and too large or ill-sorted. Those of the khors are more suitable in size and shape, but are mixed up with silt and would require washing out. Localities W3, W7 and T1 on line C.C. seem to be sources of gravel.

Materials for Cement

25. The abundance of marble at Damazin suggested the possibility of making cement locally. Marble had been burnt for lime at localities north of Roseires and chemical analyses of " limestone " made for the Sudan Geological Survey encouraged the cement possibility. I selected two samples of very pure marble for experiment and hunted for suitable " clay " to mix and burn with them. The brickyard south of Roseires supplied

one sample of silty clay—I obtained the other from a dried up pool west of the Rest House near Jebel Bagis. Intimate fine grained mixtures* corresponding to average limestone/clay for cement proportions were heated to various temperatures ranging from 1,250° C. to 1,400° C.

The marble-brickyard clay mixture did not even sinter. The marble-Jebel Bagis clay sintered but on powdering and wetting did not set. I understand that it is much more difficult to make marble plus clay into cement than limestone plus clay. The experiment is continuing but if an extremely high temperature is required the cost of fuel will make it cheaper to import cement.

Impervious Materials

26. Adequate materials are available in the locality for the construction of water retaining earth embankments. The various components of the sedimentary cover have, however, differing porosity and permeability characteristics, and further investigations will be necessary before a final selection can be made. In all probability the impermeability of such earth embankments would be enhanced by the deposition of river silt.

GEOLOGICAL HISTORY

27. After so short an acquaintance with so limited an area it is very presumptuous to relate its history. The following may be regarded as the thoughts of an onlooker trying to piece together the evidence of the exposed rocks, of the boring records, of microscope study and of information gathered from other observers. It is in no sense to be regarded as a solution of Blue Nile geology.

28. The oldest rock of the Damazin channel is the granite-gneiss which shows strong foliation. This foliation predominantly trends between N.-S. and N.E.-S.W., but especially where there is granite or pegmatite invasion the gneiss is contorted and any pre-existing trend is lost. Whether the foliation is due to retention of pre-gneiss characters during regional metamorphism or to injection processes is not discoverable, neither am I sure that its composition can always be expressed as granite gneiss or biotite-granite gneiss. The intrusion of granite and pegmatite forms the next episode—I regard these as " dry and wet " injection of the same kind of material. Before granite-pegmatite intrusion the foliated gneiss had been shattered : neither the granite sills nor the pegmatites avail themselves (Fig. No. 4) of foliation directions. I have already emphasised the small amount of the granite and prefer to visualise it as being derived from the gneiss by partial softening or possibly melting ; this would account for the small mica content of the granite. The pegmatite which is often very coarse contains even less mica ; it runs amok in the gneiss forming very wide veins but seldom cuts the granite except as thin veins. In some places it looks as if the sheets of granite have cut the pegmatite but I interpret this as the compact unjointed rock forcing the more fluid pegmatite to find a way round. Aplite (fine grained quartz-felspar veins) is rare. Jointing of the granite, like foliation in the gneiss, has two major trends N.-S. and N.E.-S.W. with components at right angles to these.

It will be noted that the trends of A.A., C.C., and B.B., broadly run N.E.-S.W. following the direction of the major fundamental joint system.

29. Next above the Acid Gneiss series comes marble. Frankly I am puzzled as to whether this existed as marble before the granite sills were injected or not. The bulk of the evidence is against the marble being limestone baked by igneous intrusion—there is not sufficient granite, the pegmatite would be too cold, and the gneiss would be thermally impotent. There are no sharp contacts except micro-granite and marble in the Abu Ramad area. Alignment of the marble outcrop and strongly emphasised N.E.-S.W. foliation (Fig. No. 3) inclines me to include the marble with the gneiss and prior to the granite.

30. Still more problematical is the strange rock I have called Basic Gneiss. Mineralogically it could be derived by compounding marble and granite, especially if the marble were impure. In an exposure south of the Rapids, the hornblende-rich relative of the Basic Gneiss is sandwiched in thin layers in marble but the obscurity of this development is not at all clarified by its freshness. The most feasible explanation I can offer is that the whole region of metamorphic rocks, gneiss and marble suffered a temperature rise producing granite and pegmatite and basic gneiss in the strongly foliated ancient metamorphic rocks.

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* Up to 2 per cent. powdered gypsum was added to each mixture.

31. The next episode is the exposure of the region to weathering. It concerns the present report in the data of the deeper portions of the boreholes and I include here the occurrence of pale grey argillaceous limestone in X 11 and a similar outcrop near the Roseires road. In the borehole the limestone occurs above highly weathered fissured coarse biotite gneiss etc., that is, we have evidence of sub-aerial weathering followed by deposition. The fissuring and weathering is recorded in most of the holes and this, together with sediment filled gullies in the basement complex, does confirm the picture of the buried landscape.

What of the limestone ? In thin sections it is unfossiliferous, but it consists of recognisable grains of quartz, felspar, pyroxene, hornblende set in a fine grained calcareous cement, and is quite similar in these respects to rock collected above the marble which outcrops on the Roseires road. The pyroxene and hornblende grains are those of the Basic Gneiss. I have little doubt in describing this as detrital limestone derived from marble and basic gneiss mainly, although the quartz and felspar grains speak of granite or acid gneiss. There is insufficient of such limestone to overstress my interpretation but it is not inconsistent with the idea of lacustrine conditions following sub-aerial rotting of the surface. It is not possible or sensible to hazard a guess as to when (geologically speaking) this took place.

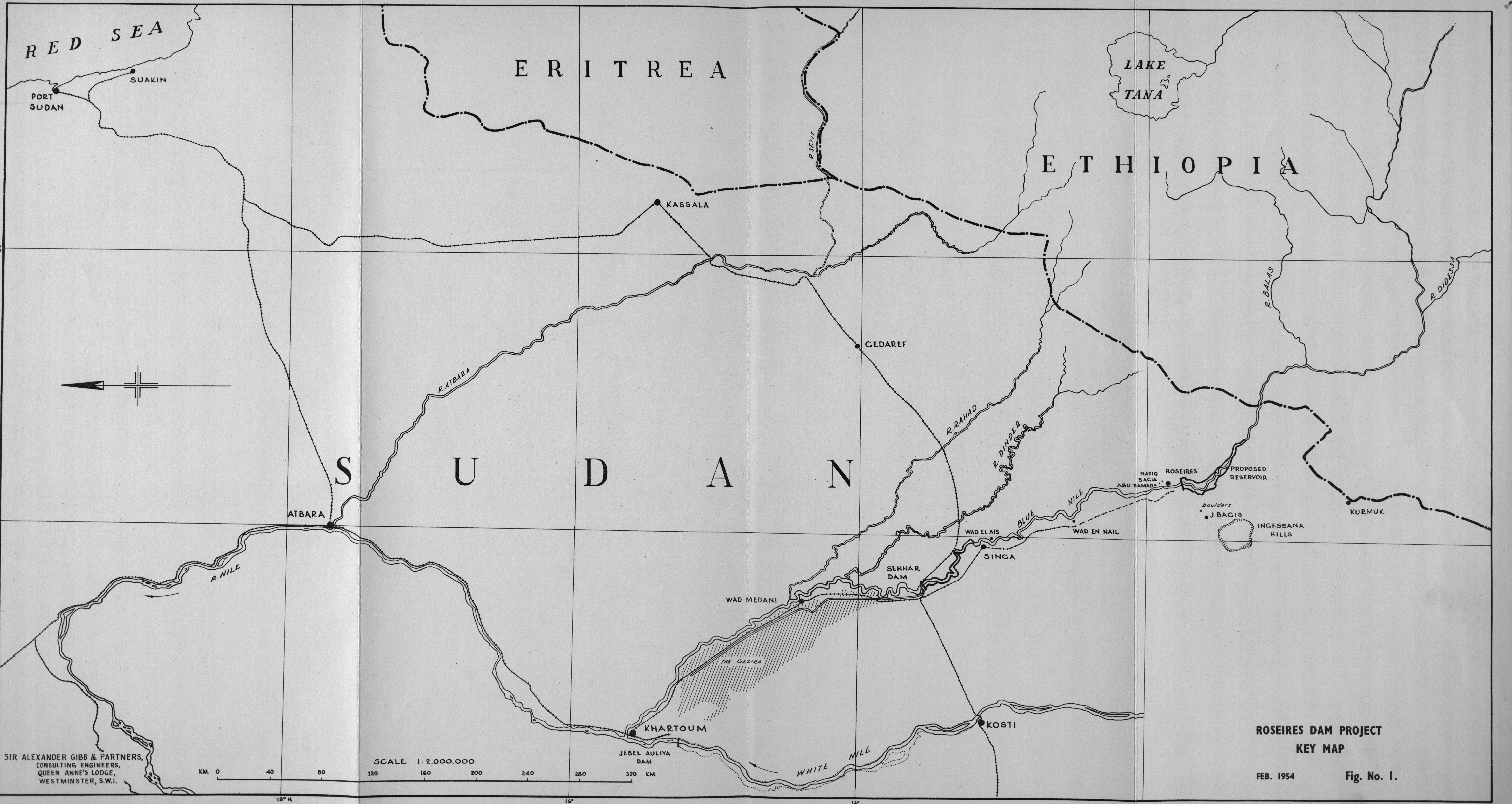
32. The miscellaneous character of the other loose deposits which cover the Basement Complex has been previously noted. If analysed in detail much explaining would be necessary for there is much local variation, but on the average they are fine grained with fine sand, silt, silty clay and clay predominating over coarse sand, angular fragments and gravel. They are certainly not marine—they could be (and in part no doubt are) aeolian, but I think that they are largely lacustrine with fluviatile modification. Judging by the absence of gypsum and salt deposits the lake was not salt water ; judging by the depth of the deposits it was not of long continuance ; judging by the extent of the peneplain it had a large area. Many of the jebels protruded through it as islands. They had previously been inselbergs sub-aerially eroded and were doomed to become inselbergs again for further erosion at the present day. I did not have the opportunity of examining many of these.

33. On the base of the East flank of the Ingessana there is limestone : in the main this is ancient limestone but there are exposures which resemble the argillaceous limestone of Damazin. In the hand specimen and in thin sections it is unfossiliferous and it contains detrital grains. This limestone poorly exposed disappears under the clay and silt soils which form the plain in the direction of the Nile. I contend that the evidence for a lake is reasonably strong.

34. If this theory is correct the question of when and how the lake was formed poses itself. I hold that it was formed by the Blue Nile in its youth—that the river, probably late Tertiary in age, did not at first discharge into the sea but fanned out into a lake and that the silts, sands, clays of the cover would be in part river borne, in part derived from higher ground by sub-aerial erosion and eventually ill-sorted by lake water. As the river increased in water volume it cut through and eventually emptied the lake.

SUMMARY OF CONCLUSIONS

1. Site B.B. is a reasonably good site for an Irrigation Dam.
2. The most vulnerable part of such a dam will have excellent foundations.
3. The wings of the dam will have to rest on unconsolidated sediment.
4. Much of this sediment seems to have a thick impervious cover.
5. There appears to be ample " clay " for redistribution to lessen leakage.
6. There is no evidence in the immediate neighbourhood of Damazin that the Blue Nile has changed its course or will change its course.
7. There is excellent stone for constructional work near the site, but Ingessana localities should also be used.
8. Geologically the West flank of the structure offers the greatest problem—excavation of, or piercing the clay cover may cause considerable loss of water.
9. To some extent damming back of the river will counteract tendencies shown in 8.
10. In clearing the site special attention should be paid to leakage problems at rock junctions.
11. Drilling records show few holes—the sedimentary cover is well packed.



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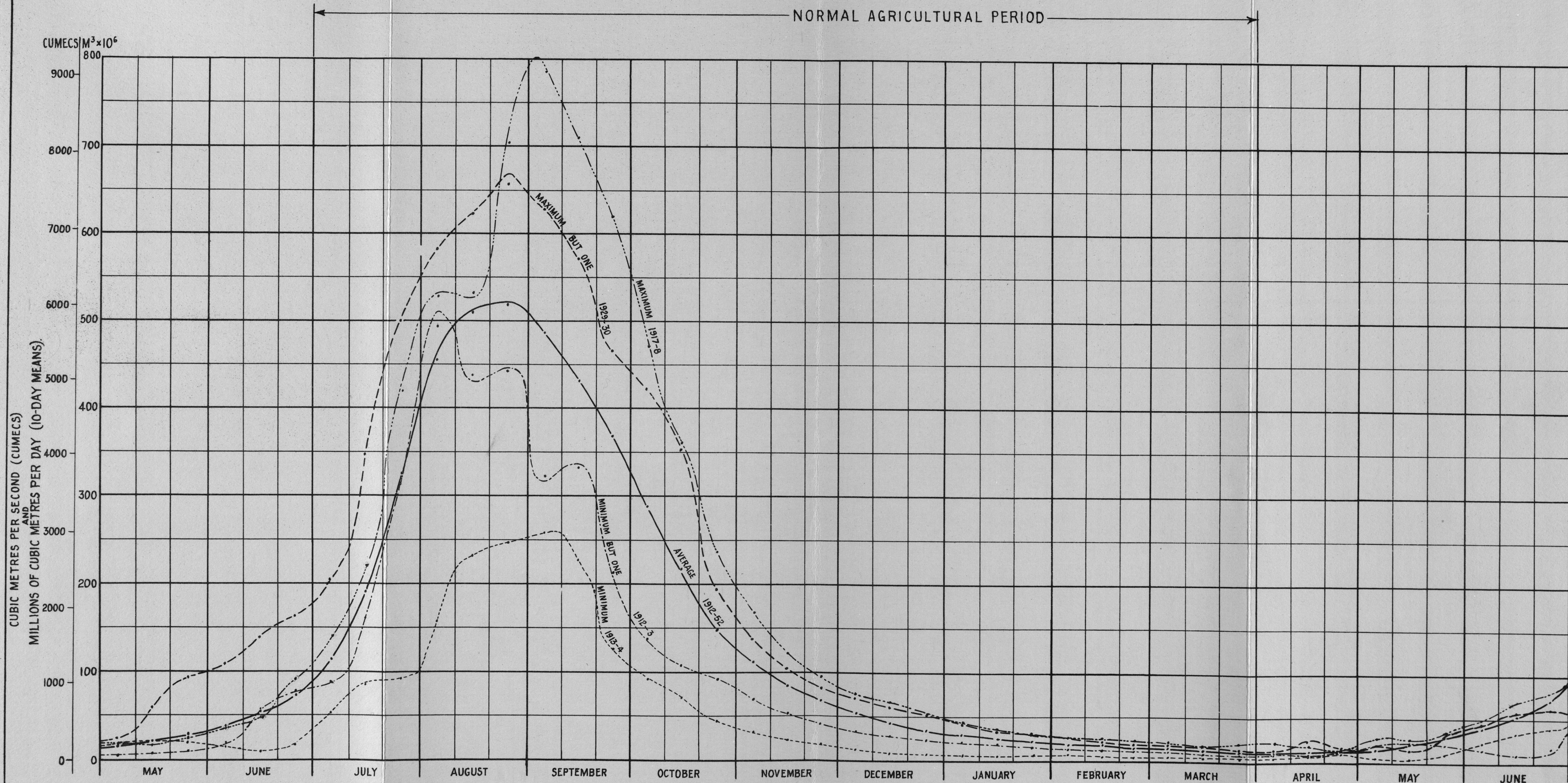
ROSEIRES DAM PROJECT
KEY MAP

FEB. 1954 **Fig. No. 1.**



TYPE OF DISCHARGE	YEARS	TOTAL ANNUAL DISCHARGE (JULY-JUNE) IN MILLIONS OF CUBIC METRES
MEAN	1912-52	49,618
MAXIMUM	1917-8	70,581
MAXIMUM BUT ONE	1929-30	66,805
MINIMUM	1913-4	20,105
MINIMUM BUT ONE	1912-3	37,211

ABSOLUTE MAXIMUM DISCHARGE OCCURRED IN AUGUST 1946 AND WAS 870·8 × 10^6 M^3 PER DAY OVER A 10 DAY PERIOD, EQUIVALENT TO A DISCHARGE OF 10,078 CUMECS.

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ROSEIRES DAM PROJECT

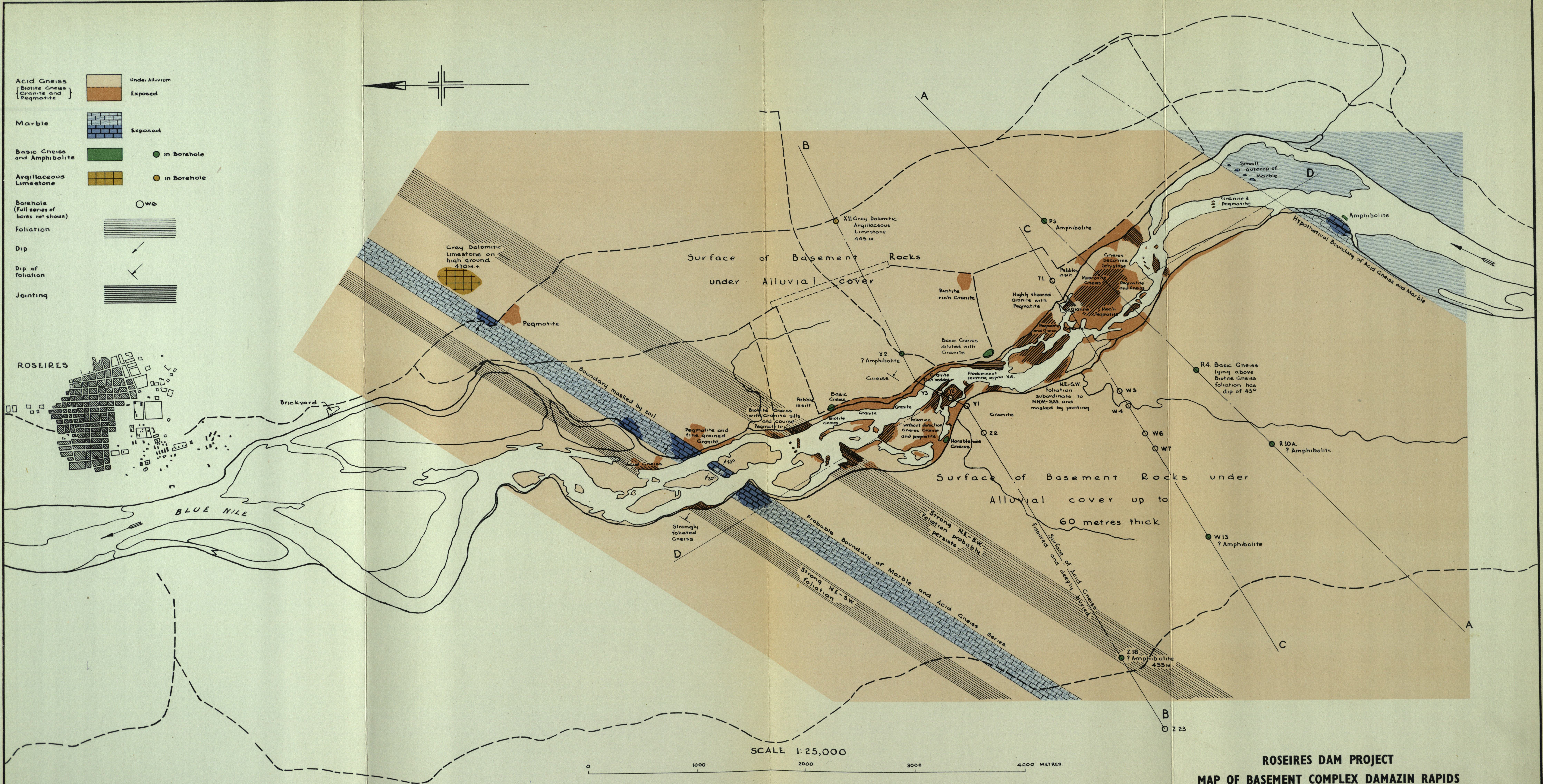
TEN DAY MEAN DISCHARGES ON THE BLUE NILE

AT ROSEIRES

FOR YEARS OF MAXIMUM AND MINIMUM DISCHARGE

FEB. 1954

Fig. No. 2.



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FOR GEOLOGICAL SECTIONS SEE FIG. No. 4

ROSEIRES DAM PROJECT

MAP OF BASEMENT COMPLEX DAMAZIN RAPIDS

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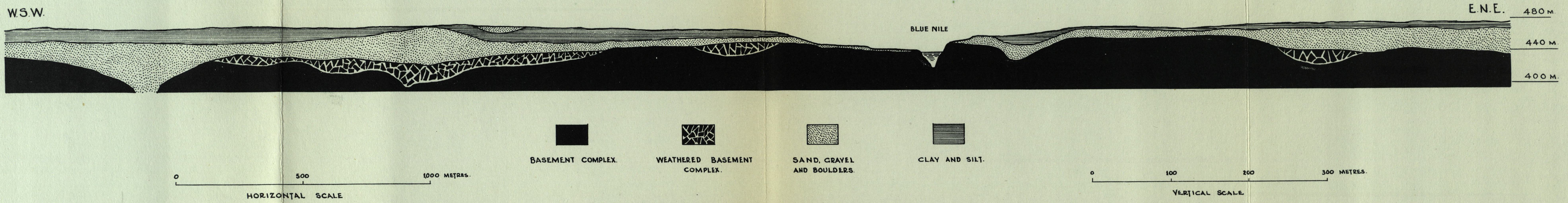
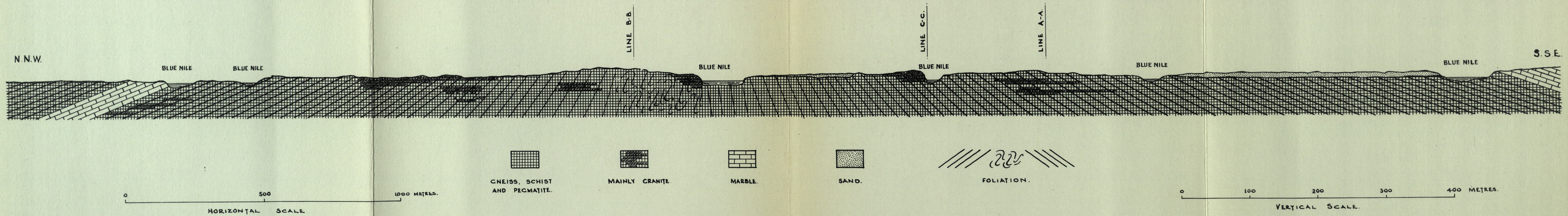
Fig. No. 3.



SECTION ON LINE B.~B.

(SHOWING SURFACE OF SOUND BASEMENT ROCKS AND VARIATIONS IN DEPTH OF SEDIMENTARY COVER.)



SECTION ON LINE D.~D.

(SHOWING CHANGE OF FOLIATION AND JOINT DIRECTION)

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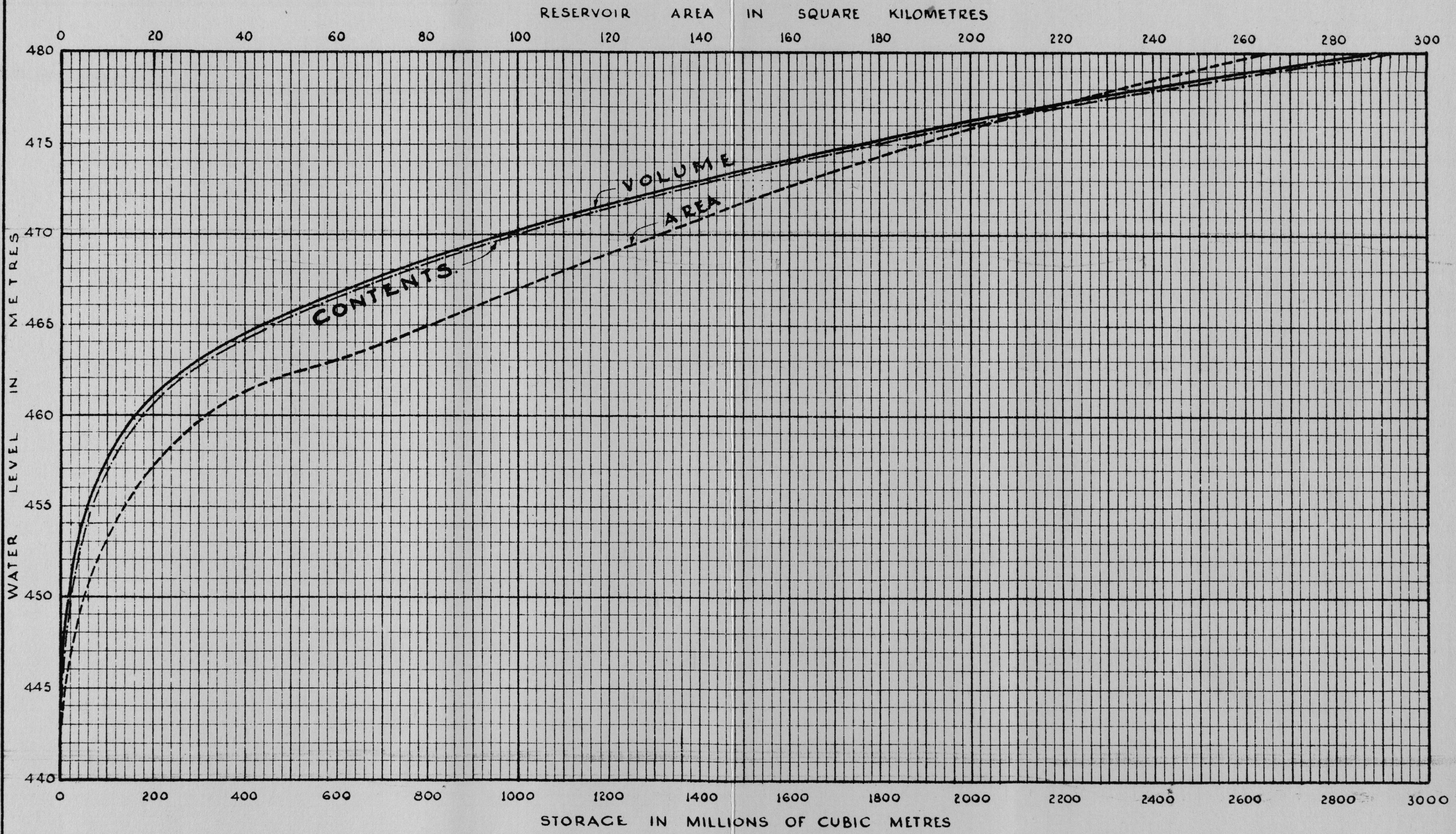
FOR LOCATION OF SECTIONS SEE FIG. No. 3.

ROSEIRES DAM PROJECT
GEOLOGICAL SECTIONS

FEB. 1954 **Fig. No. 4.**



NOTES

1. WATER AREA OBTAINED FROM CONTOURED SURVEY OF HUNTING AEROSURVEYS LTD. - - - - - - - -
2. VOLUME CURVE REPRESENTS VOLUME ABOVE RIVER SURFACE AT DATE OF AERIAL SURVEY (NOVEMBER AND DECEMBER 1952) ————
3. CONTENTS CURVE REPRESENTS ESTIMATE OF VOLUME IN RESERVOIR ADDITIONAL TO THAT PRESENT UNDER NATURAL CONDITIONS WITH READING 12·0 M. ON ROSEIRES GAUGE. —·—·—·—

ROSEIRES DAM PROJECT
ROSEIRES RESERVOIR
STORAGE AND AREA CURVES

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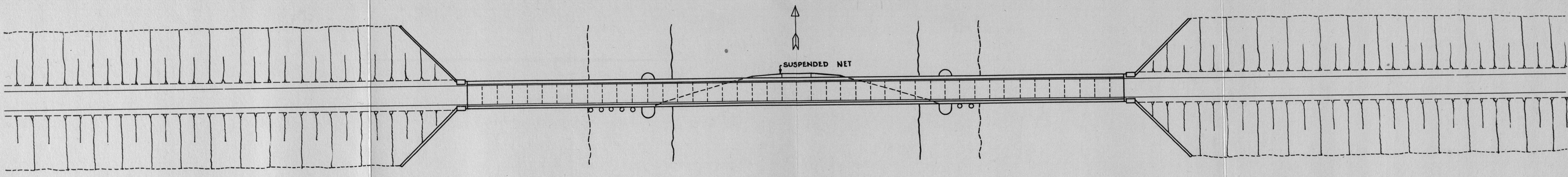
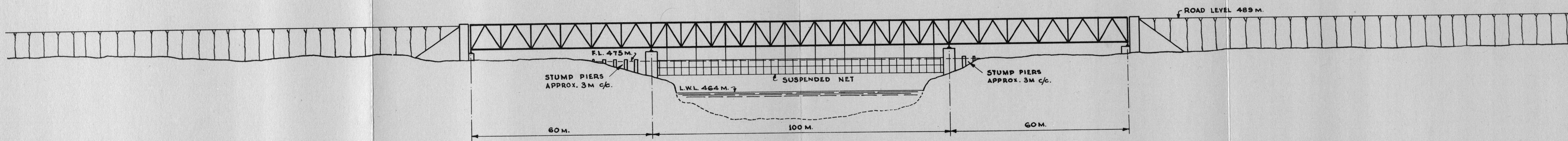


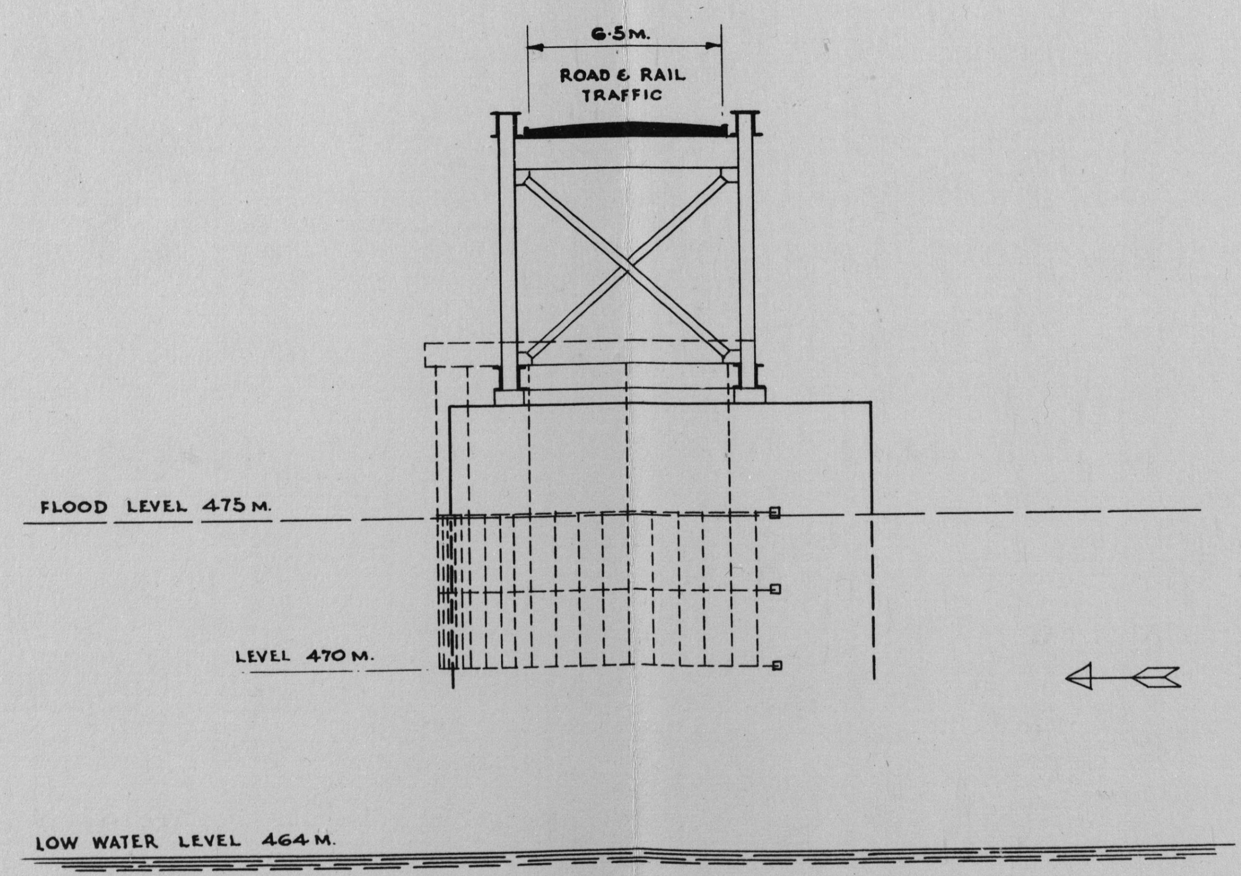
PLAN

SCALE 1:1000



ELEVATION

SCALE 1:1000



SECTION

SCALE 1:250

SUSPENDED NET.

FORMED OF WIRE ROPES, PROVIDING MESH 2·5 M. SQUARE: HORIZONTAL ROPES TO BE ANCHORED TO MAIN PIERS.

FOR SUGGESTED LOCATION SEE FIG. No. 5.

ROSEIRES DAM PROJECT

DEBRIS TRAP

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Fig. No. 9.

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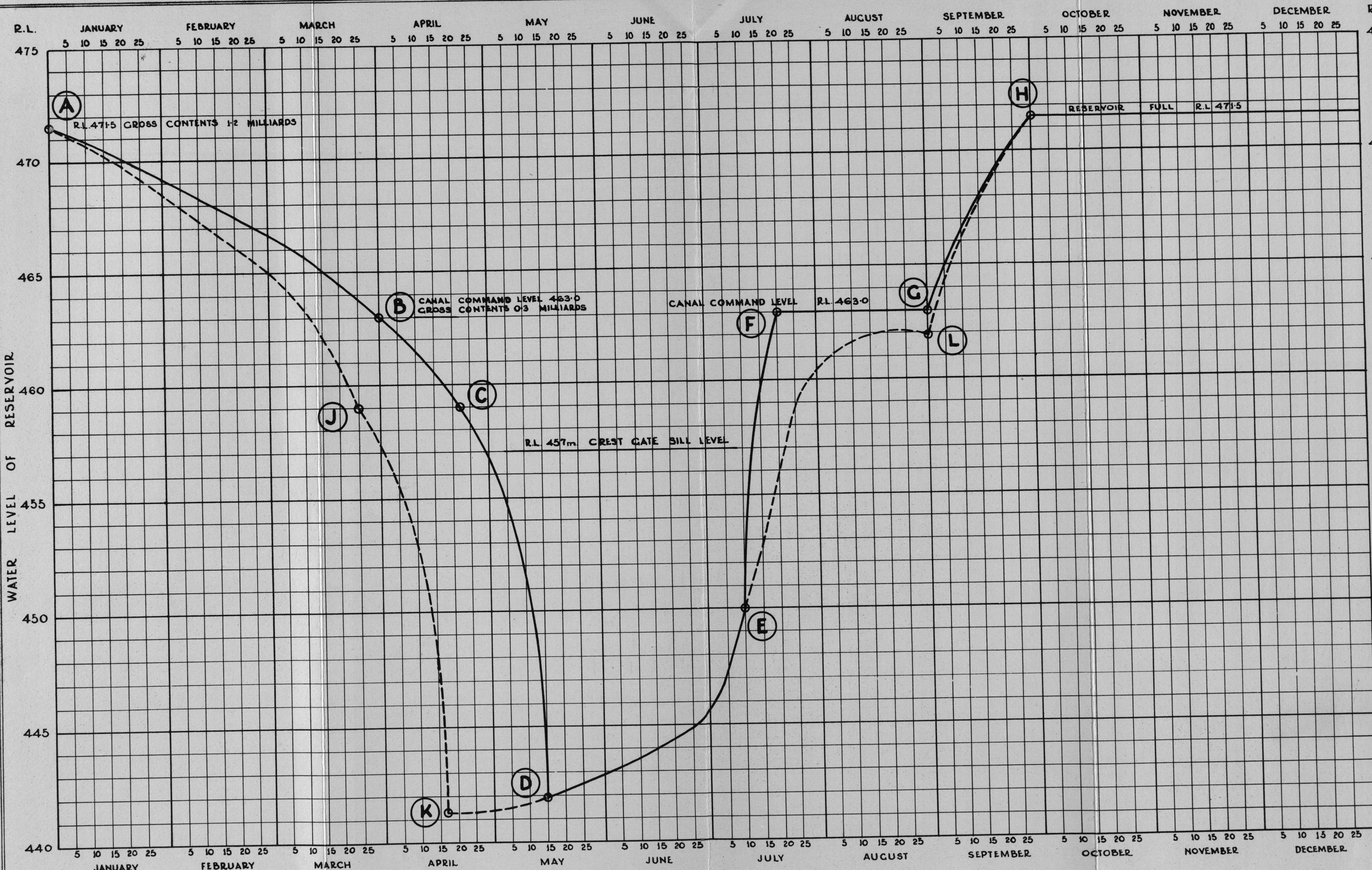

ALTERNATIVE I RESERVOIR USED TO FEED CANAL DIRECT ————

ALTERNATIVE II RESERVOIR TO SUPPLEMENT SUPPLIES AT SENNAR – – – –

NOTE:- THE WATER LEVELS SHOWN TAKE NO ACCOUNT OF ANY RESTRICTIONS WHICH MIGHT BE IMPOSED IN THE INTERESTS OF POWER GENERATION.

ROSEIRES DAM PROJECT
OPERATION OF RESERVOIR

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Fig. No. 10.

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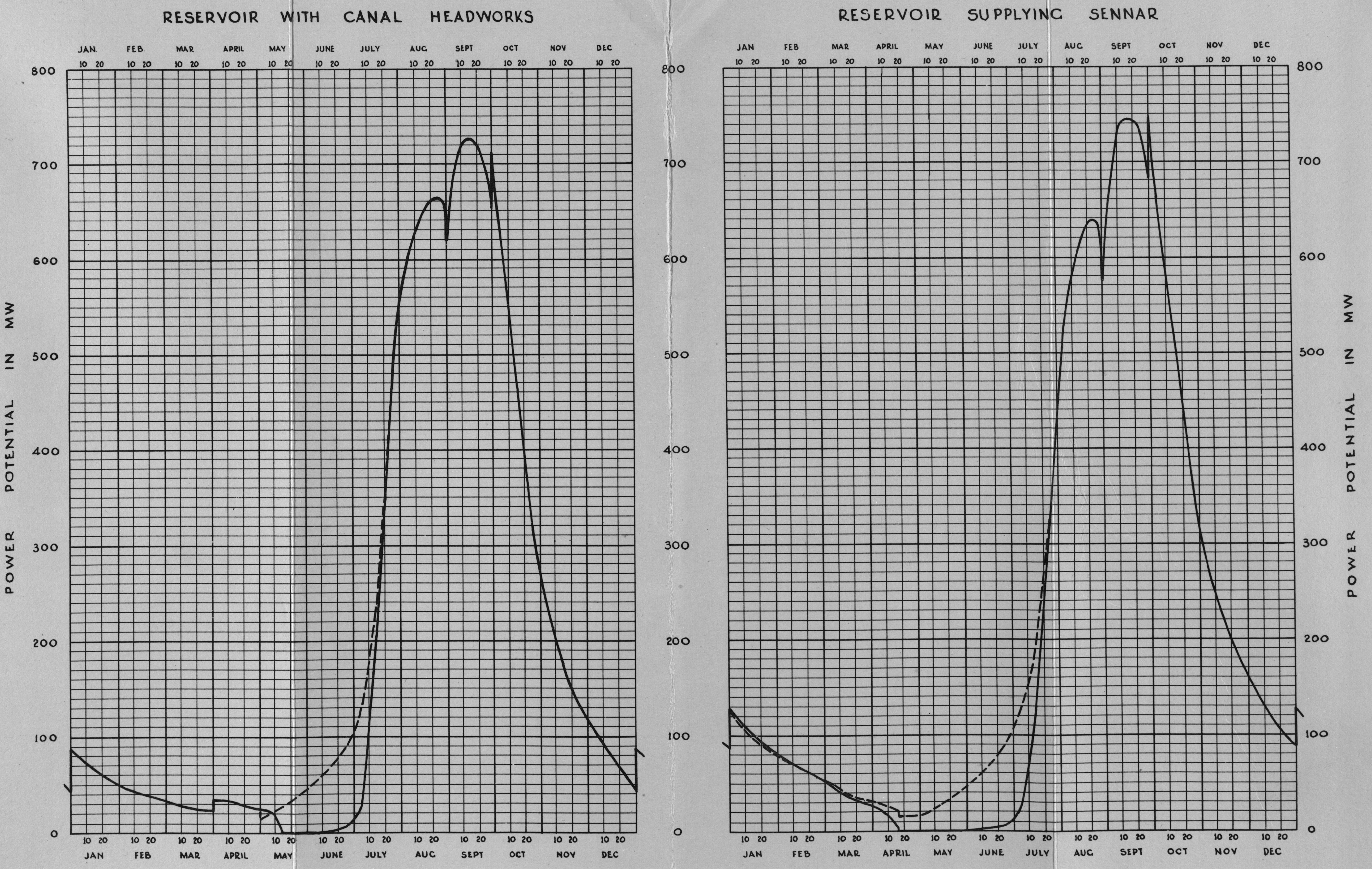

ALTERNATIVE I SHOWN THUS ————————

ALTERNATIVE IA SHOWN THUS - - - - - - - - - WHERE DIFFERING FROM ALTERNATIVE I

ALTERNATIVE II SHOWN THUS ————————

ALTERNATIVE II A SHOWN THUS - - - - - - - - - - WHERE DIFFERING FROM ALTERNATIVE II

ROSEIRES DAM PROJECT

POWER POTENTIAL IN AVERAGE YEAR

FEB. 1954 **Fig. No. II.**

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