EVALUATION OF DEGRADATION AND RELATED HYDRAULIC PROBLEMS DOWNSTREAM OF ASWAN DAM

by

Daryl B. Simons

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P R E F A C E

This report on degradation and related hydraulic problems caused by the controlled relase of clear water from Aswan Dam was prepared by Dr. Daryl B. Simons, Associate Dean for Research, Colorado State University, Ft. Collins, Colorado. The report is to the United Nations. Three copies of this report were sent to Mr. S.M. Orlic, Chief, Section for Africa, Bureau of Technical Assistance Operations, United Nations, New York 17, N.Y. Also, copies of the report were sent to Mr. Vojko Pavicic, Resident Representative of the Technical Assistance Board in the United Arab Republic, 29 Sharia Willcocks, Zamalek, Cairo and to Mr. A.Sager, Chief, Technical Assistance Cooperation Unit, Economic Commission for Africa, P.O. Box 3001, Addis Ababa, Ethiopia.

The report was prepared in accordance with the job description, Post UAR-33-G in the United Arab Republic at the Hydraulic Research and Experiment Station, Delta Barrage and the Nile Control Offices.

This assignment was made possible by a joint agreement between Colorado State University, the United Nations, and The United Arab Republic.

Evaluation of Degradation and Related Hydraulic Problems Downstream of Aswan Dam

INTRODUCTION

Purpose of Visit

In response to a request from the United Nations for an expert on sediment transport in rivers and canals to provide technical assistance to the Ministry of Irrigation and to their Hydraulic Research and Experiment Station, United Arab Republic, Dr. Daryl B. Simons, Associate Dean for Research, Colorado State University, Ft. Collins, Colorado visited Cairo and the Delta Barrage, United Arab Republic from Nov. 19, 1965 to Dec. 22, 1965. This visit was authorized for a 6 weeks period terminating Dec. 23, 1965 through a reimbursable loan arranged with Colorado State University. The reference for the assignment is Post UAR-33-G.

Upon arrival in Cairo, Nov. 20, 1965 a meeting was held with Mr. V.P. Pavicic, Resident Representative of the Technical Assistance Board and Director of Special Fund Programs; Mr. H.L. Maggs, Deputy Resident Representative of the Technical Assistance Board and Deputy Directors of Special Fund Programs; Mr. Y.Y. Kim, Assistant Resident Representative of the Technical Assistance Board and Assistant Director of Special Fund Programs and other UNTAB staff. The objectives of the visit to the United Arab Republic were discussed in general and the group specified completion of a final report at or after termination of the assignment with the Ministry of Irrigation.

The writer was welcomed to the United Arab Republic and the Hydraulic Research and Experiment Station, Delta Barrage by Mr. A. A. Eldarwish, Director. Meetings were arranged with the officials of the Ministry of Irrigation where the writer was warmly welcomed. The following is a list of the ~~m~~members of the HRES Board of Directors. The problems of the River Nile have been discussed with the first three members of the Board.

Mr. Ahmed Kamal, Under Secretary of State for the Ministry of Irrigation and Chairman of the Board of Directors for the H R E S Deltta Barrage.

Mr. Hossean Khalil, Under Secretary of State for Nile Control.

Mr. Mahmoud Hasseab Dafrawy, Under Secretary of State for Research, Ministry of Irrigation.

Mr. Mostafa El-Kadi, Under Secretary of State for Irrigation Projects, Lower Egypt.

Mr. Abd El-Hamid - Abu-El-Dahab, Under Secretary of State for Irrigation Projects, Upper Egypt.

Mr. Mohamed Mamoun Under Secretary of State for Administration and Finance.

Dr. Mohamed Hassan, Under Secretary of State, Ministry of High Education.

Dr. Anwar Khafagi, Dean Faculty of Engineering, Cairo University.

Dr. Hassan Ismail, Prof. Faculty of Engineering, Cairo University and Director, Suiz Canal Laboratory.

Dr. Hammad Yousif Hammad, Prof. Faculty of Engineering, Alexandria University.

Mr. Yousif Semaika, Technical Advisor, Ministry of Irrigation.

Mr. Mohamed Abd El-Aal El-Madani, Technical Advisor Ministry of Irrigation.

Mr. Abd El-Salam Hashim, Technical Advisor, Ministry of Irrigation.

Dr. Abd El-Fattah Fahmy, Director for Research and Planning, Ministry of Irrigation.

Mr. Ahmed Ali El-Darwish Director, Hydraulic Reseach and Exprriment Station, Ministry of Irrigation.

Mr. Mohamed Nadar, Engineer, Secretary Board of Directors, Hydraulic Research Expriment Station.

Special acknowledgement is made of the many privilages and courtesies extended by Mr. Ahmed Kamal, Undersecretary of State and Mr. Mahmoud Hasseab El-Dafrawy Undersecretary of State for Ministry of Irrigation. Also Mr. Eldarwish; Mr. Aly Fawzy, Director General, Nile Control General Inspectorate; Mr. Mohamed Lutfy, Inspector, Nile Control; Dr. Salah Shalash, Nile Control; Dr. Soud Al-Kafif, The Hydraulic Research and Experiment Station and Mr. Hassan Wahby of the Hydraulic Research and Experiment Station were all most helpful in providing detailed data and vital information pertinent to the Nile River and the hydraulic problems associated with it.

To focus attention on some of the hydraulic problems presently of major importance to the UAR Mr. Ahmed Ali Kamal, Under Secretary of State, Ministry of Irrigation, proposed the following questions : -

1. What is the probable amount of degradation in the river between Aswan Dam and the Delta Barrage ?

2. What degradation can be anticipated at the existing regulators at Esna, Nag-Hammadi and Assiut ?

3- Where are new dams or weirs required to control and limit degradation ?

4- What are the most suitable sediment theories that can be applied to the Nile River ?

5- To what extent will agradation occur upstream of the High Dam ?

6- What effect will river degradation have on the banks of the Nile ?

These are all timely and important questions that must be resolved. However, as the remainder of the report emphasizes it will be necessary to conduct continued research and field observations to give quantitative answers to some of these questions and it is essential to do so. The necessary research need includes both laboratory and field studies. These should be best conducted by cooperation between the H R E S and the NCGI. The collected data from the field should be published every year.

THE NILE RIVER

For general information a brief description of the Nile River and its importance to the life and economy of Egypt is presented. This topic was treated breifly by Bondurant and Brown (1963). The following paragraphs pretaining to the Nile were taken from their report.

" The Nile River is formed by three major tributary systems, the White Nile, Blue Nile, and Atbara which drain a humid area of equatorial Africa, However, from the confluences of the Atbara throughout the approximately 1500 miles of its course to the head of the delta near Cairo, the stream flows through an arid region with no tributaries of consequence. At the head of the delta, the river divides into two distributaries, the Damietta and Rosetta Branches, which continue approximately 130 miles to the Mediterranean Sea.

Rainfall throughout most of Egypt is generally less than 2 in. per year, and the flow accumulated in the upper tributary system of the Nile is essentially the only surface water available in the country. Some areas of subsurface water are currently being developed, but these are only a small fraction of the total . More than 90 percent of the population, and practically all the agriculture and industry of the country are crowded within the confines of the Nile valley. In addition to being the primary source of water for domestic, agricultural, and industrial use, the stream above the head of the delta is the major artery of transportation. The Nile is literally the lifeline of Egypt.

Floodwaters of the river have irrigated the valley thoughout history; however, the floods occur in August and September rather than during the periods which would better corresepond to agricultural needs. A program of storage and diversion stmuctures to enable more efficient distribution and use of the water was inaugurated with the completion in 1861 of the Delta Barrage at the head of the delta. Subsequently, additional structures were completed on the main stem and on the two delta branches, and one was constructed on the White Nile. Although this program involved storage as well as diversion, the total storage provided was only slightly over 5,000,000 acre-ft, which allowed only moderate control during flood periods.

Currently, the High Aswan Dam is under construction This project, located approximately 20 mile upstream from the upper mainstem structure (the Low Aswan Barrage) and about 580 miles above the head of the delta, will provide complete storage regulation except for extreme floods. It will also effectively divide the river so that only that portion downstream will currently need be considered in the controls.

Statistics on that portion of the stream are :-

Length (Aswan Barrage to head of delta)	560 miles
Fall	223 ft.
Average slope (varies from 8.6 to 6.5 cm/km)	0.4ft/mile
Width, 500-700 meters approximately	~~450~~ .50 miles
Flow , maximum natural approximately	450,000 cfs
Flow , minimum natural approximately	40,000 cms

The regulated discharge with the High Aswan Dam in operation will decrease from Aswan downstream, since the only replacement for the water withdrawn will be some return flow or drainage from irrigated areas. During years of high flow, the relase at Aswan will be about 143,000 cfs for the period August 20 though May, and 98,000 cfs from June 1 to August 20. During years of normal and low flows, the corresponding values will be 89,000 cfs and 52,000 cfs. Anticipated discharges during the August-May period at the various control structures downstream are shown in the following table :

Location	Distance from Low Aswan Barrage miles	Discharge, cfs High Years	Discharge, cfs Normal and Low years
Aswan Barrage	0	143,000	98,000
Esna Barrage	98	130,000	85,000
Naga-Hamadi Barrage	212	123,000	78,000
Assuit	319	99,000	54,000
Delta	560	97,000	52,700
Mediterranean Sea	660 (Approx.)	45,000	0

The Aswan Barrage is founded on rock, which almost immediately dips below the surface. The remaining structures are founded on sand, which is stated to have a depth of more than 100 ft; they are, essentially, multiported and gated structures on a slab base with upstream and downstream sheet pile cutoffs."

A sketch map of the Nile River from Aswan Dam to the Mediterranean Sea is given in Fig. 1. Note the location of existing barrages and the distances in kilometers between barrages.

DATA AVAILABLE TO EVALUATED THE DEGRADATION AND RELATED PROBLEMS

In 1955 the late Dr. L. G. Straub, University of Minnesota was retained as a consultant by the Ministry of Irrigation to suggest a data collection program that would provide the type of field data required to evaluate the degradation of the Nile River and help solve other related river problems. A plan for procurement of essential data was formulated and since that time these very valuable basic data have been and are being systematically collected in accordance with this well concieved plan by the Ministry of Irrigation.

The plan called for : -

1- Test borings of the bed of the Nile to a depth of ten meters at various location downstream of Aswan Dam.

2- The selection and operation of new river gages.

3- The systematic establishment of rating curves at the gaging stations.

4- River channel cross-section data.

5- Sediment load (silt) investigations.

Test Borings

The test borings were taken in the river channel at Gabal El-Selsela and in the vicinity of existing barrages. Twelve borings were taken at the Gabal El-Selsela location. There were three borings at each of four cross-sections. The borings extended to a depth of ten meters. The borings were analyzed to determine particle size and gradation. The results of the analyses of the borings from three of the twelve test holes is shown in Fig. 2.

Note that the median diameter, d_{50}, of the bed material is about 0.24 mm, the d_{75} is about 0.35 mm. and the d_{90} is around 0.51 mm. The average sizes of bed material based upon the analysis of a larger number of boring between Aswan Dam and the Delta Barrage are :-

$$d_{50} = 0.22 \text{ mm.}$$

$$d_{75} = 0.35 \text{ mm.}$$

$$d_{90} = 0.55 \text{ mm.}$$

It can be concluded from the analysis of the borings that the bed material is quite uniform in character to a depth of about five meters. To this depth there is apparently very little coarse material that can be depended upon to armor the bed and limit degradation. This should be verified by a more detailed investigation.

Another point of interest, the size and gradation of the bed material does not vary much between Aswan Dam and the Delta Barrage. The median diameter is approximately 0.22 mm through-out this reach of the river. This is different from most sand bed streams. In general the median diameter of the sand bed material decreases with distance downstream in accordance with an exponential equation of the form :-

$$d_x = d_{50} \; e^{-ax} \qquad \text{..........(1)}$$

where:

d_x is the median diameter of the bed material in mm at any station downstream of the refrence station.

d_{50} is the median diameter in mm at the refrence station.

a is a coefficient which varies from river to river.

x is the distance in kilometers downstream of the refrence station.

The reason for this lack of reduction in size of bed material with distance should be studied. It may be the result of the type of bed roughness and the nature of sediment transport in the Nile River. Also this reduction in size of bed material may subsequently develope during the process of degradation and may need to be considered in future analyses of river problems.

New River Gages

There are many river gages between Aswan and the Delta Barrage. The establishment of these gages and the subsequent collection of data at them provide very useful information pertenent to dealing with changes in the river. The data collected at these river gages :-

1- Provide present, and will provide future information on water surface slope, channel slope, depth of flow, velocity, width of channel and other essential hydraulic data.

2- A means of checking present loss of water between gages and more important, the gages will provide information on future river losses and gains which may begin to vary as a result of the clear water released from Aswan Dam and changes in water level in the river.

Such data are so important to river control and development that it may be expedient and economical, considering long term development, to start making periodic aerial surveys and maps of the river and more complete maps of the channel alignment, the bed configuration and maps showing the location and movement of sand bars. In fact, a model of the Nile River or models of parts of the river may be needed to help solve these river problems.

Rating Curves

Adequate rating curves have been developed at the gaging stations to provide the essential data on discharge required in the determination of the backwater curves and the magnitude of probable scour at various locations along the river downstream of Aswan Dam.

River Cross-Section Data

Data are collected on the channel cross-sections at 161 stations spaced 5 km. apart from Aswan Dam to the Delta Barrage. This provides limited data required to detect changes in channel shape, degradation and channel slope. Velocity, discharge and sediment data are not collected at the cross-section stations. In addition there are 139 cross-section stations at special locations such as in the vicinity of existing barrages. All of these data are very valuable the collection of such data should be continued and possibly expanded by special surveys, see the discussion of this problem under "New River Gages".

Silt Investigations

Periodic measurements of the sediment load carried by the Nile River have been made since 1929. In a recent report by Mr. M. Lutfy and Dr. M. Salah E. Shalash (1965) the details of the silt investigation program and pertinent silt data are presented. Their report states that an average of about 125 million tons of sediment per year was transported down the Nile prior to closure of the dam in May, 1964.

Henceforth, this sediment will be stored in the reservoir, The reservoir has a maximum water depth of about 71 meters and a length of about 500 kilometers. The reservoir has been designed to provide storge for 30,000,000,000 tons of sediment. This is sufficient space to accomodate the silt accumulations for an estimated period of 222 years. The reservoir area extends a considerable distance into Sudan.

The present well concieved plan to collect sediment data has provided information that will help to :

1- Establish the rate of sediment inflow to the high dam from which annual loss of reservoir storage can be estimated.

2- Determine the initial rate at which the clear water released from Aswan will pick up sediment from the bed of the river.

3- Fix the rate and general location of degradation in the river channel.

4- Establish sediment discharge relation for the river from which the future rate of degradation can be estimated.

5- Determine the extent of hydraulic sorting of the bed material with time after closure of the dam.

A study of the silt load in the Nile River by Y. M. Simaika, Technical Advisor, Ministry of Irrigation, showed the following percentages of sand, silt and clay for a total flood :

Size of Sediment in mm	Percentage
0.2 - 2	trace
0.02-0.2	30
0.002-0.02	40
Less than 0.002	30

It is essential to continue with and expand the collection of these sediment data in order to check estimates of river degradation. These data provide an accurate method of estimating the location, magnitude and rate of degradation in the river. They also provide a means of establishing sediment discharge relations for the river which will be very useful in future river development and planning.

River Mechanics

The degradation of the river and the analysis of related hydraulic problems must be based upon sound physical principles and adequate river and laboratory data.

In sand bed channels, such as the Nile, two regimes of flow and several different bed roughness are possible depending on the magnitude of pertinent hydraulic, geometric and sediment variables.

It has been shown by Simons and Richardson (1963) that flow phenomena in sand bed channels can be subdivided as follows :-

Lower regime flow

- ripples
- ripples on dunes
- dunes

Transition zone

Upper regime flow

- plane or flat bed
- standing waves
- antidunes.

The geometry of these bed forms and related data are shown in Fig. 3.

In the lower regime the rate of sediment transport is small, the resistance to flow is large and the average velocity is small. In the upper regime the opposite is true.

The form of bed roughness that will occur in a channel can be predicted with fair accuracy from a diagram relating stream power, median fall diameter of bed material and form of bed roughness. Simons and Richardson (1965). A schematic of this relation is shown in Fig. 4.

At and near flood stage the Nile River probably had a plane or flat bed in the main channel, transported a relatively large sediment load and had a rather large velocity and a small resistance to flow. Now that river discharge is reduced by storage in the reservoir and as degradation increases in total amount with time, the slope of the river will decrease and the stream power will be reduced to a range where lower regime flow will be established in most of the channel. The river bed will finally stablize at some reduced slope that will probably produce ripples on much of the bed. There will be a very low rate of sediment transport, a relatively large resistance to flow & a smaller average velocity. Of importance is the question what will the resultant stable slope and depth of degradation be along the river? This problem will be discussed.

Degradation

The magnitude of degradation that may occur on the Nile River in the vicinity of Aswan Dam and downstream to the Delta Barrage is a problem of great importance and interest. The extent of degradation has been estimated by various groups and individuals. Answers range from a few centimeters to several meters. For example Mr. Y. M. Sinaika, Technical Advisor to the Ministry of Irrigation and former Under Secretary of State thinks that degradation of the river will be negligable. His estimate is based upon river cross-section surveys some 30 kilometers downstream of low Aswan during a period when the low dam was used to store flood waters. Conversely, Mr. A. Fathy, formerly Professor of Hydraulics, University of Alexandria, estimated that degradation in excess of 11 meters was possible. Certainly, if nothing else such a large figure helped bring attention to the problem. Intermediate values were determined by Dr. Gamal Mostafa (1957) based upon a transport study. He estimated ultimate values of 8.5, 9.0, 7.0 and 6.6 meters downstream of structures starting at Aswan Dam. In (1963) Bandurant and Brown used critical transport values determined for Missouri River sand and the critical tractive force equation :

$$S_o = T_c / \gamma D \qquad \text{..........(2)}$$

where:

- S_c is the critical energy gradient,
- T_c is the critical tractive force,
- γ is the specific weight of water,
- D is depth of flow in feet.

to estimate a maximum degradation of 7.0 meters below Aswan Dam. This value is in close agreement with the value given by Dr. Mostafa.

The Swedish consultant firm VBB (1960) discussed the water power of the River Nile between Aswan and the Delta Barrage. This analysis required an estimate of the anticipated degradation after closure of the High Dam. They emphasize the importance and complexity of this problem and implied the need for further study of degradation to help evaluate the need for new dams between existing barrages to protect existing structures and to provide additional power generation sites.

Figure 5 was taken from the VBB report & illustrates typical backwater curves for different discharges and the degradation curve. Note that maximum degradation is shown near the dam and there is some fill just upstream of Esna. The maximum degradation shown is on the order of 3 to 4 meters. It was not possible to determine the method utilized to estimate this degradation curve.

Recently Mr. Mohamed Lutfy and Dr.M. Salah E. Shalash used the river data collected prior to and since the closure of the high dam to estimate degradation. The results of their analysis is presented in a paper entitled " A study of Degradation of Nile Bed after Sad-el-Aali", which the writer had the privilage of reviewing.

Based upon sediment data, Mr. Lutfy and Dr. Shalash established a relation for sediment transport in the Nile of the form.

$$C = 0.375 \quad (Q - 20)^{1.15} \quad \text{---------} \quad (3)$$

which

C is the silt concentration in ppm
Q is the water discharge in millions of m^3 per day.

The number 20 in equation 3 signifies that $C = 0$ when $Q \leq 20$ million m^3 per day.

The total annual sediment discharge observed as part of the silt investigation in the various reaches downstream of Aswan Dam after closure in 1964 are given.

River Reach	Sediment discharge in millions of tons per year
Gaaffa to Esna	26.22
Downstream of Esna	29.42
Downstream of Nagi-Hammadi	36.43
Downstream of Assuit	38.67
Upstream of Delta Barrage	51.76

The foregoing values are in good agreement with values predicted by their transport relation. The sediment discharge has not been subdivided into percent of sand, silt and clay.

The magnitude of degradation caused by the removal of sediment from the river bed are given for 1964.

River Reach	Degradation in cm.
Aswan to Esna	1.27
Esna to Nagi-Hammadi	2.08
Nagi-Hammadi to Assuit	0.75
Assuit to Delta Barrage	2.01

To estimate these values a length of the river from Aswan Dam to the Delta Barrage of 964 km and a mean average wetted perometer of 900 m was used. The corresponding approximate value of the water cross-section is 5000 m^2 and the average bed depth is on the order of 5.6 m.

In general the computations presented by Mr. Lutfy and Dr. Shalash point out that degradation will total a few centimeters per year. They conclude that only a minor reduction in river slope will result.

It is suggested by the writer that :-

1- This excellent method of checking degradation should be continue and expanded so present results can be revised based upon a longer period of clear water flow and corresponding sediment transport.

2- The measured silt load between barrages should be analysed to determine percent of clay, silt and sand. For example, is the total tons of sediment measured upstream of the Delta Barrage about one third sand or is the percent of sand relatively smaller than for normal floods ?
Future rates of degradation may be more intimately related to the sand fraction of sediment transport than the clay and silt fractions.

3- In computing the average degradation in the river consider a wedge of sediment being eroded from the bed instead of a rectangle. This may double the estimated degradation computed by Mr. Lutfy and Dr. Shalash.

4- The silt investigation program should be expanded. Silt data should be collected at more cross-sections and more frequently.

OTHER METHODS OF ESTIMATING DEGRADATION IN THE RIVER.

To estimate the magnitude of degradation in a river certain basic data are required, certain assumptions must be made regarding the magnitude of variables such as width, depth and slope and comutational proceedures must be adopted.

Such data as : resistance coeficients, slope of energy gradient, geometry of channel cross-section, the characterestics of the bed material, the characterestics of the water, sediment discharge relations and other data are necessary. The essential data and information required for preliminary computations are available.

The computational proceedures suggested by the writer are :

1- Determination of degradation based upon sediment discharge data and sediment discharge relations as presented by Mr. Lutfy and Dr. Shalash. The initial data and degradation resulting from the first years of closure of the dam can be used to estimate the final conditions in the river. Also, the results can be periodically revised as dictated by future data and measurements.

2- Other transport relations such as the one proposed by Colby (1964) can be used to check degradation.

This proceedure would be similar to that proposed by Mr. Lutfy and Dr. Shalash but utilizes a transport relation developed for other, but similiar, rivers.

3- The final slope of the Nile can be estimated using stable channel design criterion. From the difference between original channel slope and stable channel slope an estimate of degradation for each reach of the Nile can be made.

4- The stability criteria for channels based upon basic data collected by Simons and Richardson (1961) in the hydraulic laboratory at Colarado State University can be used to estimate degradation.

5- The recnt laboratory studies of degradation completed by Dr. Ismail and Mr. Wahby (1964) at the Hydraulic Research and Experiment Station, under the direction of Mr. A.A. Eldarwish, can be used to approximate the degradation of the Nile River. Also a resent Study of degradation completed by Dr. Al-Khafif (1965) can be used to estimate river degradation.

6- The critical tractive force proceedure using Shields data can be used .

7- A recent paper by Prof. Komura and Dr. Simons, still unpublished, establishes a proceedure for estimating degradation. A copy of the rough draft of this paper will be given to Ministry of Irrigation. An estimate of ultimate degradation in the Nile between Esna and Aswan is made using methods 3, 4, 5 and 6.

Stable Channel Concepts.

Several mehtods of selecting a stable channel slope for a canal or river has been proposed. Simons and Miller (1964). One such relation is

$$S \times 10^3 = 2.09 \ d^{0.84}/Q^{.21} \quad .... (4)$$

where

S is slope of energy gradient
D is the median diameter of bed material
Q is the design dishcarge.

This equation was selected because it has been checked using large flows in Pakistan and the United States and it is a function of the size of bed material.

Based upon existing field data it is assumed that the median diameter of bed material of the Nile is 0.25 mm and that the dominant discharge, that which is exceeded not more than about 15-20 percent of the time, is about 250 million cubic meters per day. For these figures the stable slope is.

$$S \times 10^3 = \frac{2.09\ (0.25)^{0.84}}{[(2.50)\ (1100)\ (36.7)]^{0.21}} = 0.058$$

$$= 5.8 \ cm/_{km}$$

This combination of slope, river discharge and size of bed material gives a channel with fairly stable slopes, and a channel capable of transporting about 50 ppm of sand. To reduce the sediment transport to a negligable value, using existing sediment transport theories the slope should be further reduced to about 4 cm/km. Assuming the backwater upstream of Esna barrage would control degradation for about 50 km the degradation can be estimated by subtracting the suggested stable river slope of 4 cm/km from the existing river slope which is 6-8 cm and multiplying this diffrence by the length of channel above the backwater of Esna to the high dam (166-50= 116 km)

Hence, the degradation at the high dam should be about

$$\frac{(7-4)\ (116)}{100} = 3.5 \text{ meters}$$

This is a first approximation of the degradation at Aswan Dam. Assuming, as we have, the uniform bed material conditions exist and the absence of other controls upstream of Esna, the estimated 3.5 meters of degradation makes good engineering sense.

Without any backwater above Esna to reduce the average velocity, slope and degradation the total degradation could be

$$\frac{(3)\ (166)}{100} = 5 \text{ meters}$$

Degradation Based Upon Observations at Colorado State University.

A study of sands similiar to the sand which forms the bed of the Nile River was completed by Simons and Richardson (1961). This study showed that significant sediment transport with graded sand having a median diameter of 0.28 mm starts when the boundary shear is about 0.04 lbs/ft^2. Assuming that the depth associated with the dominant discharge is about 5 meterd (16.7 ft) this criteria gives a stable slope.

$$S = \tau / \gamma D = \frac{0.04}{(62.4)\ (16.7)} = 0.000038$$

which is about 3.8 or 4 cm per kilometer.

This is approximately the same answer arrived at by using stable channel theory modified by sediment transport relations. To provide a more positive check to prove that this slope is sufficiently small to stop degradation use the Einstien (1951) Bed Load Function, the Colby (1964) method or the method proposed by Bishop, Simons and Richardson (1965) to verify that the bed material discharge and hence the degradation will be negiligable after a slope of 4 cm/km is reached.

Degradation Based Upon Experiments at The Hydraulic Research and Experiment Station, Delta Barrage.

Studies conducted by Dr. Ismail and Mr. Wahby (1964) can be used to approximate the degradation of the river Nile. Treating their study as a model of the Nile it is observed that degradation experiments run for as long as 600 hours only reduced the initial channel slope, established with sediment transport, by about 40 percent. Using a model - prototype time scale, the 600 hours of time during which degradation occured in the model represents several years of prototype operation.

It is suggested that the percentage reduction in the slope of the river will be on the order of that observed in the flume study or model. Using this proceedure the original river slope of about 7 cm per km will be reduced by 40 percent to an ultimate value of

$$7 - (7)(.40) = 4.2 \quad \text{cm/km}$$

This slope indicates that degradation in the Aswan-Esna reach, considering backwater as before, will total about $\frac{(2.8)(116)}{100} = 3.1$ meters at Aswan Dam. This value is in close agreement with previous estimates by the two other methods.

Degradation Based Upon Critical Tractive Force.

Using the Shields criterial and assuming the Nile River will degrade until the boundary shear is reduced to the critical shear stress or tractive force (the critical tractive force or shear stress is defined as the force per unit area required to start motion of the bed material) larger degradation is indicated. From the Shields diagram the critical shear velocity - Reynolds number is

$$\frac{U_{*c}\, d_{50}}{\nu} = 12.0$$

Assuming as before a depth of about 16 ft., a median diameter of bed material equivilant to d_{95} = 0.7 mm and $\nu = 0.9 \times 10^{-5}$ ft^2/sec. one can solve for the critical channel slope.

That is :

$$\frac{\sqrt{9\ (16)\ S}\ (0.7)\ (10)^5}{(0.9)\ (2.54)\ (10)\ (12)} = 12.0$$

Solving for the critical slope:

$$S = 0.4 \text{ cm/km.}$$

This indicates a total degradation between Esna barrage and Aswan Dam, considering backwater, of

$$\frac{(7 - 0.4)\ (116)}{100} = 8.8 \text{ meters.}$$

This value is in close agreement with the one a proposed by Dr. Gamal Mostafa (1957) and by Bondurant and Brown (1963).

The writers experience with canal and river problems indicates that the use of the Shields criteria suggests more degradation than will actually occur because or armoring, boundary layer effects and boundary roughness. Most transport theories will show that degradation will essentially stop before the slope of the channel is reduced to the small value indicated by the Shields criteria. Also, there is usually an appreciable amount of sediment supplied to the river from intermittent tributaries. This may be a significant factor that will limit the degradation of the River Nile.

Using present data, theories and experience the writer believes that an ultimate limiting slope of about 4 cm/km. and a degradation at Aswan of about 3 meters are realistic.

OTHER HYDRAULIC PROBLEMS

In the introduction to this report several hydraulic questions, for which answers are needed, were asked. The question of degradation between Esna and Aswan has been considered. Using the same procedure an estimate of degradation at other barrages can be obtained.

There has not been sufficient time to become well enough acquainted with the river to suggest the need for and the location of new barrages and weirs to limit degradation and accomodate new diversions. However, considering the estimated degradation at Aswan, the need for new structures in this reach of river may be fixed by the need to divert water more than by the need to control degradation at intermediate points along the river. However, the safety of each existing structure must be carefully and continuously considered in the light of new data. Where larger distances exist between barrages new weirs may be required to limit degradation and protect existing structures. There is the possibility of generating power at these new structures as suggested by VBB (1960).

The sediment transport theories most applicable to the Nile River is a controversial subject but in the writers opinion :-

1- Transport relations based upon measured data that have been corrected to include bed load transport is the most reliable procedure. A good estimate of the bed load transport to be added to the suspended sediment load to obtain total load can be made using the Modified Einstein Method, Hubbel and Matejka (1959). Detailed use of this method is illustrated in their paper. Other similar reports that discuss the Modified Einstein proceedure are available though the U.S. Geological Survey. A copy of the Hubbel - Matejka report was given to the laboratory.

2- Another good choice is the method proposed by Colby (1964). This method has the advantage of simplicity and it is based upon a large range of field conditions including conditions similar to those in the Nile. This method relates sediment discharge, average velocity, size of bed material, depth of flow, concentration of silts and clays and water temperature. The report by Colby was given to the laboratory and is available from the U.S. Geological Survey.

3- Other excellent methods are given by Bishop, Simons and Richardson (1965) and by H. A. Einstein (1951). The Bishop, Simons, Richardson report is available from the American Society of Civil Engineers.

The condition at the entrance to the reservoir upstream of the high dam will be of interest and importance. The larger sediment particles will deposit in the backwater of the reservoir and at the entrance to the reservoir. In fact, a delta will form. This delta will be quite unstable because of changing water level in the reservoir. Nevertheless, with certain engineering works to give some stability to the delta and after a long time a new limited agricultural area might be developed. A detailed study of the development of the reservoir delta and methods of stabilizing and utilizing it should be considered as well as other effects of agradation upstream and the development of agriculture and related activities around the lake.

The question of erosion of the banks of the Nile is also a problem. Earlier, the writer emphasized the need for both laboratory studies and field observations to evaluate this problem. In time, as the silts and clays presently forming the banks of the river are eroded away, bank areas much less stable and more erodable may be exposed to the flow. The failure of such areas may require extensive use of bank protection works of various types. Also, as mentioned earlier in this report as large sand bars and a low water channel form the channel may meander and cause a lowering of bed level, and as the meanders approach the original bank the bank will come under attack and may fail. A more detailed study of this problem is certainly warrented.

Similarly the future stability and hydraulic performance of irrigation canals should be considered. A loss of silts and clay from these channels may cause significant changes in them and complicate groundwater and drainage problems as well.

PROPOSED RESEARCH AT THE HYDRAULIC RESEARCH AND EXPERIMENT STATION AND IN THE FIELD

The conversion of the Nile from the partially controlled to the completely controlled state & the subsequent dramatic changes in the water from a heavilly silt ladden condition to a clear water release at Aswan will introduce many new and unique problems that must be studied as soon as practicable in order to provide basic information required to solve them.

In many instances the initiation of these research projects will require addition to new staff, equipment and instrumentation.

Instrumentation Needs

Some of the instrumentation essential to such research was cited by Bondurant and Brown (1963). Additional instrumentation needs include :

1- Laboratory and field sonic equipment capable of accurately measuring bed configuration, channel cross-sections and channel profiles. In particular, this equipment must work accurately at shallow depths. Such laboratory equipment is available through Colorado State University, Ft. Collins, Colorado and Automation

Instruments, Inc., Boulder, Colirado. Each unit of such equipment including an accurate recorder costs approximately $ 4000 .

2- Hot-Film velocity measuring equipment capable of measuring and recording the instantaneous velocity fluctuations in time and space in liquids. Such equipment can be procured from Honeywell Manufactures, U.S.A. or a similar device will be available from Colorado State University by January 1967. Such a unit will cost about $ 4500.00 including an adequate recorder.

3- A complete set of glass tubes for the visual accumulation equipment. The large size tubes are essential to analyze samples of bed material of both the river and flume studies.

4- Appropriate sampling equipment to obtain systematic samples of the river bed and banks, the suspended sediment load and total sediment flow passing each barrage are necessary. Standard sampling equipment and sampling proceedures are described by the Inter-agency Sedimentation Sub-Committee and both publications and equipment can be obtained from the Corps of Engineers, U.S.A. or similar equipment is available from the other countries. The importance of instrumentation is sufficiently great to warrent special evaluation.

Research and Field Studies

To achieve the maximum results with minimum effort it is necessary to develope a close and coordinated working relation between the various subdivisions of any agency and in particular excellent cooperation between these groups and research staff. Close cooperation make possible a more complete utilization of staff and the data resulting from both laboratory and field studies. One of the greatest obsticals to a coordinated activity is lack of appreciation of each others assignments and objectives.

To help solve the many complicated engineering problems that will result from a controlled clear water release from Aswan Dam, the Ministry of Irrigation should make continued and expanded use of the Hydraulic Research and Experiment Station.

At the outset of the report several problems that may result from the release of clear water from Aswan Dam were cited. Many of these problems can be best solved by conducting properly designed and executed studies at the laboratory and in the field. A few such studies that are of sufficient importance as to warrent immediate consideration are suggested.

1- River Degradation. Using natural river sand from the Nile, study the mechanics of degradation, the effect of the courser particles comprising the bed material on the armoring of the bed on the reduction of scour and in particular the magnitude of degradation. Suitable flumes for such a study are available at the laboratory and initial studies of degradation have been completed, Ismail and Wahby (1964).

2- The stability of the banks of the Nile should be examined. Possibly undisturbed samples of the bank material should be carefully obtained and subjected to erosive forces of different magnitude to determine the stability of such material when subjected to clear water flows. Such a study should be conducted in the laboratory but simultaneous observations and measurement should be made at selected field stations or sites.

3- The change in channel geometry should be studied in detail. It is possible that the present width-depth ratios of the Nile are too large for the reduced flow rates of the future. This may induce the development of more large sand bars and a smaller channel within the large natural channel. This development of a channel within the existing channel is accelerated by the development of large sand bars. The possible changes in the channel and increased meanundering will endanger existing hydraulic structures, water intakes, bridges, bank stability and etc. Furthermore this new channel may be less stable in alignment than the old channel. This new channel may cut into the bank of the old channel doing serious damage to property unless controlled.

It is proposed that a three-dimensional model study of a qualitative nature should be considered to establish the possibility of the development of a new channel and its many consequences on the river and upon river operation and development.

One minor advantage of the development of a new channel meandering on the bed of the original channel is a greater channel length, reduced channel slope, increased resistance to flow and less favorable conditions for continued degradation.

4- Channel bank instability from seepage forces caused by a high water table and return flow may be of increasing importance, particularly at low flow and upstream of the back water effect of barrages. With a water table higher than the water level in the river the banks will seep, and may slide into the river channel. Special treatment of such unstable banks may be required. The location of problem areas should be investigated and methods of locating and stabilizing such bank conditions should be investigated in both the hydraulic laboratory and the field.

5- Navigation requirements must be established and from these requirements minimum widths, depths and radii of bends. To meet future navigation needs may require detailed studies of river mechanics, best river alignment, depth of pools, depth of crossings, minimum radius of curvature, minimum width and etc. Such problems will require close coordination and cooperation between field and laboratory staff. The consideration of navigation problems may require more detailed collection of field data to establish a more accurate alignment of river banks, the location of the main navigation channel and to help identify those reaches of the river that will require maintainance and possibly stabilization. Such data can be most economically obtained by completing periodic aerial surveys of the river and sonic surveys of the configuration of the river bed. Also, such surveys will help indentify & determine the magnitude of river degradation.

6- The development of suitable control structures for the Nile is an important problem. If a certain channel width, depth and curvature is to be maintained it will be by using many types of channel controls, bank revetments, low level sills, weirs and etc. Similarly, control structures may be required between existing barrages to limit the degradation at important structures. The best type of base level control structure should be studied in detail since the design and construction of such structures may be very important and expensive. Possibly some type of weir constructed of rock will be most economical.

7- Changes in the quality of the water for irrigation may cause significant and important changes in the irrigation canals. Apparently, the major part of the sediment load entering the canals has been silts and clays. these channels have develope a rather stable, semi-cohesive boundary. With the introduction of clear water into the canals some of the silts and clays presently forming the perimeter of the canals may be eroded away leaving more permeable and less stable banks exposed to the fluid forces. Also, the beds of these canals may be covered with coarser sand that will be formed into dunes by the flowing water. If sand dunes and bars do develope on the beds of the canals there will be an increase in resistance to flow and the ability of these conveyance channels to deliver an adequate supply of water to the fields may be reduced. This problem should be investigated in the laboratory flumes by subjecting the natural bed material of canals to fluid forces to see if the fine sediments are in fact carried away, if a deposit of coarser sand remains and if this sand is molded by the flow into dunes that will increase resistance to flow and reduce channel capacity.

8- The ability of the Nile to transport the eroded bed and bank material should be studied. The water discharge will decrease with distance downstream of Aswan Dam. It was pointed out by E. W. Lane (1955) that the general relation:

$$Q_s \, d \propto Q_w \, S \quad .....(5)$$

can be used to help identify and to solve such fluvial hydraulic problems. This relation simply states that a river developes a regime largely dependent upon Q_s, the bed material discharge; d, the size of bed material; Q_w, the water discharge; and S, the slope of energy gradient. In the case of the Nile Q_w will decrease with distance of the dam, S will be decreased by degradation of the river bed, the size of the bed material d may coarsen slightly with time and Q_s will be scoured from the bed and will decrease in magnitude with time. The future regime of the Nile should be considered from the point of view of the development of a new stable regime consistent with new conditions and the approach suggested by Lane (1955) may serve as a guide.

One specific object of such a study would be to determine whether or not the pool reaches will partly fill with sand. This development could cause serious problems to navigation and to diversions from the river for irrigation and for municipalities.

9- Travelling by airplane from Cairo to Aswan enabled the writer and Dr. Soud El-Khafif to observe that there are many large intermittent tributaries to the Nile. These must provide a relatively large supply of sand, silt, clay and some gravel sized particles to the

River Nile. The magnitude of this sediment load supplied to the river must be at least qualitatively determined. This sediment supply will reduce degradation and for periods of larger storms may even cause some agradation of the river channel. Engineers at the Esna Barrage, when asked about inflow of water and sediment to the Nile from side drainage, stated that occasionally there is enough inflow of sediment to change the color of the river water.

C O N C L U S I O N S

This study of the degradation and other hydraulic problems associated with removal of the normal sediment load of the River Nile was facilitated by the cooperation of the Ministry of Irrigation and the Director and staff of the Hydraulic Research and Experiment Station.

The existing river data and the data collection program were studied and discussed. The present data collection plan has provided information required to make initial estimates of river degradation. Also, these data can be used to help evaluate and solve other river hydraulic problems. This program should be continued and expanded. Such information must be obtained to cope with hydraulic problems which must be evaluated and solved. More data are needed on sediment transport, river geometry, the presence or absence of coarse bank and bed material that may armor the channel, the amount of sediment inflow from intermittent tributaries and changes in bed configuration and flow regime with time.

Methods of estimating river bed degradation were presented and applied to the Aswan - Esna reach of river. An ultimate degradation of about 3 meters is anticipated in this reach. These methods can be applied to other parts of the river. Computations should be checked as more data are collected. This is essential because of the complex and uncertain nature of this problem.

Other hydraulic problems were considered and discussed briefly to emphasize the problems of the future and how they might be solved. These problems should be given the immediate and continued attention of a highly competent staff. Such an effort will require the appropriation of additional funds for research, field studies and instrumentation.

The efficient solution of the problems of the River Nile will require very close cooperation of all groups and Ministrys responsible for the use of and development of the river. In fact, it may be worth while to coordinate and execute this work within one organisation. A lack of coordination of effort will increase the expense and difficulty of solving these problems.

A staff of competent engineers and other interested in the development of the river should be encouraged to work continuously on these problems. Frequent changes of staff reduces the continuity of effort and the ability to efficiently and economically achieve the desired objectives. These staff should be adequately compensated for their efforts. Otherwise, they will look for more rewarding assignments.

Continued use should be made of technical experts and consultants that have specialized in river engineering and water resources development. The periodic use of a particular consultant is preferable to the periodic use of various consultants. Such a plan avoids the loss of time required to orient new experts, is more productive, allows the individual time to discuss the problems with his associates and increases the interest of the expert in the problems because of continued participation. Also, it gives the expert the necessary time to become acquainted with the country and its background. Often this knowledge is necessary if best solutions of problems are to be found.

APPENDIX - A

Program at the Hydraulic Research and Experiment Station :

The present activities at the Hydraulic Research and Experiment Station at the Delta Barrage was reviewed in detail in a report entitled "Experiments and Research, Hydraulic Research and Experiment Station, Delta Barrage, U.A.R. September, 1965 by the Director, Mr. A.A. Eldarwish.

A list of current Experiments and Research Studies follows :-

1- Development of the water wheel design for field irrigation.

2- Tests on flow regulation through Isna Barrage.

3- Model study of shoaling at the entrance of Leathy Pumping Station on the River Nile.

4- River training downstream from Nag-Hammadi Barrage.

5- A study of tidal currents and the littoral drift at the entrance of Lake El-Borolos.

6- A model study for the design of the Ather.Elnabi Canal Intake.

7- River training at Kafr El-Zayat bend.

8- Experiments on perforated sheet piling.

9- A model study of the Wurno Irrigation Project.

10- A study of seepage forces by electric analogues.

11- New river survey equipment for research at the Hydraulic Research and Experiment Station, Delta Barrage, U.A.R..

12- Soil Mechanics Laboratory.

The laboratory has excellent space and is planning an additional building 40m x 100m. The laboratory can continue with present studies and still expand its activities to help solve the variety of important river problems that will result from the change in flow conditions caused by construction and use of Aswan Dam. Refer to the research problems discussed under Proposed Research in the main report.

To obtain maximum usefulness of the Research Laboratory and Experiment Station it will be necessary to :-

1- Continue to provide training opportunities for staff at agencies and universities that specialize in: hydraulics, river mechanics, water resources development and water resources economics.

2- Study in detail the instrumentation requirements of the laboratory and continue to procure the required instrumentation. In this regard, as the complexity of instrumentation increases it will be essential to obtain, as staff, an electronics and instrumentation engineer and possibly electronic technicians to help select and utilize new instruments.

3- As mentioned previously, a unified effort involving both applied and research staff is essential if the maximum benifits are to be obtained from the technical and engineering staff. A close cooperation makes all groups aware of each others problems , talents and improve conditions for high level, top quality engineering work.

The problems and suggestions have been dischased in some detail with both the field engineers and with Mr. A. A. Eldarwish and his staff at the Delta Barrage Laboratory of the Ministry of Irrigation.

A shematic, Fig. 6, shows the laboratory arrangement and facilities at the Hydraulic Research and Experiment Station, Delta Barrage.

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MAX. DISCHARGE IN MILL.M³/DAY	
HIGH YEAR	NORMAL AND LOW YEARS
110	0
239	129
242	132
301	191
318	208
350	240

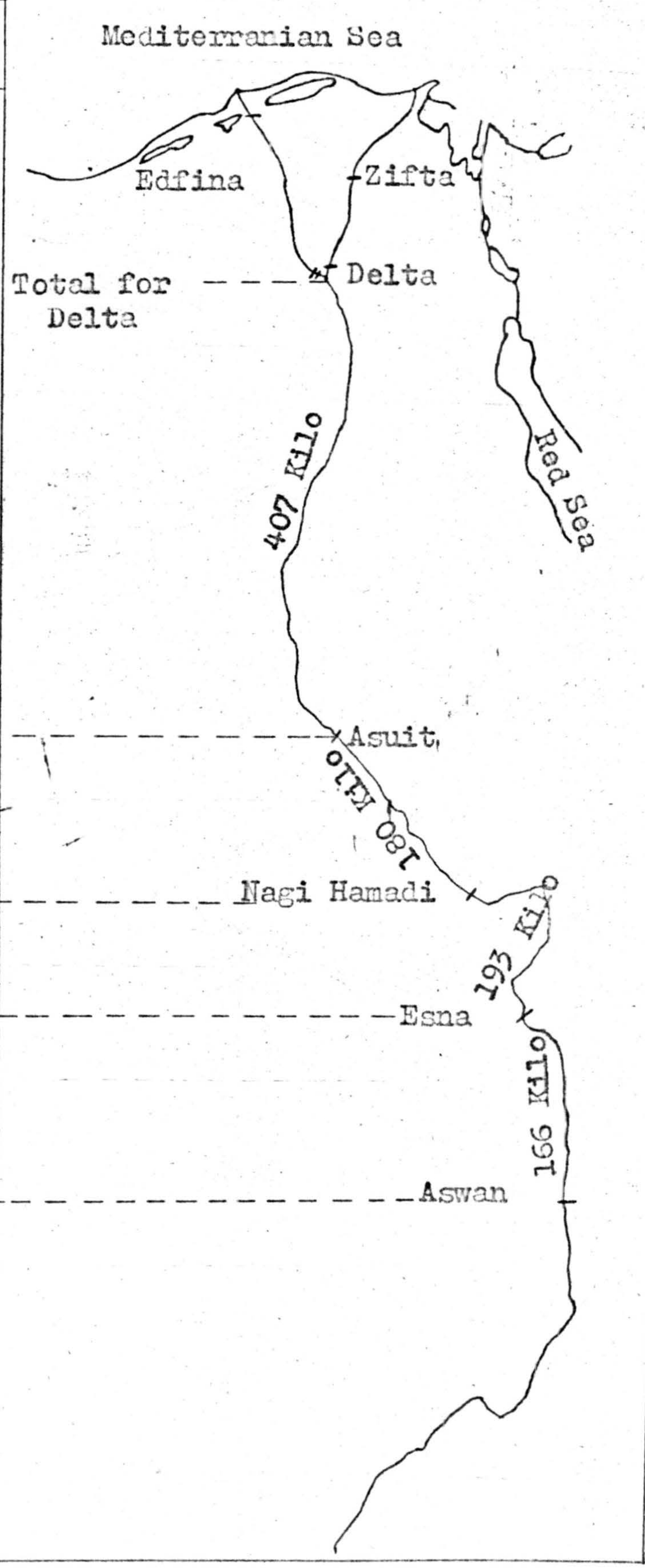

Figure 1: The River Nile within Egypt and approximate high and normal and low river discharges after closure of Aswan High Dam.

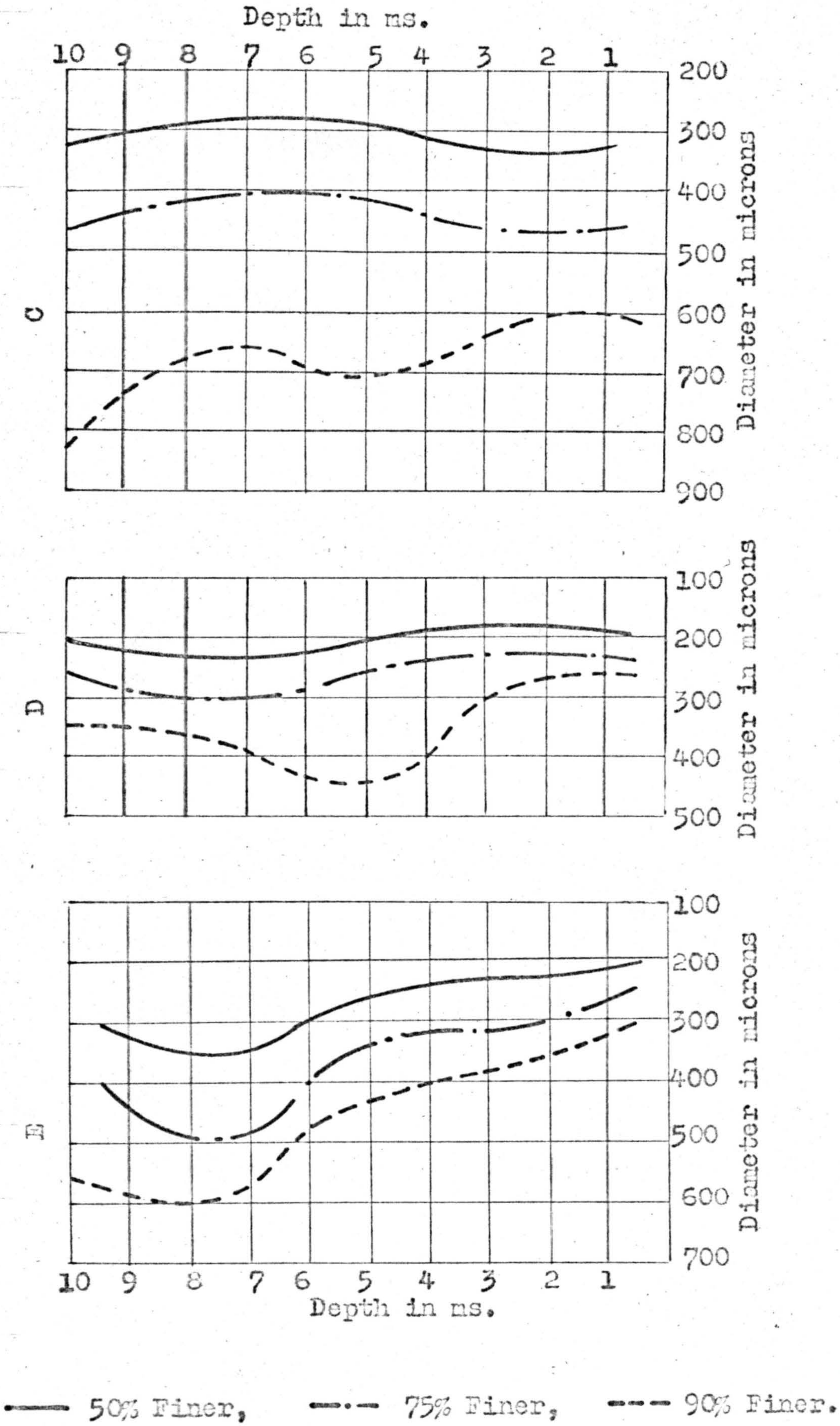

Figure 2: Size analysis of bed-material from three borings, Gabal El-Selsela Location.

FLOW REGIME	BED FORM	BED MATERIAL CONCENTRATION	MODE OF TRANSPORT	WATER SURFACE BED PHASE RELATION	RESISTANCE TO FLOW
LOWER	Ripples	0-200 ppm	Discrete Steps	Out of Phase	Form Roughness Predominates.
	Dunes	100 - 1200 ppm			
TRANSITION	Washed out Dunes	1,000 - 2,000 ppm			Variable
UPPER	Plane	1,800 - 6,000 ppm	Continuous	In Phase	Grain Roughness Predominates
	Antidune	1,800 - 6,000	Continuous		
	Breaking Antidune	1,800 -	Discontinuous		

Figure 3: Forms of bed-roughness and related information for sand-bed rivers and canals.

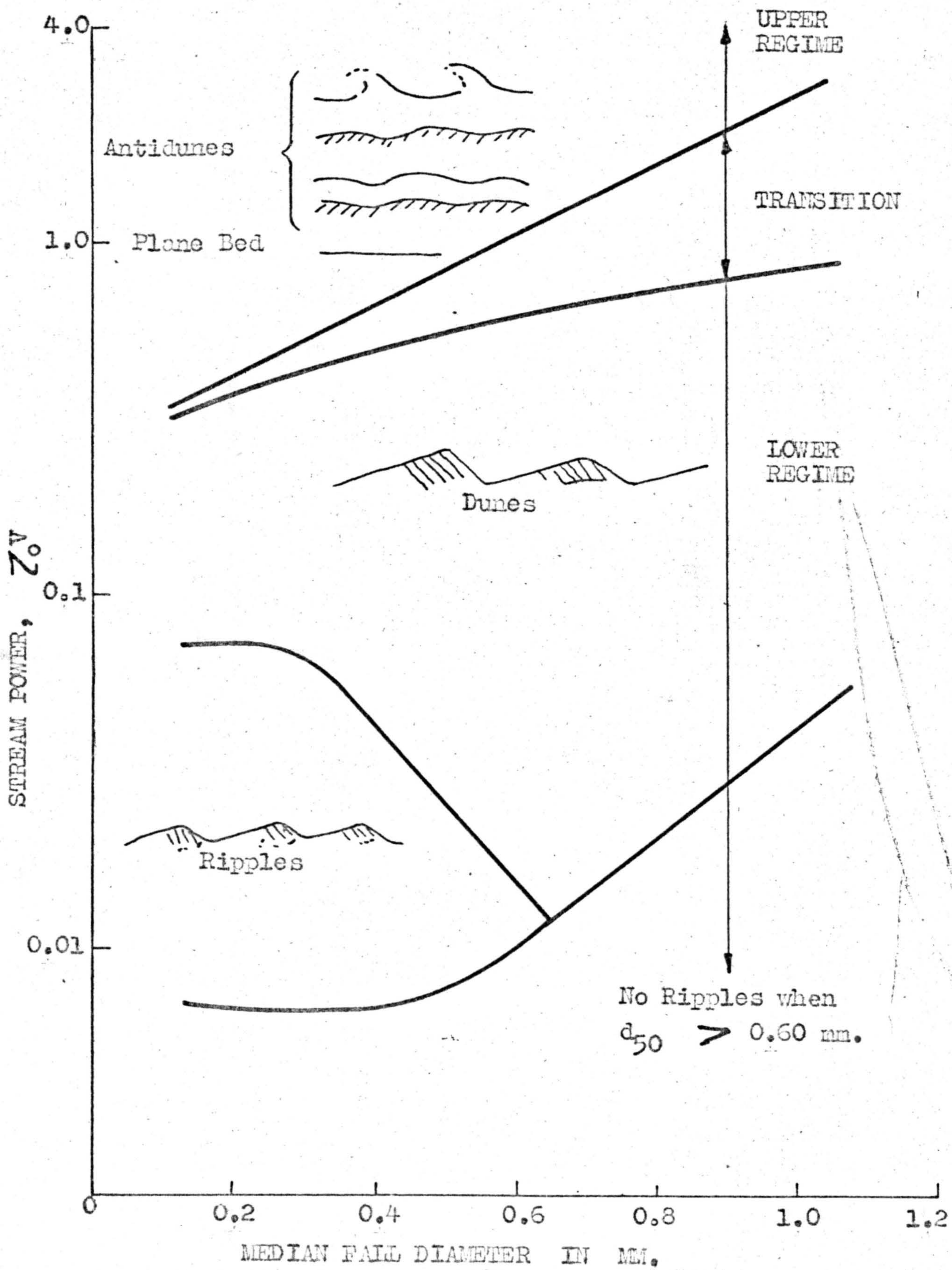

Figure 4: Prediction of bed-roughness in sand-bed channels.

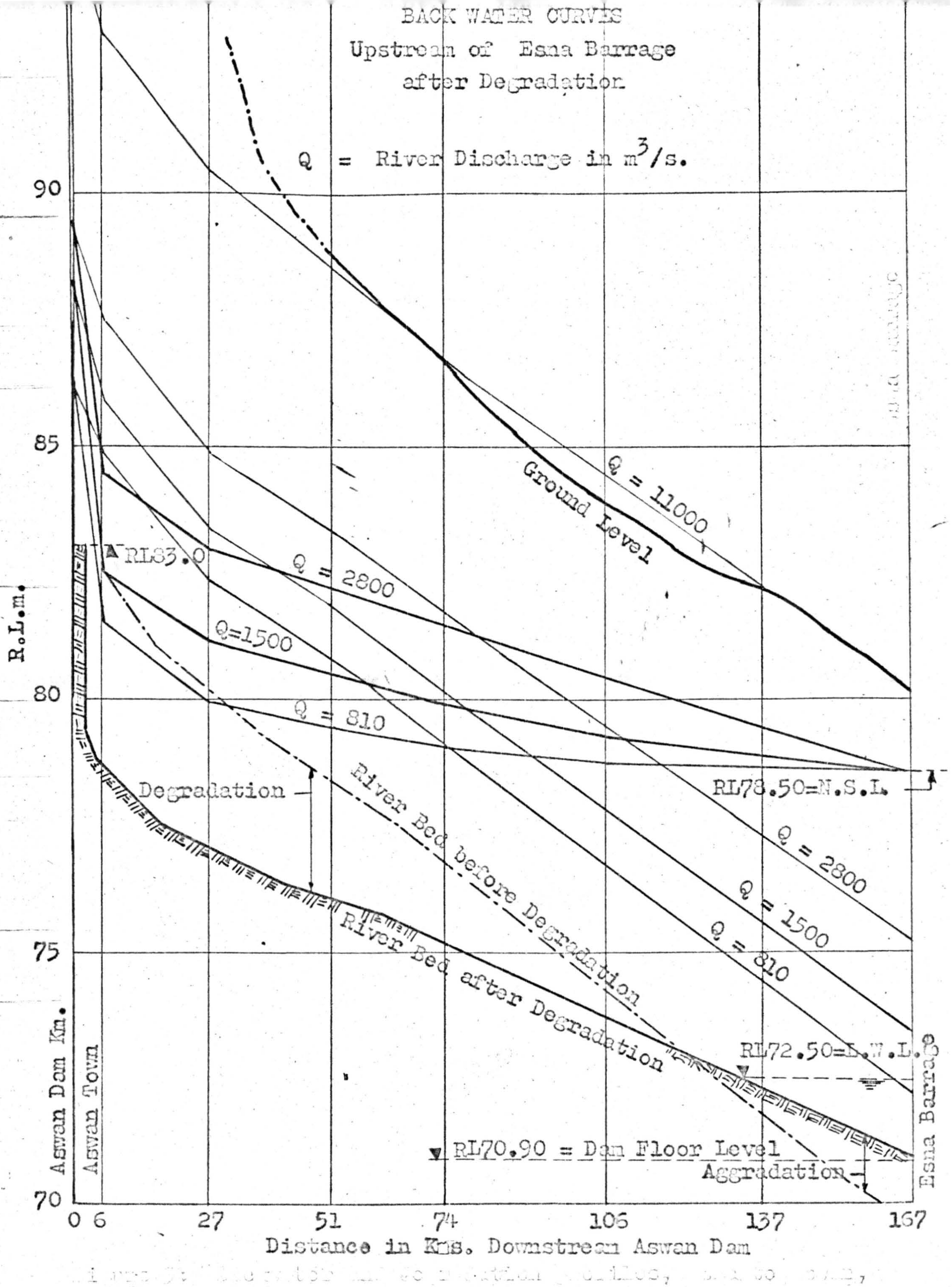

Figure 5: Backwater and degradation profiles, Esna to Aswan, After VBB.

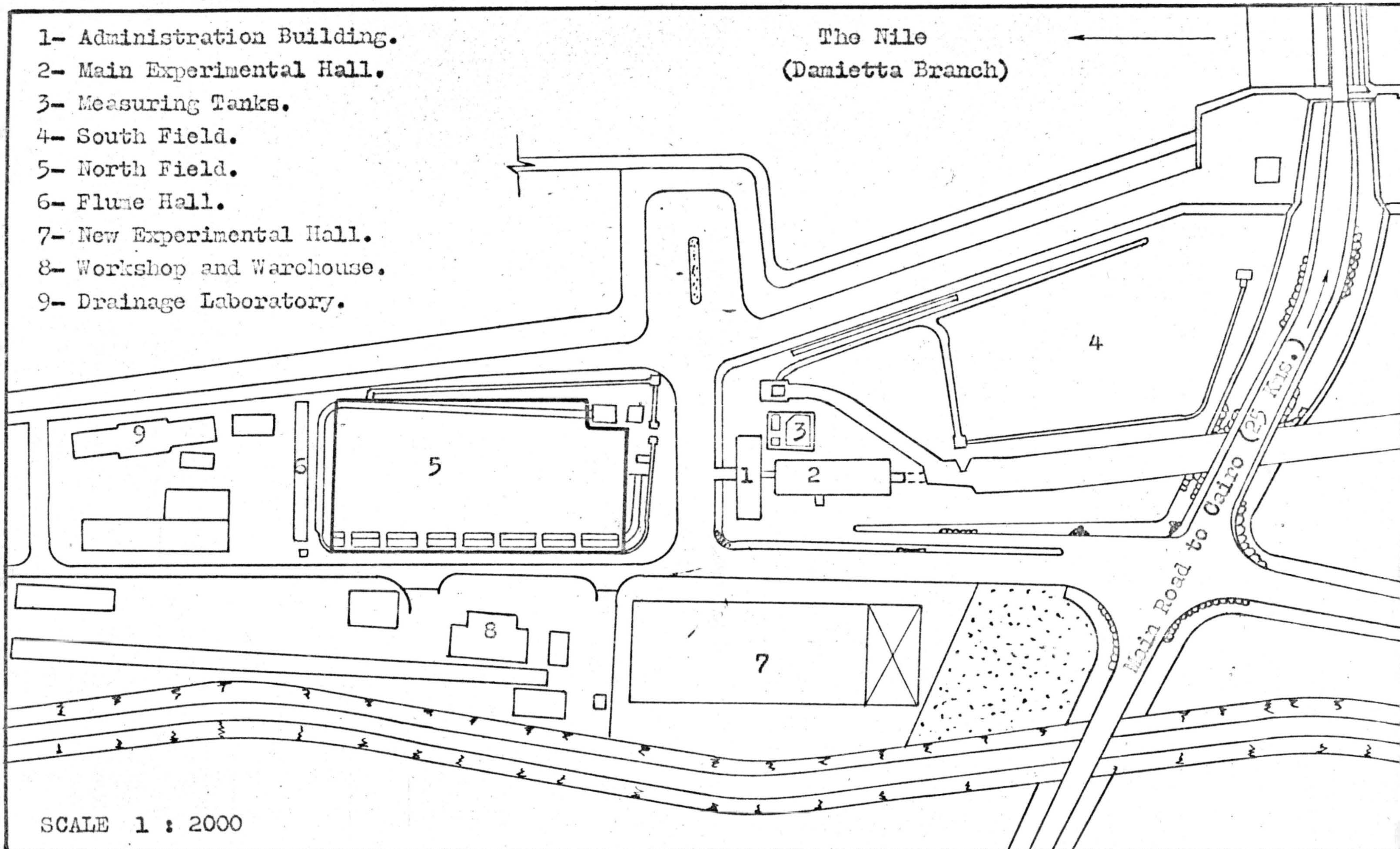

Figure 6: Hydraulic Research and Experiment Station, Delta Barrage.