THE RECORDED BEHAVIOUR

of

THE RIVER GASH

in

THE SUDAN

Reham Bannaga
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By

C. H. SWAN, B.Sc. (Eng.), A.M.I.C.E.

CHIEF ENGINEER, GASH BOARD, 1954-1955

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GLOSSARY

N.B. The writer deplores the practice of introducing into a report a large number of words in a language foreign to that in which the report is written. He has done his best to avoid it, but a certain number of Arabic and Beja words have proved essential. They are listed below for reference as well as being explained in the text as they crop up.

Angareeb - A Beja word now common to the whole Sudan. Means a bed made of a wooden frame strung with native rope.

Badobe - A cracking clay soil.

Balag - Beja for the phenomenon of sheet flow - see text, p.48.

Dawran - Arabic; used in the Gash to denote the rounded "nose" of pitching on the downstream side of the entrance to an irrigation offtake. It also has many other uses but that given is the only sense in which this word is used in this report.

Feddan - 1.038 acres or 0.420 hectares. Conveniently regarded as approximately one acre.

Gitta - Arabic; used in a specialized sense in the Gash for the basic unit of land allotment. Contains 10 feddans exactly.

Haboob - Arabic for a dust storm to which the Gash area is particularly prone.

Haffir - Arabic; an excavated pond for storing water over into the dry season.

Hod - Arabic for a basin; used in the Gash in the specialized sense of an area of land allotment. It contains 25 "murabbas" of 16 "gittas", i.e. a total of 4,000 feddans.

Jebel - Arabic; a hill or mountain.

Kantar - Arabic; a variable quantity but in the Gash it signifies 312 lb of unginned cotton.

Khor - Arabic; a water course which normally only carries water during the rainy season or even only after individual storms.

Kurmut - A round leafed shrub; Cadaba rotundifolia Forsk.

Lebad - The alluvial Gash silt.

Misga - Arabic; a secondary distribution channel or the area watered by such a channel. This is again a specialized meaning.

Murabba - Arabic for a square; in the Gash used in the specialized sense of a unit of land allotment, being the smallest permanently demarcated area and consisting of 16 "gittas", i.e. 160 feddans.

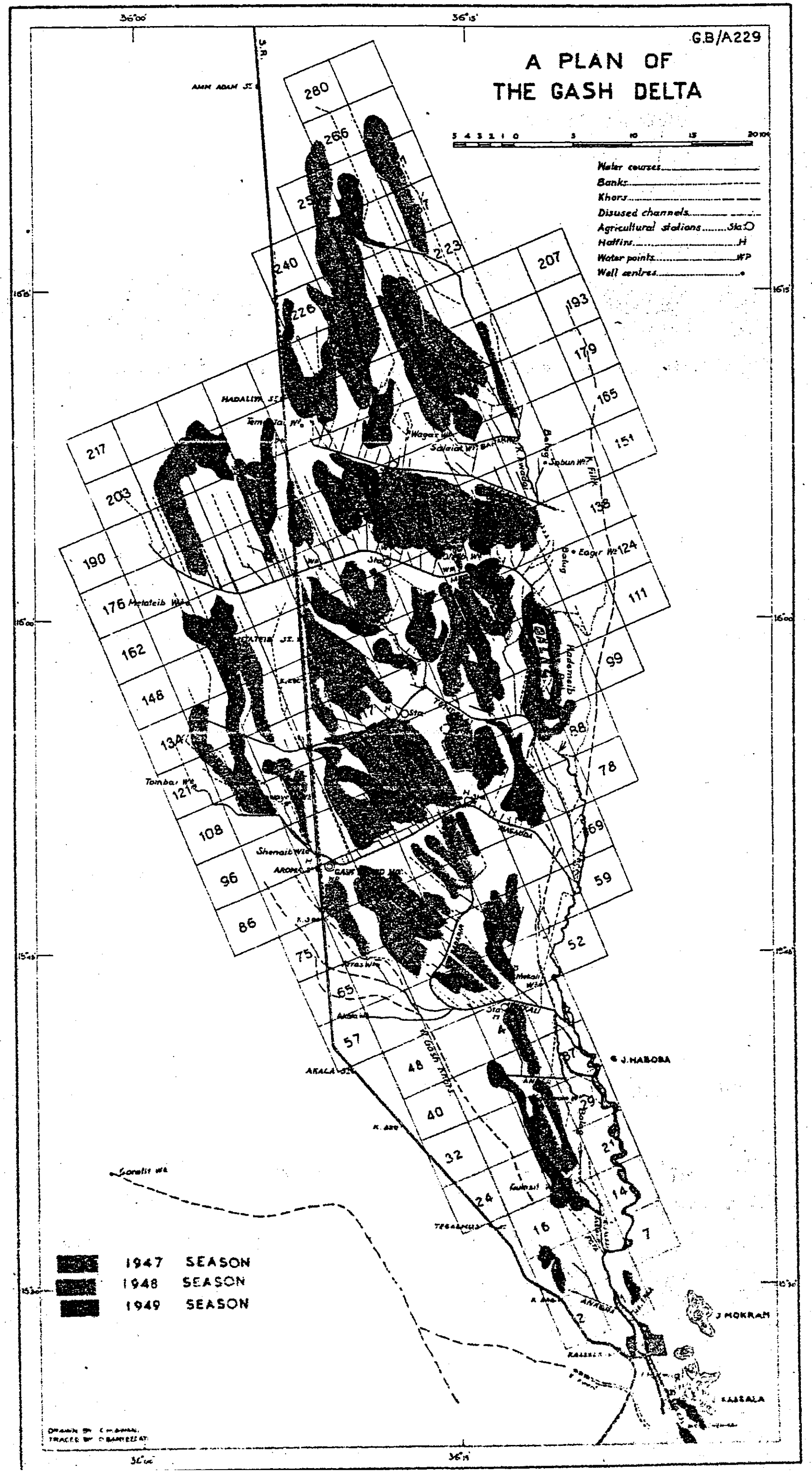
Sagia - Arabic; the Persian water-wheel and, near Kassala, the land watered by it.

Shaiyote - An area of land watered by a cut from the Gash or a balag area as distinct from cultivation served by the modern irrigation scheme.

Sudd - Arabic; an earthen dam in a water channel.

Tundub - A leafless shrub of the semi-desert areas; Capparis decidua Pax.

Turfa - The common tamarisk tree of the Gash; Tamarix articulata Vahl.



THE RECORDED BEHAVIOUR OF THE RIVER GASH IN THE SUDAN.

INTRODUCTION

The River Gash rises in Eritrea a few miles to the south of Asmara and its catchment is partly in that country and partly in Ethiopia. It runs generally westwards until it debouches on to the great central plains of the Sudan in the neighbourhood of the political frontier between Eritrea and the Sudan. Here it swings northward and, after passing the town of Kassala, fans out into an inland delta where the water is finally lost by percolation and evaporation. In its lower reaches the Gash is an ephemeral stream, normally flowing only during the months of July, August and September. During this period the discharge is very variable and the water carries a heavy load of silt; as a result its course, particularly in the delta, has been subject to many, and often violent fluctuations.

Irrigation has been practised on the Gash for many years, and one of the major problems has been that of obtaining reliable off-takes of water from such an unstable river. A succession of engineers have confronted this problem and considerable success has been achieved. All have left their records behind them in the form of drawings and reports. The object of this report is to gather together this mass of material and to condense it into one consecutive story in the hope that a study of past behaviour of the river will help when future problems are considered. A secondary, but no less important object is to prevent past mistakes in dealing with the river from being made again.

To this end that part of the river with which this report is concerned, that is to say downstream of the Sudan frontier, has been divided into reaches and each reach is dealt with separately. Each section of the report deals with a reach of the river and includes a discussion of the irrigation canals which take off from it. It is emphasized that the hydrology of the river as a whole and the details of watering from the canals are outside the scope of the report. No reference is made to the political or commercial aspects of the irrigation schemes in the Gash delta, except in so far as they have some bearing on the technical running of the schemes.

PRELIMINARY SECTION

GENERAL DESCRIPTION OF THE GASH DELTA

1. <u>Catchment</u>

In its upper reaches the Gash is known as the River Mareb. The headwaters of this stream are only about twenty kilometres south of Asmara. From here to the Sudan frontier the river basin is long and relatively narrow, varying between thirty and ninety kilometres across; see Fig. P.1. The total area of the catchment has been estimated at 21,000 square kilometres. The upper reaches of the river are perennial, dropping down from a height of 2,000 m above sea level to 1,100 m in the first 175 Km. In this area some specimen average rainfall figures are :-

Decamere	635 mm
Addi Caieb	543 mm
Adi Ugri	571 mm

Lower down, but still in Eritrea, the river becomes ephemeral and assumes the characteristics it has in the Sudan, that is to say an even, sandy bed from 75 m to 200 m wide and with well defined banks between one and two metres high. The bed slope varies between one and two metres per kilometre. Some specimen rainfall figures in this area are :-

Barentu	461 mm
Tessenei	343 mm (1955)

2. <u>Rainfall</u>

Rainfall is sparse over the whole of the Gash delta and decreases sharply from south to north, as is shown by the following ten-year average rainfall figures for the period 1943 to 1952 :-

Kassala	269 mm
Mekali	185 mm
Aroma	188 mm
Degein	165 mm
Tendelai	165 mm
Metateib	161 mm
Hadaliya	142 mm

The particular period is chosen because abnormal rains in 1953 rendered untypical any ten-year average which included that year. The thirty-year average for Aroma is 197 mm and the fifty-year average for Kassala is 317 mm. About 40% of the rain falls in August and nearly 30% in July. Nearly all the remainder falls in June and September.

Normally the rain falls in violent storms of short duration and, owing to its intensity, produces considerable run-off. In the southern half of the delta the local inhabitants often hold up the run-off by building low banks and the water so impounded percolates into the soil sufficiently to produce crops of millet. In the neighbourhood of Aroma and to the north this is only possible in particularly favoured spots or in years of exceptionally heavy rainfall.

3. Climate

Like the central part of the Sudan the climate is conditioned by two main air streams, the dry northerlies in winter and the moist southerlies in summer. These give rise to a climate of a tropical continental type. Winter weather is very pleasant and differs slightly from the weather further west by its greater humidity which is shown up by quite heavy dews from December to March. High summer in April, May and June is intensely hot and during that season the Gash delta is particularly prone to "haboobs" or violent dust-storms. These storms are connected with frontal conditions; they can be seen approaching some time before they break, looking like a great wave rearing up, dark brown and menacing. Once the "haboob" has broken visibility is reduced to a few metres and it becomes quite dark; a howling wind carries a thick dust, so fine that it can penetrate anywhere. The storm may last for two or three hours; it is usually accompanied by a perceptible drop in temperature. High summer is not a pleasant time in the Gash delta. In July, August and September, that is during the rains and the Gash flood, the weather is far cooler and is usually quite pleasant. The rain falls in a few intense storms and the rest of the time it is usually sunny and fine. At this time the delta transforms itself completely; dust is a thing of the past,

new grass shows up and soon the country takes on a fresh greenness which seems almost incredible after months of aridity. The drawback to this season is that it brings out myriads of flying and buzzing and creeping things, particularly at night. Some carry malaria, some bite, some sting, some blister, some stink and a few are merely annoying by bumping into one unexpectedly or by expiring in one's cup of tea. The rains are followed by another hot spell, rather shorter than in the central plains of the Sudan, without dust but with insects, until the north wind sweeps both heat and creatures away and winter is back again.

4. Soil

There are two main soils to be found in the Gash delta. The best, known locally as "lebad", is a rich silt which is highly permeable. Moisture penetration, after normal flooding, may extend more than five metres below the surface of the ground. The other soil, known as "badobe", is a heavy, cracking clay, a form of cotton soil. It absorbs moisture more slowly (after the initial wetting has sealed the cracks) and normally produces a smaller crop of cotton. All gradations between "lebad" and "badobe" occur. Nowhere is any appreciable quantity of material to be found with a particle size greater than 0.1 mm.

5. Demarcation

The whole area of the Gash delta has been divided into large squares known as "hods". Literally this word means a basin, such as is used for irrigation; it has no such significance in this connection, however, being a precisely demarcated square of 4098.78 m side containing exactly 4000 feddans of 4200 sq.m each. These "hods" are numbered from an origin near Kassala and are shown on the 1:250,000 scale map attached to this report. The "hod" is subdivided into 25 "murabbas" by lines running from the fifth points of the "hod" sides. Each "murabba" is therefore a square of 819.76 m side and contains 160 feddans. The corners of the "murabbas" throughout the delta are marked by beacons formed of angle irons projecting some two metres above ground level, each carrying a sheet metal cross piece near the top, with "hod" and "murabba" numbers stamped and painted on it. Steel cross pieces underground can be used as bench marks when a little soil is cleared away. The whole beacon is painted white for the sake of visibility. "Murabba" literally means square, which is just what it is. Each one is subdivided by lines from the quarter points of its sides into sixteen squares of 204.94 m side containing 10 feddans. These squares are known as "gittas", literally pieces, and are the basic units of land distribution. They are not permanently marked out in any way and are re-chained as and when necessary.

This demarcation system, though expensive in first cost and maintenance of beacons (which are spaced five times as densely as in the Gezira) is a very great help in both agricultural and engineering operations. It makes accurate mapping possible to Inspectors of Agriculture and others not trained in survey work, facilitates quick reporting and reference to flood movements and allows land allotments to be marked out by chainmen with a minimum of supervision. Last, but not least, a wise man who always carries a 1:250,000 map with him cannot get badly lost in the otherwise rather featureless delta.

6. Population

The indigenous population of the Gash delta is Beja, of whom the main tribe in this area is the Hadendowa. These people are the "Fuzzy-Wuzzies" of Kipling's poem, who "broke a British Square". They are primarily pastoral people and nomads; they still live in matting tents and move from one grazing ground to another as one season is succeeded by the next. The men are nearly always armed with sword and knife. They have taken to cotton cultivation unenthusiastically, if at all. Though they have first priority to the land very few of them, even yet, have settled down in permanent villages, preferring to leave the cultivation to which they are entitled to be worked by agents and hired labour. Other Beja tribes to be found in the delta are small sections of the Amarar and Beni Amer; near Kassala are the Halenga who have taken more

c--1 10/10

kindly to agriculture than the others. From the point of the agriculturist or engineer it is probably just as well that there is a large number of West Africans, largely Haussa and Fellata, settled in the delta. These people were originally transient pilgrims on their way to and from Mecca, but many of them have now settled in villages scattered about the delta. They are a cheerful and colourful people, excellent workers on whom the main reliance must be placed for the running of the cotton scheme, both for engineering and agricultural labour.

One other tribe to be seen in the delta which is worthy of mention is the Rashaida. These people are Arabs, one of the latest tribes to enter the Sudan. They are light skinned, pastoral people living in tents. They water their animals at the well centres but play little part in the cotton growing, though they sometimes engage in the picking. They also are a colourful people. Women and girls are always veiled; indeed some of the smallest girls can be seen wearing a minute veil and nothing else at all ! The veils are heavily decorated with silver braid ornaments. The men, always armed, wear large turbans, tunics and baggy trousers; they are girt with decorated leather belts and make an impressive sight riding their camels across the plains.

It is an astonishing thing that so many diverse and polyglot peoples of frankly barbaric nature can live together in the confined space of the delta with so little friction. The "lingua franca" is Arabic; most of the Hadendowa and West Africans with whom the official comes in contact in the course of his duties have at least a smattering of it.

7. Labour

As a labourer the Hadendowa leaves much to be desired but fortunately it has seldom been necessary to rely on him. In the early days labour for the scheme was imported from southern Egypt. These men are magnificent diggers but involve a good deal of extra work and expense in transport from and to their homes. The local West African runs a very good second and more and more reliance has been placed upon him with the passage of time, until now it is rare that Egyptians are imported.

Excavation is carried out by small contractors who supply the labour, tools, baskets for carrying earth, water (an important and often expensive item) and facilities for the men to buy their food and simple luxuries. The contractors agree to a rate per cubic metre of excavation (when the work is banking or fill the borrow pits are measured) which covers everything. Compared with other stations in the Sudan the Gash is fortunate in having a body of competent and reliable contractors who get the work done with a minimum of trouble.

During the flood labour must be available at all times along the banks of the river. For this the "patrol" system has been evolved. Bodies of ten to twenty men on a flat daily rate are stationed at strategic points along the river; temporary grass huts are erected to accommodate them. Each patrol comes under the orders of a regular chairman and may be called upon for any type of river defence work at any time of the day or night. The patrols also are supplied by contractors but the control, distribution and supply of materials in this case come directly under the Gash Board. Although the patrols may be called upon for prolonged and intensive work during an emergency, it is on the whole an easy if uncomfortable life and attracts a very poor standard of labour. The better workers prefer the piece-work rates to be obtained at this time of year for hoeing and other agricultural operations. Fortunately most emergencies occur in July. Then there is no labour problem at all. Tenants, madly keen to get the water on to their land, turn out in hundreds and the contractors can usually still raise large bodies of good men who have, up till then, been employed on canal clearance and other works. Once, however, the watering of the first rotation is completed, everybody, tenants and labour, are out in the fields and if an emergency arises then nothing is left except the patrols.

1) The …
3) The texture of the surface
4) The weather.

8. Watering the Land

A glance at the map reveals that the canals run more or less parallel to one another across the delta from east t west. Their bed slopes vary from 1:2,000 to [redacted],000, whil the land has a general slope of [redacted]00. None of these statements is universally true, but they indicate the genera trend. 1m/km

We shall now attempt to answer the question: Why ar the canals so arranged and how are they used ?

There are many factors affecting the [redacted]ing of [redacted]e, some of which are purely agricultural. Those chief affecting the engineer are the slope, the nature of the soi and the texture of the surface. In a flush irrigation sche water is released from the canals at selected points, known in the Gash as "misga" heads, whence it flows over the land without any further control and is under the influence of t three factors mentioned above, plus the weather. Impervio soil having a smooth, bare surface set at a steep slope wil make the water run fast and far. At the other extreme a rough, porous soil covered with grass and set at a gentle slope will allow little spread of the water. In this case a small area will become saturated to a great depth in a short time, while in the first instance a large area will ta a long time to become saturated. Moreover the impervious soil will not be saturated to a depth greater than that to which the surface cracks penetrate; this is not usually mo than a couple of metres. But the porous soil will saturat to a depth of ten metres or more.

On steep slopes in "lebad" soil there is a tendency for watercourses to form. These are the greatest enemy of good spread of water. Steep slopes without other favourab factors result in long, narrow areas being watered which is an unsatisfactory shape. The best combination of conditio for a good spread of water is a gentle slope combined with bare, smooth surface and "badob" soil. Better agricultura results may, however, be obtained from a smaller area if th soil is "lebad".

If a steady rate of flow is maintained at the misga head equilibrium is eventually reached between the absorption and evaporation off the wetted surface on the one hand and the inflow on the other, after which no further spread will occur. When this condition has been reached water is still required to maintain a cover over the wetted area until all the land is saturated. The misga head is then closed and the watering of that area is over for the season. The marginal areas will be less heavily watered than those near the misga head; areas too lightly watered for cotton are usually sown with millet. The period of spread usually lasts from ten to twenty days, after which the watering is maintained for a further ten to twenty days, according to the nature of the soil.

The optimum spacing between canals is such that watering from one canal will just reach the next, but will not accumulate against the bank of the canal. Thus, on steeply sloping land the canals should be far apart and on flat land close together.

The Gash has a very variable flow. Consequently the water in the canals cannot be maintained at a constant level notwithstanding regulation at the canal head. This characteristic can be turned to good account in increasing the spread of water if the misga heads are designed to be able to pass a big discharge when the canal is full. The periods of high discharge can thus be used to obtain a rapid spread, while the intervals of low discharge are usually sufficient to maintain the water over the whole of the wetted area. The open masonry misga head is more favourable than a pipe for passing a high discharge when extra water is available and is now almost always installed in new areas despite the advantage a pipe has in being moveable from place to place as the rotation requires.

The selection of the site for the misga head is important. It is best sited on the highest point of relatively high ground, that is to say where the contours form a promontory. This tends to produce a wide spread of water rather than a long, narrow one. The silt-laden water emerging from the misga head deposits its silt almost immediately.

This results in a delta being formed round the misga head through which, in time, a channel must be cut. The channel needs to be increased in length each year the land is watered and reduces the area available for cultivation. This is an undesirable feature, which can be countered by breaking the cut to the left or right, or on both sides simultaneously. Eventually, however, it becomes necessary to abandon the misga head altogether and to move to a new site a few hundred metres away on the canal.

The variable degree to which the different parts of the same misga are watered makes it difficult to estimate or express the water requirement of the land in terms of cubic metres of water per feddan. (The word "misga" signifies both the area of land watered by an off-take from a canal and the off-take channel itself). For canal and misga design a rough rule of thumb has been evolved purely on experience. This is that a flow rate of one cubic metre of water per second is required to water each 500 feddans. This seems a curious way of denoting irrigation demand until the over-riding importance of rate of application in flush irrigation is appreciated. The actual quantity of water put on to the land, of course, depends on the number of days during which it is applied. This is an elastic system which leaves room for the judgment of the agriculturist, who must watch the spread and at the same time will bear in mind his own estimate of the duration of the flood. If the period of watering is thirty days the depth of water applied works out at 1.22 m.

A modification to the above rule has been found necessary on Mekali and Kassala stations. Here the soil is particularly deep, rich "lebad" and absorbs water at a very high rate. It has proved more satisfactory to double the rate of application of the water, i.e. one cubic metre per second for every 250 feddans. In this part of the delta, where the slope of the land is relatively steep, it has been found that a number of pipe misga heads set about 500 m apart and running simultaneously gives a good watering and discourages the formation of watercourses. Existing watercourses can sometimes be suppressed by blocking them at frequent intervals with banks higher than the surrounding land and extending on both sides for a considerable distance.

The shapes of the areas watered by flush irrigation are irregular; long in the direction of greatest slope and narrow parallel to the contours. In order to preserve an orderly crop rotation it is desirable that different misgas should not run into one another. On the other hand, if they are spaced very far apart, the land in between is wasted. Therefore, after the first watering the sides of the watered areas are trimmed to straight lines by putting up small earth banks running across the contours. These are called inter-misga banks and form the boundary between one misga and the next.

Careful observations are recorded every ten days showing the spread of the water (here the beacon system is invaluable) and watering maps are made which form the basis for the design of any future modification of the watering system.

The land is watered in two rotations. This word is not used here in the sense it usually has in agriculture but means that the total area to be watered in any one year is divided into two parts. These are known as the first and second rotations and watering does not begin on the second rotation until that on the first rotation has been completed. The system suits the average useful duration of the Gash flood well; "badobe" soils normally require [illegible] to 30 days watering and "lebad" soils 23 to 25 days. It has the advantage, also, that in years of short-lived flood at least the first rotation gets fully watered. The proportion of first to second rotation area is of the order of 3:2.

Using the word rotation this time in its agricultural sense, the land is cropped on a three year rotation. That is to say, one year watering and two fallow. This is not a strict rule and is varied locally to suit special conditions.

9. Discharge Gauging

Until 1929 discharges were gauged at Kassala weir. Before the middle third of the weir was removed in 1921 a broad crested weir formula was applied. It is not known what method was used thereafter until 1929 when the weir was

outflanked and the Gash became too wide to allow even moderately accurate gauging. A suitable gauging site was then found at Magauda above Magauda North head but below Magauda South head. Discharges taken when Magauda North head was in operation have been adjusted by the deduction of the estimated discharge of Magauda canal. This means that all Magauda discharges are exclusive of the canal draw-off. The Magauda gauging site had so deteriorated by 1949 that a new one had to be found at Tendelai. This is upstream the present Tendelai head and as it is only some four kilometres below the Magauda site, it was to be expected that the readings of discharge would be about the same at the two sites. Observations were made at both sites for the first year and they were found to agree fairly well.

Discharges are measured by the surface float method. A cross-section is plotted at the discharge site both before and after the flood. Every time an engineer has occasion to go to the site he makes a velocity measurement by surface float and reads the gauge. In this way about one measurement is made on each day of the flood at various times of day. After the flood, the average of the two cross-sections is made and a gauge-area diagram is drawn, i.e. cross-sectional area of waterway for each gauge reading. From this and the various gauge-velocity observations made during the flood a gauge-discharge curve can be drawn. The scatter of the points on this curve is a good indication of the suitability of the discharge measuring site. Mean velocities are calculated from the observed surface velocities by the formula :

$$Vm = C' \ Vs$$

where $$C' = \frac{1}{1 + \frac{14}{c}}$$

where $$c = \frac{1}{n} \, 6 \, \overline{}\!\!\!R$$

$1/n$ = 55
R = hydraulic mean depth
Vm = mean velocity
Vs = surface velocity

To the writer this method of computation seems an absurd refinement in view of all the other possible sources of error such as wind, infrequency and irregular timing of gauge readings and the fact that the cross section itself is almost certainly varying continuously. A constant of 0.8 would seem more logical. However, the main value of the discharge measurements is to obtain a comparison with previous years rather than a precise estimate of the actual discharge, so it seems unwise to alter the method of computation unless one is prepared to recompute all the figures for preceding years, which the writer was not !

Gauges are read at six in the morning, at noon and at four in the afternoon of each day, which is administratively convenient if hydraulically unsound. These three readings are then averaged and that is regarded as the mean gauge for each day. The discharge for each day is calculated on the mean gauge reading from the gauge-discharge curve and the cumulative total is the total flood discharge. This paragraph perhaps makes clear the meaning of the phrase "other possible sources of error" in the preceding paragraph !

10. <u>Flood Records</u>

The following table gives details of Gash floods since regular measurements began in 1907. Discharges are divided into those taken at Kassala and those taken at Magauda and Tendelai which, as has been mentioned, exclude the discharge of Magauda canal and, of course, all off-takes south of it together with the losses between Kassala and Magauda.

Year	Duration of continuous flood (Kassala) From	To	Days	Discharge mm3	Effective Cotton Area (feddans)	Remarks
Discharges measured at Kassala						
1907	9.7	18.9	71	540		
1908	3.7	11.10	100	450		
1909	1.7	25.9	86	250		
1910	2.7	24.9	84	380		
1911	10.7	30.9	82	250		
1912	1.7	18.9	79	300		
1913	12.7	18.9	68	430		
1914	9.7	23.9	76	600		
1915	6.7	26.9	82	260	377	
1916	16.6	28.9	104	810	1,617	
1917	27.6	27.9	92	220	4,606	
1918	10.7	17.9	69	210	3,000	
1919	6.7	19.9	75	360	2,460	
1920	20.6	2.10	104	790	8,400	
1921	11.7	27.9	78	140	6,000	a
1922	2.7	26.9	86	640	7,000	
1923	6.7	14.9	70	380	9,000	
1924	28.6	1.10	95	460	15,000	
1925	18.7	23.9	68	230	11,400	
1926	27.6	20.9	86	890	26,800	
1927	5.7	27.9	85	870	25,870	
1928	20.6	20.9	92	400	28,037	
1929	10.6	26.9	109	1260	55,456	b

Year	Duration of continuous flood (Kassala)			Discharge mm3	Effective Cotton Area (feddans)	Remarks
	From	To	Days			
Discharges measured at Magauda or Tendelai						
1930	29.6	19.9	83	340	37,938	
1931	6.7	28.9	85	540	17,500	
1932	16.6	4.10	111	710	19,147	
1933	26.6	2.10	97	360	31,146	
1934	23.6	30.9	100	420	28,210	c
1935	19.6	10.10	114	330	36,257	d
1936	24.6	3.10	102	540	30,335	
1937	22.6	1.10	102	410	31,850	e
1938	7.7	5.10	91	500	33,292	
1939	8.7	2.10	87	220	24,400	
1940	5.7	13.9	70	500	22,158	
1941	3.7	29.9	88	700	31,711	
1942	5.7	30.9	87	630	31,053	f
1943	9.7	24.9	78	530	32,220	
1944	28.6	30.9	94	380	30,631	
1945	30.6	5.10	97	430	26,866	g
1946	15.6	7.10	114	670	27,448	h
1947	14.7	2.10	80	370	33,240	
1948	22.6	5.10	105	360	46,537	
1949	4.7	16.9	74	320	44,840	i
1950	28.6	6.10	100	750	63,000	j
1951	7.7	29.9	85	220	37,661	k
1952	28.6	10.10	104	600	72,109	
1953	28.6	10.10	104	840	55,337	l
1954	27.6	17.10	112	500	41,788	

Remarks:
a) Smallest flood on record.
b) Largest flood on record: flush in April.
c) Flush in May.
d) Bracketted longest flood on record: complete stoppage in mid-July.
e) Two flushes in May.
f) Two flushes in May.
g) 21 days continuous flow in May.
h) Bracketted longest flood on record.
i) Flush in May.
j) Highest spate at Tessenei on record. Top of spate not recorded as gauge house flooded.
k) Flush in November.
l) Second largest flood on record.

On average over 22 years 0.5% of the flood passed in June, 25.0% in July, 55.5% in August, 18.7% in September and 0.3% in October.

It is not now possible to estimate what the discharges measured at Kassala would represent on the present system of measuring at Tendelai. Discharges were measured at both Kassala and Magauda from 1923 to 1929 and at that time the Magauda discharges averaged 54% of the Kassala discharges. However, this was while the Gulosit-Gammam balag was in existence. The significance of this will become clear when the main body of the report has been read.

11. Gauges and Levels.

At the time of writing precise levelling was only just reaching Kassala and the results were not yet published. Heights above mean sea level at Alexandria, therefore, when given are approximate only. Levels are usually referred to this approximate datum but in the Kassala area and as far north as Khor Salaam Aleikum it has been more common to refer levels to the Kassala gauge. 120.00 on Kassala gauge is 501.44 metres above mean sea level at Alexandria according to the approximate levelling available.

This system of referring levels in one part of the delta to one datum and in another part to another datum is, of course, ridiculous but it dates from hoary antiquity and so many records and drawings have been made on the system that any effort to change back now would almost certainly ensure even worse confusion. It will probably be worth while to make a fresh start when the results of the precise levelling have been published but great care will be needed to ensure that all levels are properly labelled as being above the precise datum. The correction of all existing records would be a monumental task and probably not worth while so long as the date of the change-over to the new system is recorded and firmly fixed in everybody's mind.

Gauges at the regulators are usually given from floor level of the regulator. Upstream and downstream gauges of all major canal heads together with Kassala and Tessenei gauges are reported thrice daily, as mentioned before, and various other strategic points like Gammam outlet regulator and Tendelai weir and the canal levels at various points (usually at the agricultural station) are included.

12. Channel Design

Channels are designed on Mannings formula, assuming trapezoidal cross-sections and 1:1 side slopes. Experience has shown 1/55 to be a good value for "n" for use all over the delta. With the great fluctuations of discharge that are unavoidable in the operation of canals taking off the Gash (unless water is to be wasted) the application of the various theories of stable channel design in alluvium has not been easy. In particular, canals in regime in the Gash appear to be too narrow, too steep and too deep when compared with the Lacey sections and the reason probably is that the discharges are incorrectly estimated and also that the grade of silt probably varies in the draw-off from different stages of the river. Fortunately the scheme has been in operation long enough for a number of channels to have taken up naturally their regime condition and these channels make excellent models for the design of new channels with similar conditions.

The design of a canal gets modified, if only slightly, almost every time clearance is necessary. Slopes and bed widths get adjusted to economise excavation or to suit altered conditions; in every case the canal is studied to try to ascertain what its natural tendency is, and the design is made to accommodate it. It will be seen later, as the individual canals are discussed, that sometimes the nature of the supply to a canal changes radically; for example a canal that one year was drawing silty water from the main channel of the Gash itself may, the next year, be drawing almost silt free water from a swamp. If the canal was in regime under the first set of conditions it will clearly not be so under the second and efforts must be made, by careful study of the natural changes taking place, to carry out such clearance as is necessary in a way that will allow the canal to adjust itself as quickly as possible to the new conditions.

13. Silt

To the irrigator whose experience has been in the Sudan most of whose ideas originate from Indian and Egyptian practice the Gash seems to carry an exceedingly large charge of silt. When he reads about the Colorado or Yellow Rivers he realizes that other people have even greater problems to deal with. The silt load of the Gash varies enormously, the highest recorded being 9,722 parts per million by weight at Metateib in 1939, while at Hadaliya, slightly further north, the highest recorded in the same year was only 1,480 parts per million. An average figure for the Kassala and Magauda measurements made under two different sets of circumstances (see Section 5 of this report) but none the less agreeing fairly well with each other might be taken as 5,500 parts per million. This is a proportion of 0.55% silt to water by weight. The following average figures for other rivers are given for comparison :-

River	%age Silt	Authority
Nile (at Sarras)	0.15%	Buckley
Indus	0.40%	"
Gash	0.55%	Gash Board
Colorado River	0.90%	Paper No. 1957 Am. Soc. C.E.
Sutlej	1.05%	Buckley
Yellow River	As high as 38% (not an average)	Paper No. 1957 Am. Soc. C.E.

Not only does the silt charge vary with the stage of the river but it also varies along the length of the river. There are zones where the flow is held up and sheet flow along the surface of the land takes place; in these zones silt is deposited and the water issues from them almost clear. Once flowing in a proper channel it rapidly picks up silt again; the pattern of the silt depositing and the silt scouring sections of the river varies from year to year. All this will be shown in the body of this report. It is the feature which sets most of the problems in the Gash and which makes it a fascinating study for those who work there.

14. Kilometrages

Kilometrages along the Gash are measured from the site of the old weir at Kassala. A list of the kilometrages of the more important features along the river is given here for reference. These distances were measured along the river in 1938 when the river proper extended as far north as Metateib. It should be noted that at the time of writing there is no defined course beyond Tendelai.

Kilo	Site	Kilo	Site
-8.5	Wad Sherifai	33	Mekali South Cut
-3.5	Khor Kwenti	37.8	Mekali North Cut
0	Kassala Weir	52	Magauda South head
0 to 3	Kassala Spurs	53.5	Magauda North head
3	Road Bridge	56	Tendelai South head
3.5 to 5	Town Protection	58.7	South Collector bank
6.5	Halenga	60.2	Middle Collector bank
7.5	Ankora	62.2	North Collector bank

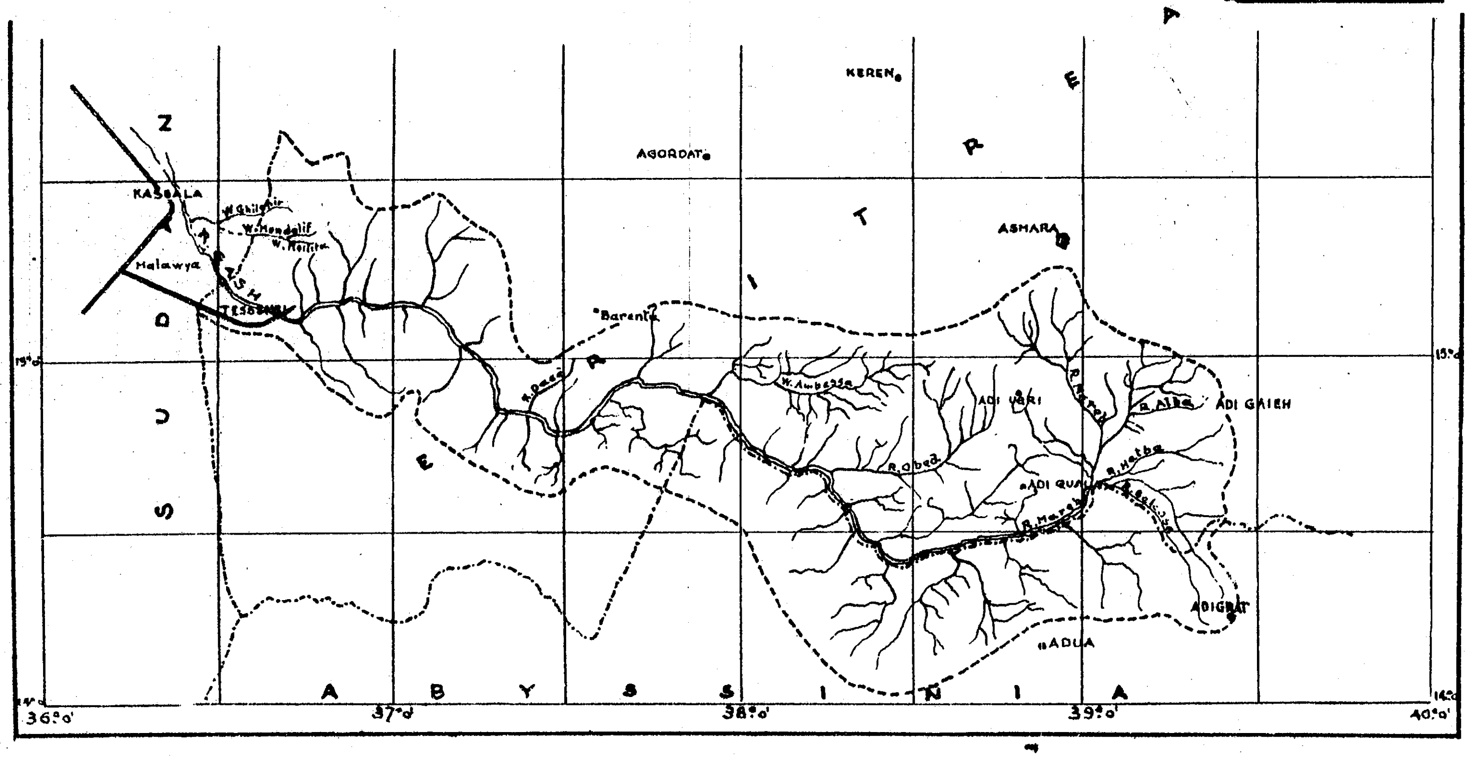
7.8	Khor Shaigia	65.9	Tendelai North head
9.3	Tukruf	77.8	Metateib 1939 head
12.5	Khor Salaam Aleikum	78.5	1938 avulsion point
18	Khor Debelaweit	79.0	Metateib South head
32	Gash Wells	79.2	Metateib North head

15. Engineering Staff

The establishment of staff on the engineering side of the Gash Board at the time of writing consists of a Chief Engineer, who has over-all responsibility, and an Assistant Divisional Engineer who acts as second-in-command and also performs the functions of the Chief Engineer when the latter is absent on leave or for any other reason. There are two junior civil engineers, one of whom usually deals with the northern part of the delta and the other with southern, though this is a very elastic arrangement and depends largely on the works in hand. In addition there are two technical sub-ordinates who are under training and in general assist the civil engineers. On the mechanical side there is a Mechanical Engineer and his assistant: they are responsible to the Chief Engineer. The following list of Chief Engineers and Assistant Divisional Engineers is given for interest :-

Chief Engineers		Assistant Divisional Engineers	
1923-28	A.M. Telford	1923-28	W.N. Allen
1928-29	W.N. Allen	1928-33	P. Hall
1929-34	W.M. Williams	1933-34	J. Warriner
1934-41	R.J. Smith	1934	P. Hall
1941-45	L.J. Dunn	1934-36	R.W.B. Bannerman
1945-48	J.M.B. Wolfe	1936-39	H.A.W. Morrice
1948-53	H. Bell	1939	C.B. Robinson
1954-55	C.H. Swan	1939-44	J.F. Glennie
		1944-45	J.M.B. Wolfe
		1945-46	W.P. Norman
		1946-48	Sayed Eff. Omer
		1948-50	Hassan Eff. Kafi
		1950-54	Elias Eff. Dafa'alla
		1954-55	Mahmoud Eff. Gadein

FIG. P. 1



RIVER GASH

CATCHMENT AREA

SECTION I

FRONTIER TO KASSALA

1. Introduction

This section deals with the river from where it enters the Sudan at Gulsa to the site of the present road bridge at Kassala. In addition it touches upon conditions just upstream of the frontier, in particular at Tessenei which is the site of the head works of the Italian-built irrigation scheme of Ali Giddir. Little attention has been paid in the past to the upper reaches of this section because there has been no attempt to irrigate from it except for small native schemes known as "shaiyotes". Records are therefore scanty. By contrast, the lower part in the vicinity of Kassala is probably the best documented reach on the river owing to the continued efforts made to protect the town.

2. Early History

The earliest history of the reach is to be found in a legend of the Halenga quoted by Mr. B. Kennedy-Cooke, M.C. This tribe, which now occupies that part to the delta just to the north of Kassala, came originally from south of Asmara. They followed the Gash until it came to a rocky barrier which held the river up. (Presumably Tessenei gap). This they split by pouring boiling water on the rocks. The river burst through and they followed it down past Jebel Kassala and onward".

Passing from legend to fairly well authenticated fact, the earliest record of the reach is that of the building of a dam across the river. It is alleged to have been built between July and September, 1840, so the Gash must have been late, or running very spasmodically. Its construction was ordered by Ahmed Pasha Abu Udan with the idea of bringing the Hadendowa in the Gash delta to heel by depriving them of water for their crops and well centres and causing them to pay a heavy sum for its release. The idea is said to have been put into his head by Mohammed Eila, the sheikh of the

Halenga, who had old scores to settle with the Hadendowa; certainly the Halenga helped extensively in its construction. The site was upstream from Kassala where the river comes closest to the Jebel. The trunks of dom palms were sunk in the bed of the river and laced together; earth was then piled behind and reinforced with baskets and palm leaf mats provided by the Halenga. The dam was 1613 m long and was 5 m wide across the top, the earthwork slopes being 1:1.

A detachment of troops was told off to guard the dam but failed to prevent its being cut by a raiding party of two hundred Hadendowa one night during a thunderstorm. It was said to be holding three metres of water when breached and the whole construction collapsed rapidly and completely.

The intention of the dam is said to have been to divert the waters of the Gash down Khor Kwenti and eventually into the Atbara. It should be noted here that there is no water-shed between the Gash and the Atbara, so the idea was not so far-fetched as may at first appear. It is significant that the first attempt at major irrigation work was a canal dug in 1841 at Khor Kwenti to water the Kwenti-Kalahote area of the Western Gash; possibly it was intended that the dam would divert water for this scheme in addition to its main purpose of curbing the Hadendowa. In any case the canal was not dependent on the weir and continued to function for about thirty years before it silted up. There is no further evidence of any major irrigation scheme until after the Mahdia.

3. <u>General Description</u>

Only the scantiest records are available of the upper reaches of this section of the river. Such evidence as there is indicates that there has been little change for at least fifty years. After passing the narrow, rocky gap at Tessenei in spectacular rapids, the Gash assumes the appearance it is to retain all the way to Kassala, a wide, shallow stream with a sandy bed and extensive flood plains on either side densely forested with dom palm. It flows slightly north of west for some twenty kilometres and then runs north for about five kilometres before crossing the frontier close to Jebel Gulsa.

Thereafter it runs NNW for about twenty kilometres to the southern bastion of Jebel Kassala. Here it is joined by a major tributary from the east, Khor Abu Alaga. A little further downstream a major spill channel takes off on the west side. This is called Khor Kwenti; it carries a lot of water during high spates and measures have been taken to control it for fear that it might develop into a major break-way.

From the frontier to Jebel Kassala the Gash varies in width between 100 m and 800 m but averages about 300 m. The flood plains vary in width from a kilometre down to nothing; they are intersected by small spill channels taking off the main stream and returning to it at intervals.

While the main course of the river has not changed for many years, the bed is most unstable. Silting and scouring, though balancing one another in general and over large stretches, cause constant changes in detail as sand banks move from side to side of the bed and erosion attacks first one bank and then the other.

The slope of the bed is relatively constant throughout at 1.3 m/Km. It is impossible to give an average figure for the depth of flow which varies widely across the section and with the discharge. In general the bed of the river is from one to two metres below the general level of the bank crests; as is to be expected the bed is made up mainly of sand. There is, however, little bed material with a particle size greater than 0.1 mm. During the flood the bed material is highly mobile. Experimental pits filled with broken brick before the flood have indicated scour as much as 2 m below the final bed level when opened up after the flood.

Downstream of Khor Abu Alaga the Gash has tended to get wider. This tendency has been controlled in the neighbourhood of Kassala by extensive protection works. Just downstream of them, however, the Gash occupies a vast sandy bed of over 1 Km in width. The slope, both through the protection works and beyond in the wide part still remains remarkably constant at 1.3 m/Km.

Silt samples taken at the weir site have indicated a total of solids carried in suspension varying between [illegible],300 and 8,100 parts per million by weight with a "sand to silt" ratio between 1.25 and 2.00. The heaviest concentration of silt was in a sample taken at mid-depth and at mid-stream so, although the method of sampling is not recorded, it is clear that the samples refer to the true suspended load and do not include bed load. The definitions of "sand" and "silt" are not evident from the records. The word "silt" as normally used in this report (i.e. without inverted commas) refers to all suspended material.

4. <u>Kassala Weir</u>

After the re-occupation, the first major irrigation work, installed in 1905 by the Egyptian Irrigation Service, was a diversion weir across the Gash some three kilometres upstream of Kassala, with a canal called the Khatmia canal taking off the right hand side of the river to irrigate rather inferior land lying between Kassala and the Jebels behind it. The weir was designed to pass a discharge of 300 m3/sec - a grave underestimation of possible Gash flows. The dry bed level of the Gash was 122.00 (on Kassala gauge - see Preliminary Section, paragraph 11) at that time and the weir crest was set at 123.00. The design was a core-wall 1 m thick built to 2 m below river bed level; rubble slopes of 3:1 upstream and 10:1 downstream were built on either side, the downstream slope ending in lines of blocks of 1 m3 each. The length of the weir was 100 m. Unfortunately no drawing of this weir can be found, but from the above description it appears that apart from the underestimation of probable discharge in the river, the designer did not realize the extent to which the bed of the Gash degrades during a spate, as described earlier in this Section.

The 1906 flood was a high one, though not an abnormal one as was thought at the time. A spate, estimated at between 900 and 950 m3/sec, wrecked the weir on 26th July. With anything more than 40 cm of water over the crest a standing wave formed over the footing blocks: when this depth exceeded 80 cm the wave formed downstream of the blocks. Actually a

depth over the crest of as much as 1.28 m occurred, the bed downstream degraded and the footing blocks moved, followed in quick succession by the downstream pitching and the core-wall.

The weir was entirely destroyed but unfortunately much of its material appears to have remained on site and the river over it was described as a cataract. This possibly helped, by preventing normal bed erosion, in the next disaster three days later when the Gash broke out to the east three kilometres upstream the weir site and breached the Jebel Tie bank. Efforts were made to hold up the flood, first along the line of the Khatmia canal and then along the line of Misga 4 (see Fig. 1.1) but these efforts were unavailing. The flood broke through behind Kassala town and swept through it in a stream over 100 m wide and 60 cm deep; it was estimated to be flowing at at least a velocity of 1 m/sec. All irrigation works were more or less destroyed and damage in the town was considerable though no lives were lost. The Gash discharge at the time of this second spate was estimated at 750 m3/sec !

When the weir was reconstructed after the 1906 flood, it was lengthened by 20 m and its crest level reduced from 123.00 to 122.25. Fortunately a continuous wall was built at the toe of the downstream rubble slope; the foundation level of this wall was 121.00 and it rose to 122.00. Thus the crest of the weir was only 25 cm above the footings and it looked as though it would offer no appreciable obstruction to the flow of the river. Clearly the extent to which the river degraded its bed while in spate was still not appreciated. As usual, after the 1907 flood the dry bed level appeared at much the same level as before the flood, at 122.00, but the footing blocks had disappeared leaving the footing wall exposed. When the sand was cleared away the blocks were found lying anyhow, some having sunk as low as 120.00. The footing wall saved the day; had it failed, and it must have been very near failing, the weir would again have been wrecked. After the 1907 flood, the footings were extended and stepped down to 121.50 (with foundations at 120.50) and a continuous wall, 50 cm high, was built along their downstream faces. As thus built, no further trouble was experienced.

The original area watered in the Kassala irrigation scheme is not known but by 1910 it was 1920 feddans. The middle third of the weir was removed in 1921 to scour the Gash bed and reduce the danger of the Gash taking a westerly course down Khor Kwenti. The weir was finally outflanked in 1929.

No trace is now left of the weir except its left hand side which has been incorporated as a part of a spur in the Kassala training works. The site, however, remains as the zero of kilometrages measured along the Gash. The possibility of reinstating Kassala weir has never been seriously considered because a major off-take is not suitable in that area; on the right bank the land is poor and on the left bank ground-water supplies are so abundant that the best line for future development in irrigation lies in tube-wells. The danger of a westerly break-away is also still with us.

5. Gharb El Gash Canal

This channel was dug in 1913. It took off the Gash about 2.5 Km below the weir on the west side and watered an area of land behind the present village of Gharb el Gash. No record is available of the early history of this canal, nor is it known whether it had head-works or not. It was very dependent on the vagaries of the Gash and is reported, in a good year, to have watered up to 7,000 feddans. There is almost no trace of it now though the line of it can be detected along the car track from Gharb el Gash village to Ankora head. It watered an area which would far better have been irrigated from wells.

6. Wad Sherifai Scheme

The next scheme was a cut taking off the east side of the Gash some eight kilometres upstream of the weir. It waters a depression lying in the angle formed by the Gash and Khor Abu Alaga, south of Jebel Kassala. The work was done in 1920 and this remarkable scheme of about 2,000 feddans has flourished ever since. There are no head-works except a small head regulator and the off-take site has been altered

from time to time, but in general this scheme which, year after year produces excellent cotton, is very much the same today as it was thirty-five years ago. A non-engineering feature of the Wad Sherifai scheme, which is of interest, is that the same ground is used every year. This produces an appalling growth of weed such as has deterred cultivators in other parts of the delta from taking up the land. Yet the people at Wad Sherifai tackle it yearly and produce their crops in spite of the weeds.

7. The Kassala Reach before 1930

The earliest actual surveys available of the Gash in this area date from 1926 when a series of cross-sections of the river were taken south of Kassala weir. They are not reproduced in this report because it is impossible to tie the sections into their proper positions on the river, "south of Kassala weir" being the only clue to their location. They show the river varying in width from 170 m to 330 m and up to just over 1 m deep. As a comparison, the river now has a fairly constant width of 700 m for three kilometres upstream of the weir site.

The first accurate, levelled survey of the reach that we have was made after the 1926 flood. The relevant parts of this survey have been reproduced in Fig. 1.2. The Kassala Cotton Company's Annual Flood Report for 1926 says: "The Gash at Kassala is yearly widening its bed and the matter of river training works will have to be considered. The recent flood has eaten away the east and west river banks at places and has done considerable damage to native quarters on both sides of the river".

The damage to the town referred to above took place downstream K.3 and will be discussed in the next section, but the widening tendency can be noted as beginning just downstream the weir where agricultural plots are being eroded on the west side.

The flood of 1927 was a high one and the erosion was increased. Just south of Gharb el Gash canal head the west bank was eaten away on a frontage of 500 m and to a maximum depth of 150 m. Various spurs, both of brushwood and of earthwork, were built out into the river before the flood to try and guide the river down a central channel; they were soon washed away.

Further training spurs, built before the 1928 flood, were effective in keeping the Gash in one channel about 400 m wide at K.3. These spurs, which can be seen in Fig. 1.3, were mainly downstream of K.3 but the Flood Report for 1928 points out that it would be necessary to extend the training system upstream as far as the weir to ensure stability. Up to this time it had been usual to grow crops in the Gash bed, which tended to cause silting; the practice was therefore very rightly stopped though one can imagine that there was a good deal of sickness about it at first. The survey after the 1928 flood is reproduced (Fig. 1.3) with the 1926 outline superimposed on it. The changes are clear, but the 1928 flood was a small one and the greater part of these changes occurred in 1927.

The 1929 flood was the greatest that has ever been recorded; major changes were to be expected. The weir was completely short-circuited and the system of training spurs largely swept away. A survey made after the flood, Fig. 1.4, shows very deep erosion on the west bank just downstream the weir as far as the off-take of Gharb el Gash canal. This erosion carried away valuable agricultural land. The bed of the river was very wide, the deepest channels being, in general, at the extreme east and west sides. It was realized that plain earth or sand spurs were incapable of giving the necessary protection during heavy floods.

There was practically no further erosion downstream the weir site during the much smaller flood of 1930. The Gash bed at Kassala was nearly a kilometre wide and the river ran, at medium discharges. in three main channels, one to the east, one to the west and one, the largest, in the middle. Further heavy erosion occurred south of the weir, presumably on the west side. Unfortunately no survey for 1930 remains.

It does not appear from the surveys available of this period that the Gash bed was rising in the area. Indeed the

reverse is the case after the great 1929 flood. However, the evidence is too slight and over too short a period for any definite conclusions to be drawn. A statement made at the time indicates that, in general, river bed levels at Kassala were rising before the training works were put in. It seems probable that this was the case, but we have no concrete proof of it left now.

8. <u>The Kassala Training Works</u>

The [redacted], noted above, for the Gash to [redacted] and to become increasingly unstable in the neighbourhood of Kassala was a dangerous development. In this area there are abundant [redacted] supplies which permit intensive [redacted]; the land is divided into relatively small plots, each watered from a well with a water-wheel operated by a bull or, occasionally, by a camel or a donkey. Latterly the more efficient but less picturesque centrifugal pump has been gaining in popularity at the expense of the water-wheel or "sagia" as it is called in Arabic. Whatever the means of lifting the water, this area is still known as the Kassala sagia lands. It is a most attractive bit of country with citrus groves and banana plantations alternating with plots of green fodder crops and millet and onions. Most of the people live on or near their plots; houses are dotted over the whole area with shade trees planted about them.

Clearly this land was too valuable to lose. Moreover the frontages of the town of Kassala and the village of Gharb el Gash, opposite, were suffering considerable erosion. But the over-riding consideration was the danger of a dispersal of the Gash water to the west, which would rob the Gash delta canalization of its water supply. Upstream of this zone there is high land to the west of the river, but here, where the spill channel of Khor Kwenti runs out, there was a very real danger that a large proportion, if not all, of the water would take a westerly course. The fact that works designed to prevent such a possibility also afforded protection to the towns and sagia lands was most convenient, but when considering these works one should not lose sight of the fact that their in purpose was to avoid dispersal of Gash water before it eached the canalization.

After the 1930 flood the first masonry spur was built n the neighbourhood of the weir site. It was decided that there was no advantage to be gained by trying to confine the river in its old channel, as the main channel was by then about 200 m west of the weir. The spur had a brick head wall and a crated stone apron. Unfortunately no drawing remains of it; it was on the west side of the river, just about where K.O West spur now stands, opposite the remaining part of the weir on the east side. For the first part of the 1931 flood it stood up well and appeared to be straightening the course of the river northwards past Kassala. A good body of silt had been collected on the upstream side of the spur when a high spate in mid August started erosion on the unprotected part of the spur and finally breached the shank. At the same time the river, which had been confined to a channel 200 m wide between the spur and the old weir, scoured a course three metres deep along-side the spur head and undermined the apron so that the whole structure collapsed. As a result of the breaching of the spur and the obstruction caused by the remains of the masonry head, the river swung over to the east (see Fig. 1.5) to make a strong attack on Kassala town. Following on this easterly swing the erosion on the west bank downstream of the weir started to silt up again.

Although the failure of this spur was a set-back, it had indicated the proper approach to the river training works. After the flood a new spur head was constructed approximately on the site of the old one. To quote from the Chief Engineer's 1932 Annual Report :- "The principle of the design was to direct the river in a permanent straight path normal to the main spur and to remove eddies and disturbed water to a safe distance from the flanks of the work. For symmetrical reasons the banks and spur heads are constructed in pairs, one on each side of the river. The essentials for the design are proper alignment, a sufficient still-water area upstream the main shank, an impregnable head built in such a way as to reduce embayment and an ample apron to protect the impregnable head. The impregnable head consisted of a bank protected with a

rubble facing in cement mortar. This rubble facing was built in strips three metres wide with 5 cm gaps between each strip to allow any strip to slide individually as scour took place. The protecting apron, eight metres wide, was formed of rubble, crated in wire crates 2 m by 2 m by 75 cm. When the current attacks the impregnable head scouring takes place, the apron sinks with the scour, taking up a final slope depending on the intensity of scouring.

"The upstream end of the pitched guide bank is curved to reduce disturbances and sinuosities and is advanced eccentrically to the main shank so as to prevent any permanent embayment outflanking the spur head.

"The whole lay-out is further strengthened by transverse spurs, 50 m apart, set at right angles to the shank, each spur increasing in length according to the distance from the impregnable head".

The design is shown in Fig. 1.6. Subsequent experience has not modified it to any great extent and it is virtually the design used today. The above description, however, does not make the basic principle of the system quite clear. This is that when erosion causes an embayment in a river bank the embayment increases in depth until, at a certain critical radius of curvature, a natural cut-off will occur. This critical radius of curvature is characteristic of any particular river. The shank and head of a spur must be so designed that the critical embayment, held at a fixed point by the spur head, cannot reach the line of the shank.

Present practice has made two minor amendments to the design of the head: a backing of at least 15 cm of gravel is laid under the rubble on the slopes to prevent the earth filling from being washed out from behind the grouted pitching if the latter cracks and it is no longer the practice to crate the stone in the aprons. As the Gash is quite capable of displacing the 35 cm granite of which the aprons are formed it is the writer's opinion that this latter is a retrograde step. If seriously attacked a crated apron would stand a far better chance than an uncrated one.

The spur was successful throughout the big flood of 1932 and was the basis on which the Kassala Training Works were designed. At the same time a masonry wall tip was built on to the old weir on the east, making it form the other spur of the pair.

Observations were made at this time of the Gash very much further downstream at Magauda where it was running in a relatively stable regime. A relationship between average velocity and depth of the Kennedy form was obtained which, in metric units, is set down as :-

$$Vo = 0.71\ D^{1.60}$$

It is a pity that the original calculations are missing and only one reference to this relation exists. It seems highly improbable that the non-silting velocity could be found to vary with the depth to a power greater than unity and it is likely that a typing error has occurred and the relation should be :-

$$Vo = 0.71\ D^{0.60}$$

It is not now known how the design of the spur system was arrived at. The results, however, are shown in Figs. 1.6 and 1.7. The centre lines of the spurs were set 138 m apart, giving a mean width of water-way of 125 m. The maximum water depth appears to have been taken as 1.75 m. though from Fig. 1.7 it is seen that actually it was more like 2.30 m. The bed slope is 1.30 m/Km. Clearly any calculation of maximum flood capacity would be extremely difficult because afflux through the pairs of spurs is almost impossible to measure.

Having found a suitable spur design, a general system of protection was worked out. The first instalment of this system was carried out before the 1933 flood. Masonry spurs were built out from the east bank at K.1, K.2 and K.3 downstream the weir and from the west bank at K.1. The landward ends of the shanks of these spurs were connected by tie banks on either side of the river to prevent any outflanking, and unprotected earthen spurs were thrown out at the half-kilometre intervals between the masonry spurs.

The year's work can be seen in Fig. 1.8, which also shows the result of the 1933 flood. The river entered the first pair of spurs from the east side and set against the unprotected spur at K.0.5 West, which it removed. It was just held by the masonry spur at K.1 West; the transverse spurs on the shank of the spur were carried away and the shank was only held by anchoring trees along its length which deflected the water. The effect of spur K.1 West was to set the Gash over against the unprotected spur at K.1.5 East, forming a complete "S" bend. This spur was eroded but the masonry spur at K.2 held and the unprotected spur at K.2.5 East was only eroded to a lesser extent. There is no evidence of any change in river bed levels from previous years due to the building of these spurs.

As a result of the experience of the 1933 flood, it was decided that an interval of one kilometre between pairs of spurs was too great; it permitted an embayment between spurs deep enough to endanger the shank of the downstream spur. It was realized that the outflanking of one spur, as very nearly occurred, would put the whole system in danger. The project, as originally conceived, was therefore revised; the interval between pairs of spurs was reduced to half a kilometre. A further modification was made to the system by re-designing the shanks of the spurs with the object of withdrawing them still further from the line of the critical embayment. They were made to retire at an angle of [illegible] to the direction of flow.

Five more masonry spur heads were built before the 1934 flood. These were at K. 0.5 on both sides, at K. 1.5 on both sides and at K. 2.5 on the east side only. Those built at K. 0.5 East, K. 1.5 East and K. 2.5 East were superimposed on the remains of the previous unprotected spurs. The unprotected spur at K. 0.5 West had ceased to exist. The layout and the action of the 1934 flood on it can be seen in Fig. 1.9. The flow of the river through the spur system on four different dates during the 1934 flood is shown diagrammatically in Fig. 1.10. The first diagram shows the start of the flood; the river followed its course from the previous year and made a sharp set against the new spur at K. 0.5 West.

This time the spur, with its new masonry head, held, and the second sketch shows the position by mid August, just before the heavy spates came down. The Gash enters the system very obliquely and attacks the spurs on alternate sides throughout the system. The third sketch shows the flow during a strong spate; although the spaces between the spurs have filled with water, the general flow pattern has to some extent straightened up, as it tended to during spates. The last sketch shows the last flow of the year running evenly between the spur heads with a much straighter approach to the system. It is not until after K.2 that the river shows a tendency to wander.

An attempt had been made before the flood to straighten the approach of the river to the spur system by digging a leading cut down the centre-line of the system south of K.0. This was a complete failure as can be seen from the sketches. The Gash, however, having thus shown its independence, appears to have obliged on its own account later in the flood.

It was noted, during the flood, that the main attack of the river was made on the upstream nose of the armoured spur heads. This was to be expected as it is the fixed point which is holding the flow sweeping out from the characteristic embayment upstream. On the spur head at K.0 East a direct measurement of afflux was possible; at high discharges the water level on the landward side of the spur head was 60 cm higher that it was on the river side; this head was imparting extra velocity to the flow passing the upstream nose where the energy was destroyed in considerable turbulence. In one case, at K.1 East, the attack caused a settlement of 70 cm in the nose of the spur. The spur design was successful in permitting this settlement to be taken up by sectional cracking of the masonry without reducing the effectiveness of the spur as a whole.

It will be seen, therefore, that the spur system was completely successful in training the river to a straight course and in protecting the tie banks. Careful examination of river bed levels still fails to show any tendency to scouring since the system was started.

The scheme was completed in 1935 by the building of three more spurs, at K.2, K.2.5 and K.3 all on the west side. The final spur system is shown in Fig. 1.11. Throughout 1935 the flow through the spurs became increasingly axial and the embayment between spurs decreased, finishing up with the highly satisfactory flow pattern shown in the figure. Careful record of bed levels in the area was again made and no changes can be observed; indeed the longitudinal section of the river bed passing Kassala appears to be well inside the envelope of the levels of the preceding seven years.

9. The Approach to the Spur System

There is very little more to say about the spur system. Since 1935 it has fulfilled its purpose with a minimum of trouble: systems which function efficiently and without fuss do not make history. Our account now takes us to the area just upstream of the weir site where the Gash approaches the first pair of spurs. The 1935 flood had been a small one and, as shown above, it finished up with a good straight approach and an axial flow through the spurs. The 1936 flood, however, was a large one. Early in the flood an island formed just south of the spurs and the stream split in two. The western branch soon silted and the entire flow passed down the eastern branch and made an embayment just upstream the K.0 East spur; some concern was felt that the Jebel Tie bank would be breached and that the water would escape down the old Khatmia canal and flood Kassala. The situation was saved by the fixing of fallen trees along the shore line. The very oblique entry caused sinuosity through the spur system as is shown in Fig. 1.12, but no damage was done.

The value of short stub spurs made of brushwood for discouraging embayment was strongly brought out at this time. These consist of a number of stakes driven in a triangular pattern out into the river (with the shore-line as base) and filled with brushwood. Light poles are often lashed across the tops of the stakes to hold the brushwood down. Where the water is too deep to drive the stakes, it is effective simply to chop down small trees and hang them over the edge of the eroding shore line anchoring them back by wires to stakes driven in solid ground. This means of protection has the great advantage that it can be initiated immediately by the man on the spot without awaiting stores and materials: wire, of course, is essential and it is dumped at strategic points before the flood to be ready for emergencies.

After the 1936 flood a training bank was built south of K.O East spur to control the embayment there and to ease the approach to the spur system. The layout of this bank is shown in Fig. 1.13. It was connected back to the Jebel Tie bank and the free end was faced with grouted pitching and provided with a crated rubble apron. The result was excellent and by the end of the 1937 flood the approach flow was straight again and sinuosity through the spurs had been eliminated. The embayment behind the training bank silted up.

In 1938 there was no trouble. There was some slight erosion in the gap between the East Training bank and K.O East spur, but it did not develop and soon silted up again.

The 1939 flood was a very weak one, such as is not associated with great change. The course of the river upstream of the spurs held closely to the 1938 channel until about mid August when there was a change. Instead of advancing evenly with the heavier part of the current on the west side, the whole stream lay on the west side and set directly against the head of K.O West. It curved sharply round the nose of the spur and set up some minor sinuosity in the spur system.

The river had set against the western spur before and on that occasion it had swung back east again later. In addition to this the erosion and sinuosities involved were slight, so the only action taken was to protect the embayments with brushwood groynes. The intention was to build a West Training bank to balance the East Training bank only if the threat developed.

Kassala was seized by the Italians on the 4th July, 1940. Almost nothing is known of the behaviour of the river during the flood, but it is understood that the brushwood protection served its purpose. Certainly there were no serious developments.

The 1941 flood was the heaviest since 1929; the angle of entry into the spur system varied and the course of the river through the system tended to swing from side to side. No damage was done then or in the next year but the embayment upstream K.O West was undoubtedly developing and the flow at the entrance to the spurs was erratic; these two facts are probably related but it is not clear which was the chicken and which was the egg.

Before the 1943 flood an earth bank 300 m long was built across the embayment. It was provided with a stone pitched tail and an effort was made to plant tamarisk cuttings along its length. Unfortunately the exact position of this bank is not recorded; it was swept away by a spate early in the 1943 flood and no drawing of it remains. The position of its pitched tail, however, is known as it was in the same position as the tail of a new bank built in 1944. This bank is shown in Fig. 1.14. It was constructed about two-thirds of the way across the embayment and was pitched and had a falling apron on the river side. This pitching and apron were carried round the downstream tail of the bank and a short distance back on the other side. The design was successful; the embayment silted up to such an extent that a complete "sagia" area, which had been lost, was reclaimed. The bank was called the West Training bank. The problem of the approach to the spurs had now been solved and no further trouble was experienced for eight years.

10. Recent History

The Gash has shown a fairly consistent tendency to become wider upstream of the spurs and by 1949 it was 500 m wide two kilometres upstream of K.O as compared with 300 m in 1936 and 150 m in 1904. There was, in 1949, a narrower portion nearer to the spurs but this was gradually being widened also. Bed levels, in general, showed no change.

The 1950 flood was a big one. At first the approach to the spurs was from the east side, as it had been for some years. This approach set the current against the spur at K.O.5 West, which eventually caved in. The spur head was held, however, by sand bags and stone. The flood was marked by some very high spates - one of them never equalled before or since - and these started an embayment on the west side upstream of the West Training bank. As the flood continued, the main approach swung from the east to the west side.

The 1951 flood was a very small one and produced no problems, but in 1952 there was a big flood and the water was considered by several independent observers to be more than usually silt-laden. The approach was down the West Training bank where it increased the existing embayment and breached the bank at its upstream end (where it joined the shore line). Sand bag blocks were used to prevent the stream establishing itself on the wrong side of the bank. The position after the 1952 flood can be seen in Fig.1.15, which also shows the measures taken in 1953 and 1954.

In 1953 it was decided to put a new upstream nose on the bank and so turn it into another impregnable head and to connect the bank to the high ground by another bank as shown in the figure. The whole thus formed another complete spur. It was decided, also, to experiment with bitumen as a sealing for the spur. Although the experiment failed it is worth a fairly full description for future reference. Further trials of bitumen spurs will probably be worth while and records of all earlier efforts will be of value when such projects are attempted.

The mix was designed by Messrs. Shell, who also supervised its execution. The bank was built of normal Gash bed material, i.e. rather coarse sand, and the slopes were dressed at 2:1 down to a level about 2 m below average river bed level. The slopes were then divided into sections 1.5 m wide by battens, to allow screeding of the coating to a 5 cm thickness. The following materials were then mixed :-

1 part granite metal 1" to ½"
1 part granite metal ½" to 3/8"
¼ part granite chippings
¼ part coarse sand

After mixing, 15% by volume of "Colas" (bituminous emulsion), some water and 1% by volume of salt were added and the whole was mixed for a further 1½ minutes. The amount of

water used was fixed at 1 pint for each batch of the mixer, which produced 0.1 m3 of mixed product each batch. It was a normal concrete mixer. The mixture was then laid on the slopes, screeded and lightly tamped. After three days the surface was rolled by a ½-ton roller drawn up and down the slope by a power operated winch. Immediately after rolling the surface was sealed by brushing with pure "Colas" mixed with a little water. The total cost of the process worked out a little more expensive than the traditional method of pitching, but as it was only in the experimental stage this might have been reduced later. Indeed the main object of using bitumen is to reduce the thickness of the protective coating and so to save costly stone. It has been used successfully in Holland.

With the first arrival of the Gash flood of 1953 it was noticed that the "Colas" sealing coat peeled off with the mud deposited by the water when it subsequently dried off after a slight spate. The first heavy spate of the flood, a few days later, set straight at the new spur head and removed it completely. The connecting bank to the high ground and over 200 m length of the West Training bank were lost despite continuous efforts throughout the flood to hold it by means of sacks filled with loose stone. These efforts were, however, successful in holding the last 70 m of the bank and so preventing the embayment from moving on downstream to K.O.

The cause of the failure is not known. It has been suggested that a suitable grade of bitumen heated in a boiler instead of bituminous emulsion might have given better results. Another possibility completely unconnected with the method of sealing, however, presents itself. It has been known for some time that the bed of the Gash degrades to a depth of over 2 m when in spate. Such a degradation is particularly likely at points of high velocity such as occur when the main current sets against a spur head. Now the sealing of the bitumen spur was only taken down to 2 m below river bed level. This figure was probably decided upon because masonry spurs have been thoroughly successful in the same area with their aprons founded on the sand only 1.60 m below bed level. But these aprons are flexible structures of considerable weight and they extend from three to six metres out from the toe of the bank.

Their function is to settle into any degradation of the bed and, in doing so, to control any further degradation. It would seem that, in the case of the bitumen spur, any degradation below 2 m would suck out the filling of the spur and cause its collapse. The question then arises how far below dry bed level should bitumen faced slopes be taken ? There is, as yet, no experience on which to base an answer but the fact that scour pits have shown scour down to 3.5 m below bed level (and that at some distance from any obstruction to the flow) is not without significance.

The remainder of the West Training bank after the 1953 flood was converted into a more conventional spur with a masonry head and the shank was retired to conform with it, as shown in Fig. 1.15. It functioned satisfactorily in 1954, though that small flood was no real test of its efficiency.

The Gash is still getting wider upstream the spurs. It now averages 700 m width for about three kilometres above the weir site; there will probably be further developments in this area in the future.

11. The Ali Giddir Scheme near Tessenei

Italian interest in the Gash waters caused some anxiety even as far back as 1901 and the question was taken up between the Governments concerned. This exchange ended in a declaration by the Italians that Eritrea, while recording its rights to the waters of the Gash, would conform to the principles of "bon voisinage" in the matter. In 1905 the Governor of Eritrea informed the Governor-General of the Sudan that the Italians had started a study of the Gash which would be promptly followed by works intended to exploit the waters of the river. Lord Cromer, however, warned the Italian Government not to begin any such works until a detailed agreement had been reached.

In 1906 the results of the Italian study were published in a report by Commendatore Colletta; this made it clear that the only suitable area for the development of irrigation was near Tessenei. The report itself is descriptive and of

general interest but does not go deeply into the hydrological side of the problem.

Nothing further occurred until 1923 when it was observed that works were in progress at Tessenei. Approaches were made to the Italians based on the 1901 Declaration. Technical discussions ensued and were followed in 1925 by an agreement between the respective Governments. The Italian requirement was stated to be an average flow of 15 m3/sec for fifty days, i.e. some 65 million m3 in all. It was proposed to build a weir in the rocky gorge at Tessenei which would raise the river level there by 1.85 m above the highest known flood record. This, it was agreed, would not seriously disturb the regime of the river downstream, and there was no danger of a total diversion as a result of it.

The agreement laid down that the first 5 m3/sec of flow in the Gash were exclusively the right of the Tessenei Scheme (in any case they would not reach as far as the delta). Any flow above 5 m3/sec was to be divided between the two countries in such linear proportion that by the time 20 m3/sec was reached the shares would be equal. Thereafter equal shares were to be maintained until the maximum discharge required for Tessenei, said to be 17 m3/sec, was reached. All further water was for the Sudan. This result was to be achieved by a spillway in the Tessenei weir, whose cill was fixed at such a level as would supply the canal offtake with 5 m3/sec. The width of the spillway was such that the discharge over it was 10 m3/sec when the canal was drawing 10 m3/sec and the same principle was followed for larger discharges. The Sudan was to make an annual payment to Eritrea of 20% of such part of the Sudan Government share of the product of the Gash cotton as exceeded £E.250,000. The agreement lapsed after the war.

The 1925 crop at Ali Giddir failed because the weir had not been completed and even by 1926 the western half of the weir was still not finished. Only 2,000 feddans were cultivated in 1927 and 1928 and in the latter year the main canal breached; by that time the eventual target of 35,000 feddans had been whittled down to 8,000. It is doubtful whether the scheme has ever drawn off the full discharge allowed for in the agreement and it is only at times of very low water that any serious effect is felt downstream.

The head-works of the scheme at Tessenei are not only impressive but hydraulically most peculiar. The off-take, some hundreds of metres upstream of the weir, feeds into a long stilling basin with an escape spillway along the length of the right-hand side. There are escape sluices in the weir below the off-take, set lower than the off-take cill level, whose purpose is to allow the main channel of the river passing the entrance to be scoured. The canal sluices are at the far end of the stilling basin and escape sluices take off at right angles to them to the right; these sluices are set lower than the canal sluices. It is not known, now, what were the original arrangements at the head, but when the scheme was first operated by the British in 1941 after the occupation of Eritrea it was assumed that the best method of operating was to leave a small discharge running permanently through the escape sluices. The idea, a perfectly logical one, was that this would draw off the bed-load since the sluices were set low and at right angles to the main direction of flow. Under this regime, however, considerable silt was deposited in the canal, despite three more de-silting escapes set in the bank of the canal in the head reach. In about 1946 two circular, staggered silt vanes were built, which successfully diverted the bed silt through the escape orifices and reduced silting in the canal. Unfortunately they were subsequently removed by the agricultural staff under the mistaken impression that they restricted flow through the canal head-works. Finally the entire system was changed and now the escape sluices are left closed except for one hour per day when the canal head is closed and the entire discharge is passed down the escape sluices. At the same time the sluices in the weir are opened and the river bed is scoured. In the same way the de-silting escapes in the canal are only opened periodically when they take the maximum possible discharge. This system has answered perfectly and there is now virtually no silt deposited in the canal.

The reason why the present system of operation should be so much more efficacious than what appears to be the more logical system tried out at first is not certain, but it may be argued that the length of the de-silting basin between the

off-take from the river and the escape sluices is too short a distance to allow the bed-load to settle into steady movement after the turbulence set up at entry, so that the draw-down effect of the sluices is ineffective. The fact that some success was achieved with silt vanes points in this direction: silt vanes should not be necessary in such a system if the bed-load is being carried in the normal way, since a right angle offtake set low should be sufficient in itself to draw off the lower, slower moving water and the bed-load with it. The remarkable feature is that the bed-load now settles in the stilling basin rather than filling it within a short period and then passing on through the canal sluices.

The canal feeds a series of basins at different levels, one emptying into another, and surplus water is discharged into the Gash. Cotton yields have never been high. An interesting feature of the distribution system is the use of vertical "needles" rather than horizontal stop-logs in the control points. The former are much easier to handle as they can be made of much lighter section; stop-logs are essential in most places in the delta because by leaving the bottom two or three logs permanently in position much of the bed-load can be excluded from passing through the regulator.

12. Future Development Upstream of Kassala

It will be brought out in this report that the best land in the Gash delta is in the south, that is to say between Kassala and Aroma. Unfortunately this area is also the most difficult to water owing to the instability of the river in the neighbourhood. One possible solution that has been put forward suggests major diversion works upstream of Kassala and a major canal bringing water down on the west side of the Gash, which would serve a supply system branching out at about the apex of the delta. The problems which such a scheme would involve would be formidable. Sir Claud Inglis has stressed that not the least of them is that any silt-excluding off-take drawing a large discharge from the river must increase the proportion of silt in the river downstream, altering its regime and producing results which would be extremely difficult to forecast.

Undoubtedly such a scheme must be very carefully investigated first but it seems that its inherent advantages may well make such an investigation worth while when staff and money can be made available for it.

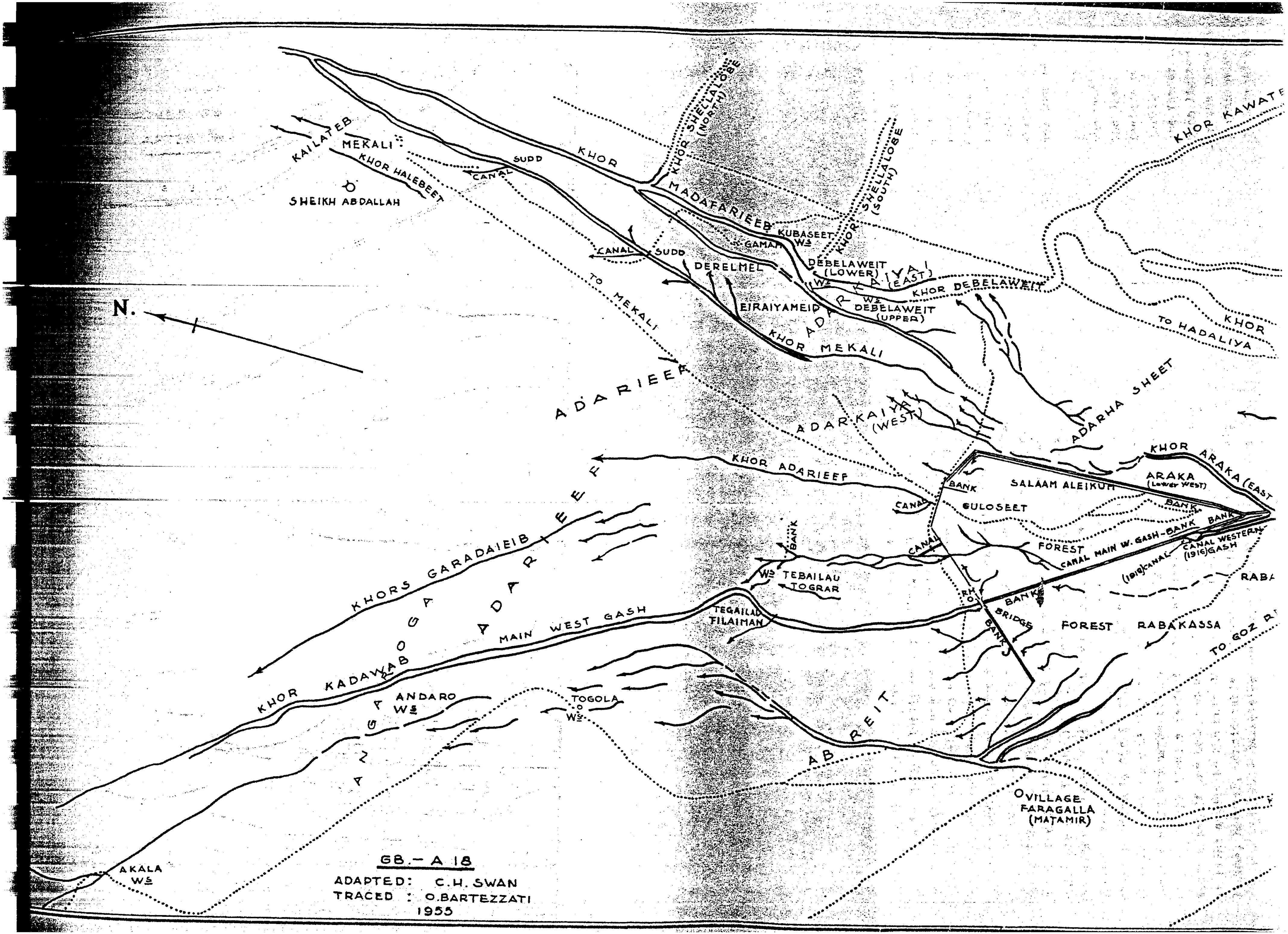
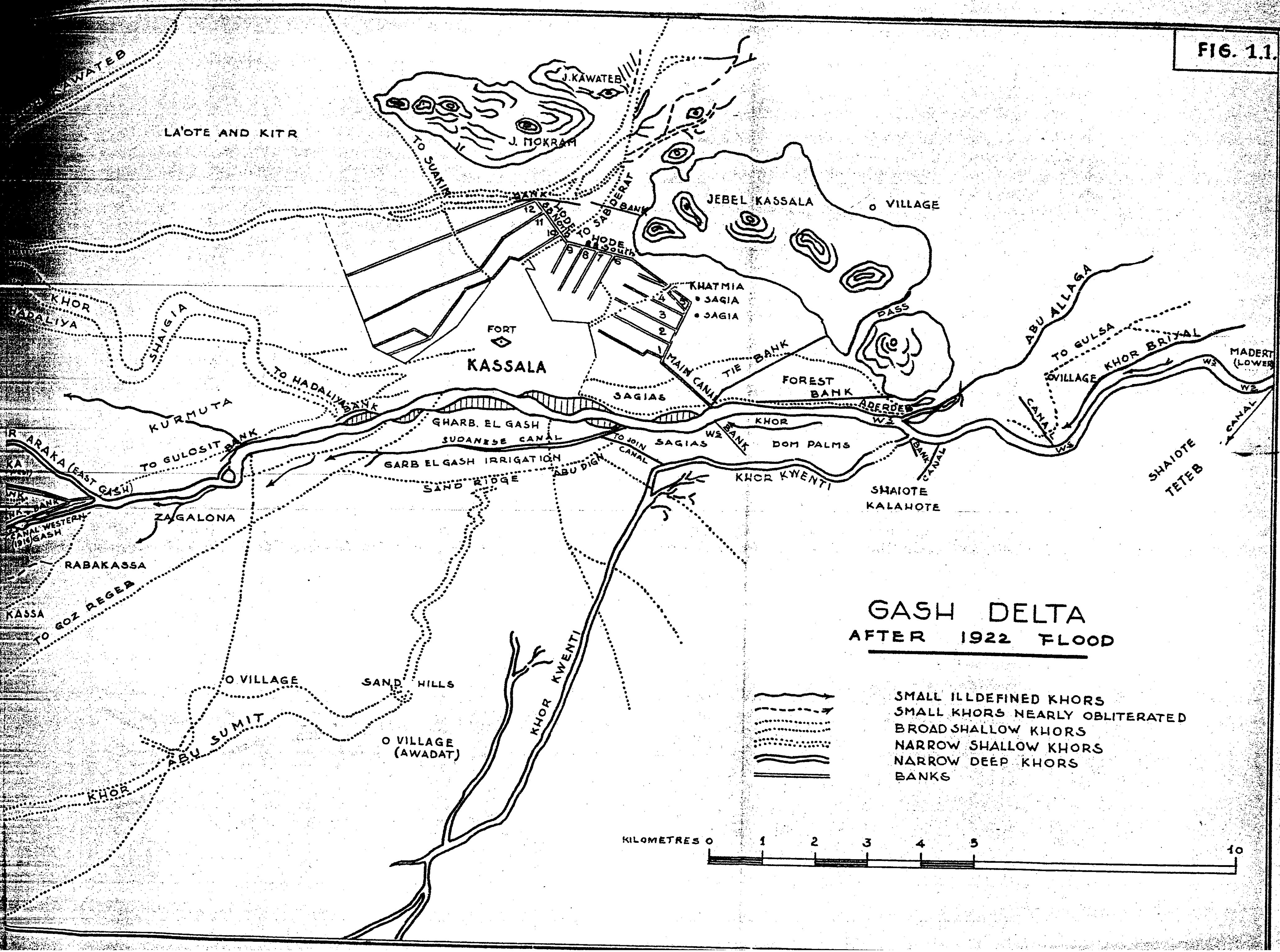

KHOR KAWATE
KHOR SHELLALOBE (NORTH)
KHOR SHELLALOBE (SOUTH)
KAILATEB
MEKALI
KHOR HALEBEET
SHEIKH ABDALLAH
SUDD
CANAL
KHOR
MADAFARIEEB
KUBASEET Ws
GAMAM
DEBELAWEIT (LOWER)
Ws
ADAR KAIYAI (EAST)
KHOR DEBELAWEIT
Ws DEBELAWEIT (UPPER)
DERELMEL
EIRAIYAMEID
KHOR MEKALI
TO MEKALI
TO HADALIYA
KHOR
N.
ADARIEEF
ADAR KAIYAI (WEST)
ADARHA SHEET
KHOR ADARIEEF
KHOR ARAKA (EAST
ARAKA (Lower WEST)
SALAAM ALEIKUM
BANK
GULOSEET
CANAL
FOREST
CANAL MAIN W. GASH-BANK
CANAL WESTERN (1916) GASH
(1918) CANAL
RABA
BANK
Ws TEBAILAU
TOGRAR
RH
BRIDGE
FOREST
RABAKASSA
TO GOZ R
KHORS GARADAIEIB
ADARIEEF
TEGAILAU
FILAIMAN
MAIN WEST GASH
KHOR KADAWAB
ANDARO Ws
TOGOLA Ws
AB REIT
VILLAGE FARAGALLA (MATAMIR)
AKALA Ws
GB.-A 18
ADAPTED: C.H. SWAN
TRACED: O. BARTEZZATI
1955

FIG. 1.1.


GASH DELTA
AFTER 1922 FLOOD
SMALL ILLDEFINED KHORS
SMALL KHORS NEARLY OBLITERATED
BROAD SHALLOW KHORS
NARROW SHALLOW KHORS
NARROW DEEP KHORS
BANKS
KILOMETRES 0 1 2 3 4 5 10
LA'OTE AND KITR
J. KAWATEB
J. MOKRAM
TO SUAKIN
JEBEL KASSALA
O VILLAGE
KHATMIA
SAGIA
SAGIA
PASS
ABU ALLAGA
TO GULSA
O VILLAGE
KHOR BRIYAL
MADERT (LOWER)
CANAL
SHAIOTE TETEB
KASSALA
FORT
MAIN CANAL
TIE BANK
FOREST BANK
ADERDEB
SAGIAS
KHOR
DOM PALMS
KHOR KWENTI
SHAIOTE KALAHOTE
GHARB. EL GASH
SUDANESE CANAL
GARB EL GASH IRRIGATION
TO JOIN CANAL
ABU DIGN
SAND RIDGE
TO HADALIYA
KHOR HADALIYA
SHAIGIA
KURMUTA
TO GULOSIT
ARAKA (EAST GASH)
ZAGALONA
RABAKASSA
TO GOZ REGEB
KASSA
CANAL WESTERN (1916) GASH
O VILLAGE
SAND HILLS
O VILLAGE (AWADAT)
ABU SUMIT
KHOR
KHOR KWENTI
BANK
HODE
TO SABDERAT
TO HODE

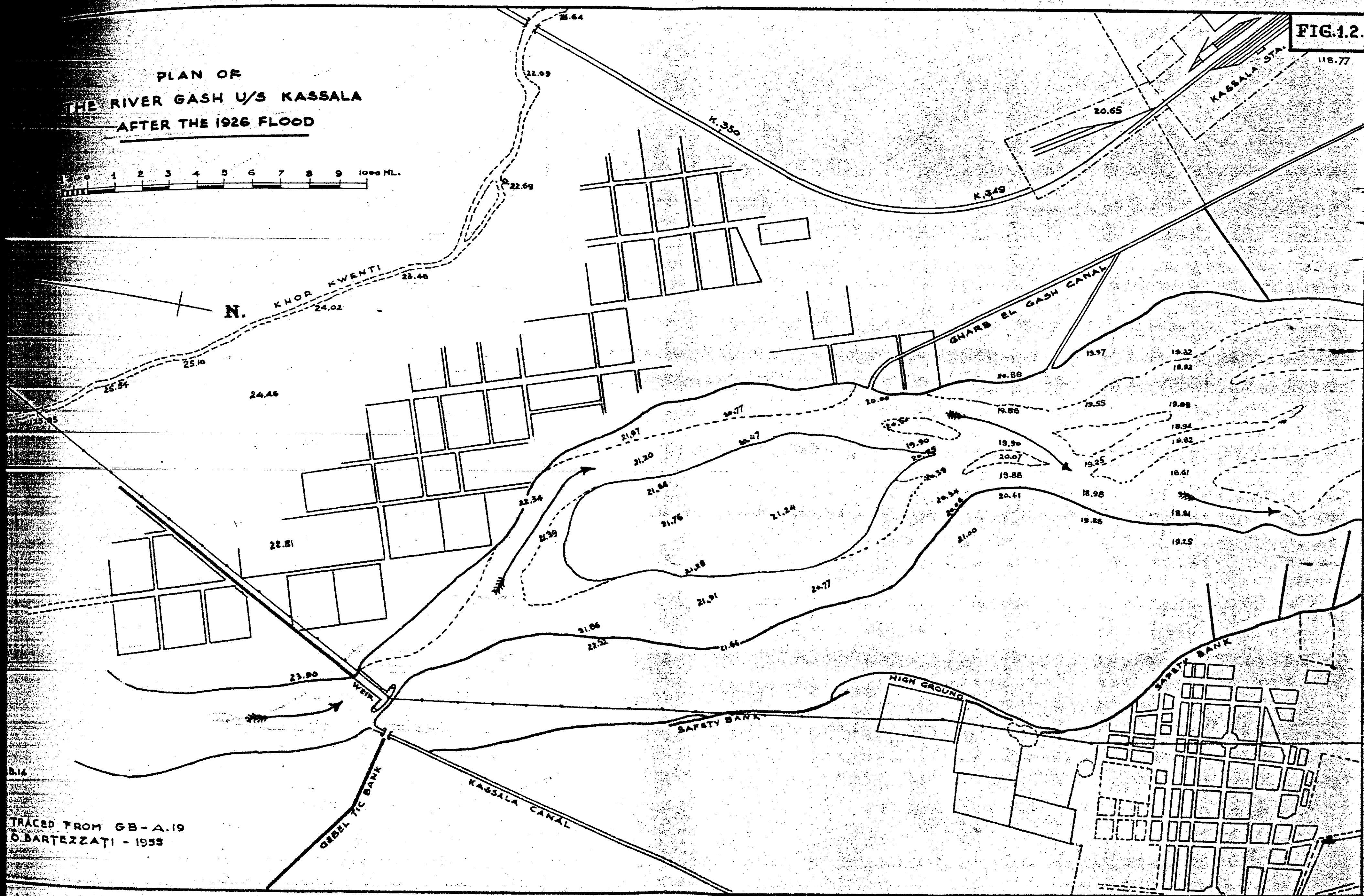


FIG.1.2.
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1926 FLOOD
1000 M.
N.
KHOR KWENTI
K.350
K.349
KASSALA STA.
GHARB EL GASH CANAL
WEIR
SAFETY BANK
HIGH GROUND
KASSALA CANAL
GEBEL T/C BANK
TRACED FROM GB-A.19
O.BARTEZZATI - 1955

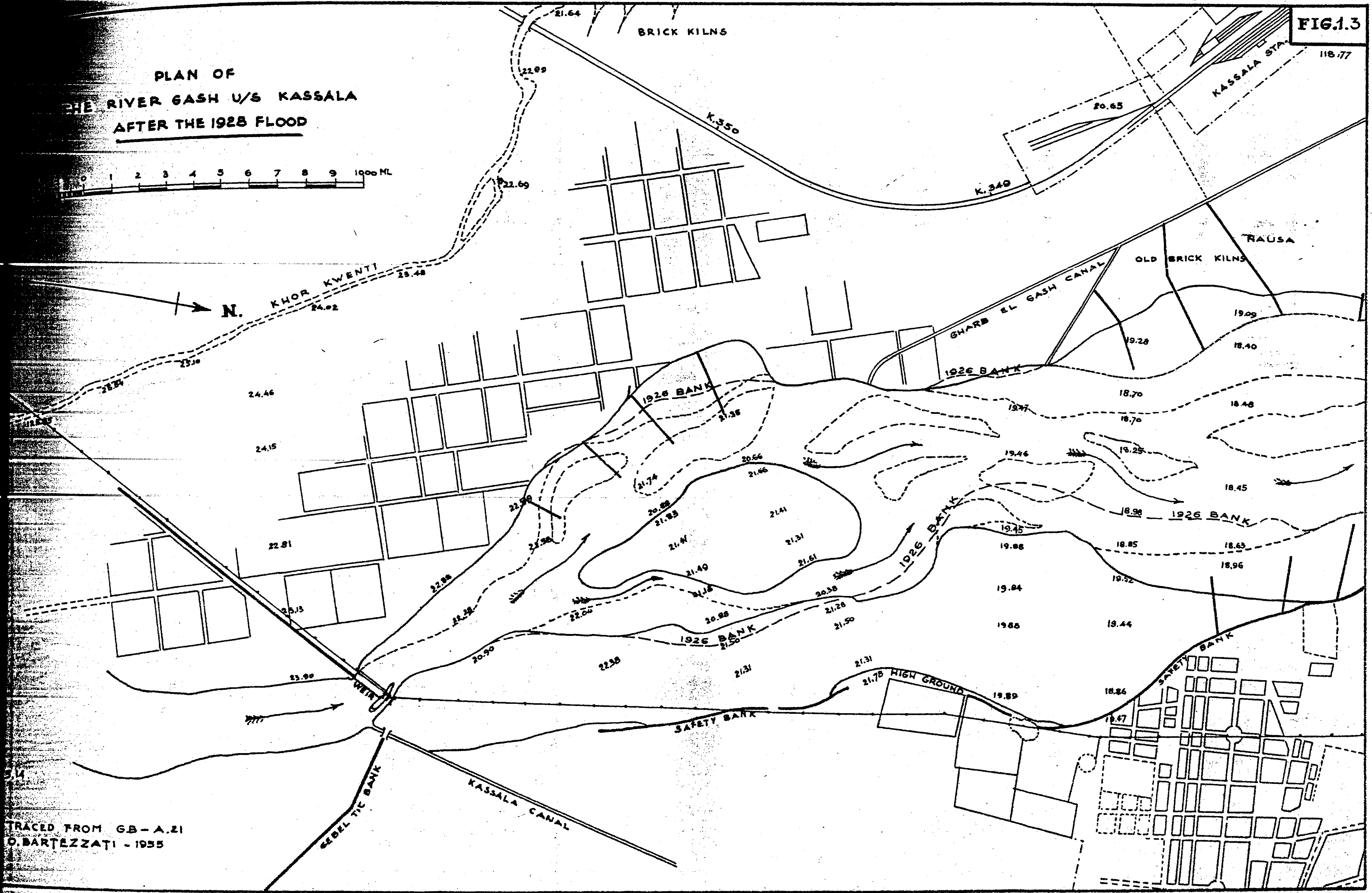

PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1928 FLOOD
1000 ML
N.
KHOR KWENTI
BRICK KILNS
K.350
K.349
KASSALA STA.
RAUSA
OLD BRICK KILNS
GHARB EL GASH CANAL
1926 BANK
HIGH GROUND
SAFETY BANK
WEIR
KASSALA CANAL
GEBEL TIC BANK
TRACED FROM GB-A.21
O. BARTEZZATI - 1955

FIG.1.3

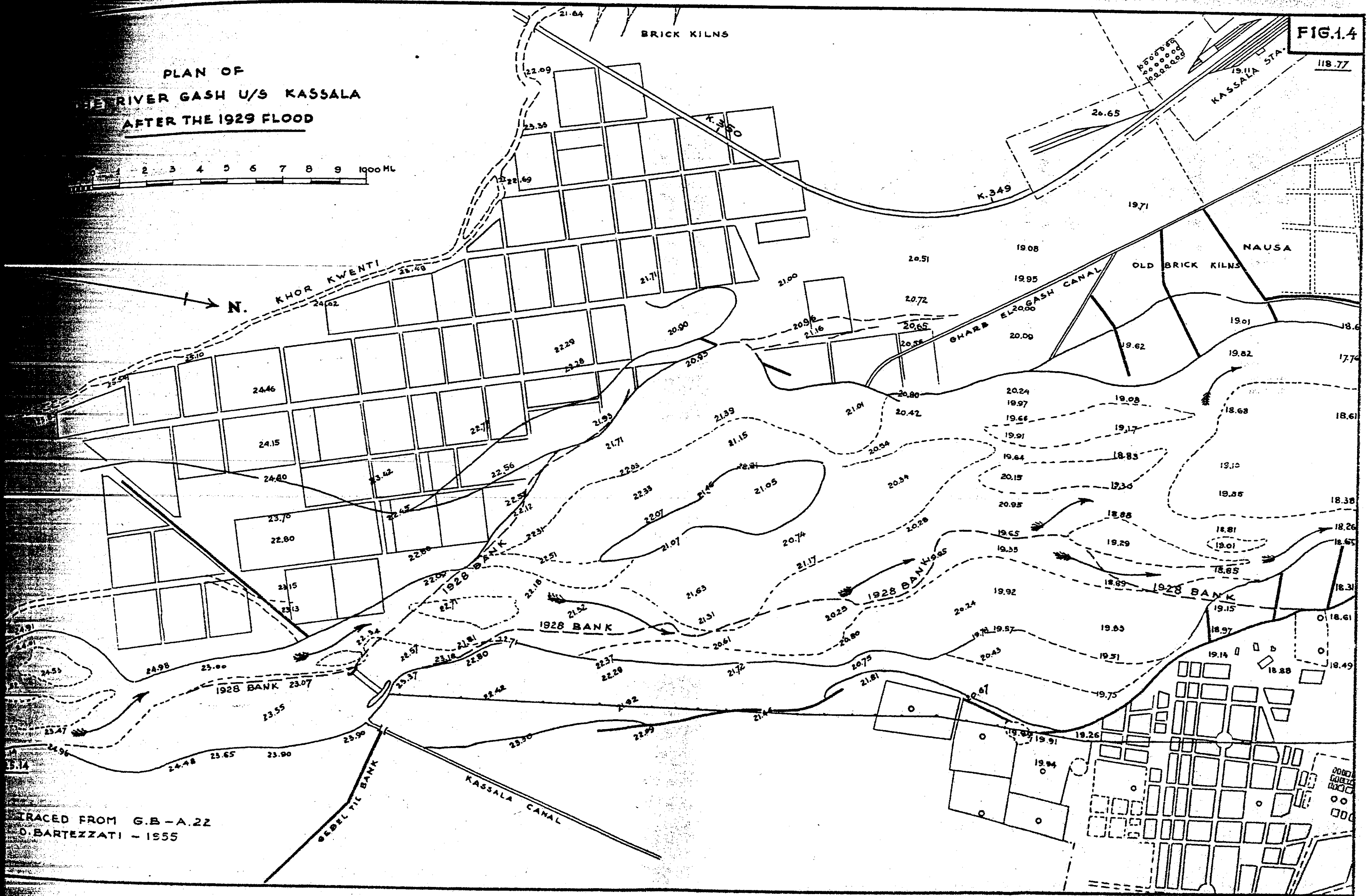


FIG.1.4
118.77
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1929 FLOOD
1 2 3 4 5 6 7 8 9 1000 ML
N.
KHOR KWENTI
BRICK KILNS
K.350
K.349
KASSALA STA.
NAUSA
OLD BRICK KILNS
GHARB EL GASH CANAL
1928 BANK
1928 BANK
1928 BANK
1928 BANK
1928 BANK
KASSALA CANAL
GEBEL TIL BANK
TRACED FROM G.B-A.22
O. BARTEZZATI - 1955

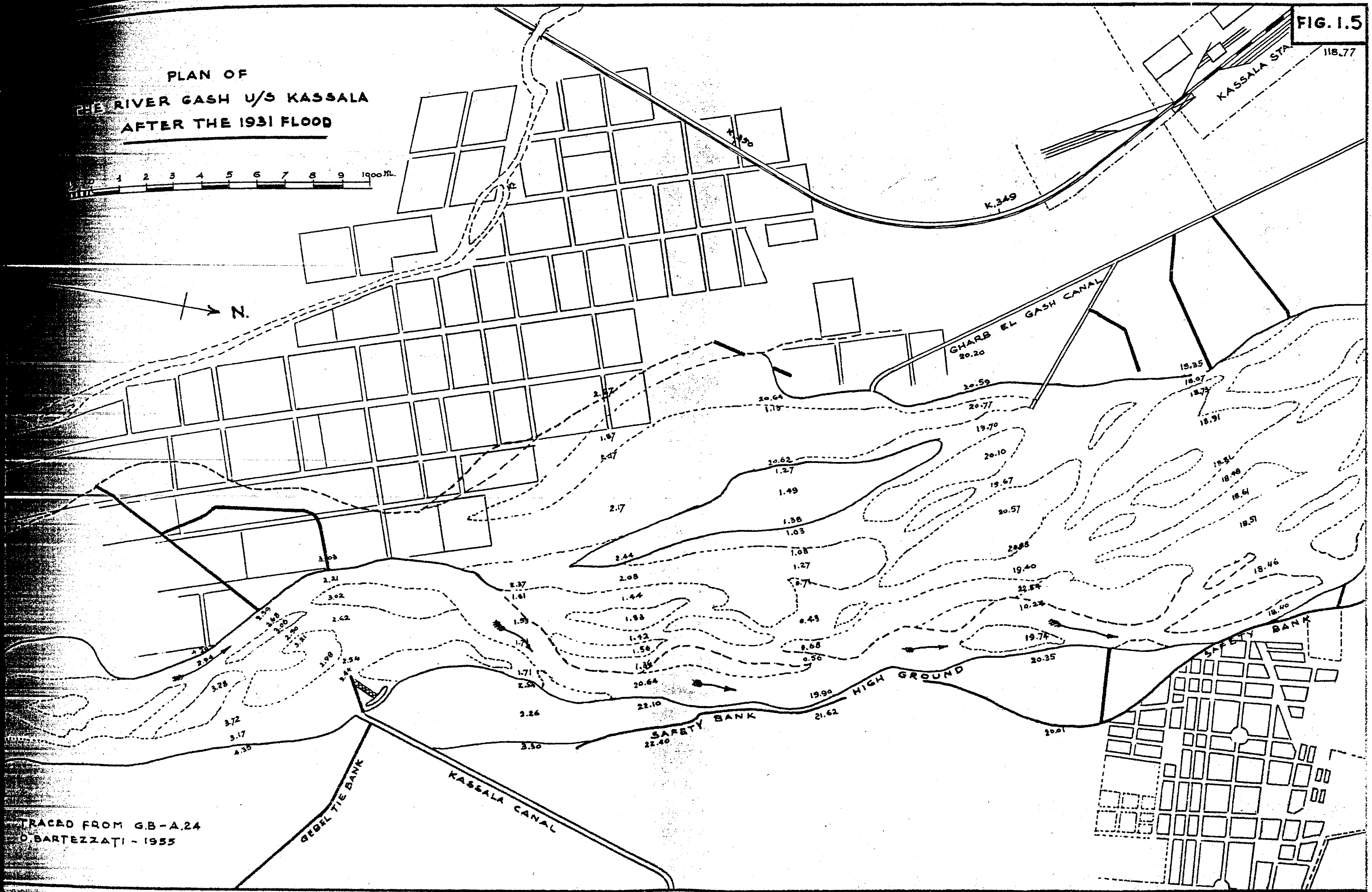
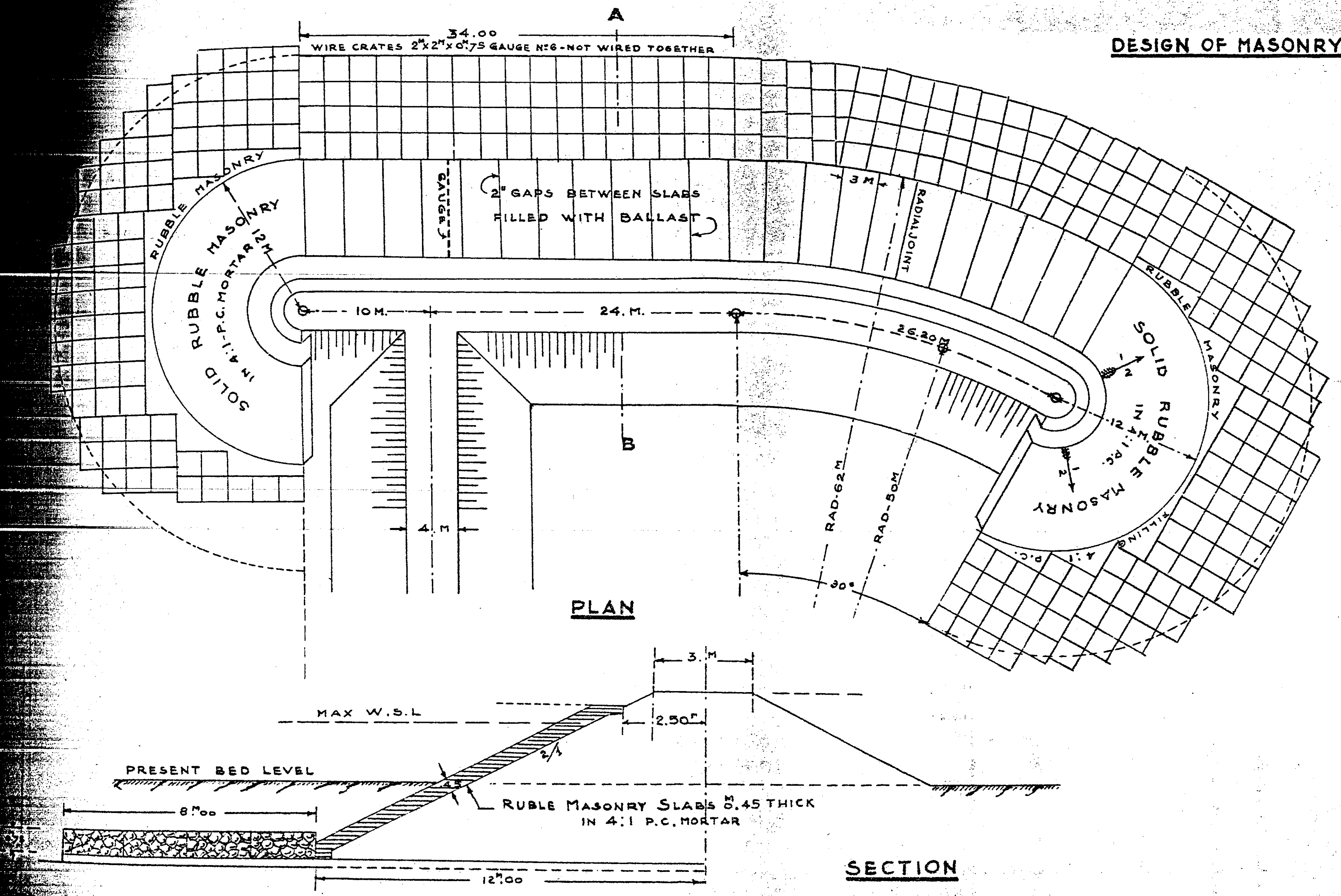


FIG. 1.5
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1931 FLOOD
1 2 3 4 5 6 7 8 9 1000 M.
N.
KASSALA STA.
118.77
K.349
K.350
GHARB EL GASH CANAL
HIGH GROUND
SAFETY BANK
KASSALA CANAL
GEBEL TIE BANK
TRACED FROM G.B-A.24
O. BARTEZZATI - 1955

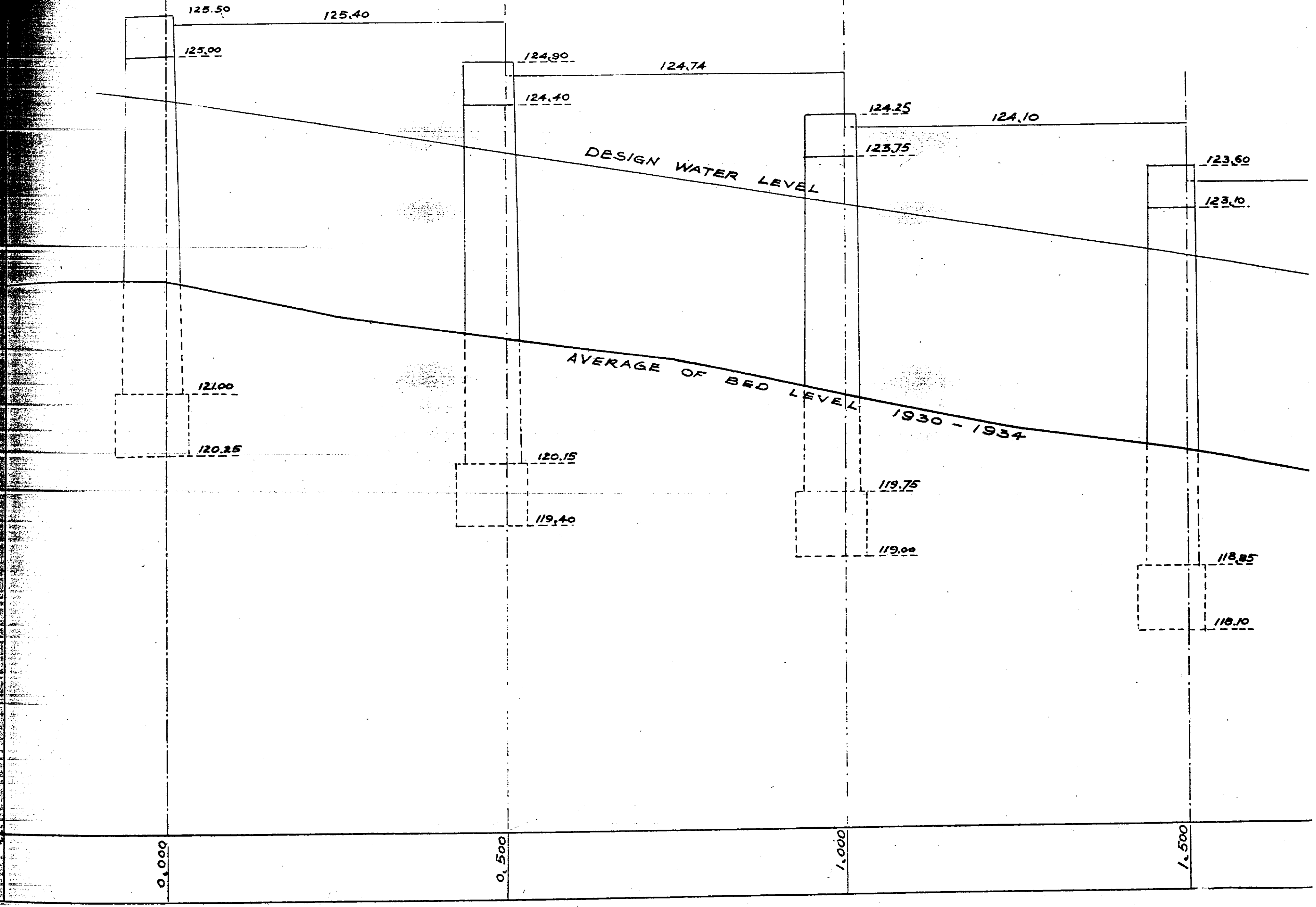
DESIGN OF MASONRY SPUR



TRACED FROM G.B-A.37
O. BARTEZZATI — 1955

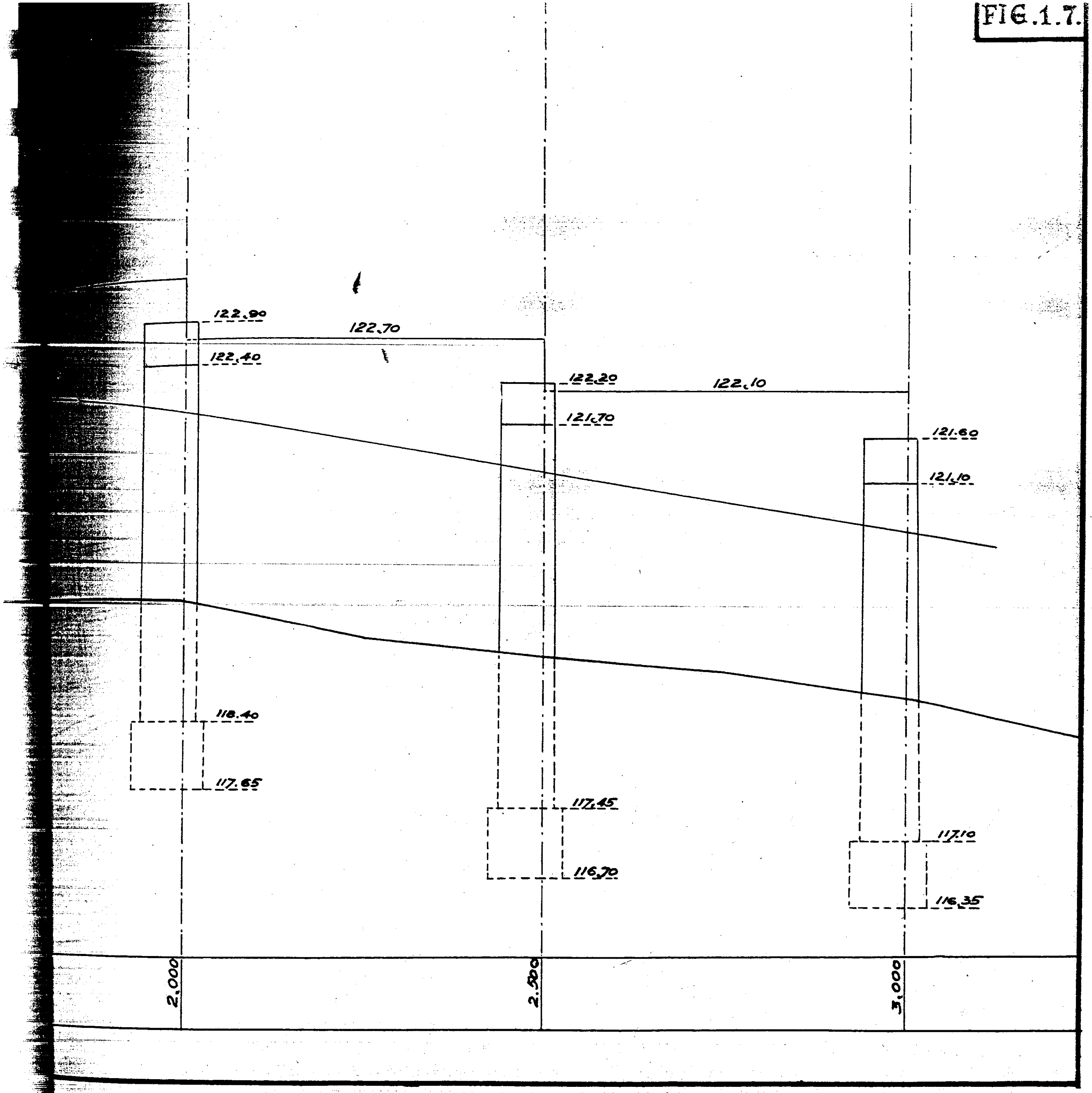
LAY - C

LONGITUDINAL SECTION RIVE
THROUGH THE KASSALA SP

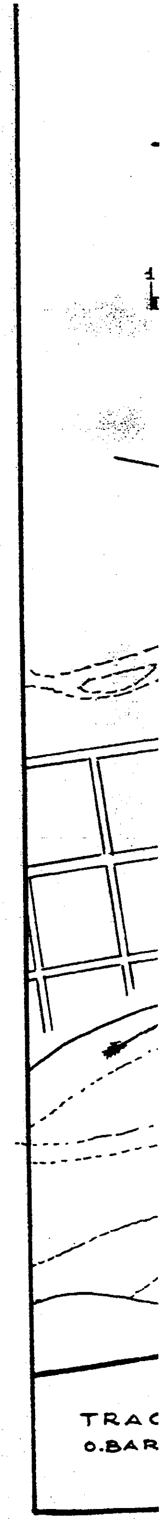


TRACED FROM G.B.- A.52
O. BARTEZZATI - 1955 -

FIG.1.7.



122.90
122.70
122.40
122.20
122.10
121.70
121.60
121.10
118.40
117.65
117.45
116.70
117.10
116.35
2.000
2.500
3.000



TRAC
O.BAR

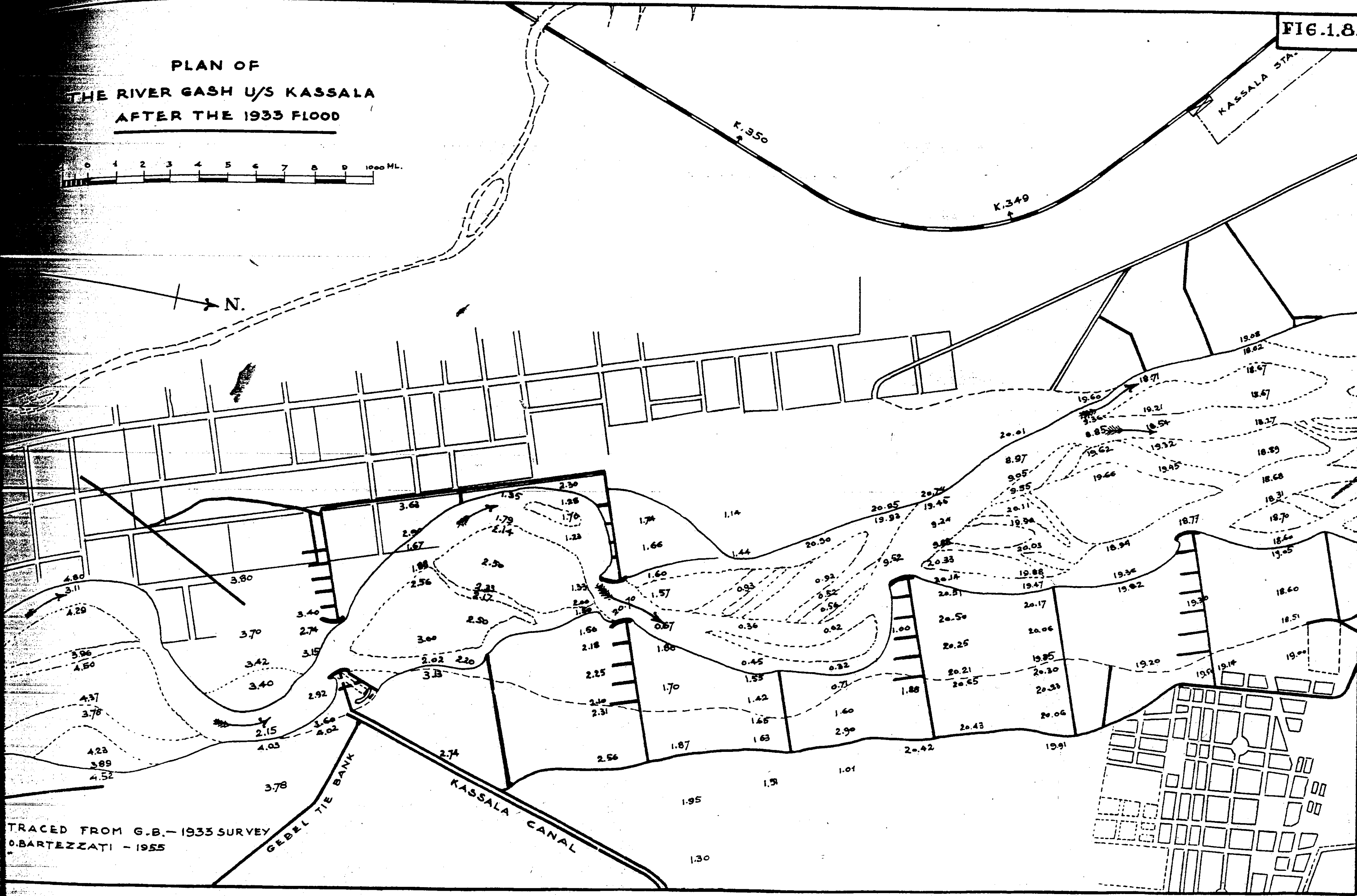


FIG. 1.8.
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1933 FLOOD
0 1 2 3 4 5 6 7 8 9 1000 ML.
N.
KASSALA STA.
K.350
K.349
KASSALA CANAL
GEBEL TIE BANK
TRACED FROM G.B. – 1933 SURVEY
O. BARTEZZATI – 1955

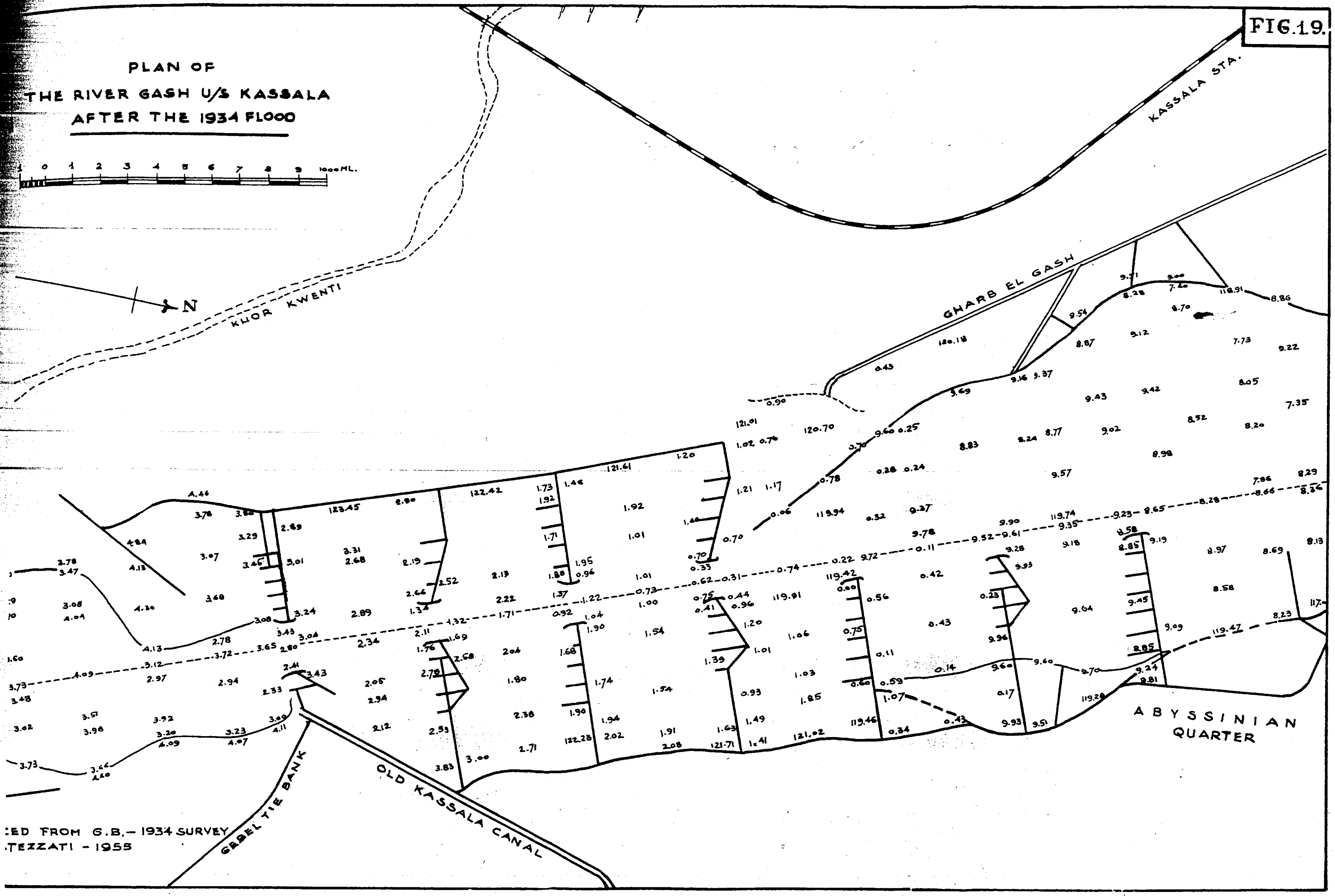


FIG. 19.
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1934 FLOOD
1 0 1 2 3 4 5 6 7 8 9 1000 ML.
N
KHOR KWENTI
KASSALA STA.
GHARB EL GASH
ABYSSINIAN QUARTER
OLD KASSALA CANAL
GEBEL TIE BANK
:ED FROM G.B. – 1934 SURVEY
.TEZZATI – 1955

SKETCHES of RIVER ACTION - KASSALA 1934 FIG. 1.10

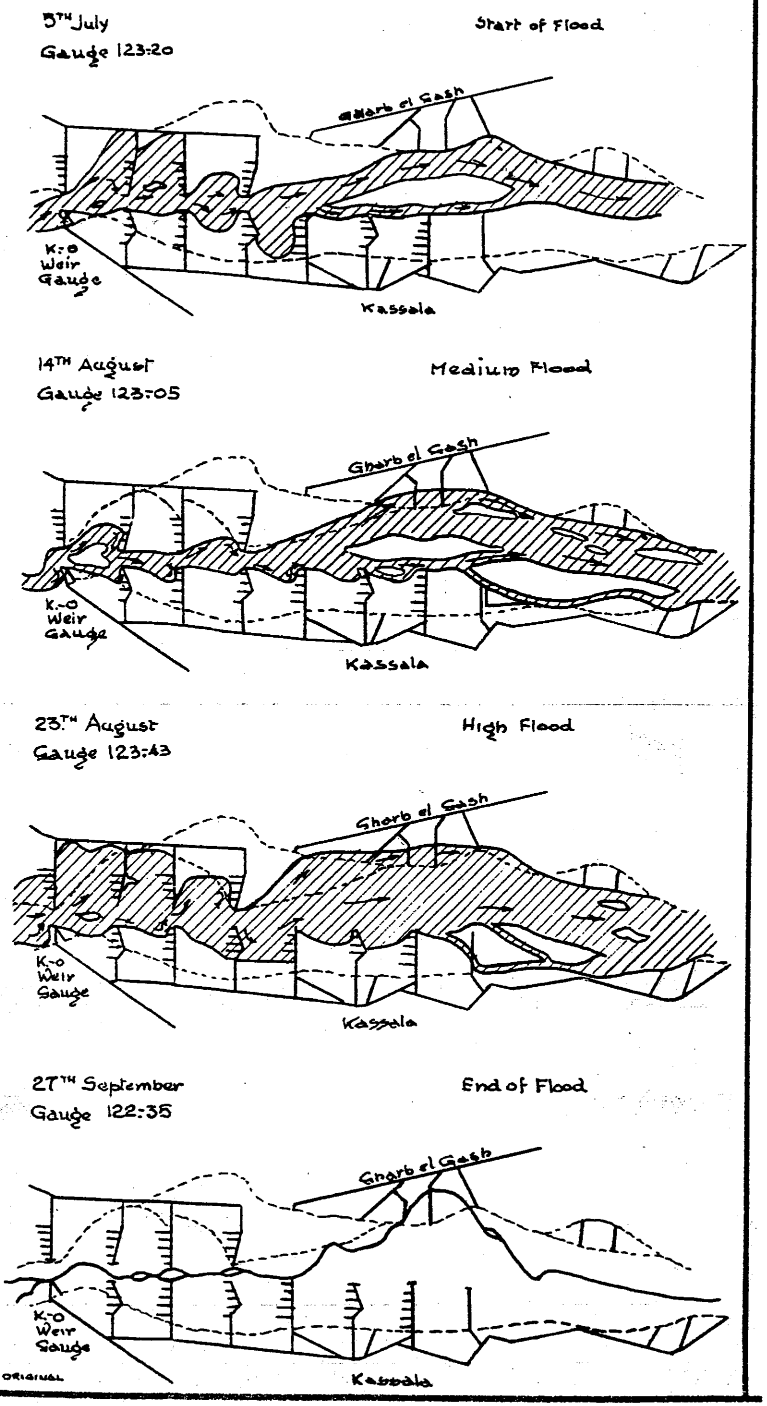


FIG.1.11.

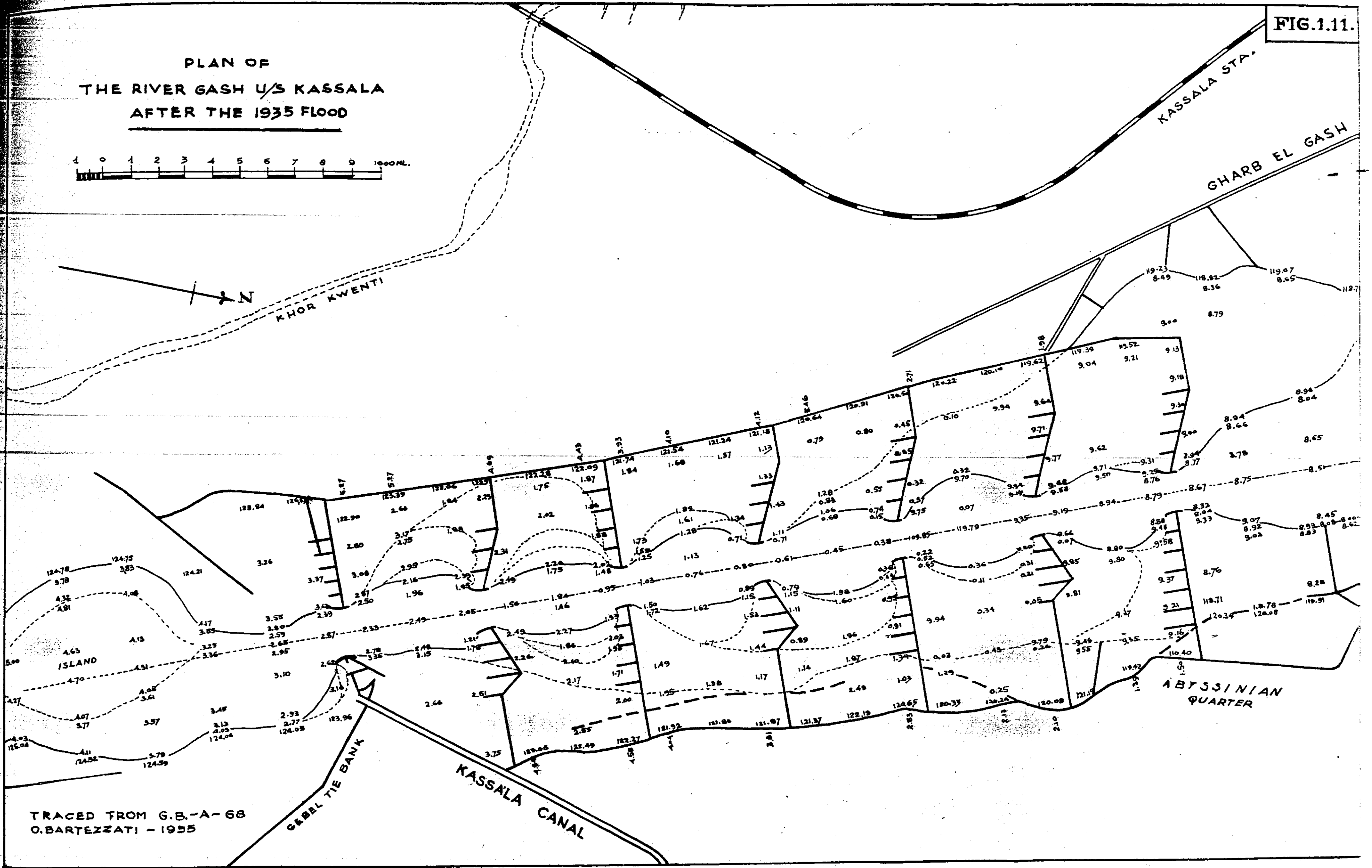
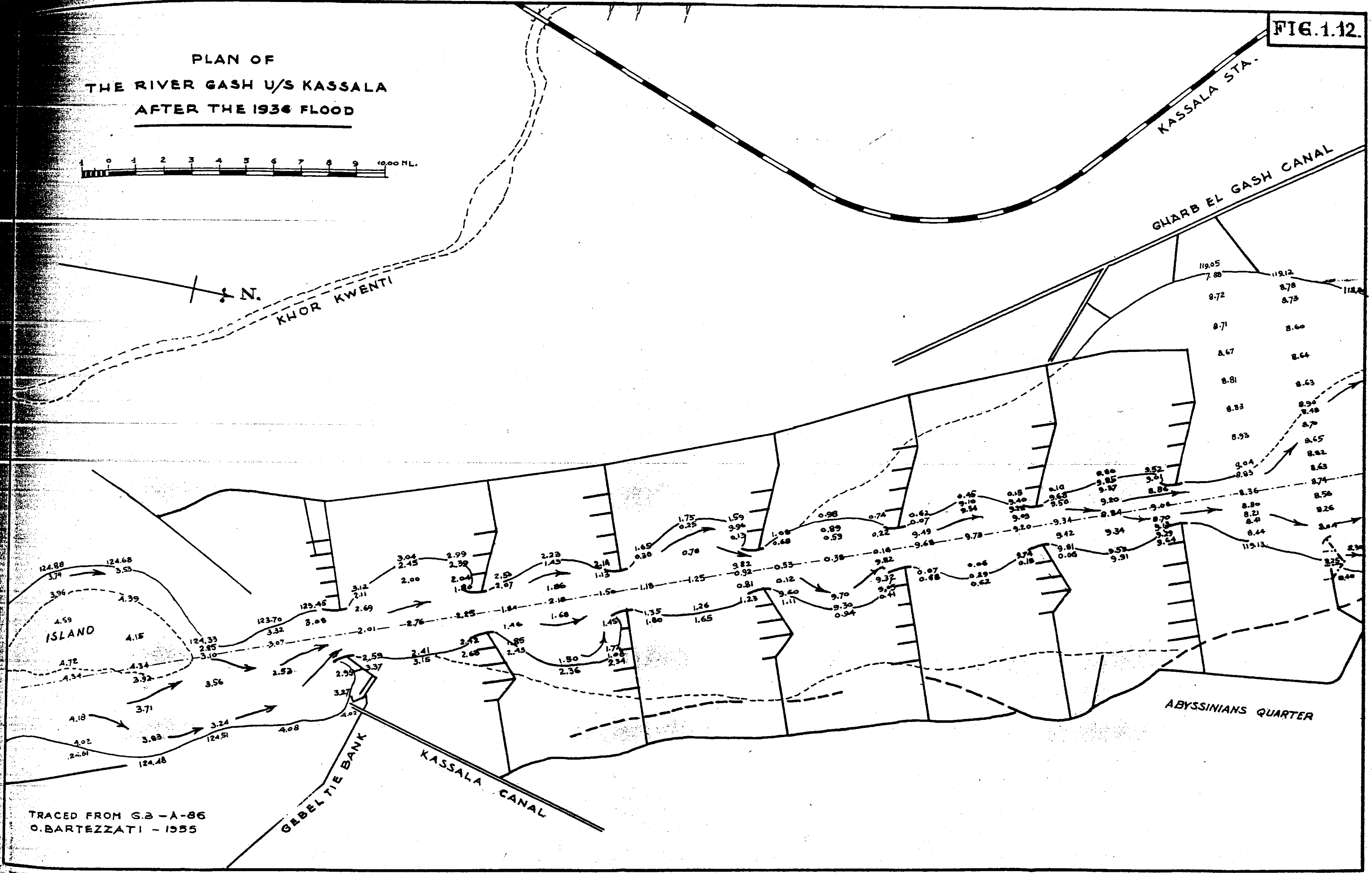

PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1935 FLOOD
1000 M.
N
KHOR KWENTI
KASSALA STA.
GHARB EL GASH
ABYSSINIAN QUARTER
ISLAND
KASSALA CANAL
GEBEL TIE BANK
TRACED FROM G.B.-A-68
O. BARTEZZATI - 1935

FIG. 1.12.

PLAN OF THE RIVER GASH U/S KASSALA AFTER THE 1936 FLOOD

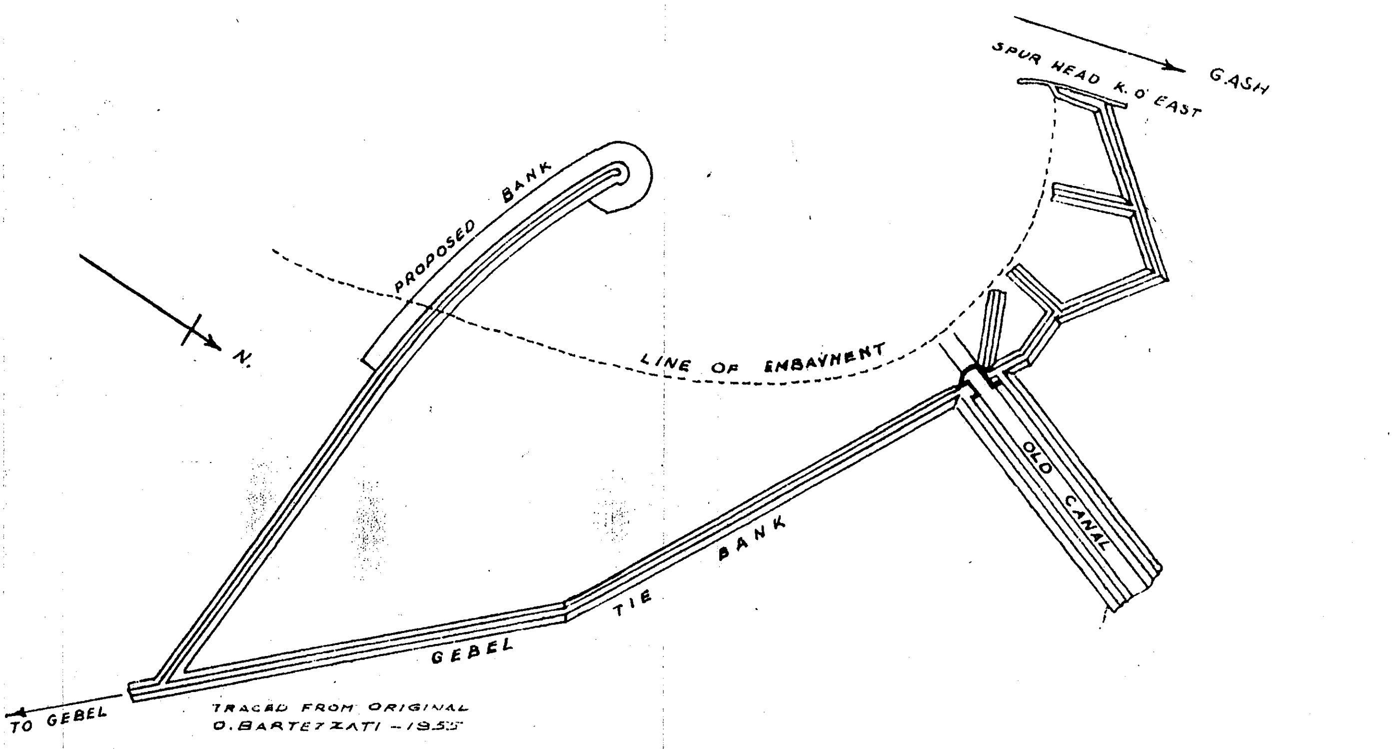


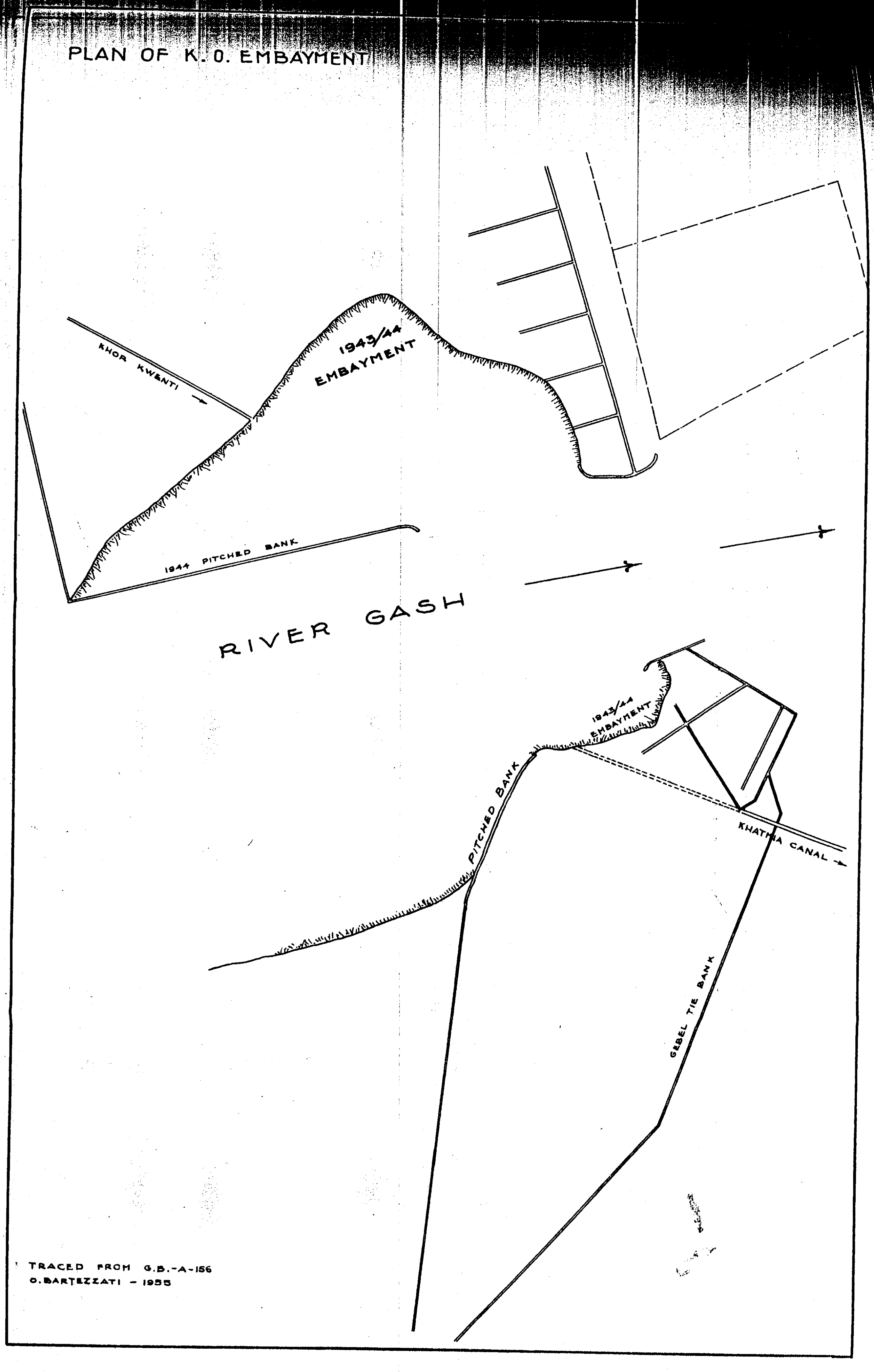
TRACED FROM G.B – A – 86
O. BARTEZZATI – 1955

FIG. 1.13.

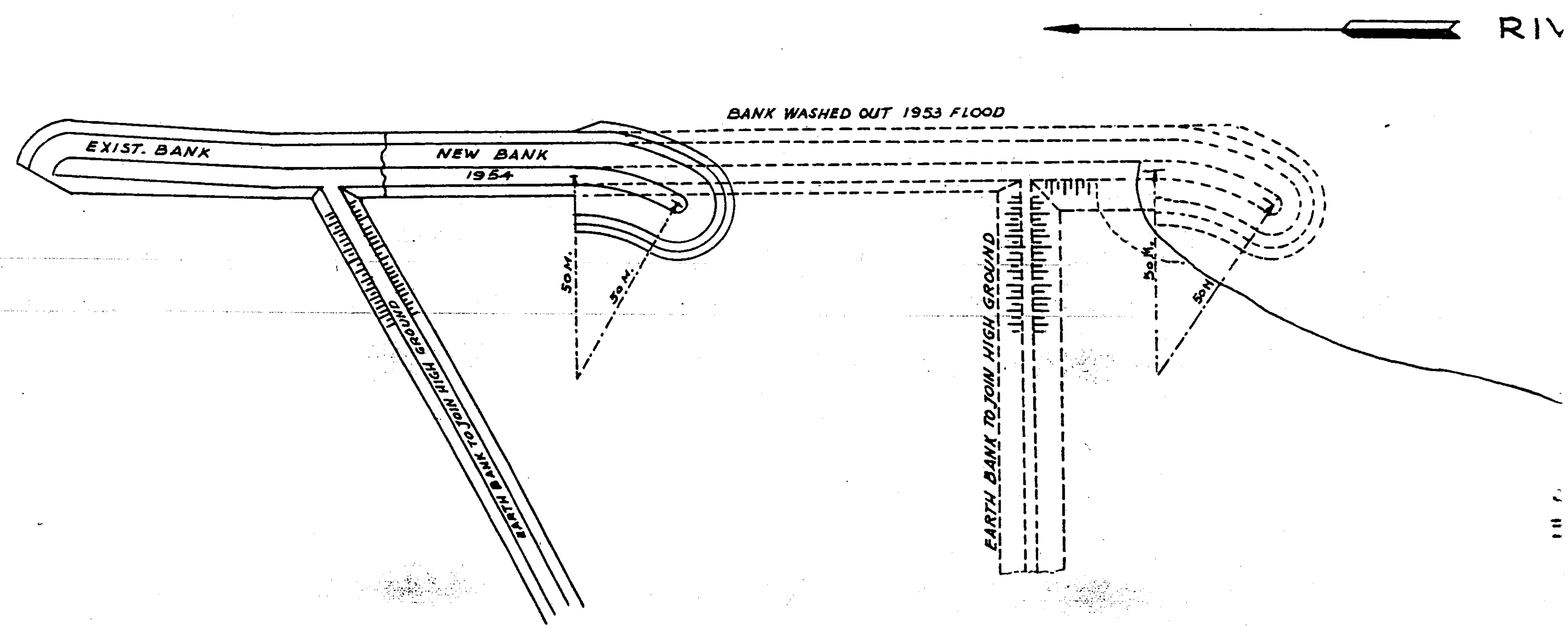
SKETCH PLAN SHOWING PROPOSED BANK SOUTH OF WEIR AT KASSALA

NOT TO SCALE



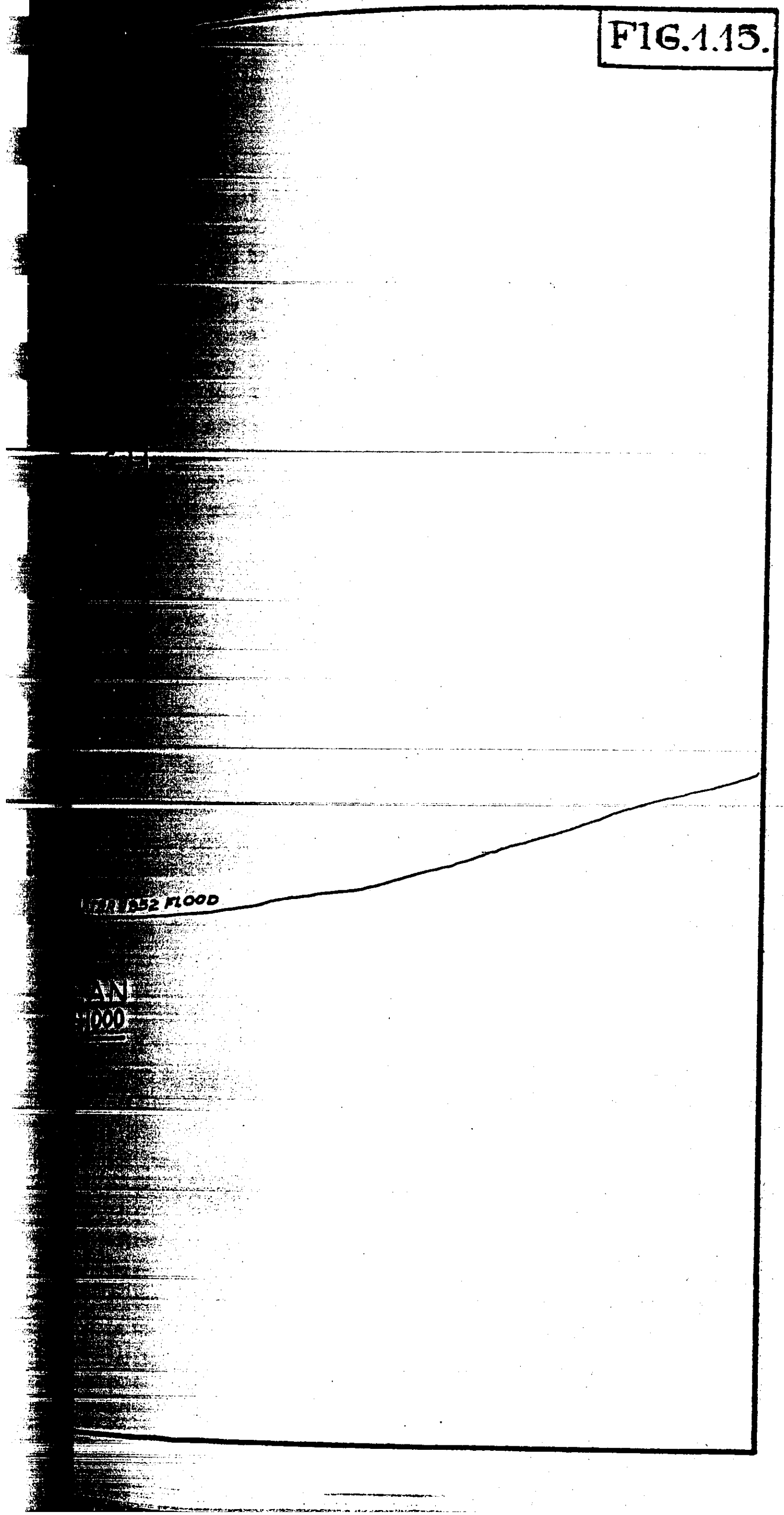

PLAN OF K. O. EMBAYMENT
KHOR KWENTI
1943/44 EMBAYMENT
1944 PITCHED BANK
RIVER GASH
1943/44 EMBAYMENT
PITCHED BANK
KHATMIA CANAL
GEBEL TIE BANK
TRACED FROM G.B.-A-156
O. BARTEZZATI - 1955

WEST TRAINING BANK
1953 AND 1954



TRACED FROM G.B-A-221
O. BARTEZZATI ~ 1955 ~

FIG.1.15.



SECTION II

KASSALA TO KHOR SALAAM ALEIKUM OFFTAKE

1. Introduction

This section deals with the Gash from below the bridge at Kassala (built in 1949) to just downstream the point where the Khor Salaam Aleikum now takes off the river, a distance of about nine and a half kilometres. Hydraulically, it is one of the most interesting reaches of the river and the problems it has posed in the past, and still poses today, have had the fortunate result that it is well documented.

No general description of the reach would be valid for all periods, because profound changes have occurred since records first began, and the appearance of the reach today must be very different from what it was fifty years ago. If we neglect Khor Kwenti, which for the last fifty years has been no more than a spill channel (and, indeed, gives no sign of ever having been more than that) the reach may be said always to have contained the apex of the delta. The constant and fairly steep slope of the reach above begins to flatten out and the instability noted in the lower part of that reach becomes more pronounced.

The upper part of the reach flows between the town frontages of Kassala and Gharb el Gash. As one goes downstream, the right bank beyond Kassala is rather barren and is only occasionally relieved by irrigated areas. On the other side, however, there is a continuation of the Kassala "sagias". Both the bed of the Gash and the "sagia" area are marked by an abundant and perennial supply of ground-water at little depth; during the dry weather the local pastoral tribes dig shallow wells in the bed of the river and thousands of camels, cattle, goats and sheep are watered daily. The wells, seldom more than five metres deep, are lined with brushwood; water is drawn up in a leather bucket on a rope, sometimes by means of a rough wooden winch fixed over the well and sometimes by direct lift. It is poured out into shallow, circular pans built up with mud, usually about two metres in diameter and about twenty centimetres deep, from which the animals drink. This is a feature of the

... throughout its course in the Sudan, but nowhere is it to ... on such a scale as at Tukruf, about five kilometres ... Kassala bridge.

Below Tukruf the banks of the river start to become ... with tamarisk trees. This tree will always be associated ... the Gash in the minds of those who have worked there. ... soft blue-green colour and the gentle sound it makes in the ... and great charm to the middle reaches of the river, and ... comes a time, each year, when one tends to regard it as ... only redeeming feature in a landscape which is otherwise ... beyond description.

This section will also deal with Khor Salaam Aleikum, originally a natural khor, which has been developed for a ... of purposes and is an excellent example of the ... difficulties involved in getting a satisfactory off-take from ... unstable river.

2. Early History

The earliest useful description of the reach is given by Dupuis in his "Note on the River Gash", attached to Sir William Garetin's "Report on the Basin of the Upper Nile" in 1904. He gives the dimensions of the channel at Kassala as 250 m wide and about half a metre deep. Below Kassala, he says, the river becomes more deltaic; the channel becomes narrower and deeper and spill occurs on either side. Proceeding downstream the spills become more and more numerous with several well defined channels amongst them until, six or seven miles from Kassala (about the end of the section we are dealing with) the Gash disappears entirely, overspilling into a zone covered in silt, where there are large areas of durra and jungle.

Dupuis does not seem to have fully appreciated the extremely heavy silt load of the Gash for he suggested that a large circular basin should be constructed to enclose the tract around the apex of the delta. The river was to drop its silt in the enclosed area and clear water would run out through regulators in the containing bank; these regulators would

become canal heads to a basin system in a concentric ring around the central circular basin. Subsequent experience has shown that any such scheme would have proved disastrous; it must be remembered, however, that Dupuis' visit was only in the nature of a reconnaissance and he had neither time nor opportunity to go deeply into the problem. The visit was in March so he did not see the river in flood.

At this time the Gash divided into two main channels known as the Eastern and the Western Gash. It seems probable that both ran out from the spill area described by Dupuis. These areas of sheet flow are locally called "balags" and are a common feature of the Gash delta. "Balag" is a Beja word, but neither English nor Arabic speaking officials in the Gash seem to have hit upon a better one and both constantly use it; for the same good reason it is proposed to use it in this report. A normal balag consists of a wide area of sheet flow; in some parts the flow may be quite swift and a number of small channels may be formed, although the water surface is continuous; in other parts the flow may be so slow as almost to stagnate. When a balag has been established for a season or two a dense growth of bush springs up, followed in course of time by forest. It will be appreciated that a balag forms a most effective silt trap.

In 1911 a project known as the Gulosit Basin was undertaken. The main idea is shown in Fig.1.1. A strong retaining bank was built across the Western Gash at a point where it was flowing in balag. The bank was turned back to higher ground at each end, thus forming a basin. A brick regulator was provided at the lower end to discharge surplus water on down the Western Gash.

The scheme operated fairly successfully for several years, but land levels were rapidly raised inside the basin by the deposition of silt and eventually this effect completely blocked the flow of the Western Gash. By 1918 the entire flow had been diverted down the Eastern branch, though some spill still found its way to Gulosit. In 1925 the Annual Report stated : "The Gulosit basin and wells and the Tugarar shaiyote are supplied by khors leading from the old Western Gash. At the point where this separates from the Eastern Gash, at Tukruf [illegible] bed is rising each year and the flow to Gulosit is [illegible] the periods of flushes. In a few years, under [illegible] circumstances, it appears that the water will fail to [illegible] wells at all". This statement is not immediately [illegible] at first sight seems to conflict with the earlier [illegible] that the Western Gash silted up before 1918, nor [illegible] conditions in the area consistent with a rising bed [illegible] main Gash. For an explanation reference must be made [illegible] 2.1 which is reproduced from a sketch made in a report [illegible] H. Thomson, the District Commissioner, in 1925. The [illegible] is a rough one and is not to scale, but together with [illegible] report to which it was attached, it gives a clear picture [illegible] situation and is in fact the only clear reference to it [illegible] been found. The report says : "When the Western [illegible] finally silted up at Futa, the main Gash Khor ran through [illegible] where the Eastern Gash branched off down what was known [illegible] Araka. This Khor Araka, though fairly deep, was never [illegible] size of the present Eastern Gash Khor which now branches [illegible] Tukruf and has replaced it, and in consequence it did [illegible] contain anything like the whole of the water which swung [illegible] east (at Futa) and much was spilled out ..... That [illegible] spilled to the west found its way easily down by Salaam [illegible] to the wells of Gulosit, more especially as the Khor [illegible] flowed fairly close to the old eastern irrigation bank. [illegible] however, the new Eastern Gash, which branches at Tukruf, [illegible] what is known as Khor Kurmuta, is a very large and deep [illegible] and can contain ..... nearly all the water in a moderate [illegible] ..... The inevitable result (is) that the water which [illegible] find its way down the old main Gash khor to Futa is getting [illegible] and less in quantity, and the state of this khor, through [illegible] silting, is such that within the next year or two it is most [illegible] likely that no water will ever go down it except in a bumper [illegible] (such) as 1916 or 1920".

Thus, we see that there were two bifurcations. The first was at Futa where the Western Gash silted up in about 1917. Thereafter there was a bifurcation at Tukruf into what could conveniently be described as the eastern and western branches of the Eastern Gash. The western branch at Tukruf silted up in about 1925. It is a common fallacy nowadays to say that the Western Gash took off at Tukruf; Thomson's report

and sketch make it clear that this was never strictly the case. It was the old main Gash which took off to the left there and Khor Kurmuta which went straight on northwards. Khor Kurmuta has now become the main Gash.

3. <u>Ankora Canal (Rabakassa)</u>

This canal was first opened in 1922. It takes off the west bank of the Gash about four and a half kilometres north of the bridge at Kassala and runs northwards to water land lying to the north of the Kassala sagia area. There are no records of its construction but it was probably developed from an earlier cut. A new head regulator was built in 1927 but was destroyed by the big 1929 flood. Thereafter the canal fell into disuse until 1940 when a new retired masonry head was built and the canal was re-excavated. The Italians tried to operate it after their occupation of Kassala and opened it, despite protests from the Sudanese staff, on an early spate; it promptly silted up. It was opened again in 1941 and has been in use ever since.

At its best Ankora canal has given as much as 1,000 feddans. It is divided into two alternative areas and in years when the canal has been drawing it has averaged about 500 feddans of cotton. Taking off, as it does, from a very unstable reach of the river, it has an unreliable supply and sometimes fails completely, which is a pity because the soil is excellent.

4. <u>Halenga Canal</u>

This cut was made in 1931. It takes off the east bank of the Gash rather less than a kilometre south of the off-take of Ankora canal. At first it had no head regulator and silted up regularly. Good areas, however, were watered in 1933 and 1934. Thereafter the Gash left the off-take, not to return until 1938. Unfortunately the cut silted up that year. There was continuous silt trouble until 1942, when a good supply was achieved. Since then anything between 100 and 300 feddans of cotton have been grown there with the exception of occasional years of complete failure. An open head, of the type normally built for misga offtakes, was built in 1952. Like Ankora, it is rather a "hit or miss" arrangement; the site of the offtake has been moved on several occasions to suit altered circumstances.

5. Town Protection and River Training: Up to 1940

It was mentioned in the last section that native quarters on both sides of the river were considerably damaged in 1926. This damage was caused by erosion and overflow and all the evidence suggests that it was due to a rise in Gash bed levels, although there are no surveys previous to 1926 to give a proper comparison.

Spurs of earth and brushwood were built out into the river in 1927 and 1928; the 1927 ones were washed away and more erosion took place on both sides; in 1928 the flood was a small one and the spurs were successful, though they were eaten away to some extent on the west side.

The system of plain sand spurs with occasional brushwood revetment was shown to be quite ineffective by the record 1929 flood which largely destroyed it. Fig. 2.2 shows the result. The bed of the river past Kassala town was by now 750 m wide and erosion was taking place on both sides. In addition, grave concern was felt about scour on the west bank above Ankora offtake; the Gash at that point was perched on a ridge and it was feared that further erosion might easily end in a major westward avulsion. It was in this year, it will be remembered, that Ankora head regulator was swept away. Heavy scour also took place below Ankora offtake.

Curiously, very little repair work was carried out on the spurs at Kassala after the 1929 flood. The 1930 flood was a small one and made little change in the Kassala area. The flow changed course repeatedly within the limits of its wide bed and eroded the west bank around and to the south of Tukruf.

The failure of the spur at K.0 West in 1931 and the way in which it swung the stream over to the east has been described in the previous section. The results can be seen

in Fig. 2.3. The main attack fell on the Abyssinian quarter of Kassala at about K.3 from the weir. Here the erosion rapidly developed into a crisis. At this point the ground levels fall away sharply from the river to the town; over one section there was at that time a fall of 80 cm in a distance of 350 m. At the height of the flood the water level was at least 30 cm above the ground level behind the small Kassala protection bank. Hundreds of sand bags and trees were strung out along the banks where a fast moving stream at least three metres deep was eating its way in at an alarming rate. By working continuously night and day the protection bank was just saved and a disaster narrowly averted. The Gash bed at K.3 was now nearly a kilometre wide.

The river eroded further the bank at Gharb el Gash and formed a big embayment 250 m deep and with frontage of 600 m just north of the newly made cut at Halenga, opposite Ankora head.

Following the 1931 flood a series of earth spurs were built to protect Kassala and, although they were finally eroded away in the 1932 flood, they served their purpose and warded off the main stream until the end of August. Another town protection bank was built as a security measure; it held intact while the old bank was cut through in several places. The new bank can be seen in Fig. 2.4. By 1933 the present spur at K.3 East had been built and the danger at this point was over. The situation after the 1933 flood is shown in Fig. 2.4.

1935 saw the completion of the spur system above Kassala, which included the K.3 West spur opposite the one built in 1933. At first the Gash came out axially from the last pair of spur heads and occupied a fairly narrow channel in the middle of its old bed. Early in August, however, it started to move over towards Gharb el Gash on the west side. The next development was the sudden appearance of another channel, this time on the east side, during a spate in mid August; this meant that there was a bifurcation just below the spur system and the two channels, one on each side of the old bed, persisted until the end of the flood. During the same flood erosion began opposite Ankora head and the Gash in general, widening its course in the Halenga-Ankora area.

A study of this reach of the Gash reveals some of the basic principles underlying the behaviour of silty rivers. The longitudinal section of the bed after the 1935 flood demonstrated the relationship between water slope, area of cross section and wetted perimeter at constant discharge. It showed a flatter slope where the river was narrow than where it was wide. This was most clearly observed near Khor Salaam Aleikum where the river had narrowed to a width of less than 100 m between well defined banks; here the slope was 1:2,200. Immediately upstream was a section nearly 300 m wide, where the slope was 1:650. Below the narrow reach the river widened out again to about 400 m with a slope of 1:670.

At low stages the Gash corrects variations in slope by meandering about in the wide reaches. During spates it fills the whole of its bed and cannot meander; consequently it evens out the slope. For a given bed-width there is a critical mean slope. Above this the river will either erode its banks on alternate sides to adjust its slope downwards by lengthening its course, or it will erode both sides simultaneously to increase the wetted permiter.

An interesting discovery was that the average slope through the spurs from K.0 to K.3, where the river was constrained to go in a straight line, was slightly steeper than the general average in the reaches both upstream and downstream. Thus, energy was dissipated at a slightly higher rate in the reach where the spurs are than elsewhere, in spite of the fact that they narrow and straighten its course. This might be explained by the fact that the river successfully contracts and expands as it passes each of the seven pairs of spurs. The additional energy absorbed in so doing may account for the slight increase in slope.

Further down the delta, variations in the bed-width of the Gash are not sufficiently pronounced to demonstrate these effects.

During the 1936 flood erosion further widened the river on the west side just above Tukruf. At Kassala itself a light stone and brushwood head had been built on to the old earth spur at K.3.5 East which can be seen in Fig. 2.4. Early in the flood the flow ran to the east after leaving K.3 and set against the spur and breached the shank. This was followed by considerable erosion further downstream and by the end of July the attack had reached the Kassala town protection work, carried out by prisoners under the District Commissioner, saved the day but the anxiety remained until the end of the flood and constant watch had to be maintained on the revetment.

Fig. 2.5 shows the results of the 1936 flood and, in dotted lines, the work carried out to protect Kassala after it. These works consisted of a light stone spur head on the K.3.5 East spur which had been damaged, and five earth spurs built out between K.4 and K.5. Of these, the downstream three had transverse banks built near the head so as to form silting basins.

During the 1937 flood the spur at K.3.5 East held and at first it seemed as though it would deflect the stream from the Kassala frontage. However, the flow soon swung back to its 1936 channel. The K.3.5 East spur seemed to have very little effect on the flow further downstream and ground was steadily lost. By the end of the flood the silting basins had been removed and the upstream spurs reduced to mere stumps. There was little appreciable change in the river below Kassala; the erosion on the west bank just above Tukruf did not recur and the stream lay well over on the east side heading straight for the narrows below the old bifurcation.

Before the 1938 flood the town protection works were repaired. In addition, the stone head built in 1937 at K.3.5 East was doubled in length to form a deflector and the first earth bank at K.4 East was provided with a masonry head, similar to that built in 1937 at K.3.5.

Again, the spur at K.3.5 East did not deflect the stream as had been hoped, and the shank of the K.4 East spur was strongly attacked early in the flood. Energetic measures throughout one night, in the face of a very high spate, just saved it. In August the river rose so high that the old

...inal bank at K.3.5 was topped. The spill was checked by ...ison labour and the main retired bank was held. Although ...e ends of the earth spurs were eroded and the river, at ...mes, ran right up against the transverse banks of the ...lting basins, these training works held out through the ...lood. Later, another channel developed, swinging west below ...3 and heading for Gharb el Gash. Conditions after the ...lood are shown in Fig. 2.6.

One kilometre downstream of the Halenga offtake water began to spill to the east into a wide depression which runs into Khor Shaigia and does not rejoin the Gash again until below the offtake of Khor Salaam Aleikum. The embayment at Khor Shaigia swung the Gash over to the opposite bank into the old embayment above Tukruf. Later in the flood the river straightened out again and left both embayments clear. The movement can be seen in Fig. 2.6. The outline of the river in 1933, five years earlier, is superimposed in interrupted line on this drawing to show the changes in the reach over this period.

It was decided that immediate action must be taken at Khor Shaigia because of the danger of by-passing Khor Salaam Aleikum, but that nothing should be done at Tukruf until it was seen what effect the Khor Shaigia protection would have. The unstable conditions below Kassala were attributed to the effect of the spur system between K.0 and K.3. There, the meandering of the river had been prevented and its course shortened so that the slope was steeper. The river appeared to be trying to adjust itself further down by meandering before it entered the relatively stable channel below Tukruf. This seems a reasonable explanation of the development. It was hoped that the Gash bed above Tukruf would prove wide enough to allow the necessary meandering to take place before the river entered the stable reach below, otherwise a definite fall in the form of a weir would have to be considered to prevent the instability going further downstream. Serious instability did not, in fact, continue below Tukruf and no such fall was put in. Much of the subsequent trouble at Khor Salaam Aleikum was, however, due to a measure of instability there and it is interesting to conjecture what would have been the effect of

such a fall built at Tukruf in 1939; it would have been a very risky undertaking.

At Khor Shaigia a strong earth bank was built across the embayment. It was pitched and guarded by an apron and the pitching was carried along the river bank for 30 m to the north and for 240 m to the south. At Tukruf a guard bank was placed across the old western khor and the banks of the river were dressed back to a slope of 2:1. Stone was stacked there for future work or in case of emergency. The line of the Khor Shaigia bank is shown for convenience sake on Fig. 2.6 although that drawing is of the 1938 flood.

The 1939 flood was a small one and the Kassala town protection was undamaged. Brushwood groynes, built before the flood to protect Gharb el Gash, were hardly needed. The river, which had straightened out near Khor Shaigia at the end of the 1938 flood, remained obstinately reversed and the new bank spent the 1939 flood high and dry; Tukruf embayment was also untouched. Instead a mild embayment on the west side developed just upstream the Halenga offtake which threw the Gash across to the east, causing further slight erosion above Ankora head. The reach from Tukruf to Khor Salaam Aleikum was unchanged except for a slight "roughening" of the curve above Khor Salaam Aleikum.

Before the 1940 flood some brushwood groynes were put in at the Halenga embayment and appear to have served their purpose - though little is known about that flood, owing to the enemy occupation of Kassala.

6. Town Protection and River Training: 1941 to date.

The 1941 flood was a high one and did considerable damage. At the beginning of the flood the river flowed out nearly straight from the K.3 spurs, but soon it fell over to the east and made a set at the spur at K.3.5 East and, past it, on to the shank of the K.4 East spur. The latter carried away, the masonry head partly collapsed, erosion took place along the river bank and part of the earth spur system was lost. From here the river swung back west again and set up further erosion at Gharb el Gash. It was possible to hold up much of the erosion by brushwood.

The flow swept strongly past the Khor Shaigia bank, and at first it seemed that the closing of this embayment had had the desired effect of preventing the reverse swing into the Tukruf embayment. Hopes were disappointed at the end of August when the full flow swing across into the embayment and again started erosion there.

Experiments were made that year with a flexible form of continuous brushwood mattress for bank protection; they were not unsuccessful but required a lot of costly maintenance during the flood. Triangular brushwood spurs, as described in the previous section, still proved the most economical form of temporary protection. In fact nothing better has been found to date.

For the 1942 flood, the defence line on the east bank at Kassala was retired to the line of the erosion of the previous flood. The tips of the old earth spur banks, as then existing, were given some slight reinforcement of loose stone. Along the bank, at the site of the demolished K.4 East spur, a short length of stone pitching was built with small masonry sub-spurs to protect it. Other small masonry spurs were added at intervals downstream. The design of these spurs was a triangular prism dipping down into the river bed. It is unfortunate that no drawing, either of the spurs, or of the general layout of the protection works, can now be found. Further small spurs of the same design were built at Gharb el Gash. These defences were well tested by a good flood; one of the stone tipped earth spurs was decapitated but otherwise there was no damage. The river again divided below K.3 and the western branch (the stronger of the two) caused some further erosion at and below Gharb el Gash.

Further downstream, heavy erosion took place above Halenga canal offtake and south of Ankora head; Tukruf embayment was enlarged even more.

Until 1942 the bed of the Gash near the offtake at Khor Salaam Aleikum had been relatively stable, sometimes showing

scour and sometimes silting. After 1942, however, it started to give trouble. It has been mentioned earlier how, as the reach widened, it steepened its bed slope. This was reflected at the offtake site by erosion of the right-hand bank, opposite the offtake, and by scour in the bed, causing a general lowering of levels to the grave detriment of the supply to Khor Salaam Aleikum.

Before the 1943 flood a 75 m length of pitched bank was built on the east side at K.3.75, and other embayments from K.3 to Halenga were protected with the small sloping masonry spurs previously described. More such spurs were put in at Gharb el Gash. Unfortunately, again, no layout of the arrangements is left. At Tukruf a length of 100 m of stone pitched bank was built out from the south end of the embayment and the line of it was extended by a groyne, 74 m long, made of boards attached to old pipes driven into the Gash bed, see Fig. 2.7. The flood, that year, set mainly against Gharb el Gash but the protection there proved adequate; Kassala was not heavily attacked. The river then swung over to the Halenga embayment and outflanked the stone spurs there. Later in the flood the river straightened out and both the embayment at Gharb el Gash and at Halenga silted up.

The bank and groyne at Tukruf were most successful; the river was kept over on the east side and the embayment silted heavily. The Khor Salaam Aleikum reach continued to get wider and erosion on the west side south of the regulator was causing a swing to the east just in front of it.

In 1944 the Tukruf bank was extended to 400 m long. It proved satisfactory so far as it went, but during the second half of the flood a cross current headed into the embayment and set up further erosion. This was caused by earlier erosion north of the Khor Shaigia bank. It is a general rule that, when erosion is set up by a meandering river, the eroded material is carried downstream on the same side and deposited on the inside of the next bend. This happened here; a hard sand bank was formed just opposite the Tukruf embayment which accentuated the swing-over there. The position is shown in Fig. 2.7 which shows the work done at Tukruf in 1943 and 1944, nd also the steps taken in 1945 to complete the scheme. No damage was done in 1944 to Kassala or Gharb el Gash protection and the Halenga embayment was not increased. Some further, slight, erosion took place between Gharb el Gash and Ankora canal on the west bank.

In 1945 the last instalment of the Tukruf bank was put in; this consisted of a heavily armoured bank provided with an impregnable head, built out from the north side of the embayment, 150 m long and on the same alignment as the southern portion of the bank. The final layout is shown in Fig. 2.7; the Tukruf embayment is crossed by an "interrupted spur" with a gap of about 400 m between the two parts of the bank. It has proved to be an excellent piece of work; most of the embayment has been reclaimed, leaving the bank between the spurs in the typical erosion curve which is formed upstream of an impregnable head.

At Kassala another 178 m of pitched bank were built at K.4. The flood caused more erosion at Gharb el Gash and then swung hard to the east into the Halenga embayment and back again to the west. From here, northwards, the meandering was damped by the Khor Shaigia and Tukruf banks. About one kilometre upstream of Khor Salaam Aleikum there was some bank erosion on the east side over a length of about 300 m. The eroded material was deposited downstream on the same side causing an embayment on the west side about 150 m long and 30 m deep. Thus a meander was being set up in the Khor Salaam Aleikum reach just above the offtake, which was cause for concern.

The erosion at Halenga, already described, reached a pitch during the 1945 flood at which there was a danger of a break-out to the east which would outflank Khor Salaam Aleikum. A scheme was therefore prepared for the protection of the embayment there on very much the same lines as had proved so successful at Tukruf. The layout is shown in Fig. 2.8. The work was carried out in two stages: the south part in 1946 and the north part in 1947. The gap between the spur heads this time was set at 250 m. Three more masonry triangular spurs were built between K.3.5 and K.3.8 East.

The 1946 flood was a large one. On leaving K.3 the river, at first, swung west and set up more erosion at Gharb el Gash - at one point to a depth of 75 m. Later, in August, it swung east, attacking Kassala and eroded a length of one and a half kilometres of bank downstream of K.4. Kassala was again threatened with flooding. The southern part of the new Halenga protection bank silted, as was hoped, but the unprotected northern part of the embayment eroded still further.

There was little trouble beyond Halenga until the Khor Salaam Aleikum reach where the meandering increased and widening and scour continued. In particular, the embayment on the west about half a kilometre above the head developed still further.

An interesting experiment was tried out that year. There was a prominent nose of land projecting from the west bank, just north of Gharb el Gash village, which was deflecting the flow across towards Halenga. A cut was made across it before the flood, in the hope that thereby the nose would be removed. Unfortunately the cut obstinately remained just a cut throughout the flood and its object was defeated.

Before the 1947 flood, the northern part of the Halenga protection was built and the pitching of the southern part was raised 50 cm as a result of the observed water levels of 1946. At Kassala, the pitching on the east bank was extended a further 500 m to K.4.5.

The 1947 flood was a very small one. Flow kept to the east, after leaving the spurs, and ran along the new town pitching to K.4.5. There was little erosion after the end of the pitching until K.5, but thereafter it increased. There was no erosion at Gharb el Gash. The protected area at Halenga silted up but there was some erosion north of the Khor Shaigia protection. Below Tukruf, about one and a half kilometres downstream, the east bank eroded over a length of about 600 m, in the worst place to a depth of 150 m. The narrow, stable reach was losing its virtue with a vengeance ! The embayment on the west side, 500 m upstream of Khor Salaam Aleikum offtake, noted the previous four years, increased again - by as much as 15 m at one place.

In 1948 a further extension of the pitched bank at Kassala was put in from K.4.5 to K.4.75. This is shown in Fig.2.9. This is the first comprehensive picture of the Gash in the Kassala reach since 1939 which is left to us; the 1939 survey is not reproduced here as there was little change that year and the 1938 survey is fairly representative. In all that period also, due to the war and its aftermath, there was no vertical aerial photography. The Kassala town protection as shown in the drawing does not quite tally in length of pitched banking with the construction reports which remain of it. It does not appear to be as long as the sum of the various reported instalments; possibly this is due to small sections having been washed away at various times, of which no record remains. The disagreement, however, is not great and it can be taken that, whatever may have occurred earlier. the drawing shows accurately the Kassala town protection after the 1948 flood.

The flood kept to the Kassala side and did no damage until it had passed the end of the pitched bank, where a little erosion took place around K.5. Then it swung hard over to the west side, causing slight erosion there before swinging back east and removing about 60 m length of the Khor Shaigia pitching at the south end: this part of the pitching had been built without an apron. The embayment 500 m above Khor Salaam Aleikum increased still further; eroded material was deposited in front of the regulator and gave rise to false hopes that the scouring tendency of the bed had been reversed.

History was made in 1949: a road bridge was built between the spur heads at K.3 ! Up till then a "corduroy" crossing had been laid each year across the river bed to carry traffic across the soft sand, which is impassable to normal vehicles; during the flood motor traffic ceased and those who wished to cross the river waded. Those who were too exalted to wade or were otherwise precluded by age or infirmity seated themselves on an "angareeb", a native bed-stead made of wood and strung with rope. This was hoisted aloft on the shoulders of four burly citizens, carried across the river and set down on the far side. When the river was flowing strongly it often happened that the heads of the porters disappeared completely and the occupant of the "angareeb" occasionally got a wetting.

It was not unknown for unpopular passengers to be ducked intentionally ! However, the mode of transport, though no doubt usually a genial one, was not quite in harmony with twentieth century ideas in communications; its inconvenience may be best appreciated when it is remembered that Kassala, an important town and a provincial capital, and its railway station are on opposite sides of the river !

The bridge is a reinforced concrete structure carrying a single lane road and two footways. The piers are carried on reinforced concrete slabs founded over three metres below average bed level of the Gash. These slabs, in their turn, are carried on reinforced concrete piles. The piers themselves are built of brickwork and are 1.83 m thick by 7.93 m long (in the direction of the current) at Gash bed level; they taper slightly upwards. There are six equal spans, each 20 m clear. This design was not the first to be produced; an earlier design had been evolved by the Gash Board engineers. This design, a steel Pratt truss, was aimed at giving the minimum possible obstruction to the water-way, so the spans were made 45 m long. Again the piers were to be founded on reinforced concrete slabs, this time founded rather less than three metres below average Gash bed level and again carried on concrete piles. The design appears, now, to have been an unnecessarily cautious one as the present structure, though presenting considerably more obstruction to the flow of the river, has had no unfortunate effects so far.

The south end of the Khor Shaigia pitching was repaired and provided with a proper loose stone apron. It was also extended 74 m to the south. The course of the river upstream Khor Salaam Aleikum was straightened by building a curved, stone-pitched bank across the embayment and removing the promontory below. The work can be seen in Fig. 2.10. This will be discussed later.

The flood kept to the east after leaving the spurs and set up some erosion downstream of the Kassala protection bank and at K.5.5, where that part of Kassala known as the Bornu village projects into the stream. Again it swung sharply west to return and start erosion south of the Khor Shaigia bank; this time the erosion was held by brushwood and no damage was done to the pitching. No trouble occurred further north until the Khor Salaam Aleikum reach, which is treated separately.

Before the 1950 flood, the pitching at Khor Shaigia was extended southwards 50 m and the last 37 m of the existing pitching was realigned to fit into a plan for the eventual continuous protection of the bank from Kassala to Tukruf. Though it was a big flood it did no damage in the Kassala reach.

A general extension of the Kassala town protection bank was designed in 1951, intended finally to connect into one scheme with the Halenga and Khor Shaigia banks. A further 300 m length was designed as a first instalment to carry on in a direct line with the existing bank from K.4.75 onwards. 1600 m3 of granite rubble and 300 m3 of gravel were stacked on site in neat rectangular stacks along the line of the proposed bank. At the time of writing, the extension has never been built; the stock piles have acted excellently as spurs and protected the fore-shore from further erosion so that there has never been sufficient urgency to get the job done in the face of competition from other, more pressing works.

The 1951 flood was a miserably poor one but at least it did no damage and no further works were needed in the reach upstream of the Khor Salaam Aleikum area. The 1952 flood, however, was a strong one and started violent erosion on the west bank between Ankora head and the southern extremity of Tukruf spur. The base of the spur was attacked and was only saved by sand bags and brushwood. At the same time the spur head at K.3.5 East was damaged. After the flood, the K.3.5 East spur was repaired to its original design but the Tukruf spur was provided with a head made by bitumen sealing in the manner described in the previous section. The 1952 erosion and the layout of the new work is shown in Fig.2.11.

The 1953 flood treated the new Tukruf spur with nearly as little respect as it treated the other bitumen spur upstream the entrance to the spur system. It did not quite remove it, but the spur heaved and cracked and was on the point of disintegrating when the Gash suddenly moved over to the far

side of the river and left it. Subsequent levels show that part of the spur has actually heaved upwards; no attempt will be made to explain this remarkable phenomenon ! The spur was not repaired after 1953 as the Gash seemed to be far removed from it and, indeed, has not been near it since.

Fig. 2.12 shows the river after the 1953 flood. There was little change after the 1954 flood, and the drawing can be taken as a very fair picture of conditions at the time of writing.

7. Khor Salaam Aleikum Offtake

It has been mentioned that originally Khor Salaam Aleikum was a spill channel running northwards in a balag area. The water fed other balag areas to the north which were of importance both for irrigation and for domestic water supply.

By 1927 it was noticed that the balag water in the neighbourhood of Khor Salaam Aleikum was still moving north, but that its main weight was further over to the east than before, and by 1929 it was starting to form a definite khor for itself inconveniently removed from its earlier course. This khor, as usually happens in such cases, started from the north, or downstream, end of the balag area and began to cut its way back southwards through the balag; it eventually became the main Gash khor. In 1932 Mekali canal virtually failed due to the drying up of the balag from which it was fed. During this period Khor Salaam Aleikum continued to run, but it was insufficient for its purpose and alternative sources of supply for Mekali canal were not altogether successful. The supply of domestic water from Gammam was also suffering.

The above paragraph serves merely to give a historical back-ground to the Khor Salaam Aleikum project which was started before the 1936 flood. The points touched on will be dealt with in detail in the next section, which describes the Khor Salaam Aleikum channel. Here we are discussing only the offtake site and head works.

The first instalment of the project was the enlargement of the natural khor to take 15 m3/sec and a temporary head-works consisting of ten 42-inch diameter "Armco" pipes with "Calco" doors set in an earth bank. This was built on the same site as the present head. The Gash above and below the site was about 75 m wide and was running between well defined banks. It must have seemed a very suitable place for an offtake. There was, at the time, some concern that the deep khor which the Gash was cutting back from the north would retrogress further and cause trouble, but in fact the threat never developed.

The new head was put in without a head wall and, although it continued to function throughout the flood, it gave a lot of trouble and finished up in a very battered state. The results of the scheme in general, however, were most encouraging and the following year, 1937, saw the building of a masonry regulator and the enlarging of the khor to take a discharge of 20 m3/sec. The design of the head-works, which are still in use, is shown in Fig. 2.13. It was set so that its centre line made an angle of about 50° with the centre line of the river.

It has been noted earlier that until 1942 the Gash near the offtake had been fairly stable. All the same, the new head was never altogether satisfactory even from the start; it did not draw well from low stages of the river. The dwarf-wall above the upstream pitching was opened in 1938 but as early as 1941 consideration was being given to the possibility of artificially raising river levels.

It was after 1942, however, that the trouble really began. The Gash bed scoured and the bank opposite the head eroded; the river also started to meander further upstream. The situation deteriorated steadily and by 1947 the bed level of the Gash opposite the offtake was, in places, as much as 90 cm lower than the floor level of the regulator.

In 1948 the meanders increased still further, but bed levels at the offtake rose slightly. This silting was most probably due to deposition of material from erosion further upstream, but it was hoped, at the time, that it might also mean that the cycle had reached the turning point and that natural silting might be the trend in the future. Plans for

raising river bed levels artificially were therefore postponed until it could be more clearly seen what was happening.

In preparation for works, test pits ~~filled with~~ broken brick were made to measure scour. The 1947 flood showed a maximum scour depth of 90 cm. Further inspection of the same pits, which had not been re-filled with brick, showed the brick at the same level after the 1948 flood.

Meanwhile an attempt was made to straighten the course of the Gash upstream the head. A promontory was removed and an embayment filled up; the made-up bank, 195 m-long, was curved smoothly and pitched with stone. The work can be seen in Fig.2.10; it did not produce the desired effect. The current struck hard against the pitched bank, sweeping around the curve and then crossed sharply across to the east bank and set up severe erosion; it did not return to the west bank until downstream of the head. Silt was deposited in front of the offtake. It seems that the curved bank acted on the river at the point where, due to meandering, it was changing direction in any case; the shape of the bank was such that it accentuated rather than damped the swing over as had been hoped.

The following year, 1950, the pitching was extended in a straight line for a further 100 m downstream and the Gash bed was remodelled by scraper to lead the deep channel along the left hand side past the regulator, and the bank along-side was cut straight. The project is shown in Fig. 2.14. The Gash bank on the far side was strongly protected to prevent further erosion.

During the flood the new scheme served fairly well at first, but as time went on the Gash swung back again over on the east side. This tendency was continued during the 195[illegible] flood and the supply to Khor Salaam Aleikum became very poor indeed. The Gash bed was still scouring and it was decided to build a weir across it just downstream of Khor Salaam Aleikum head.

The weir was made of concrete: it was 65 m long at crest level and the two banks of the river were retained by pitching in cement mortar. A cross-section is shown in Fig. 2.15 and a layout plan in Fig. 2.16. Retired banks were built or 3 Km on both sides of the Gash – these are shown in Fig. 2.17.

The effect of the weir on the river was exactly what had been hoped for. Gash bed levels have been raised to what they were before the scour started. The whole story can be seen from the cross-sections shown in Fig. 2.18. However, the beneficial effect on Khor Salaam Aleikum was not immediately apparent. Arrangements had been made for placing stop logs along the crest of the weir and before the 1952 flood a single row (20 cm high) was put in position, across the eastern half only, in an attempt to push the river back on to the west side. This failed completely: the river remained obstinately on the east and again a sand-bank was formed in front of the regulator. The problem of a good supply to Khor Salaam Aleikum had not been solved.

The next attempt was made in 1953. A new head regulator was built 250 m upstream the existing head; this structure consisted of fifteen 27-inch concrete pipes set in a concrete head-wall at the downstream end of the existing pitching. It fed into Khor Salaam Aleikum by a cut 400 m long; both pipes and canal were set at about 45° to the centre line of the Gash, but the head-wall, which was vertical, was flush with the bank. The design was adopted in order not to interfere with the natural stream just upstream the original regulator, which was still intended to be the main source of supply.

The new supply cut silted very rapidly; the works, however, had been carried out as cheaply as possible and it is estimated that even during the short time the head was working it drew enough water to make it an economic undertaking. The 1953 flood was a very big one and the supply from the old head was quite good that year.

It was thought possible that one of the reasons for the rapid silting of the new cut was that, as levels in the Gash rose, so did levels in Khor Salaam Aleikum, and so the new cut, which fed from one into the other, did not benefit by extra head upstream on high spates (which otherwise might have scoured it) because they were immediately balanced by extra head

downstream. It was therefore decided to give up the idea of the new head supplying Khor Salaam Aleikum and let it supply a new canal called Fota canal. The canal was dug and in 1954 it watered a moderate area before it silted up again. The 1954 flood, however, was a very poor one and at the time of writing it can be said that Fota canal has never been properly tested.

One of the troubles at Khor Salaam Aleikum head was that, of the five openings in the regulator, the three upstream ones normally silted and water only passed through the remaining two. As a result of advice from Sir Claud Inglis, who saw the structure during the dry season, the downstream masonry "nose" was extended a metre out into the stream and on the upstream side the bank screening the offtake was cut back. This worked very well during the 1954 flood and though there were never more than low levels in the Gash, such water as passed through the regulator, passed evenly through all five openings; another improvement was that no silt bar formed in front of the regulator. Nevertheless, the head did not draw enough water from a low Gash to meet all commitments, so it can be said that the problem of Khor Salaam Aleikum remains unsolved, and although supplies have been much improved, alternatively supplies are now being sought further north.

8. Pitching

The subject of pitching banks for protection against erosion has been touched on so often in this section that it seems an appropriate place to discuss constructional details. The present system of pitching is shown in Fig. 2.15. The footing is built of loose granite rubble founded about 2 m below existing bed level; it is 3 m wide and varies from 1 m to 50 cm thick. As has been stated earlier, the writer is of the opinion that there is a case for crated rubble footings in places where extreme turbulence is likely or where velocities may be exceptional, such as spur heads or the downstream "noses" of masonry regulators. Crated rubble has not been employed recently.

The banks are dressed back to a slope varying with circumstances, but usually in the neighbourhood of $1\frac{1}{2}$:1. A layer of 15 cm of gravel is first laid down and then granite rubble is hand placed on top to a depth equal to the greatest dimension of the stone, which should be about 35 cm. The rubble is packed with stone spalls to prevent undue movement.

When slopes greater than $1\frac{1}{2}$:1 are pitched the pitching has to be built in cement mortar. This has the disadvantage that flexibility is lost and it becomes dangerous if used on made up ground. The alternative is to use stone grouted with a plastic bitumen grout. A suitable mix for this purpose has not yet been found. The problem is to find a suitable filler. In Egypt quarry dust is used, but this cannot be obtained locally to the Gash and no other product can be found that is sufficiently fine. The suggestion of using cement has been put forward but an analysis of the cost immediately puts that out of court. It seems a field which might well be further investigated.

The importance of the gravel backing cannot be over-stressed. Particularly with a river like the Gash, which is subject to sudden fluctuations of level, it is important to have this reverse filter effect to prevent the back-fill from being sucked out with the percolated water when the latter runs out due to a sudden drop in level in the river. In nearly every case of failure recently the cause has been found to be the withdrawal of the back-fill; this is nearly always prevented by a gravel backing.

Building pitching without a footing, as was done at Khor Shaigia, is fatal. It is almost bound to collapse with the first attack. The footings involve a very large quantity of stone and reductions of them are likely to be a temptation to the engineer who is trying to economise; such economies are false.

FIG. 2.1.

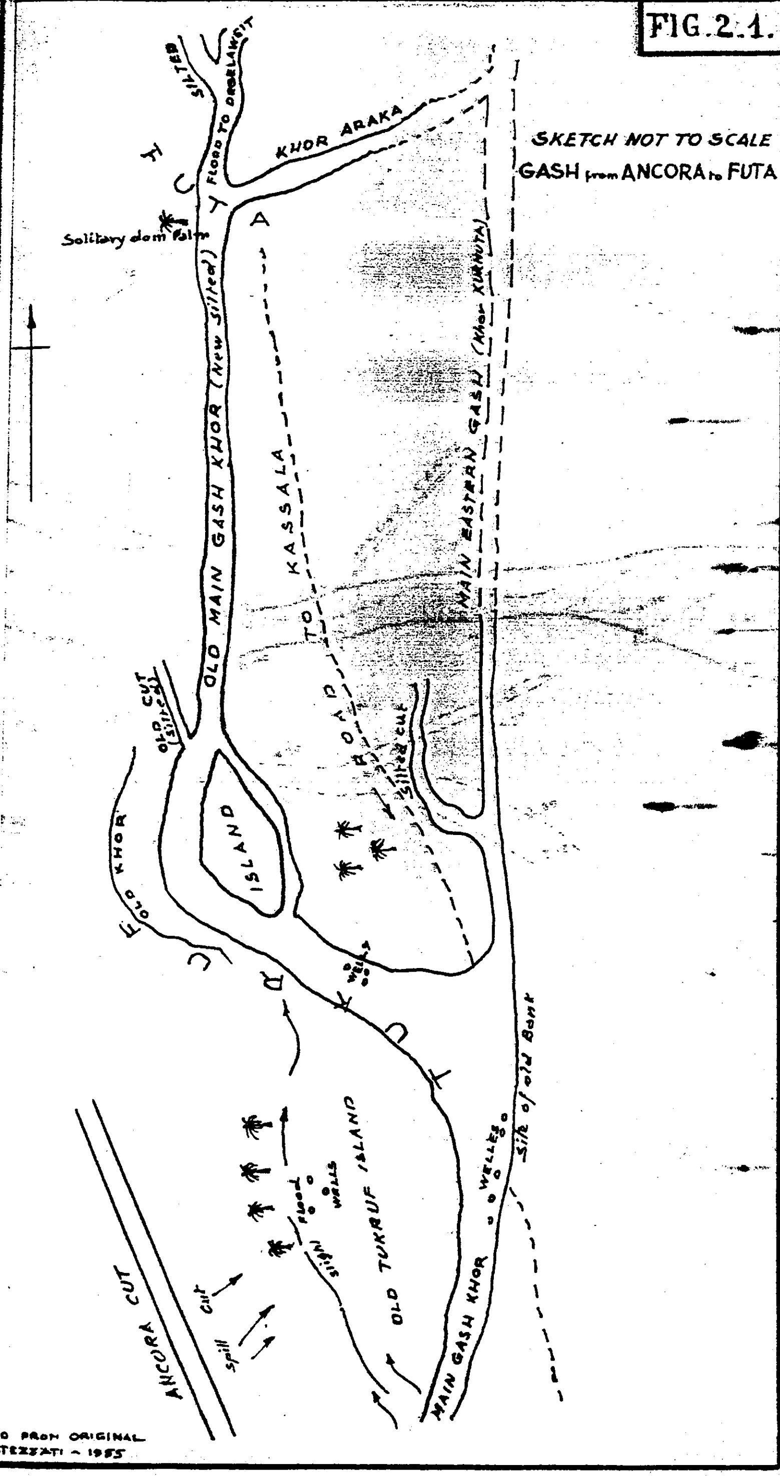
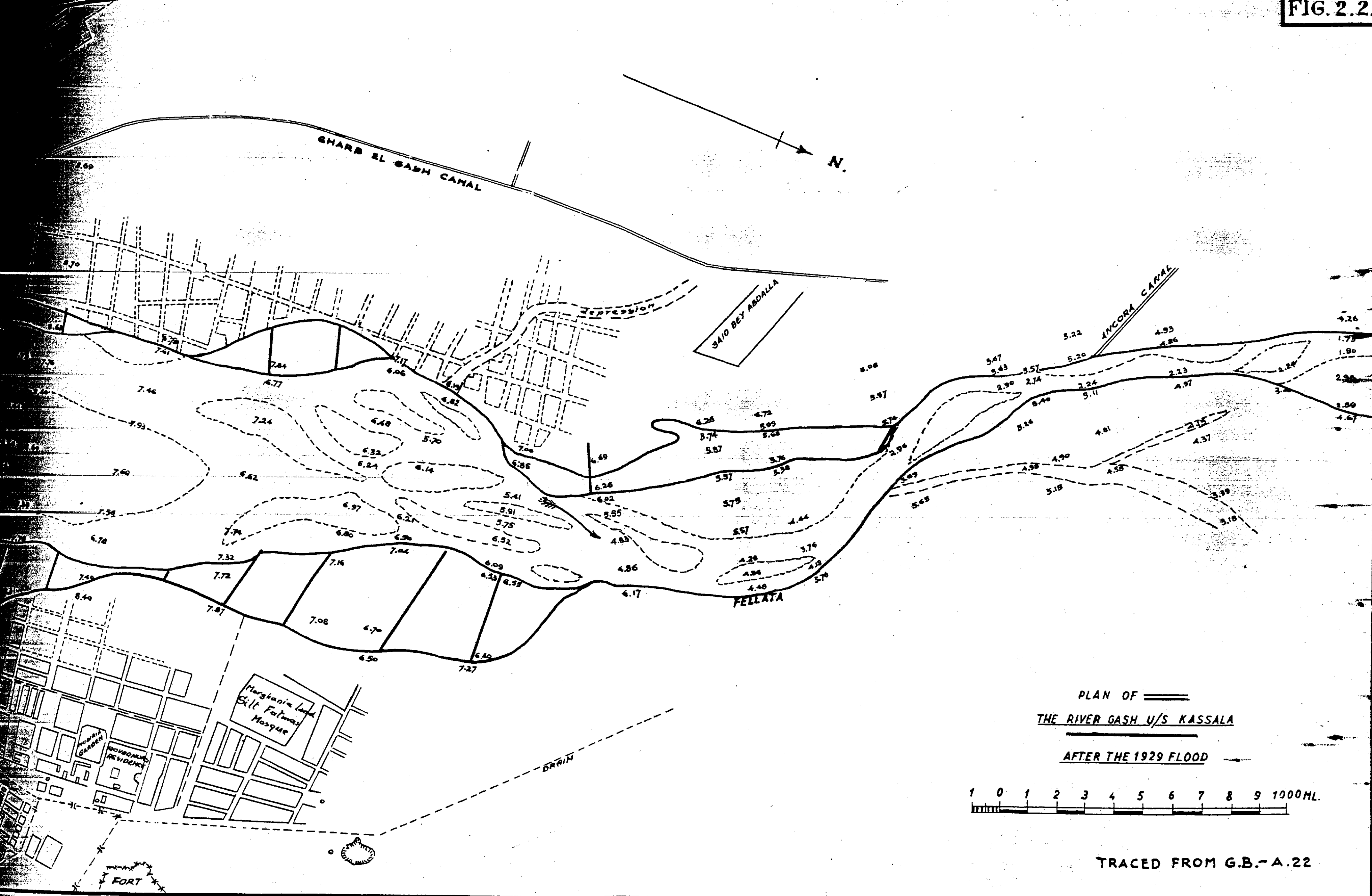


FIG. 2.2.



PLAN OF

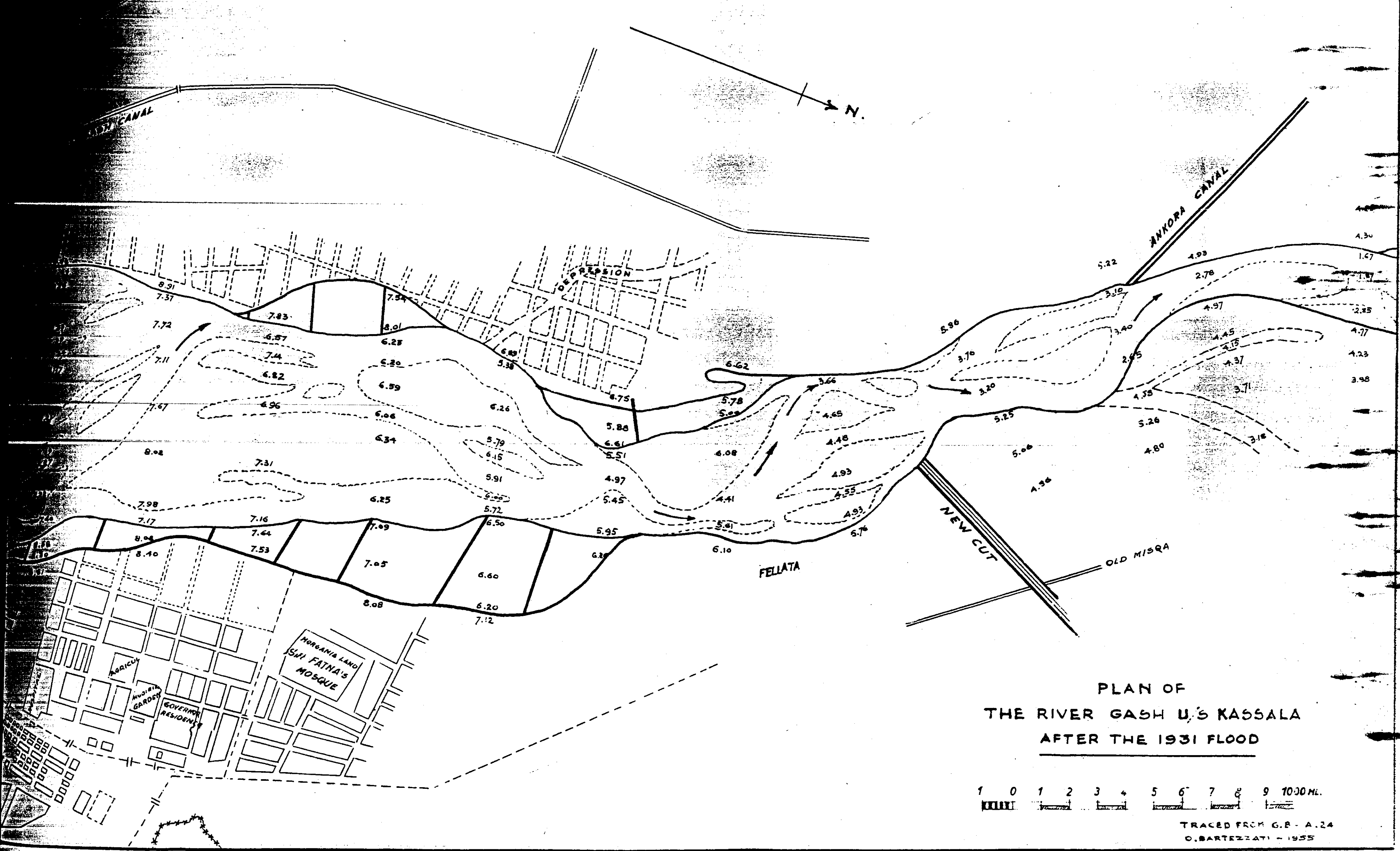
THE RIVER GASH U/S KASSALA

AFTER THE 1929 FLOOD

1 0 1 2 3 4 5 6 7 8 9 1000 ML.

TRACED FROM G.B.– A.22

FIG. 2.3



PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1931 FLOOD

FIG.2.3/a

PLAN OF
...VER GASH U/S KASSALA
...TER THE 1931 FLOOD

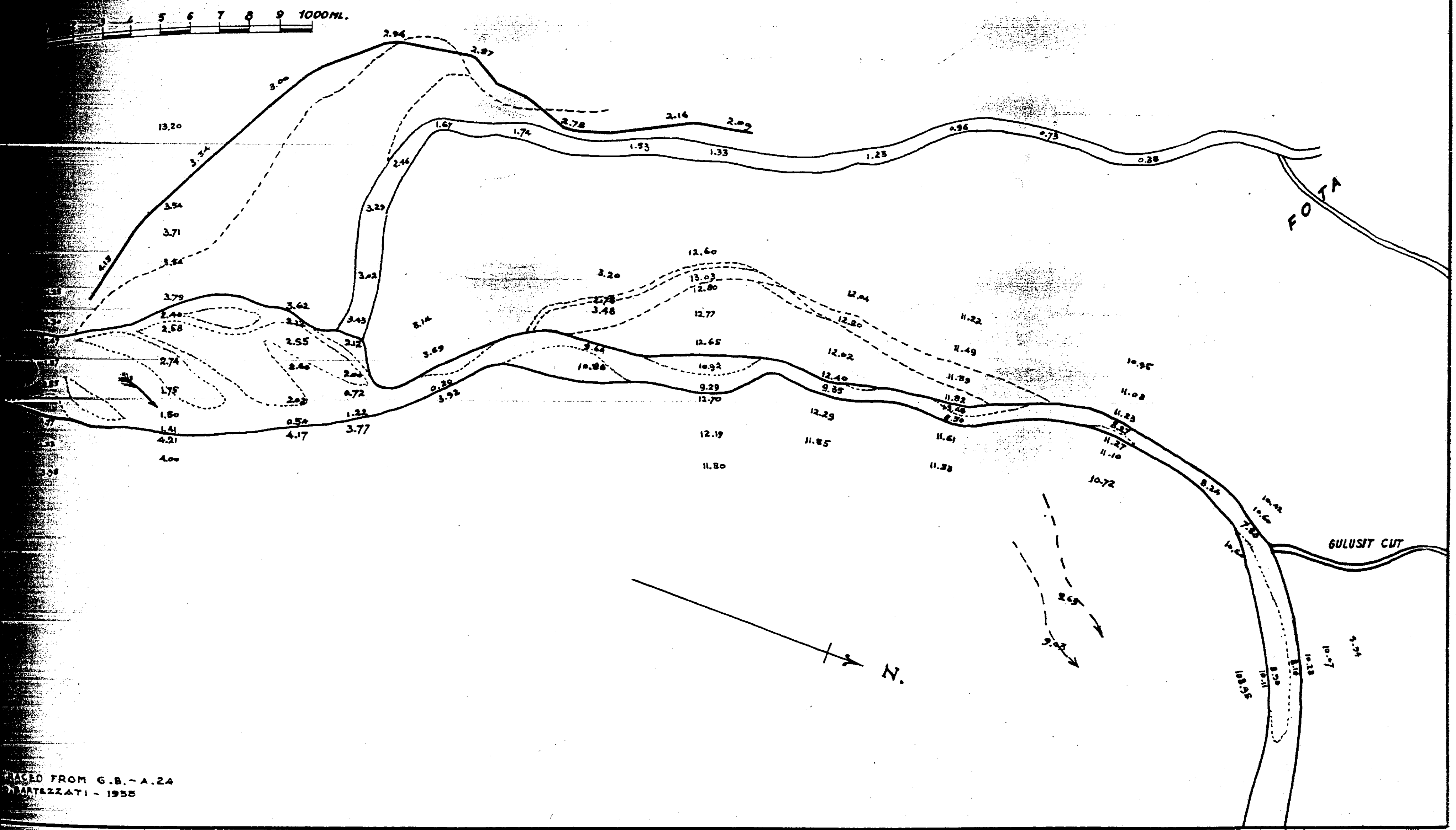
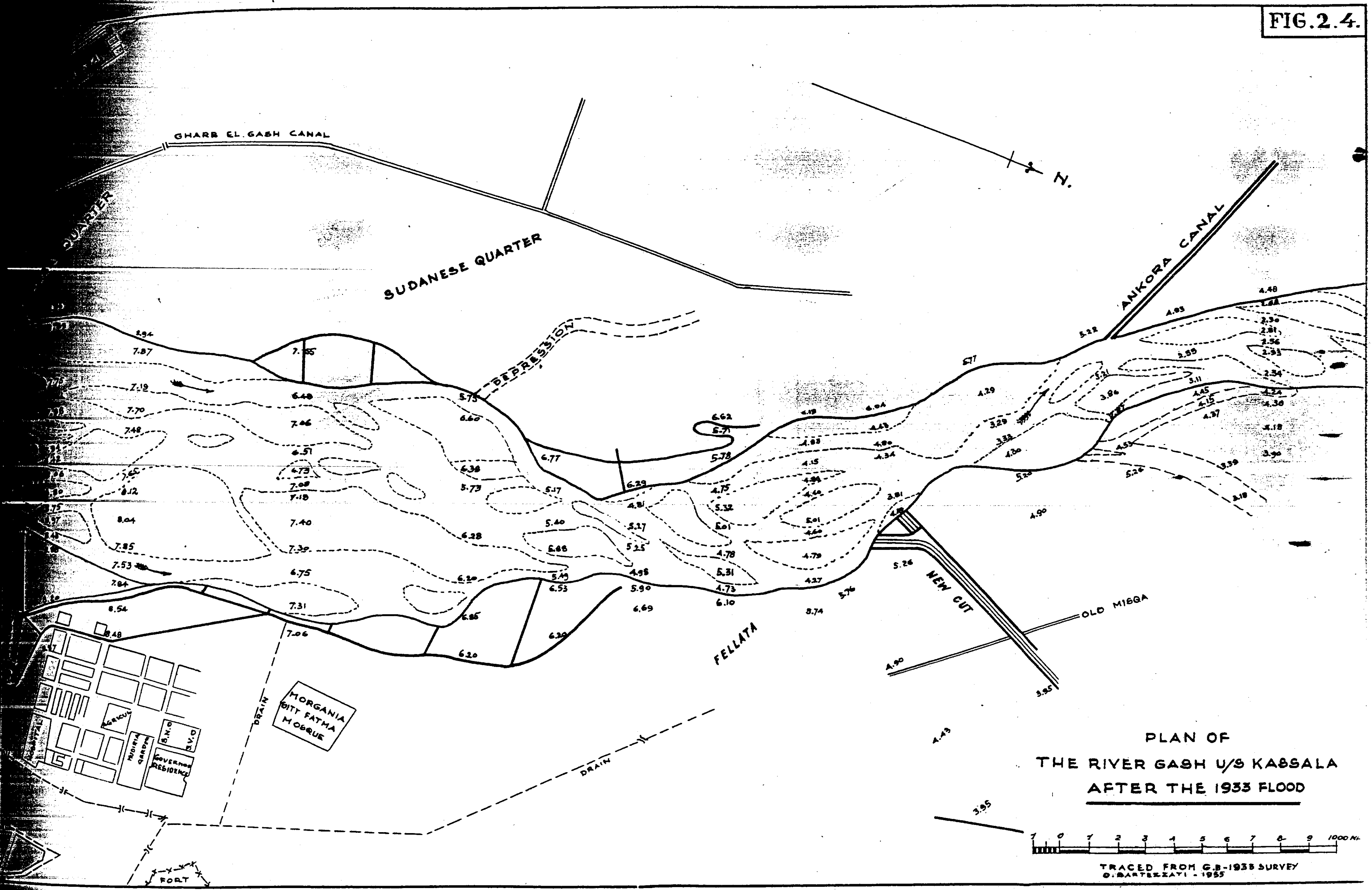


FIG. 2.4.



PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1933 FLOOD

FIG.2.[illegible]

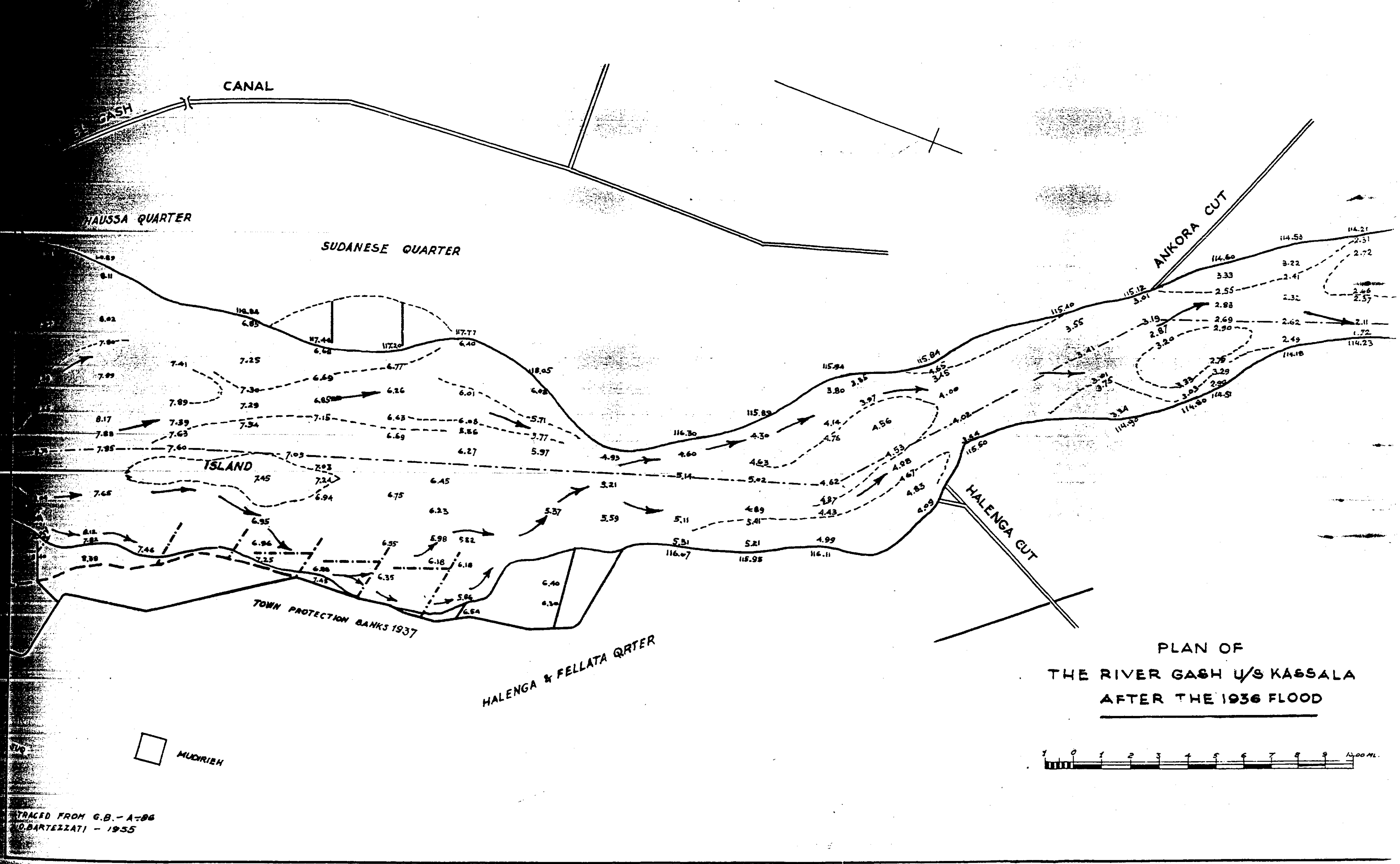

CANAL
GASH
HAUSSA QUARTER
SUDANESE QUARTER
ANKORA CUT
HALENGA CUT
ISLAND
TOWN PROTECTION BANKS 1937
HALENGA & FELLATA QRTER
MUDIRIEH
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1936 FLOOD
TRACED FROM G.B.-A-86
D.BARTEZZATI - 1955

FIG. 2.6.

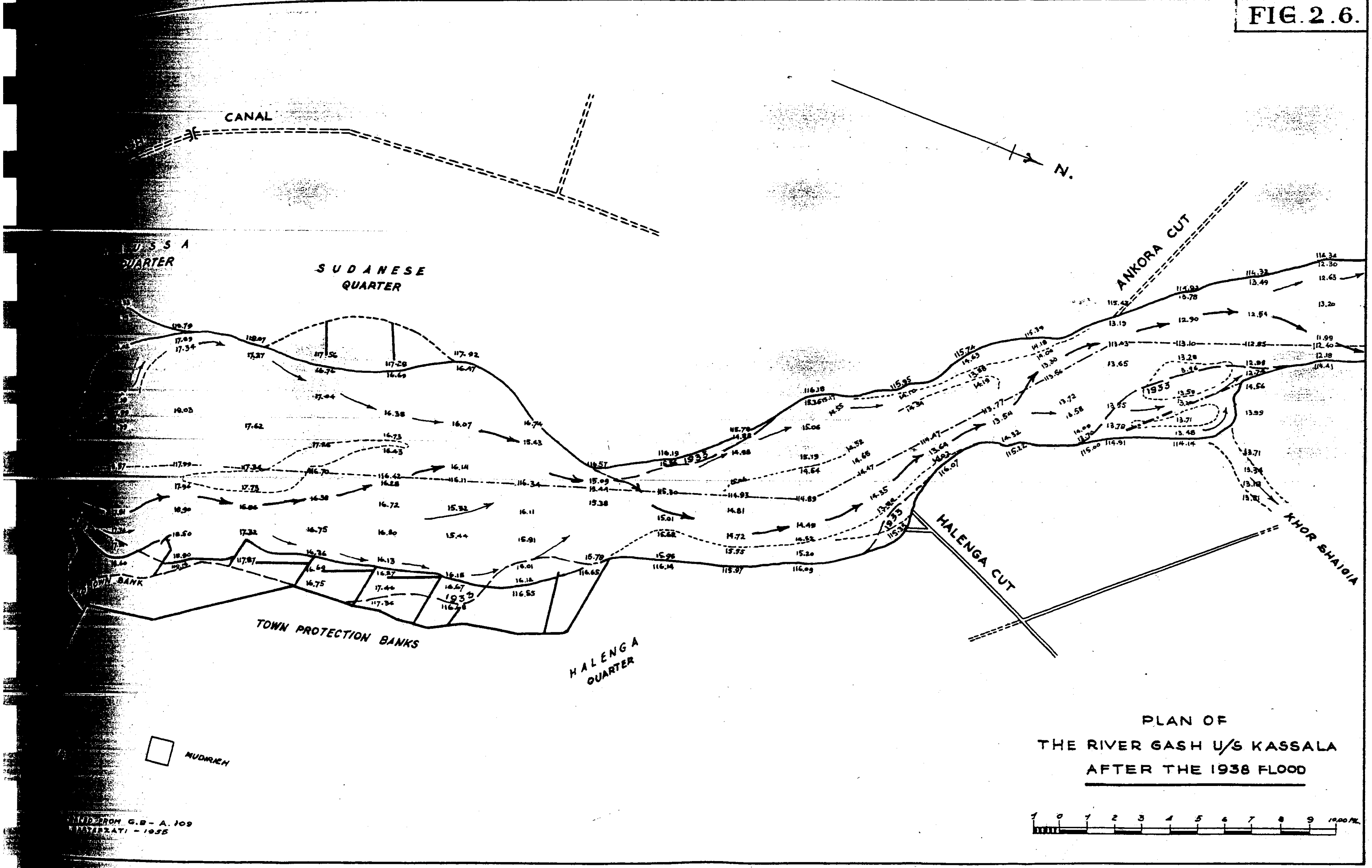

CANAL
N.
SUDANESE QUARTER
ANKORA CUT
HALENGA CUT
KHOR SHAIDIA
TOWN PROTECTION BANKS
HALENGA QUARTER
MUDIRIEH
1933
PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1938 FLOOD

FIG. 2.6ii.

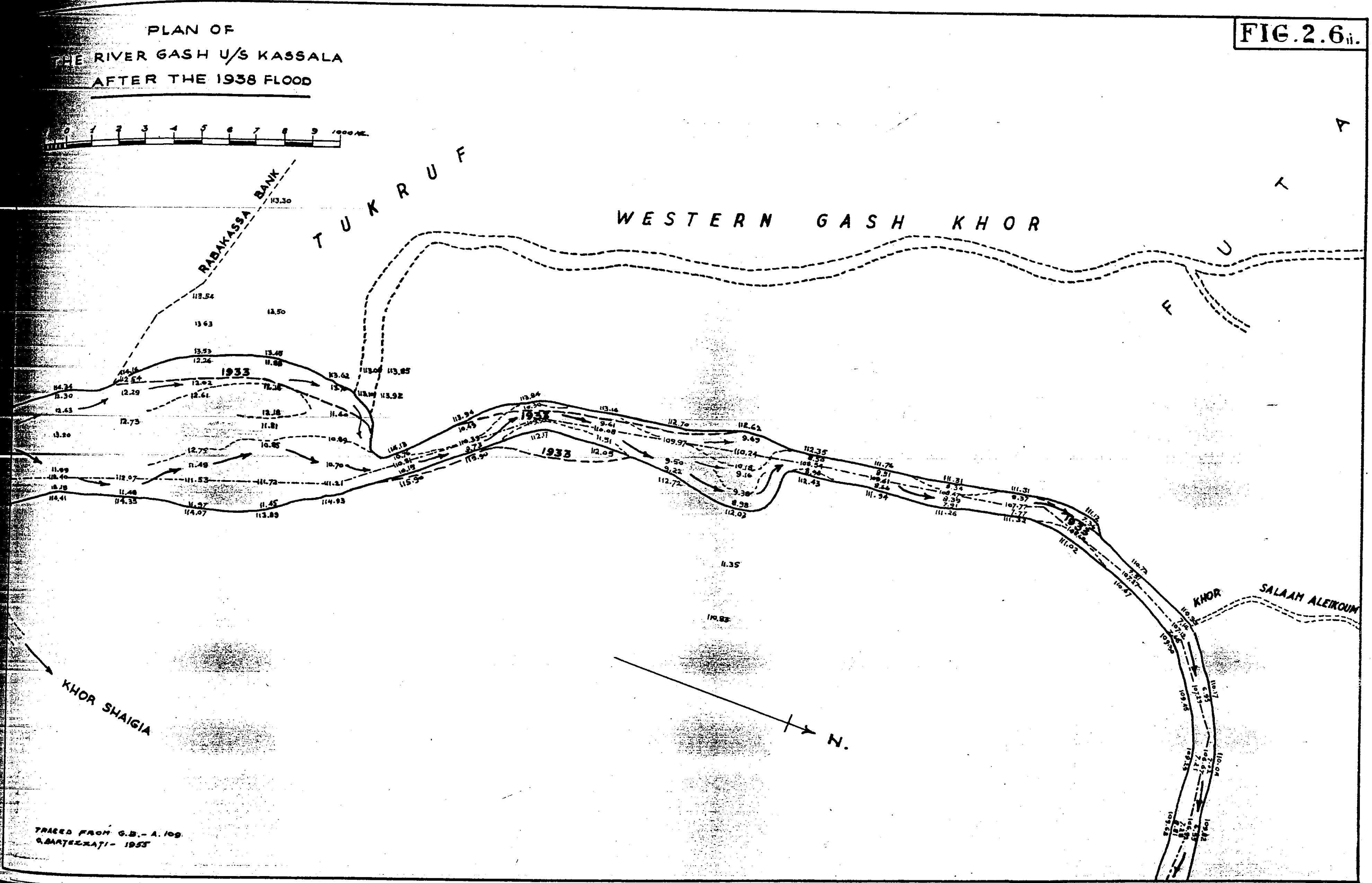
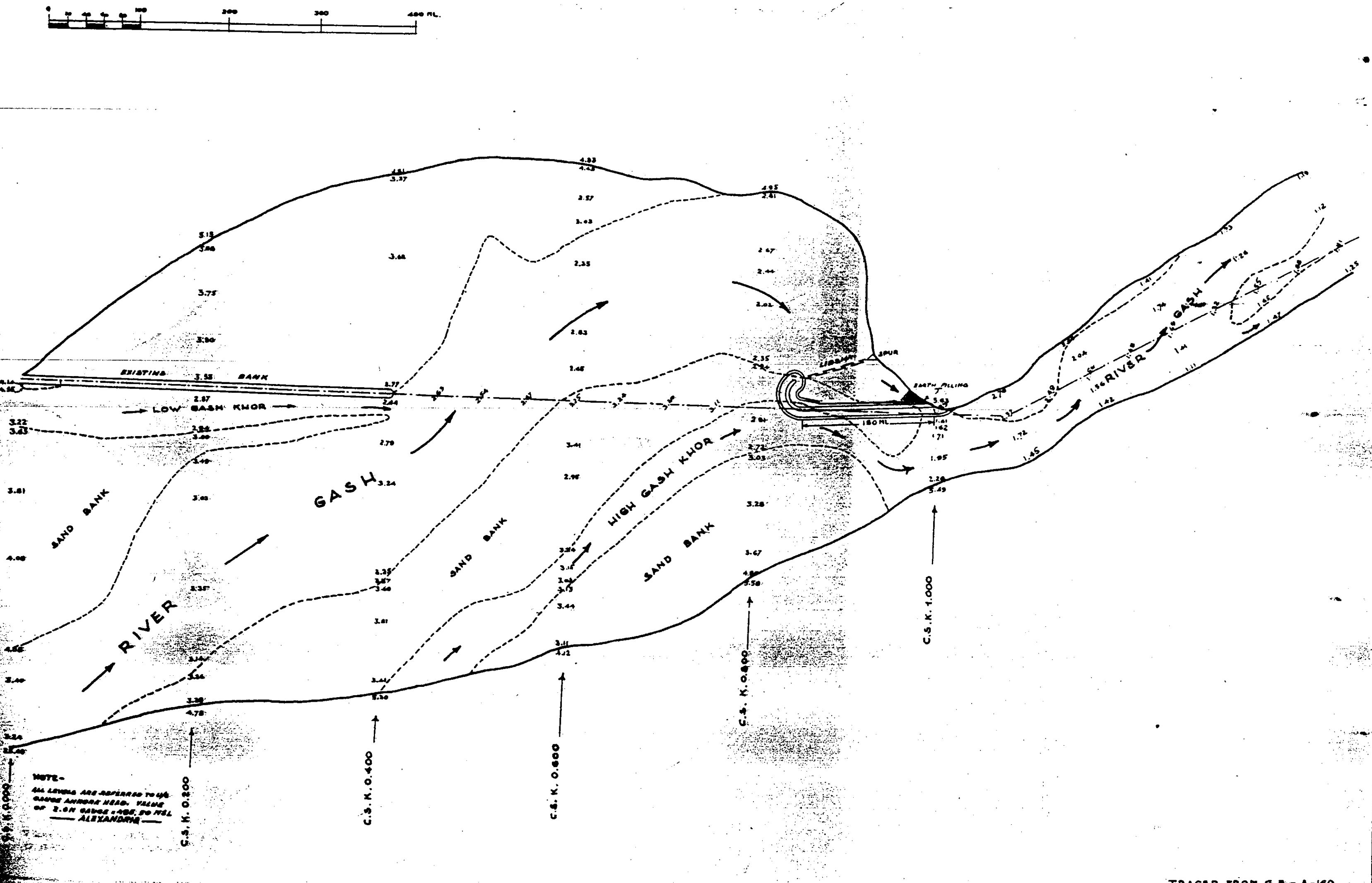

PLAN OF
THE RIVER GASH U/S KASSALA
AFTER THE 1938 FLOOD
1000 M.
RABAKASSA BANK
TUKRUF
WESTERN GASH KHOR
FUTA
KHOR SALAAM ALEIKOUM
KHOR SHAIGIA
N.
1933
TRACED FROM G.B.- A. 109.
G.BARTEZZATI - 1955

FIG. 2.7.

TUKRUF EMBAYMENT AFTER 1944

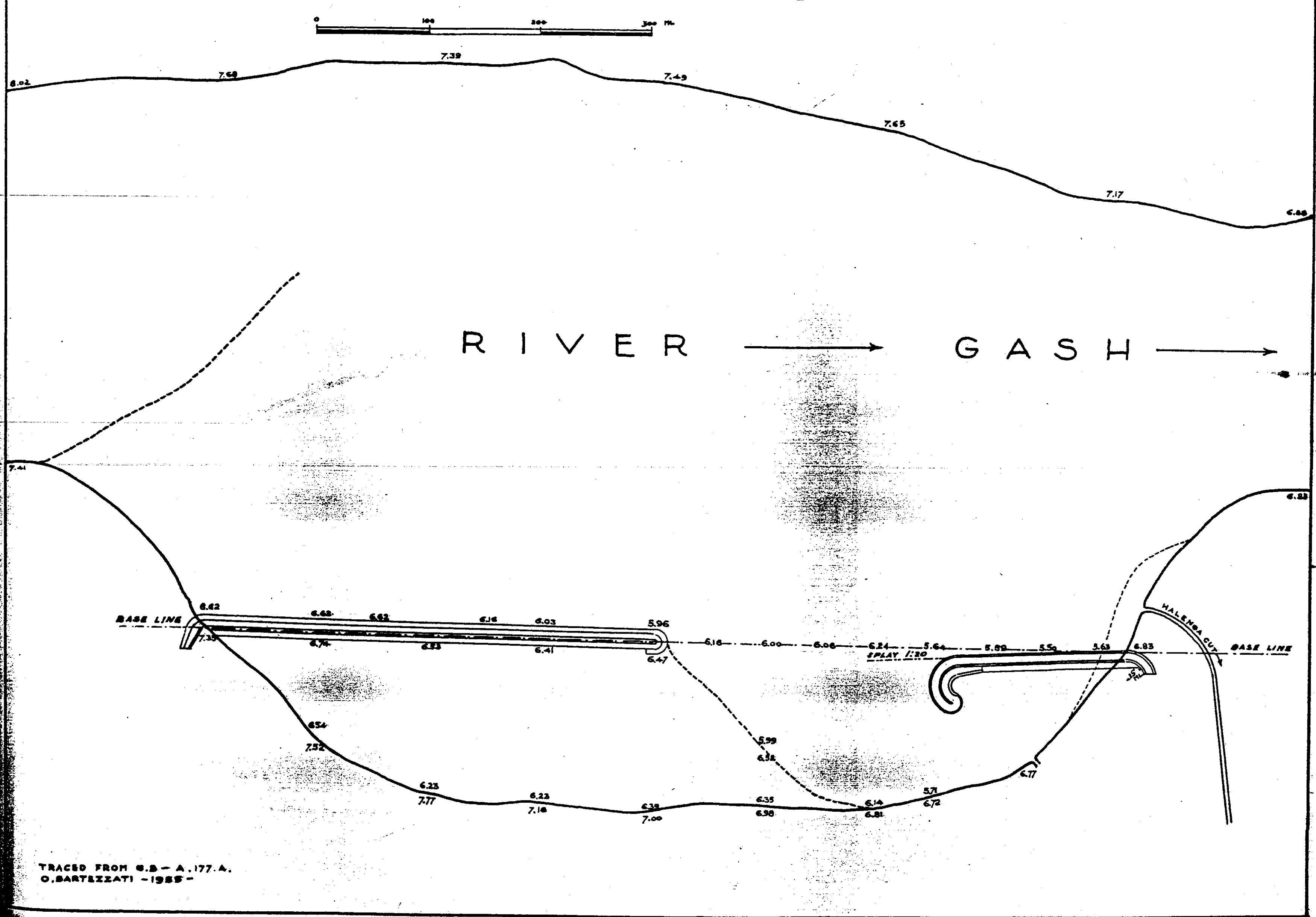
FLOOD



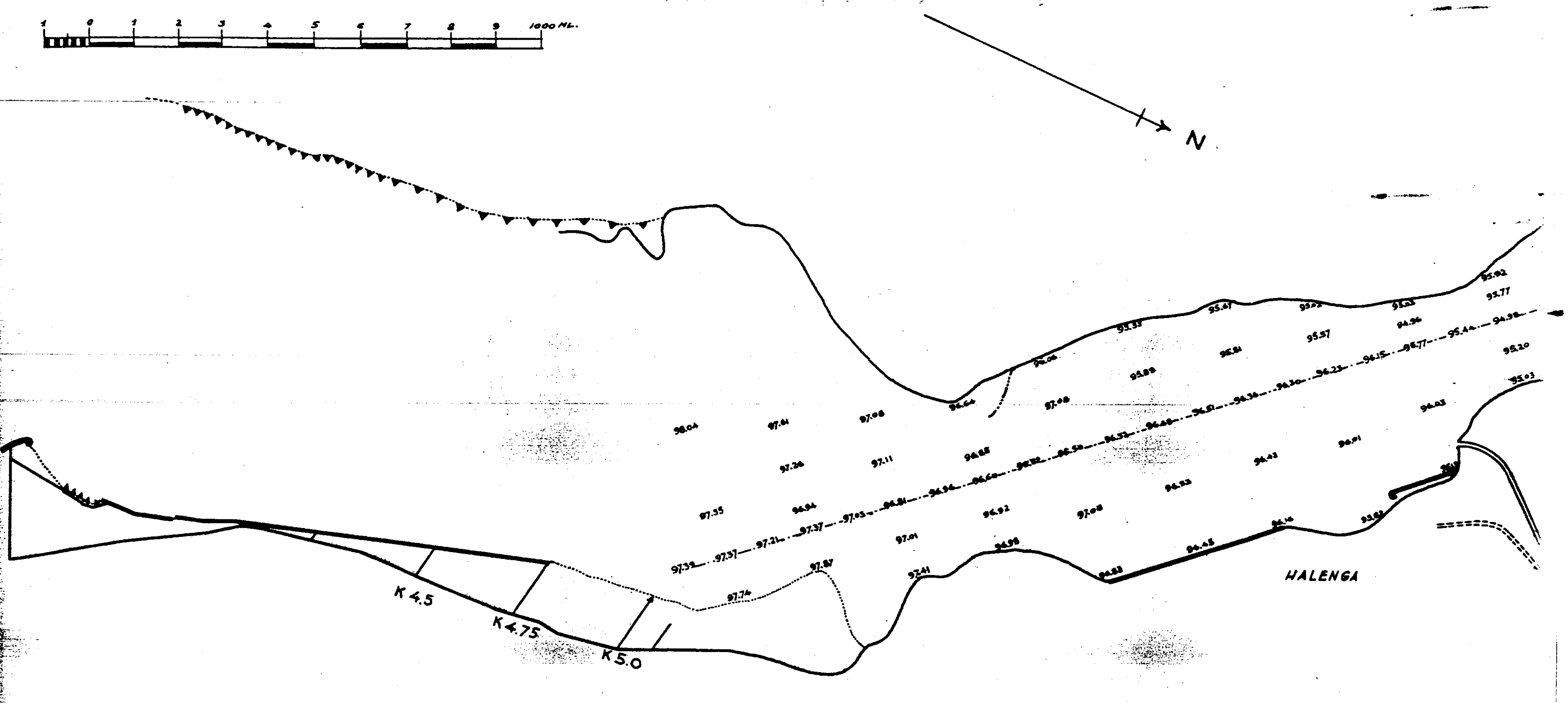
TRACED FROM G.B – A-160
O. BARTEZZATI – 1955

FIG. 2.8.

PLAN OF HALENGA EMBAYMENT AFTER 1946 FLOOD

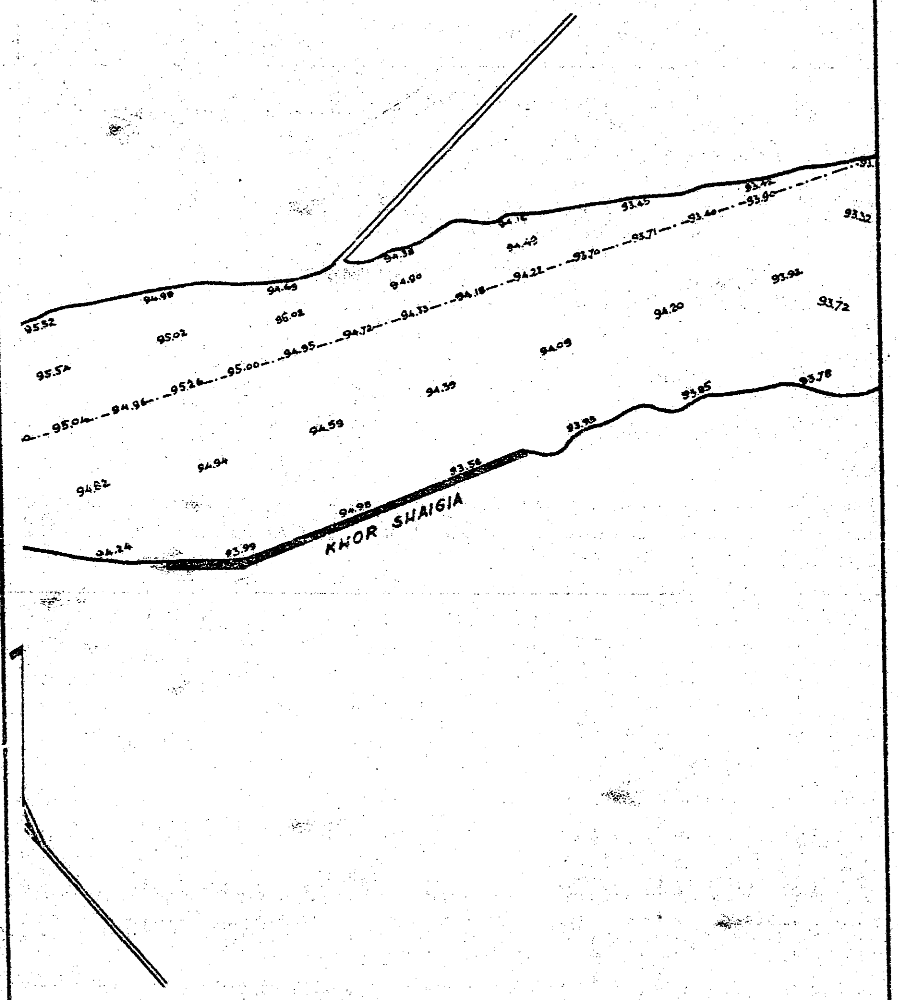


PLAN OF
THE RIVER GASH U/S KASSALA
AFTER 1948 FLOOD

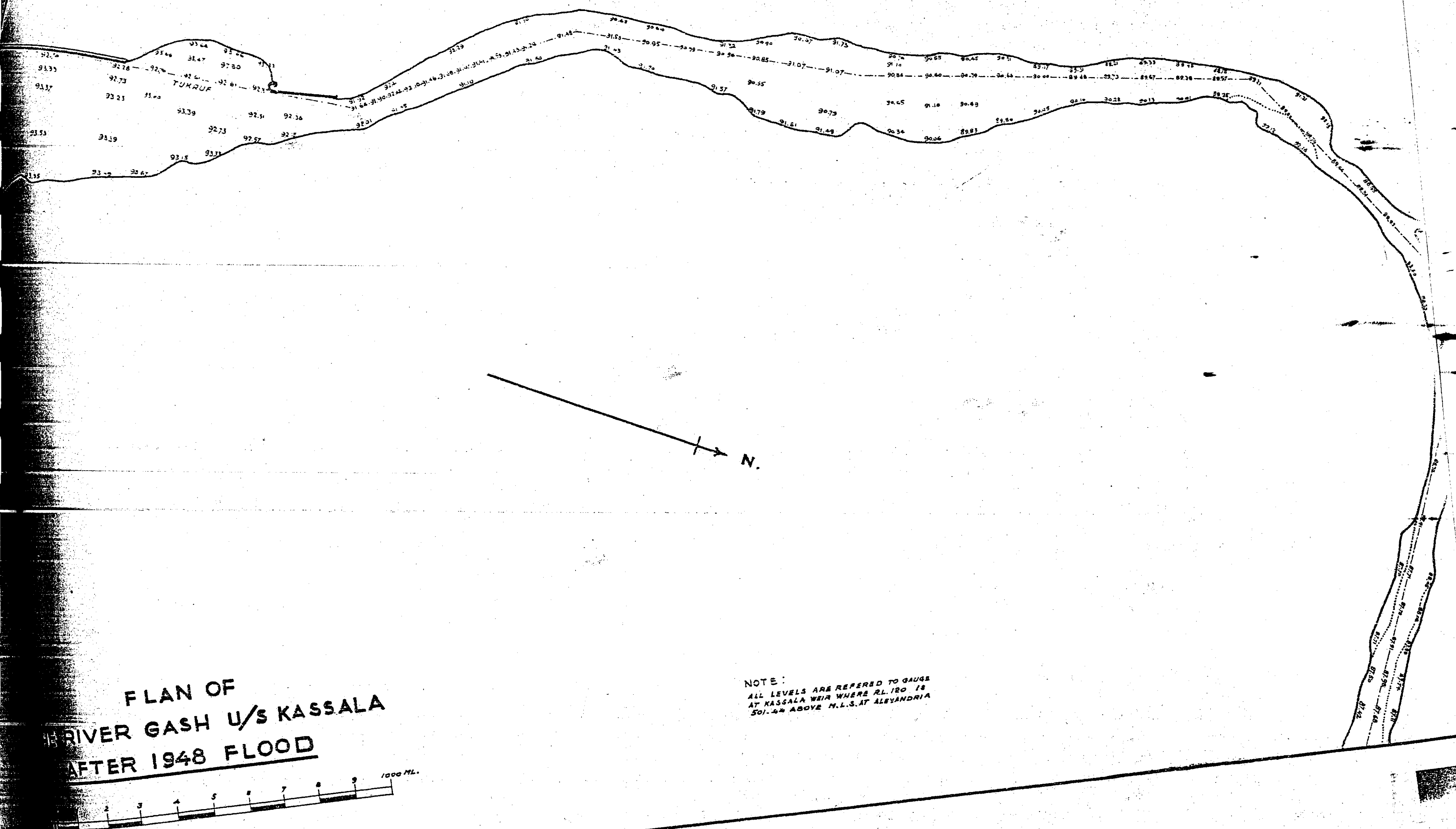


TRACED FROM G.B.– A.200
O. BARTEZZATI – 1955

FIG. 2.9i



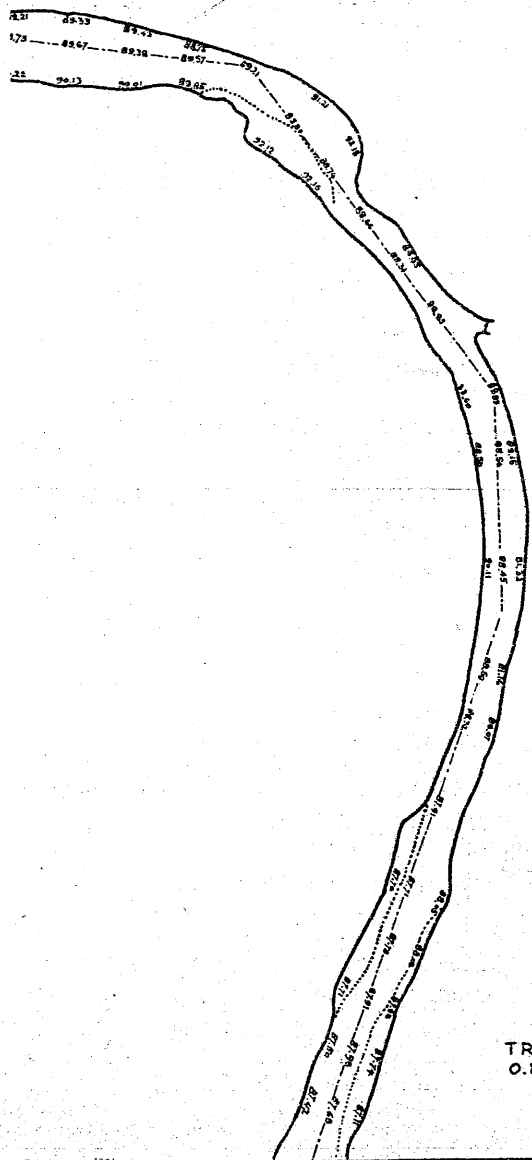
NOTE :
ALL LEVELS ARE REFERED TO GAUGE AT KASSALA WEIR WHERE RL. 120. 16 501.44 ABOVE M.L.S. AT ALEXANDRIA



FLAN OF RIVER GASH U/S KASSALA AFTER 1948 FLOOD

NOTE:
ALL LEVELS ARE REFERED TO GAUGE AT KASSALA WEIR WHERE R.L. 120 IS 501.44 ABOVE M.L.S. AT ALEXANDRIA

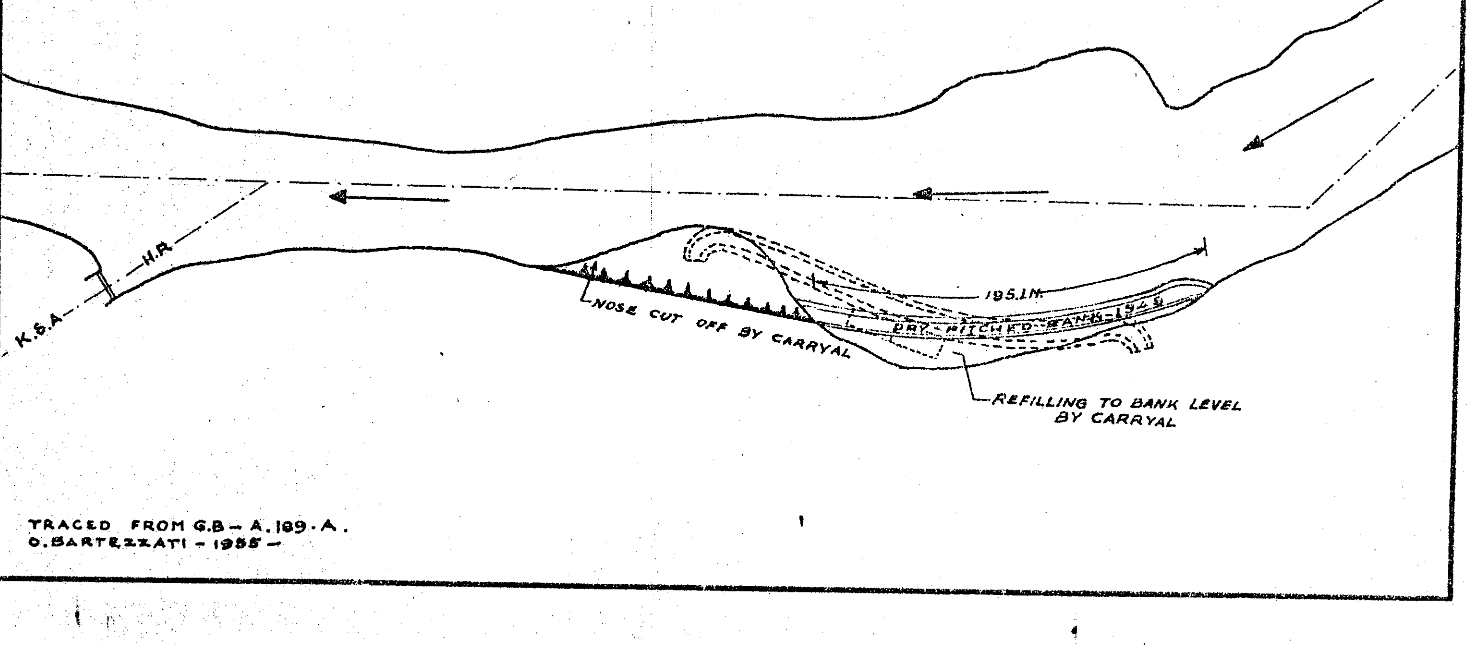
FIG. 2.9ii



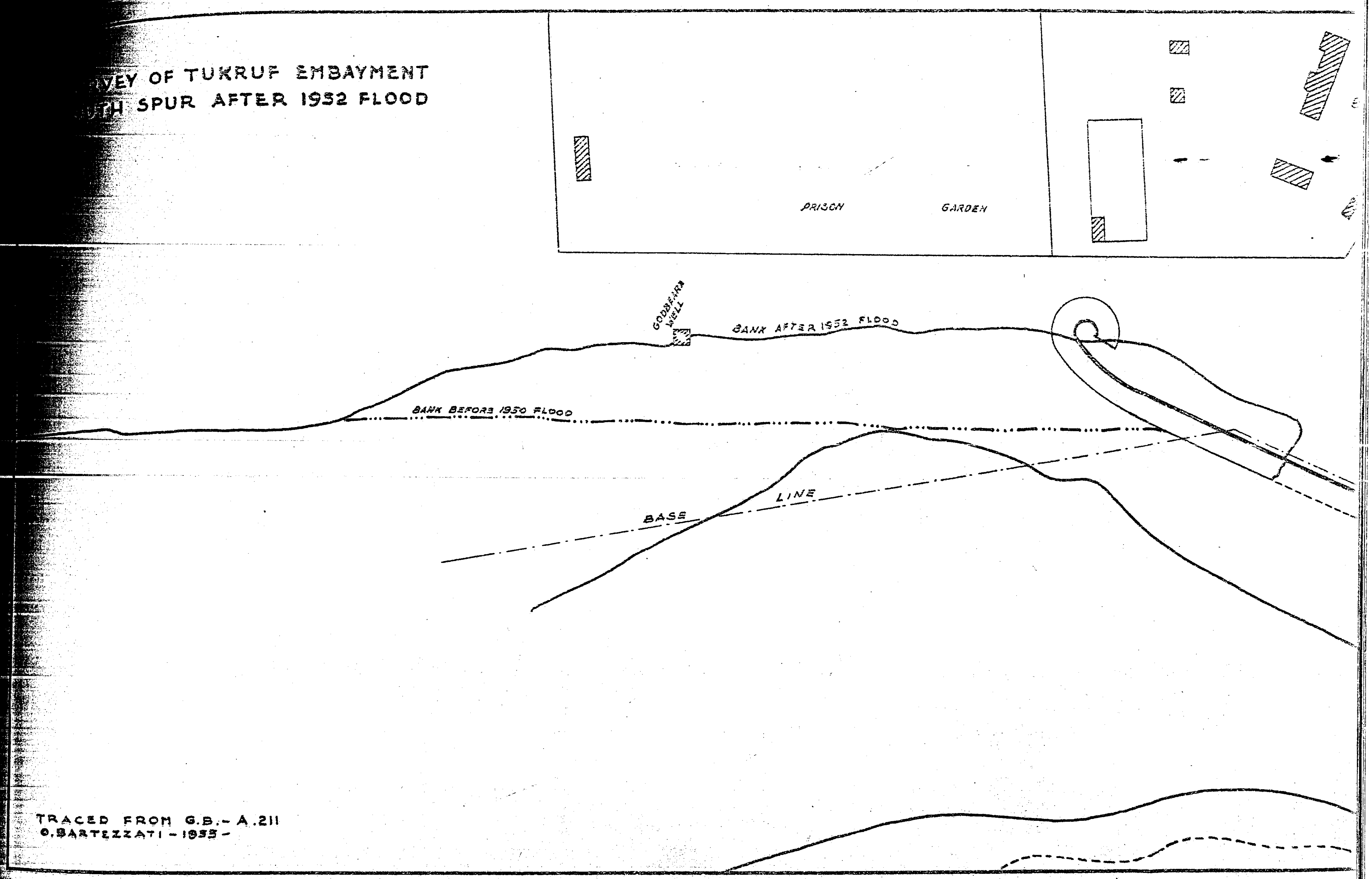
TRACED FROM G.B-A.200
O.BARTEZZATI-1955

FIG. 2.10.

GASH RIVER U/S. KH. S.A. & EMBAYMENT



TRACED FROM G.B - A.199.A.
O. BARTEZZATI - 1955 -


VEY OF TUKRUF EMBAYMENT
UTH SPUR AFTER 1952 FLOOD
PRISON
GARDEN
GODBEHRS WELL
BANK AFTER 1952 FLOOD
BANK BEFORE 1950 FLOOD
BASE
LINE
TRACED FROM G.B.- A.211
O.BARTEZZATI - 1955 -

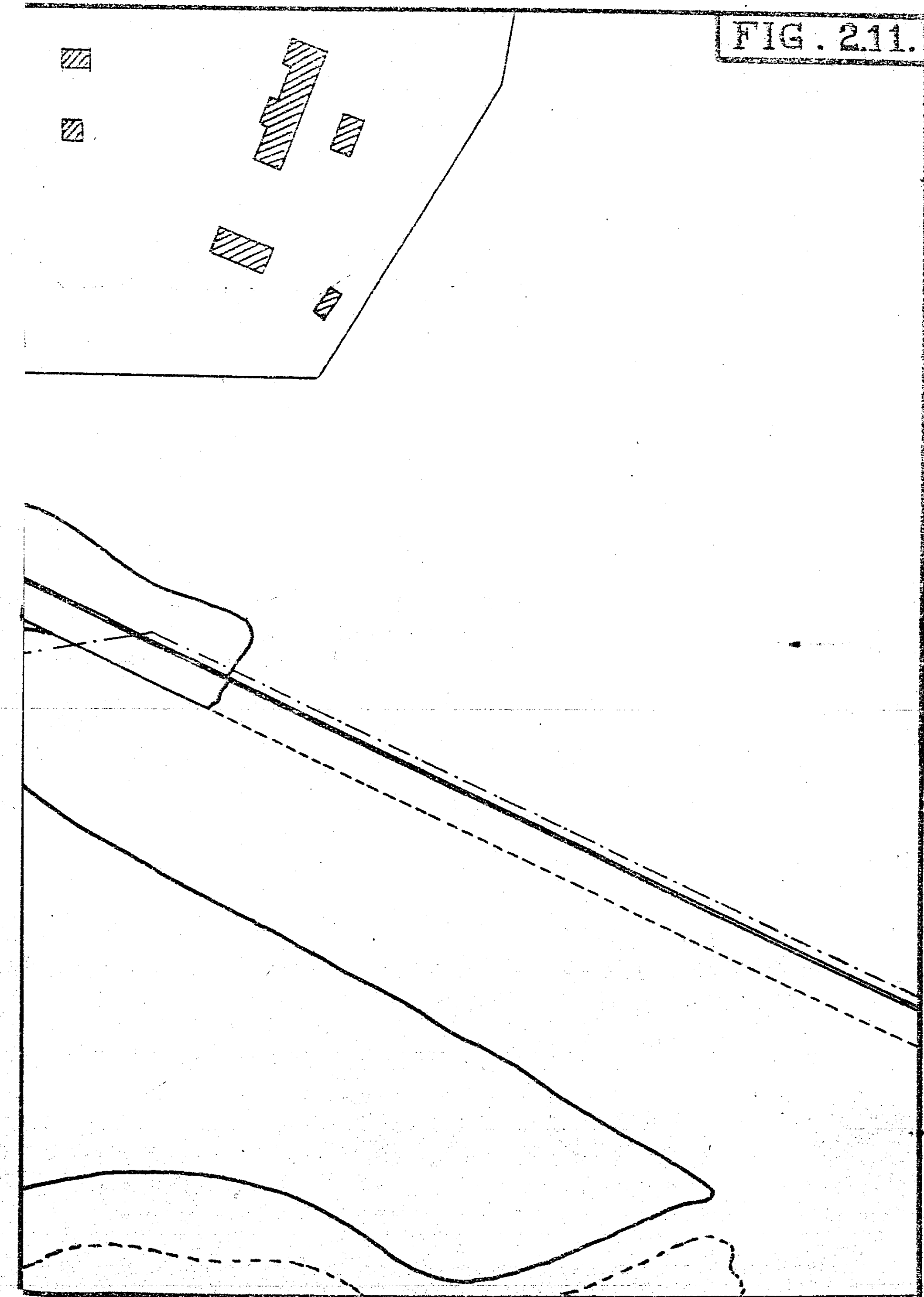
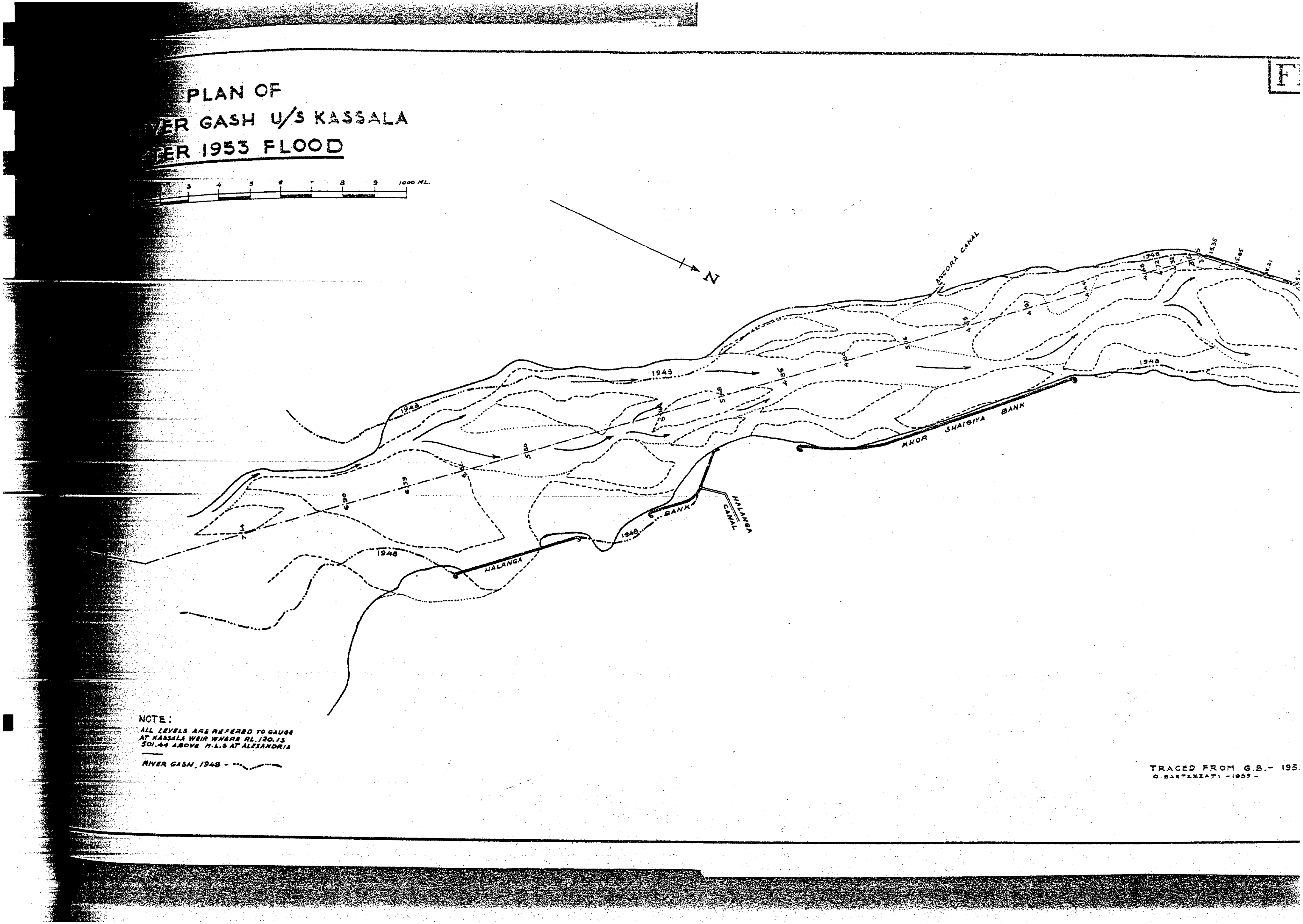
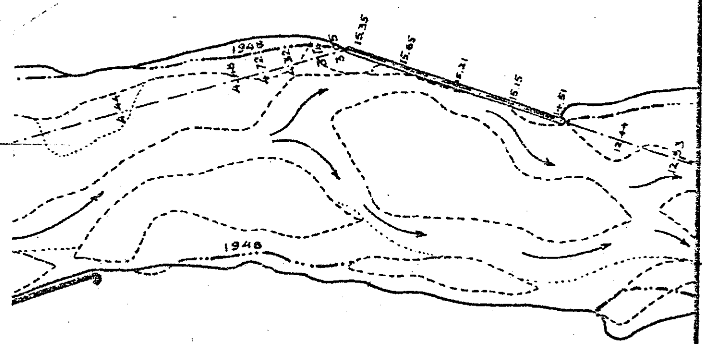


FIG. 2.11.



PLAN OF
…VER GASH U/S KASSALA
…TER 1953 FLOOD
1000 ML.
N
ANCORA CANAL
KHOR SHAIGIYA BANK
HALANGA CANAL
BANK
HALANGA
1948
1949
NOTE:
ALL LEVELS ARE REFERED TO GAUGE AT KASSALA WEIR WHERE RL. 120.13 501.44 ABOVE M.L.S AT ALEXANDRIA
RIVER GASH, 1948 -
TRACED FROM G.S.- 195…

FIG. 2.12.i



TRACED FROM G.B.- 1953 SURVEY
O. BARTEZZATI -1953-

PLAN OF THE RIVER GASH U/S KASSALA AFTER 1953 FLOOD

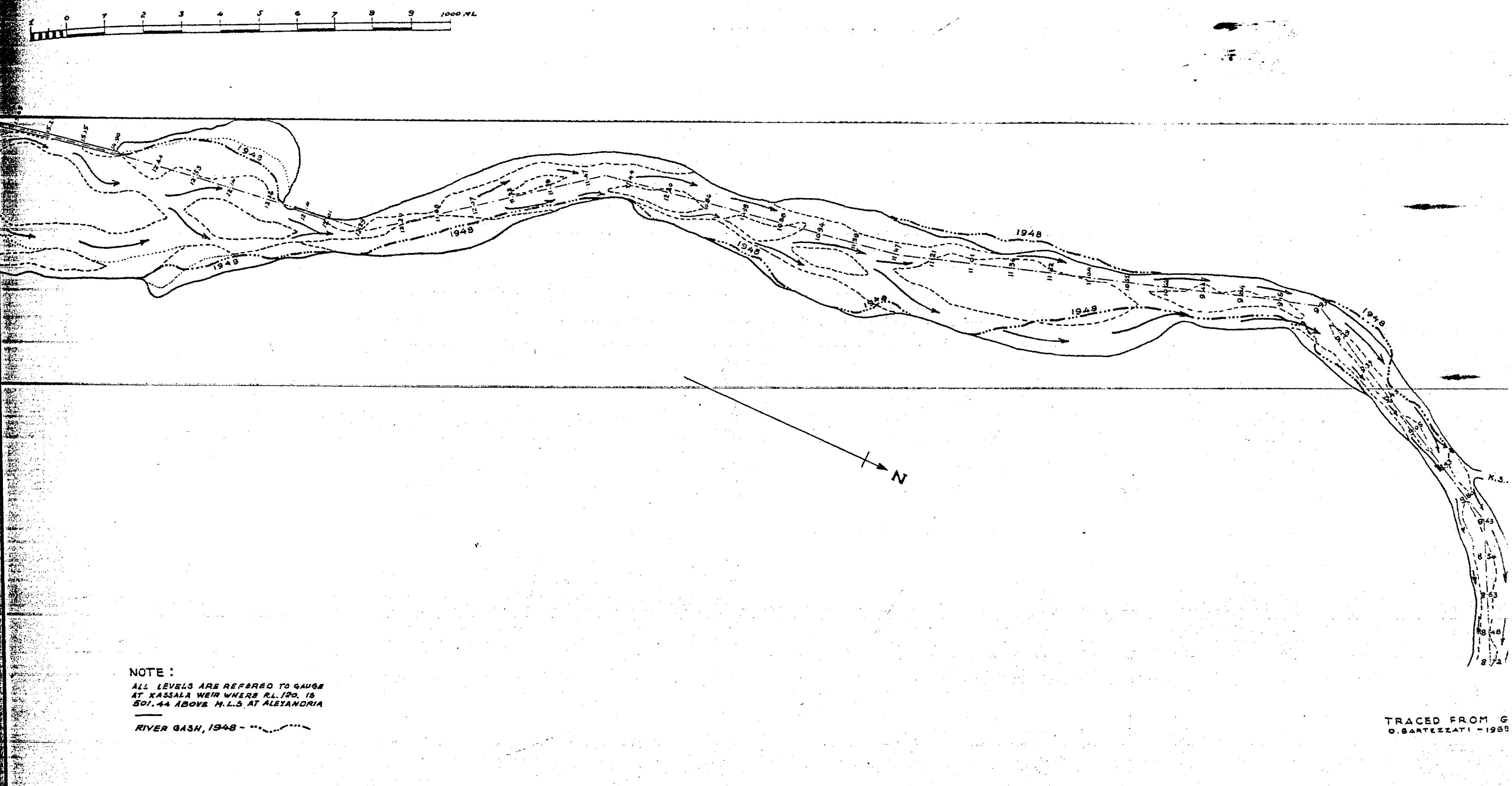
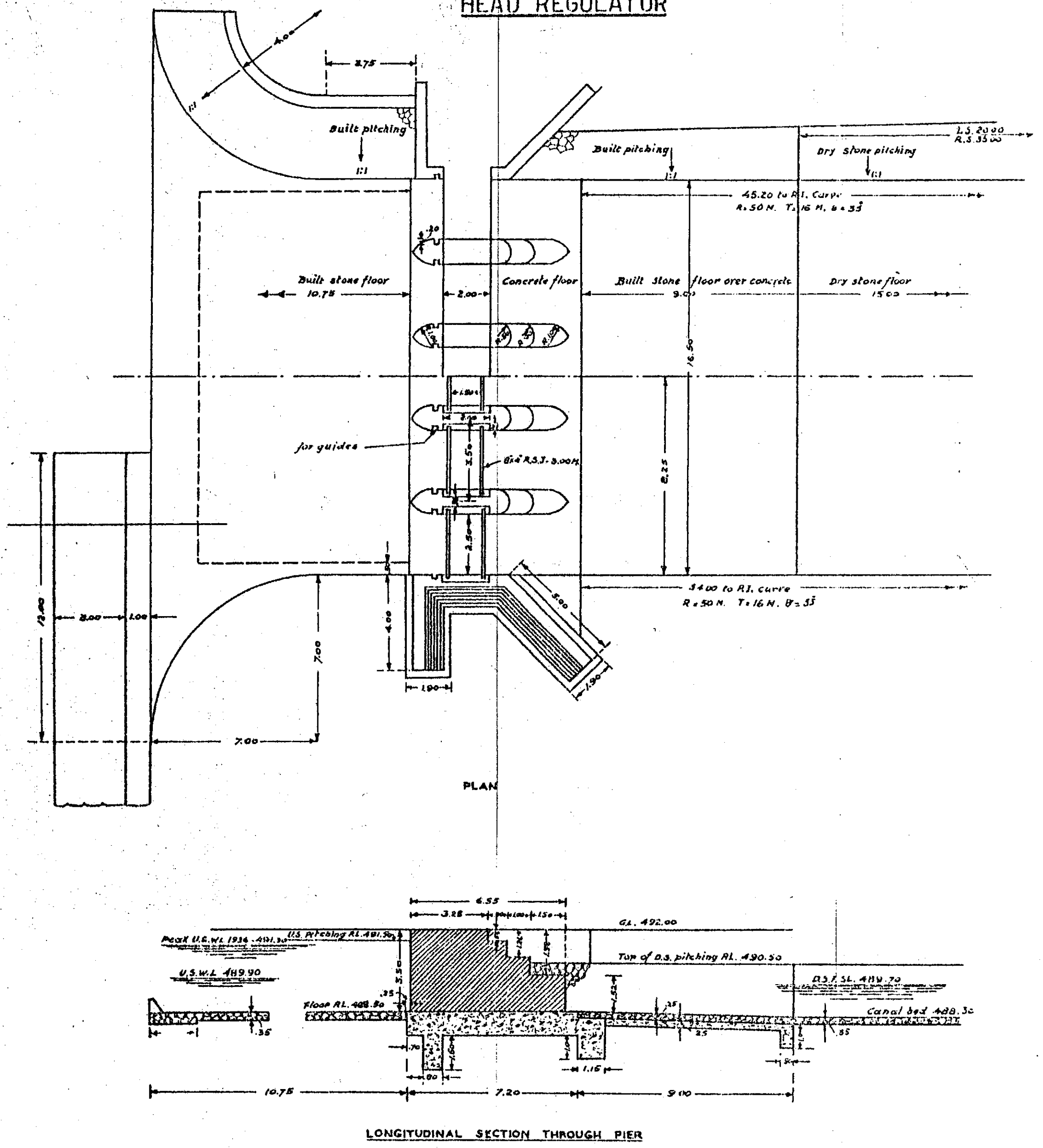


FIG. 2.13.

KHOR SALAAM ALEIKOUM

HEAD REGULATOR



TRACED FROM G.B. – A.79
O. BARTEZZATI – 1958 –

PLAN
GASH KHOR PITCHED BANKS
EXTENSION OF KHOR S.A. BANK

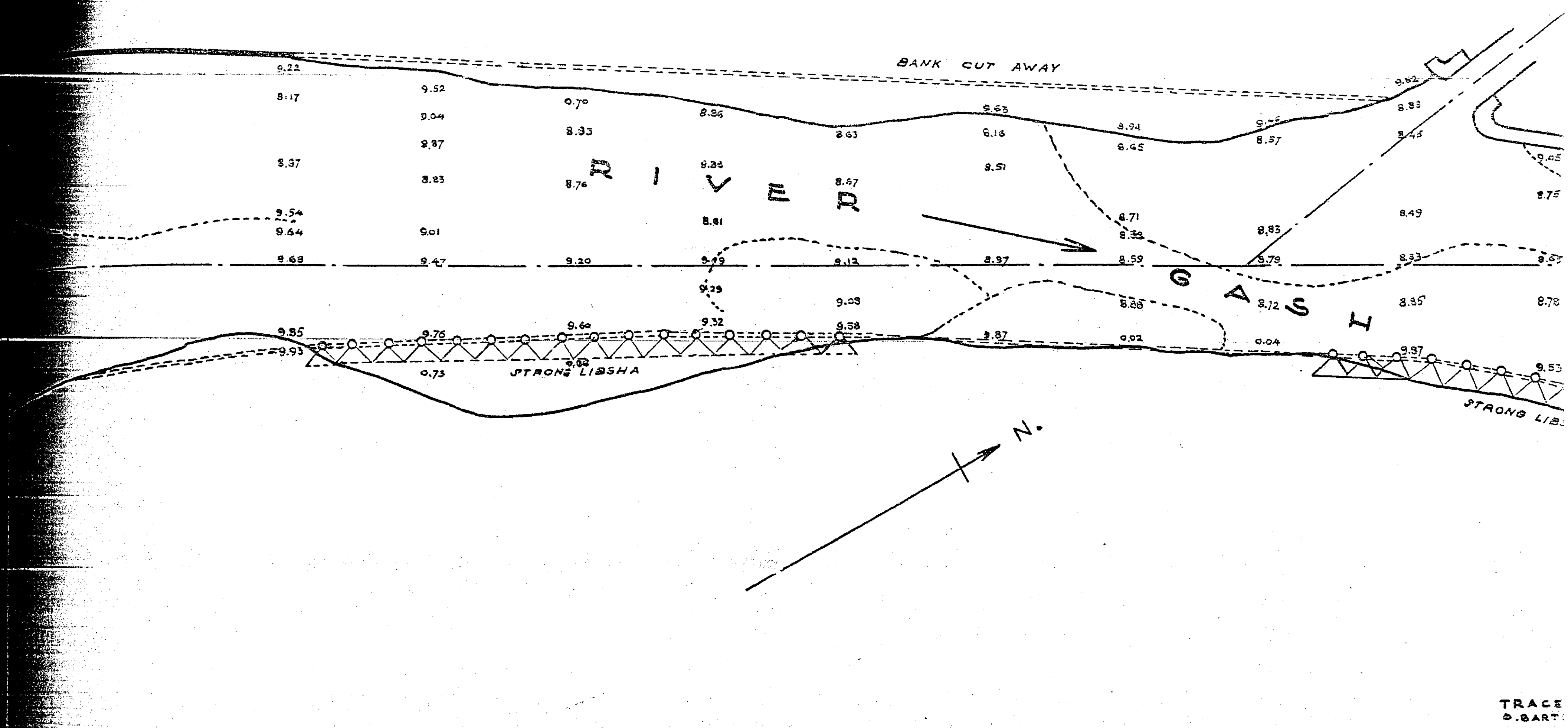
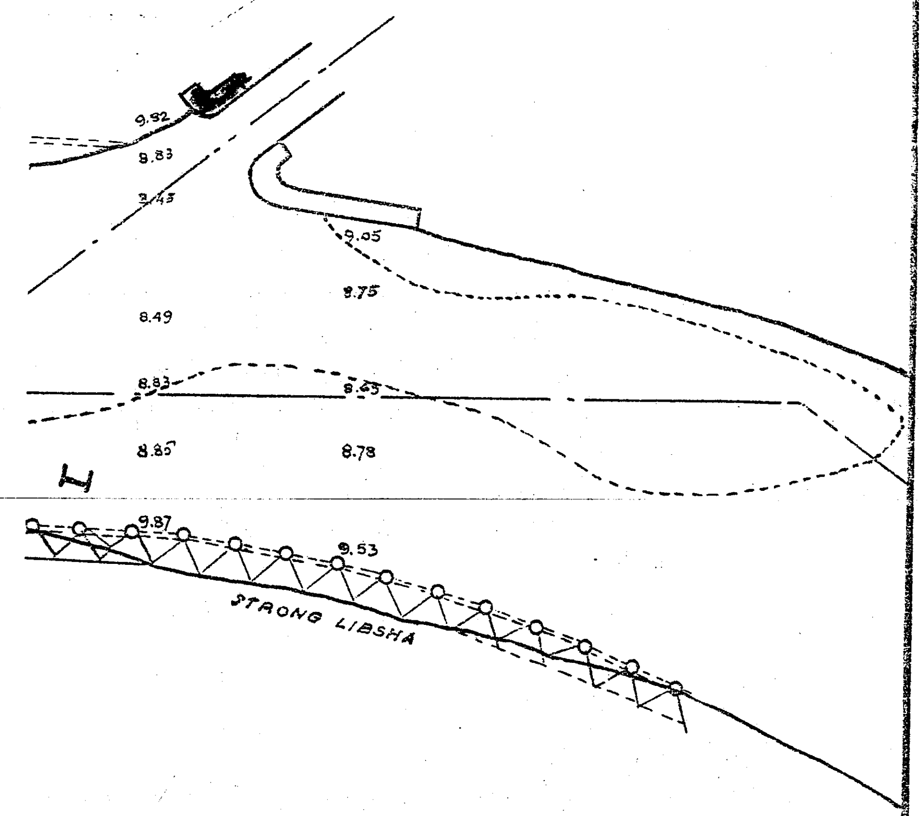
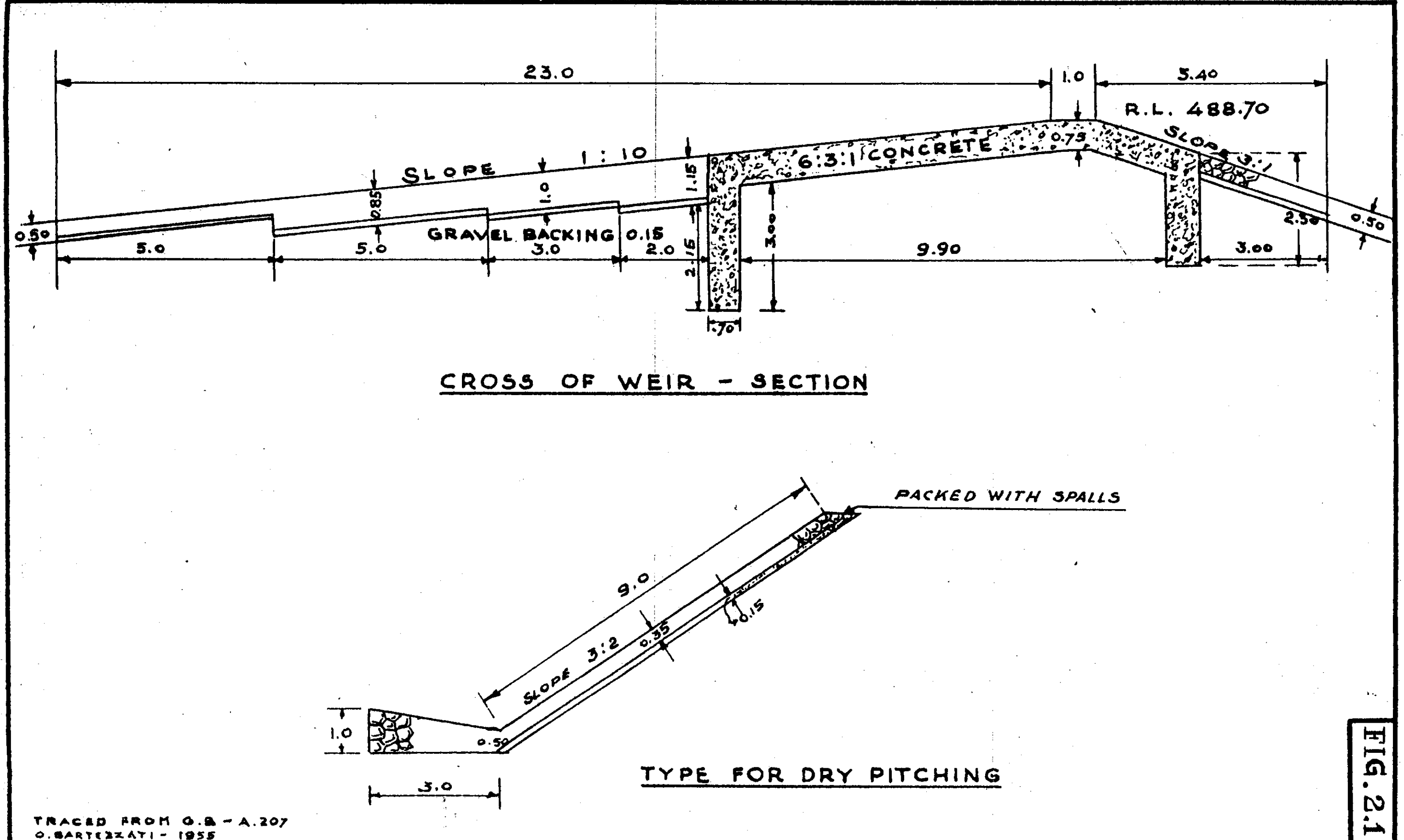


FIG. 2.14.



TRACED FROM G.B. – A.193
D.BARTEZZATI – 1955 –



23.0
1.0
5.40
R.L. 488.70
SLOPE 3:1
0.75
6:3:1 CONCRETE
SLOPE 1:10
1.15
1.0
0.85
0.50
GRAVEL BACKING 0.15
5.0
5.0
3.0
2.0
2.15
3.00
9.90
3.00
2.50
0.50
.70
CROSS OF WEIR - SECTION
PACKED WITH SPALLS
9.0
0.15
0.35
SLOPE 3:2
1.0
0.50
3.0
TYPE FOR DRY PITCHING
TRACED FROM G.B - A.207
O.BARTEZZATI - 1955

FIG. 2.15.

RIVER GASH AT K. SALAAM ALEIKO

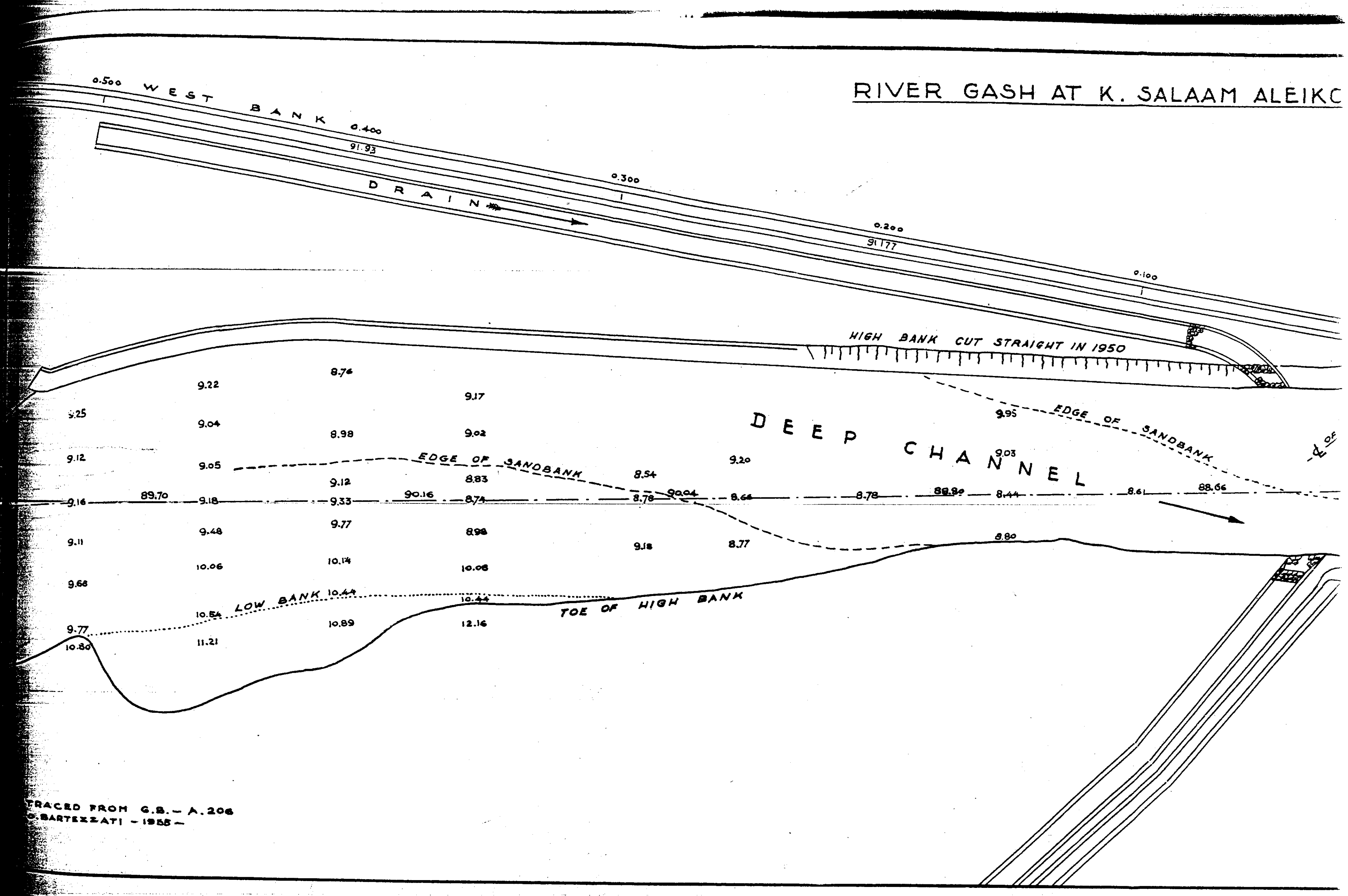
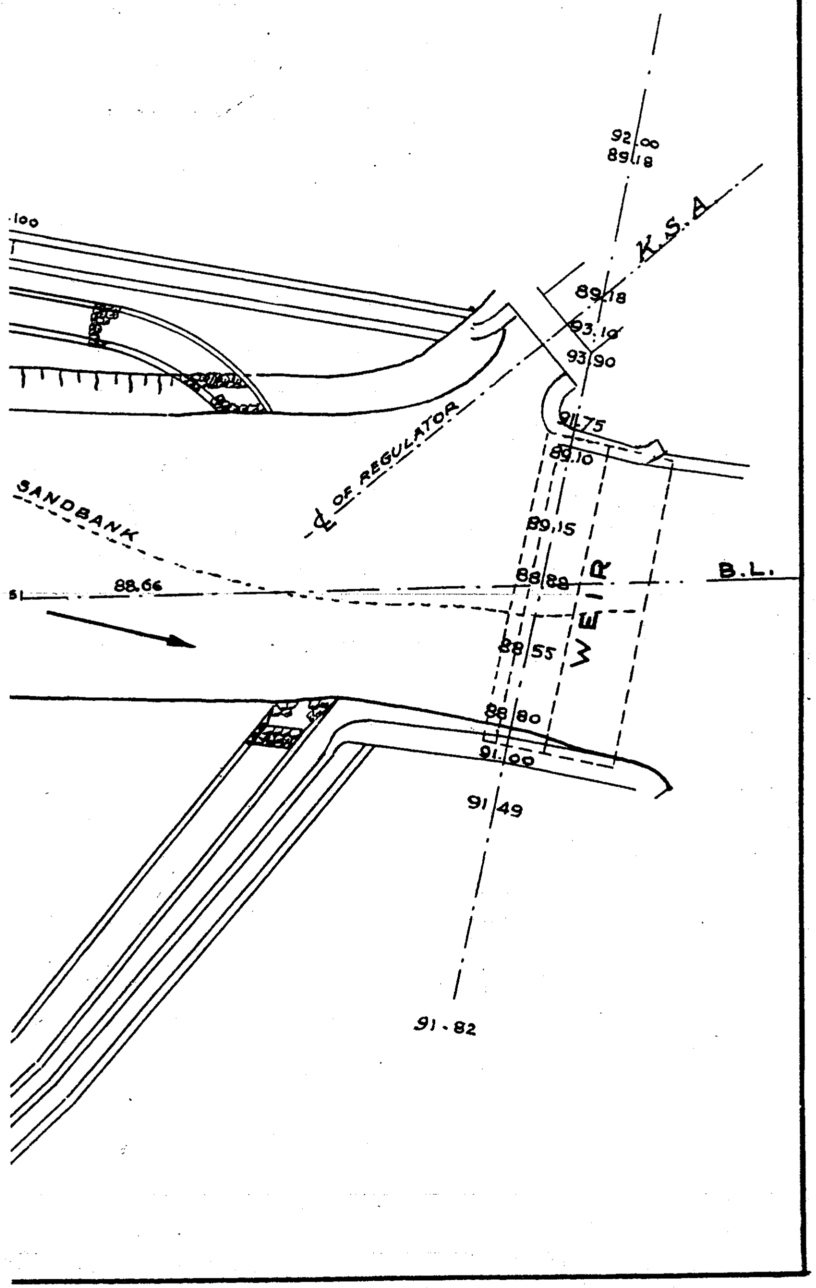
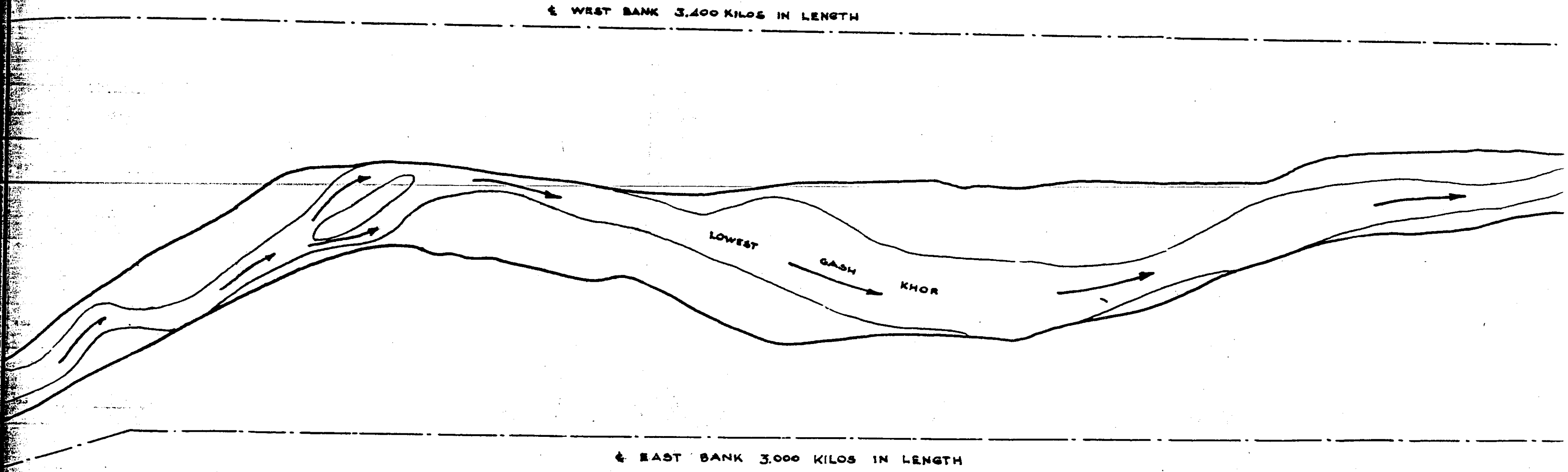


FIG. 2.16.

SALAAM ALEIKOUM 1951

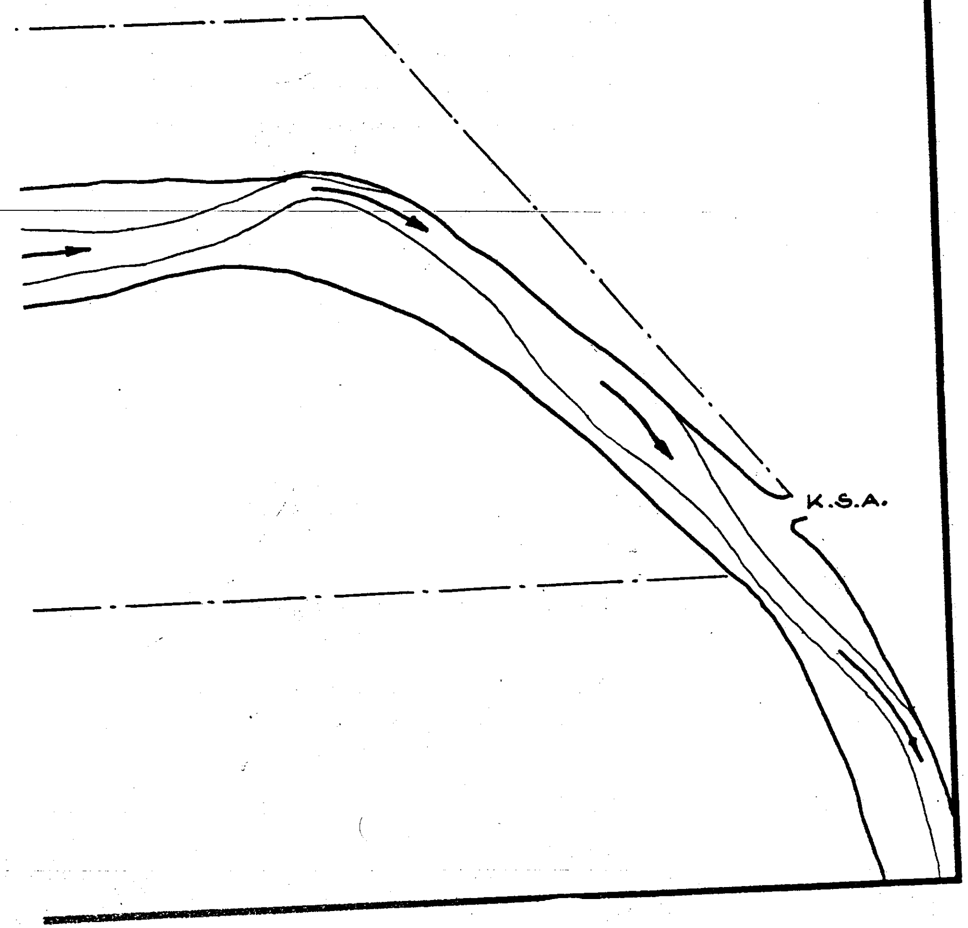


SURVEY OF GASH KHOR
KHOR SALAAM ALEIKOUM

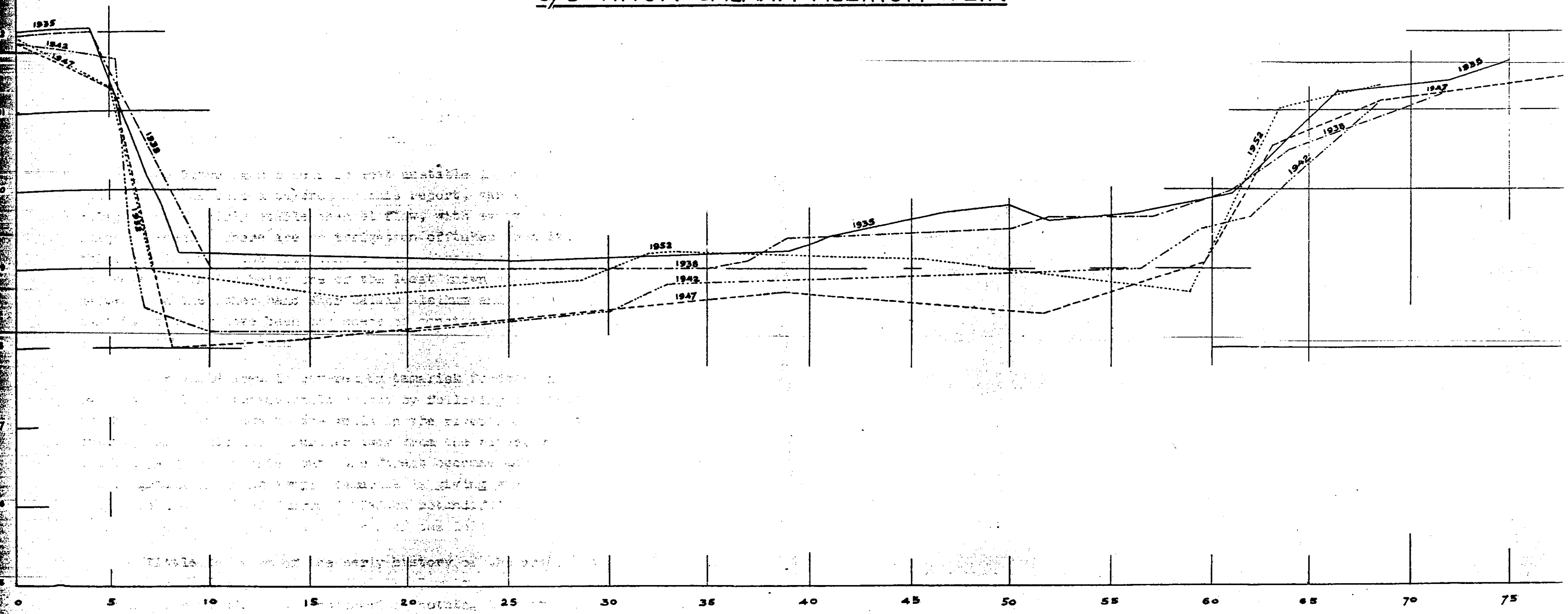


TRACED FROM G.B.-A.216
O. BARTEZZATI -1955-

FIG. 2.17.

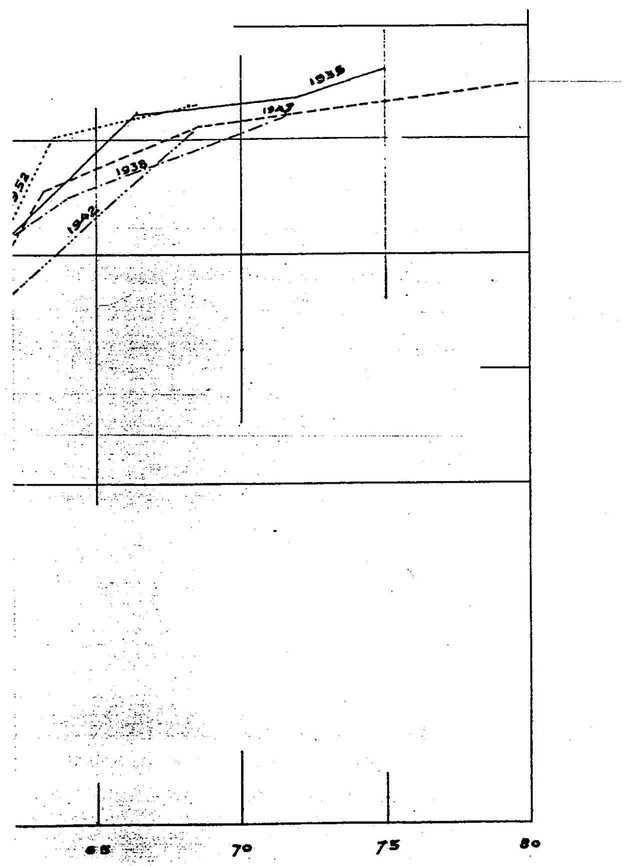


CROSS SECTION OF GASH
U/S KHOR SALAAM ALEIKUM WEIR



TRACED FROM G.B. – A.224
O.BARTEZZATI – 1955–

FIG. 2.18.



SECTION III

KHOR SALAAM ALEIKUM OFFTAKE TO GAMMAM

1. Introduction

This section deals with the Gash from just downstream Khor Salaam Aleikum offtake, with Khor Salaam Aleikum itself. and with the associated balag flow in the area. It also deals with irrigation from Khor Salaam Aleikum and touches upon the subject of domestic water supply from Gammam. The section finishes just below the Gash Wells on the River Gash and at the offtake of Khor Mekali from Gammam.

The River Gash itself is most unstable in this area and has, within the period covered by this report, varied from balag flow to fairly stable channel flow, with every intermediate stage between. There are no irrigation offtakes from it, and this, coupled with the fact that it runs through dense forest, has resulted in its being one of the least known areas of the delta. On the other hand Khor Salaam Aleikum and its associated balag have been the scene of constant effort and are consequently well documented.

The whole area is covered by tamarisk forest; near the Gash it is almost impenetrable except by following the cattle tracks which lead down to the wells in the river bed from the grazing lands outside. Further away from the river, where the old balags have now dried out, the forest becomes more sparse and is gradually dying away; tamarisk is giving way to "tundub" (Capparis decidua) and "kurmut" (Cadaba rotundifolia), the common shrubs of the more arid parts of the delta.

Little is known of the early history of the area. A system of basins was constructed at Debelaweit in about 1906, but they were abandoned as uneconomic; nothing is known of them now. Even as late as 1923 the area is described in a report on the proposed development of the Gash in the following words : "The area of dispersion is covered with a dense and, in many places, impenetrable growth of trees and other vegetation, and the course of the water cannot be followed. The water the case last year". The approximate flow pattern is shown in Fig.3.1.

The eastward shift became more pronounced in 1928 and resulted in a poor supply for Gulosit wells; at the same time the system of collection banks in Gammam forest for the supply of Mekali canal had to be extended. The great 1929 flood, however, temporarily reversed the trend and a slight westward shift was noted. It is interesting to speculate on whether the reason for this was sheer momentum of water during the high spates that year. We can, however, do no more than speculate because it may have been caused by any number of other, more local, influences. But 1929 was an exception and the eastward tendency continued in 1930.

After the 1930 flood a useful sketch was made, approximately to scale, of the pattern of flow in the area. It is reproduced in Fig.3.2. The changes in 1931 and 1932 were marked on it subsequently. Aerial photography did not come to the Gash until 1932 (though it seems incredible that such an obvious aid should have been neglected so long) and the toil that must have gone into the making of this simple little sketch can only be guessed at by those of us who came later and know what dense balags are like but have vertical photographs to map them with. The sketch shows how, in 1930, the balag was collected by a series of khors near Gammam wells and how one of them cut back into the balag, until by 1932 it was almost half way back to the beginning of the dispersion, where Khor Salaam Aleikum now takes off. In 1933 it finally reached the main Gash there and the natural balag was doomed. Further downstream silting troubles had already begun.

4. Gulosit and Tugarar

The construction of the Gulosit basin and how it led to the silting up of the Western Gash has already been described in the last section. By 1925 it was no longer possible to grow cotton on any scale, although attempts were still made. Gulosit basin, however, was also a very important well centre. Apart from the bed of the Gash, there are a number of well centres dotted about the delta. There is no general water

table in the delta and these wells draw from perched water tables of varying capacity which must be recharged, naturally or artificially, each year. By no means all of the well centres can maintain a supply throughout the year and those that can are naturally of great importance; it must be remembered that the Gash delta, quite apart from being a cotton-growing area, supports a very large number of people whose livelihood depends on their flocks and herds. Many of the well centres are watered artificially; a bank is built around the area and the basin so formed is flooded by a cut leading from the nearest canal or branch of the Gash. The water table is recharged partly by percolation and partly directly down the old well shafts of the preceding year. The well, of course, have to be re-dug annually. Naturally year by year, land levels inside the basin are raised by silt and by the droppings of the animals watered there; previously, when this happened to such an extent that it could no longer be watered, the well centre was abandoned - in any case the Gash which supplied it was constantly shifting and its life was not likely to be a long one. Nowadays it is not so simple; when every effort is made to keep the Gash within fixed limits the well centres have to be semi-permanent. It has been found necessary, recently, to lower levels inside the wells basin by scraper and to use the spoil for strengthening the surrounding banks. The scraping also has the beneficial result of removing accumulated dung and thereby increasing the permeability of the basin.

Gulosit, as we have said, was (and still is) a very important well centre; one of those which lasts throughout the year. In addition, opening off it to the northward and watered by a cut in the old bank was a cotton-growing "shaiyote" known as Tugarar. The manner in which this complex watered in 1925 is shown in another of Mr. C.H. Thomson's sketches, which is reproduced in Fig.3.3. The supply was failing, as we have seen.

In 1926 a new collecting bank was pushed out into the balag to catch water for Gulosit wells and a new head regulator was built for Tugarar cut. The bank was the beginning of what is now known as the Adariai bank, whose final form is shown in Fig.3.2. It was not sufficient, however, to restore the evidently deposits a great part of its silt in passing through this area, a fact which has an important bearing on the problem of irrigation. Whereas at Kassala the Gash is running in a shallow channel with a sandy bed several hundred metres wide, it acquires a totally different character in passing through this area, and it is found at a distance of fifteen miles north of Kassala flowing in a channel seven or eight metres deep and about twenty metres wide". Fifteen miles north of Kassala brings us nearly to Mekali.

How the Western Gash at Futa dried up in about 1917 and how Khor Araka spilled out to the northward have been described in the last section and are well illustrated in Fig.1.1. The picture that emerges is one of a vast area of balag starting from the spill a few kilometres below Kassala and only beginning to be collected again into a series of definite channels by the time Gammam is reached. The effect of this balag on the rest of the delta, and of its subsequent drying up, has been profound.

2. Balag Flow

In 1926 an attempt was made to estimate the loss of water due to the balag. The following estimated discharge figures were the result :

Year	Million m3 passed Kassala	Million m3 arrived Magauda	%age Loss
1924	456	291	36
1925	230	123	47
1926	600	346	42

The 1926 figures are complete only for that part of the flood up to and including 19th August. Roughly it could be said that there was a 40% loss in the balag, which was exaggerated in years of poor flood, just when the water could least be afforded. On the other hand the balag had the advantage of providing copious channel storage and thereby ironing out the more violent fluctuations of discharge to the north of it. Also the balag acted as a most efficient silt trap.

At this time, all supplies for Mekali canal were drawn from the balag and any tendency for the balag to drain out to the east was discouraged by stop banks. Flow was guided into Khor Mekali by a number of collecting banks near Gammam: this will be discussed in the next section.

3. The Drying out of the Balag

The fundamental reasons for the drying up of the balag are not far to seek. The Gash, after falling steeply to Kassala, began to flatten out and drop its heavy silt load, and to fan out over the deltaic formation so caused. Balag type of flow with its attendant dense vegetation increased the rate of silt depositions and built up land levels. Finally the Gash slipped eastwards off the high promontory of silt that it had built up. This process was aided and abetted by another quite normal feature of balag flow. Water running off downstream from a balag area is relatively free from silt; as it flows off the delta of silt which forms the balag its slope is increased. These two factors work together to produce erosion in the form of a number of small channels which tend to coalesce into one deep one. Cutting back through the balag area, this channel usually keeps to one side or other of the main body of the balag. Silt laden water is then carried on downstream, and the whole cycle begins again further along.

The actual mechanics of the drying out of the balag under discussion, sometimes known as the Gulosit-Gammam balag, can be seen from a reference to Fig.1.1. When that map was drawn the main balag was fed by spill from Khor Araka but, as we have seen in the last section, by 1925 this supply was silting up and a larger proportion of the water was flowing down Khor Kurmuta - this was a distinct eastward shift. By 1927 Khor Kurmuta was already being regarded as the main Gash. It is this flow that is referred to by the Chief Engineer of the Kassala Cotton Company in his 1927 report when he says: "The Gash this year has taken a very distinct turn to the east about four or five kilometres to the north of Tukruf. Here the river, as such, dies out and the waters flow northwards purely as balag ..... The main body of balag water opposite Gulosit wells now flows northwards more to the east than was position at the wells or Tugarar in the face of the easterly shift of the Gash, and it was therefore extended in 1928 to cut across the spill channels of Khor Salaam Aleikum. In order to improve the supply still further a cut, known as the Arak cut, was made off the Gash in 1931 to feed directly into Khor Salaam Aleikum; it is this cut which, developed over the succeeding years, is now itself known as Khor Salaam Aleikum. The results were excellent and encouraged the making of two more misgas watering off Tugarar head, one in 1931 and one in 1932, thus giving the canal a three year rotation.

By 1925 the supply from Khor Salaam Aleikum was deteriorating. It was hoped that the head regulator put in before the 1936 flood would improve the flow. The enlargement of the khor was taken up to the balag area lying against the Adariai bank; eight 42-inch Armco culverts were put under the bank to pass the resultant balag water northwards towards Gammam. From the balag a channel led along Adariai bank to Gulosit. As a result of damage to the pipe regulator at Khor Salaam Aleikum head, however, control was difficult. The big discharge from the khor cut a deep channel right across the balag to the Adaiai bank and carried it away. Fortunately Gulosit well had been watered, but Tugarar failed.

In 1937 the present Khor Salaam Aleikum head was built. The failure of the first structure had proved that an earth bank protected with brushwood is not strong enough to resist the Gash at a head regulator. It had also shown that if "Armco" pipes are used with "Calco" doors in an exposed position, the relatively heavy doors must have independent support. In fact the timber cut-off of the original structure was not under the gates and this was one of the fundamental causes of the failure. Khor Salaam Aleikum itself was further enlarged to carry a discharge of 20 m3/sec. Just south of Adariai bank a masonry control structure was built - at about K.3 along Khor Salaam Aleikum; this consisted of a 3 m regulated opening to the branch leading to Gulosit and a 6 m opening to pass the main discharge north into the balag. The structure was also intended to check any tendency to retrogression in the khor bed. The Gulosit branch was cleared and enlarged but, on account of the steadily rising levels due to silting in the wells basin, the bed slope had to be set at

1:3,000 as compared with 1:1,500 in the parent channel. The slope was insufficient and the channel silted up before Tugarar could be watered.

It seemed that Tugarar could no longer be watered from Gulosit wells basin and so in 1938 a special channel was dug right through the basin to Tugarar; this allowed a bed slope of 1:1,250 but meant that the wells had to be watered separately down a channel taking off Gulosit branch at another control point, at K.3 Gulosit, which provided a 3 m opening for Tugarar and a 42-inch pipe for the wells.

Again, in the 1938 flood, the channel silted up. By blocking the eastern half of the main group at K.3 Khor Salaam Aleikum it was possible to water the wells but not Tugarar. The heaviest silting was just downstream the offtake from Khor Salaam Aleikum. Fortunately there was abundant water in the balag and it was possible to break some of it out to the west, later, on to the Tugarar area.

In 1939 a steel silt vane was installed at K.3 Khor Salaam Aleikum. The offtake of the Gulosit cut there was set at 45° to the centre line of the parent channel and appears to have drawn off most of the bed load, leaving the upper, clearer water to pass straight on through the larger opening. It is remarkable that this should have happened in a 45° offtake, which is designed specifically to avoid such an eventuality, but the fact remains. The silt vane merely divided the channel, well upstream of the offtake, approximately in proportion to the required discharges. The result was excellent; in the next few years the area suffered from shortage of water for a number of reasons (mainly connected with Khor Salaam Aleikum) but silt was not one of them.

By 1942 the levels in the wells basin at Gulosit had risen still further and it was no longer possible to command them from the offtake at K.3 Gulosit branch. A new supply channel was therefore dug, taking off at K.3 Khor Salaam Aleikum and running alongside the Gulosit branch up to the point where the original wells supply took off. This satisfactory arrangement is still in operation; the wells channel silts up fairly badly, but it is sufficient to perform its function and, being only a very small channel, it is quickly and cheaply cleared.

After about 1950, rising levels in the wells basin again made it increasingly difficult to water, until, after the 1952 flood, it was scraped by machine; the spoil was used to make a bank which sub-divides the basin into two for greater ease of watering.

Of recent years Tugarar has done very well, averaging about 1,000 feddans of cotton. The soil is excellent.

5. Gammam Balag and Wells

The details of the Gash delta piped water supply scheme are strictly outside the scope of this report. As they are of some general interest a description of the scheme and an account of its history have been added at the end in the form of an appendix. Some account of it must be given here, however, because a great deal of the work done in river training and in the control of balag flow in the area was for the express purpose of improving the domestic water supply.

It was impracticable that a static administration should be dependent upon the rather ephemeral native well centres in the same way as the nomadic population. When the Kassala Cotton Company was given the concession for exploiting the delta they straightway put in a piped water supply fed from wells at Mekali. Here there were two aquifers, one above the other. charged to some extent by water from the Gash bed close by, but normally recharged artificially as well. As the cotton scheme expanded Mekali was found to have insufficient capacity and, after some casting around, Gammam was picked on for development as the supply centre. The work was carried out in 1931.

The rise of the water table at Gammam normally occurred sometime after the arrival of the Gash flood and this, coupled with the increased hardness of the water, was interpreted as meaning that the aquifer was replenished by "distant lateral percolation". It would appear that "distant lateral

percolation" was largely a catch-phrase bearing little relation to the facts. It was an entirely false conception and unfortunately it took a long time before this was realized. When pumping began the water table began to fall. It became apparent that replenishment came from the balag itself which was drying out and not from lateral percolation quite so distant as was at first hoped. By 1933 the flow through the forest had been greatly reduced; this was the year in which the Gash finally cut back to the head of the balag. The supply to Mekali came mostly from Khor Debelaweit, but the water passed Gammam in a series of small khors without producing balag. Khor Debelaweit had, at that time, only just cut back to the Gash; the general flow can be seen in Fig.3.4. The water table at Gammam did not rise at all that year and steps were taken to revive it. The cause-way leading from Gammam to the higher ground to the west was repaired to form a stop bank and a small spur bank was built out to the east. Khor Debelaweit was enlarged and cleared. This time there was a good flooding of the Gammam area, as shown in Fig.3.5 and the water table rose sharply; it reacted, in fact, like any artificially charged well centre.

The improvement was not enough and by the end of the year the water table had fallen further than ever. The Debelaweit source was developed still more and the east stop bank was joined on to the Gammam collecting bank (see Fig.3.6); at the upper end of this bank an 18-inch pump was placed to augment the flooding directly from the Gash. Thus it can be seen that these first attempts were aimed at purely local flooding; but the conception of "distant lateral percolation" was not yet dead.

Because these measures were only moderately successful an attempt was made to simulate more closely the original flow pattern of the Gash from the direction of Arak. It was considered that the porous zone through which the Gammam aquifers had been replenished formerly would most probably lie somewhere along that general direction. It was this line of reasoning that gave birth to the Khor Salaam Aleikum project.

The flood pattern in 1936 is shown in Fig.3.7. As can be seen, the idea was to release the water from the corner of

Gulosit basin to follow as closely as possible the old flow line of the Gash. The idea was partly frustrated soon after the start of the flood because the Adariai bank gave way. In general, however, the scheme worked and water levels at Gammam were restored and retained for several years.

By 1941 consumption of water had risen and in 1942 a new banking system was undertaken at Gammam to hold up the balag flow there and to permit direct and controlled flooding of the well centre. A cross-regulator was built in the stop bank, and the balag flow was concentrated into the basin. The outflow ran down Khor Mekali as before, but now it was controlled by the regulator. Thus it was practicable to flood the entire well centre of Gammam to a depth of several feet of water and to leave it so throughout the period of the flood. The result was startling; the water table at Gammam reached a level fourteen feet higher than the average of the preceding five years and the yield was increased by 30%. So much for "distant lateral percolation" !

In 1938 the flow from Khor Salaam Aleikum north of Adariai bank had been confined on the east side by a new bank known as the Araka bank, and by 1943 a silt bar had been deposited between this bank and the Adariai bank. A cut, one and a half kilometres long, was therefore dug through the bar to join up with some natural khors cutting back from Gammam. This had the effect of speeding up the flow to Gammam, which was desirable because of the necessity of getting water past there to Mekali. By 1946 the natural khors in the balag had eaten their way back into the artificial cut and one fall had to be put in at K.5.6 in 1947 and two more at K.6.3 and K.7.3 in 1948.

In 1951 a new bank was built to join the Adariai West bank to the Gammam Collector bank. The work is shown in Fig.3.8. This finally enclosed the Gammam balag area. In the big floods of 1952 and 1953 the Gammam area was given such a soaking that the water table rose to an unprecedented level; despite pumping to an extent for which the scheme was never designed, levels after the 1953 flood remained so satisfactory that the 1954 flooding, though less in extent than before, raised the water table even higher still.

One feature of the Gammam balag requires comment. It has been seen how at first the excavated channel of Khor Salaam Aleikum was taken to K.3 and the water then spread out over the balag. It has also been seen how the cut had to be extended through the silt bar so formed until it runs into a natural khor cutting back from Gammam and how falls had to be built in the channel. This channel, in its turn, has had to be cleared and, at the time of writing, the maintained channel of Khor Salaam Aleikum is ten kilometres long. The filtering effect of the balag has been lost and silt is being carried much further north. It has not yet created a very serious problem at the well centre itself, but it is significant of the general trend in balag levels that the three falls in Khor Salaam Aleikum, built in 1947 and 1948, have now completely silted up. This raises the question as to whether they were really necessary in the first place. Undoubtedly they were, as otherwise the natural khor cutting back from Gammam would have threatened the regulator at K.3 Khor Salaam Aleikum. The fact that subsequent raising of levels due to silting has rendered them superfluous does not mean that a crisis at K.3 could not have arisen before the present silting conditions established themselves. It may be mentioned in passing, however, that the shortcomings of Gammam as a supply centre have long been known and, at the time of writing, active steps are being taken to instal a new supply system based on the excellent ground-water supplies near Kassala. Gammam will then be relegated to the status of a subsidiary supply.

6. The Gash Khor

It has already been recorded how the Gash cut its way through the balag between 1930 and 1933. Since then the reach has been widely unstable; interest has been concentrated on the flow from Khor Salaam Aleikum and the Gash proper in this area has attracted little attention. It has not been of much use for practical purposes but it is not without interest.

Fortunately, an excellent series of aerial photographs was made of the reach in 1933, just after it had cut through. This is fairly accurately reproduced in Fig.3.4, but a great deal can be seen in an aerial photograph that cannot be set down in a drawing. Previously the river had fanned out into balag flow in Hod 8; the balag had swept diagonally across Hod 7 and then swung northwards. The river bed here is shown as being very wide in 1933, as indeed it still was, but the flow was actually concentrated into two deeper channels, one on either side of the bed. Such was the part that had just cut through. Further north, the channel was becoming more defined; at first the main channel, in Hod 14, was about 75 m wide, swinging widely through a mass of minor channels which it was in process of cutting off and silting up. There was heavy spill to the east. This part, too, had only cut through earlier in the same flood. The northern part of the reach, which had cut through in the preceding three years, appears to have been quite stable. It was little over 40 m wide and ran fairly straight. The mass of minor channels on either side can still be detected on the photographs, though in a more restricted zone, and they give the impression of running only at times of high spate, if at all.

We have seen that in 1934 Khor Debelaweit was developed for water supply. No photography is available but Fig.3.5 is probably accurate. The river from some distance below Khor Salaam Aleikum offtake to Khor Debelaweit was still unstable with wide and narrow sections alternating; there was no flooding to the west of the river at that time, though it still occurred to the east. Further downstream a big bend (in the middle of Hod 14) was threatening to cut in and rob Khor Debelaweit of its water.

The small 1935 flood caused only local changes. North of the big bend, below Khor Salaam Aleikum offtake, the Gash tended to become more sinuous, and the other big bend, noted in 1934, which was threatening Khor Debelaweit, eroded to within ten metres of the khor. All this is well shown in Fig.3.6. It was in this year that the first well was dug at Gash Wells, a site near the river on the west bank on a level with Gammam. These wells fed into the main tanks at Gammam and have always yielded well until about March each year; they are all brick lined, open wells.

It was about this time that a deeper channel was noticed below Khor Salaam Aleikum offtake and it was feared that it was

cutting its way back and would affect the regulator there. However, it never developed and by 1936 it had silted up again.

Conditions in 1936 are shown in Fig.3.7. The Gash is becoming far more sinuous and the big bend in Hod 14 has now cut into Khor Debelaweit, which is reduced to a short-cut across a bend in the Gash. Further north two very acute bends, where the Gash almost doubles back on itself, have formed between Hods 14 and 21. Up near Gash Wells a bend was digging into the bank just to the south of the wells themselves.

Another excellent set of photographs was taken in 1937. These show up a new manoeuvre on the part of the Gash. In several places bends have become so acute that the river has folded right back on itself, forming a deep bay straight ahead in the original direction of flow, before swinging off in a narrow channel to the right or left. This can be best explained by a series of sketches: see Fig.3.9. This formation has become typical of the reach in recent years and at present the Gash in this area is a series of such bends, first to one side and then to the other. The formation is much longer lived than might be expected because the tendency to erode ever further into the concave bank is balanced by the tendency to cut off, and the river swings erratically from its shortest to its longest course, changed by each successive spate and altering its shape continuously, but in general retaining its form and character. The northward bend just below Khor Salaam Aleikum offtake was one of the first to develop on these lines.

An interesting attempt at river training was made at Gash Wells before the 1938 flood in order to protect the wells there. Two porous spurs were built out into the Gash, as shown in Fig.3.10, and a leading cut was made to draw the flow past them. The porous spurs were built of stakes, made of old piping, driven into the river bed and wired together, as shown. Brushwood was piled into the interstices. At first the scheme worked well and the porous spurs collected a 2 m depth of silt; later, however, a series of heavy spates removed the downstream 50 m of the north spur and emergency work with trees and wire rope failed to restore the position. Severe erosion took place on the promontory between No.2 and No.4 wells and eventually No.4 well was left in mid-stream - quite undamaged. In spite of the inconvenience of moving pump and engine before each flood and replacing them afterwards, the well continues to supply water. It looks rather odd, because the brick lining stands up above the bed of the Gash more like a factory chimney than a well; nevertheless it must have been well built, because each year it has to stand up to the Gash flood and the impact of the trees and timber carried along by it. Since that time it has often been necessary to put in brushwood protection at Gash Wells, but no more of them have been claimed by the river yet, though it skirts along the lining of No.2 well now.

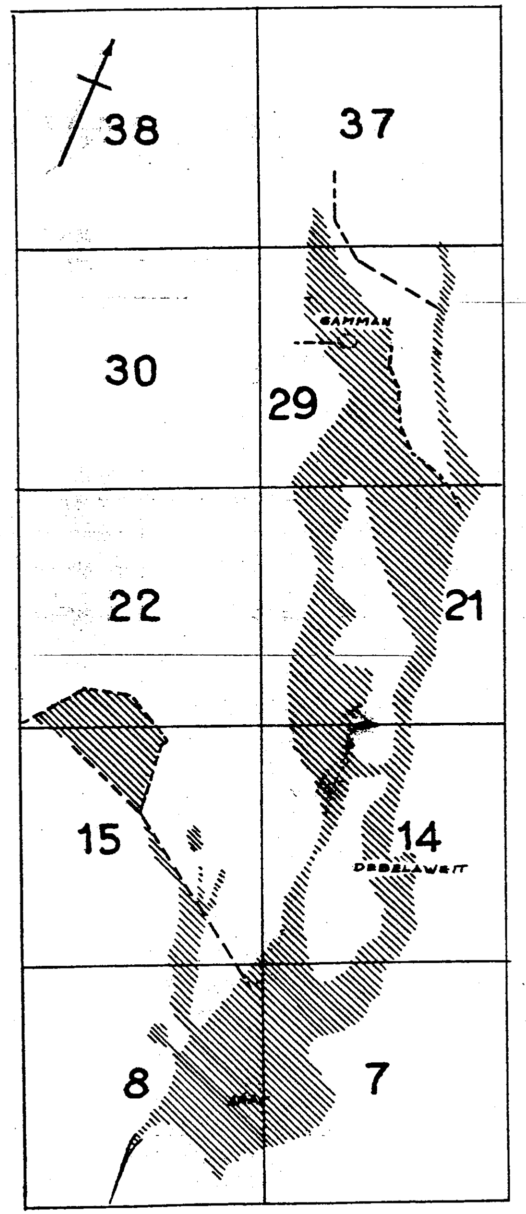
A line of levels was run through the reach after the 1938 flood. These were not talweg levels and so must be treated with caution. However, the river in general from Khor Salaam Aleikum to Gash Wells is shown to have a bed slope fluctuating irregularly, but averaging out at 1 m/Km. There does not seem to be any relationship between bed width and slope.

It is almost impossible to follow the developments that followed during the war years. There was no aerial photography and though the river was inspected each year on camel-back, it was never worth anyone's while to survey it. All that remain are descriptive passages in reports from which it is possible to gather that the river remained unstable, constantly cutting off bends and forming new ones. This instability was far more marked below Debelaweit than above it. It was not until 1951 that another comprehensive air survey was made; it is interesting to compare it with the last air mosaic produced before the war in 1939. The river has changed to such an extent that it is difficult to compare reach for reach. The first thing that leaps out from the 1951 survey is the enormous increase in both the number and size of the loop formations shown in Fig.3.9. These great sweeps, often as much as 800 m in width, now occupy nearly 50% of the total length of the river course. Between them, and particularly in the neighbourhood of Gash Wells, the river has become much wider. At Gash Wells itself it is nearly 300 m wide and further upstream where it runs between the loops it averages nearly 100 m. There is every indication of extreme instability.

It is interesting to note that the bend northwards below Khor Salaam Aleikum offtake remains very much what it was in 1939. An outline sketch of the section, taken off the air survey, is reproduced in Fig.3.11. The river is still very much as it was in 1951, though the detail, due to instability, is constantly changing.

FIG. 3.1.

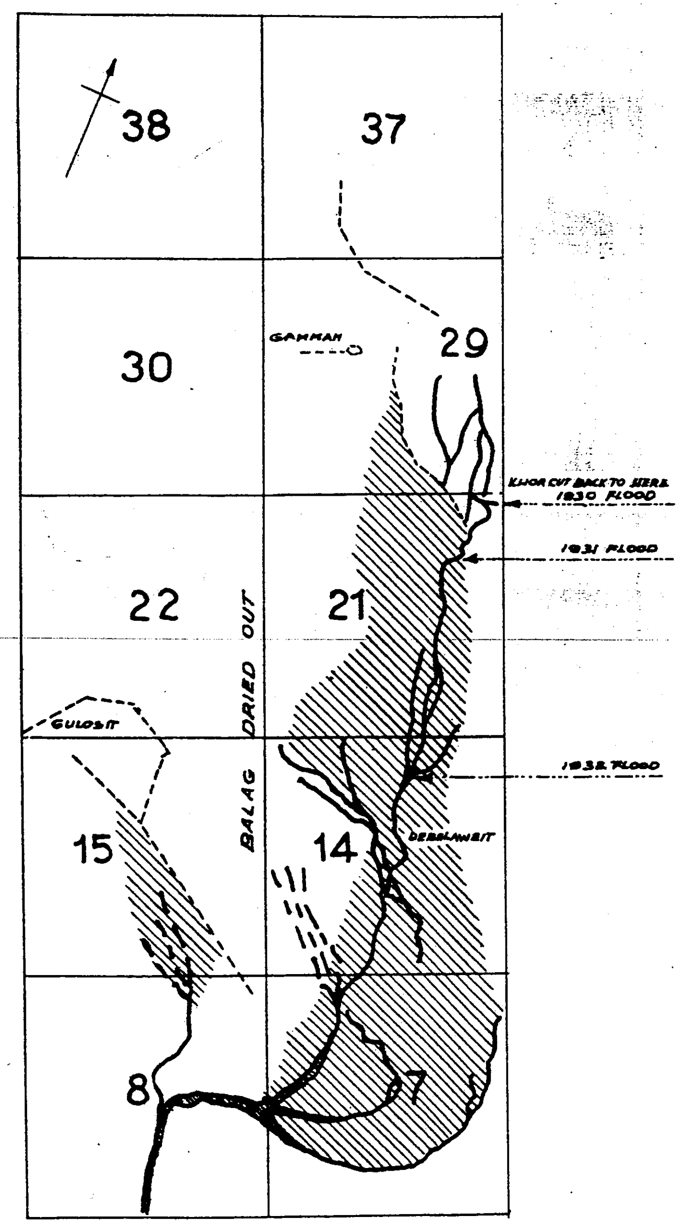
FLOODING SOUTH OF GAMMAN 1927



TRACED FROM ORIGINAL
O. BARTEZZATI 1955

FIG. 3.2.

FLOODING SOUTH OF GAMMAM 1930-33



TRACED FROM ORIGINAL
O. BARTEZZATI 1955

FIG.3.3.

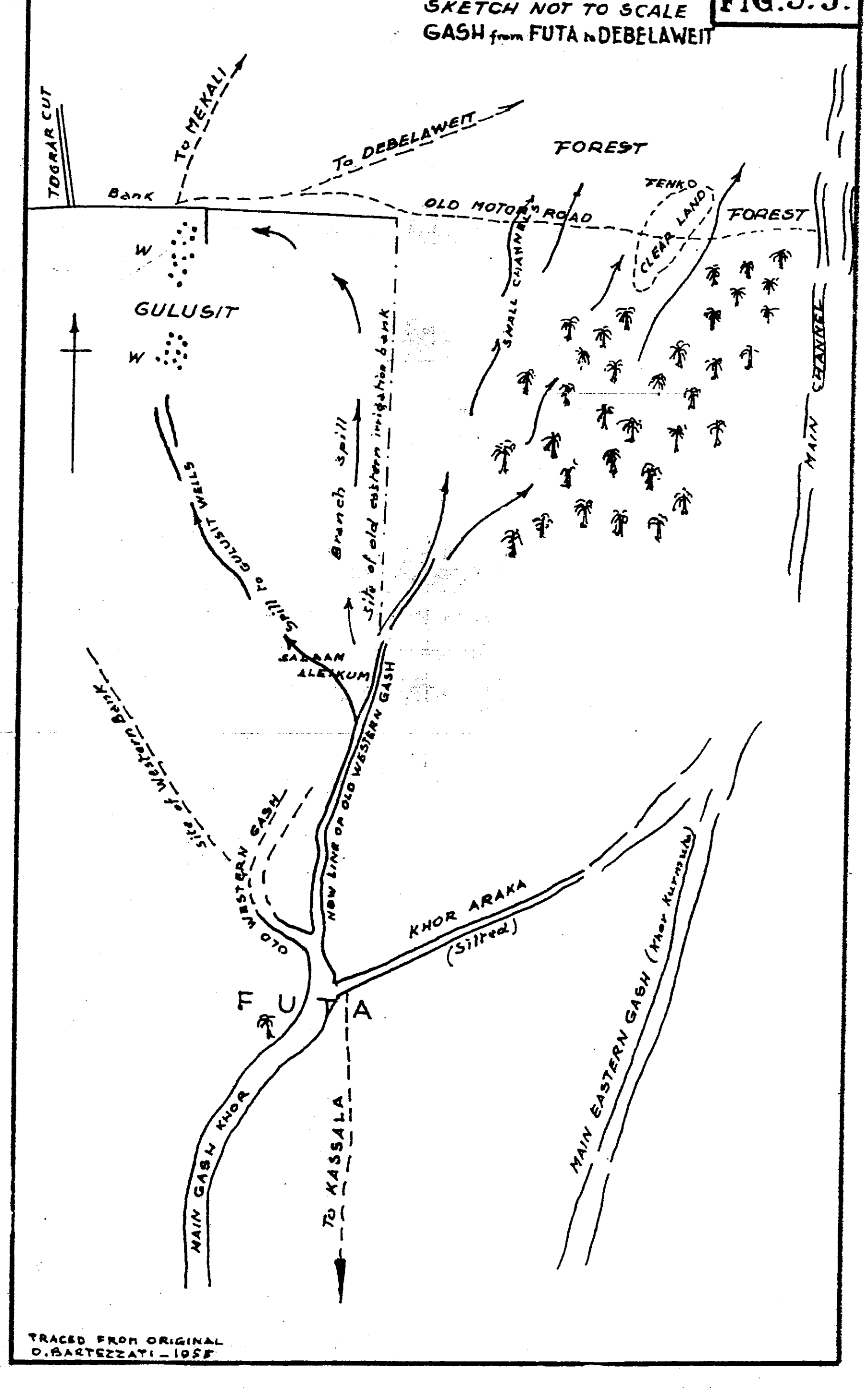
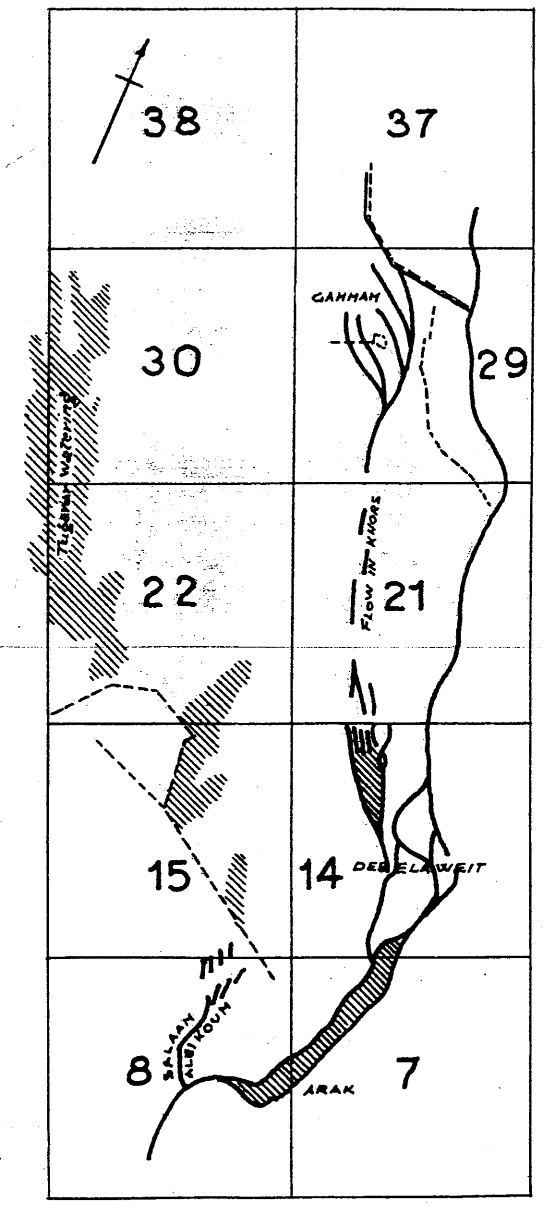

SKETCH NOT TO SCALE
GASH from FUTA to DEBELAWEIT
TOGRAR CUT
To MEKALI
To DEBELAWEIT
FOREST
TENKO
CLEAR LAND
FOREST
Bank
OLD MOTOR ROAD
SMALL CHANNEL
MAIN CHANNEL
W
GULUSIT
W
Branch spill
Site of old eastern irrigation bank
Spill to GULUSIT WELLS
SALAAM ALEIKUM
NEW LINE OF OLD WESTERN GASH
Site of Western Bank
OLD WESTERN GASH
KHOR ARAKA
(Silted)
F U T A
MAIN GASH KHOR
To KASSALA
MAIN EASTERN GASH (Khor Kurmuta)
TRACED FROM ORIGINAL
D. BARTEZZATI – 1955

FIG.3.4.

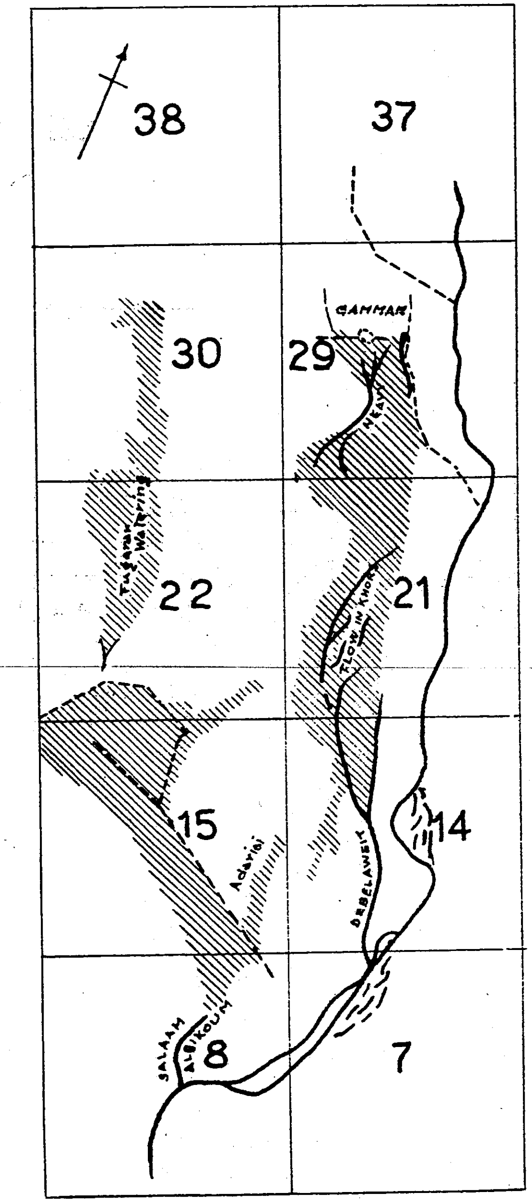
FLOODING SOUTH OF GAMMAN 1933



TRACED FROM ORIGINAL
O. BARTEZZATI 1955

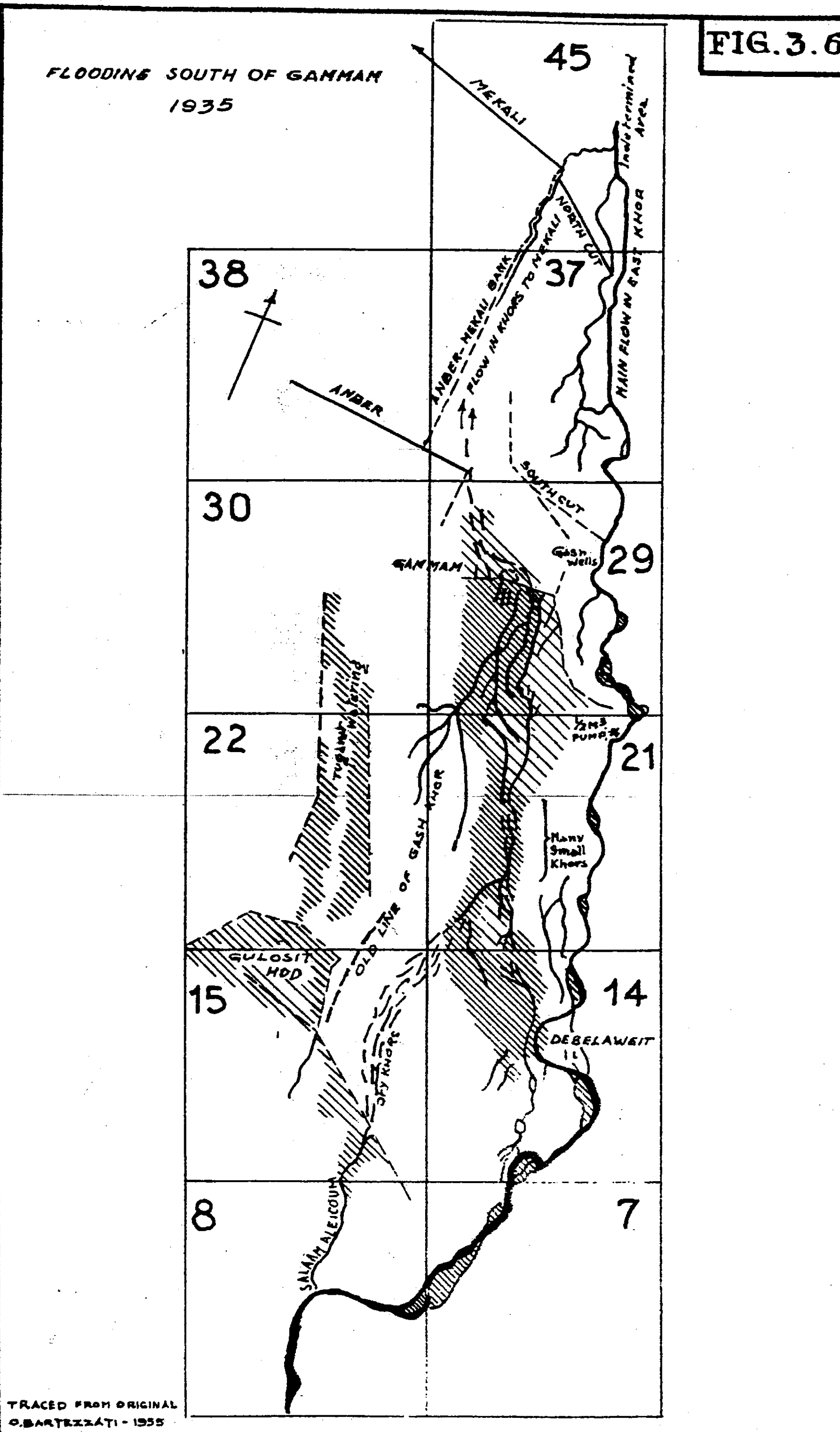
FIG. 3.3.

FLOODING SOUTH OF GAMMAN 1934



TRACED FROM ORIGINAL
G. BARTEZZATI 1955

FIG. 3. 6.



FLOODING SOUTH OF GAMMAM
1935
45
37
38
29
30
21
22
14
15
7
8
MEKALI
Indeterminate Area
MAIN FLOW IN EAST KHOR
NORTH CUT
ANBER-MEKALI BANK
FLOW IN KHORS TO MEKALI
ANBER
SOUTH CUT
Gash Wells
GAMMAM
PUMP
Many Small Khors
OLD LINE OF GASH KHOR
GULOSIT HOD
DRY KHORS
DEBELAWEIT
SALAAM ALEICUM
TRACED FROM ORIGINAL
O.BARTEZZATI - 1955

FIG. 3.7.

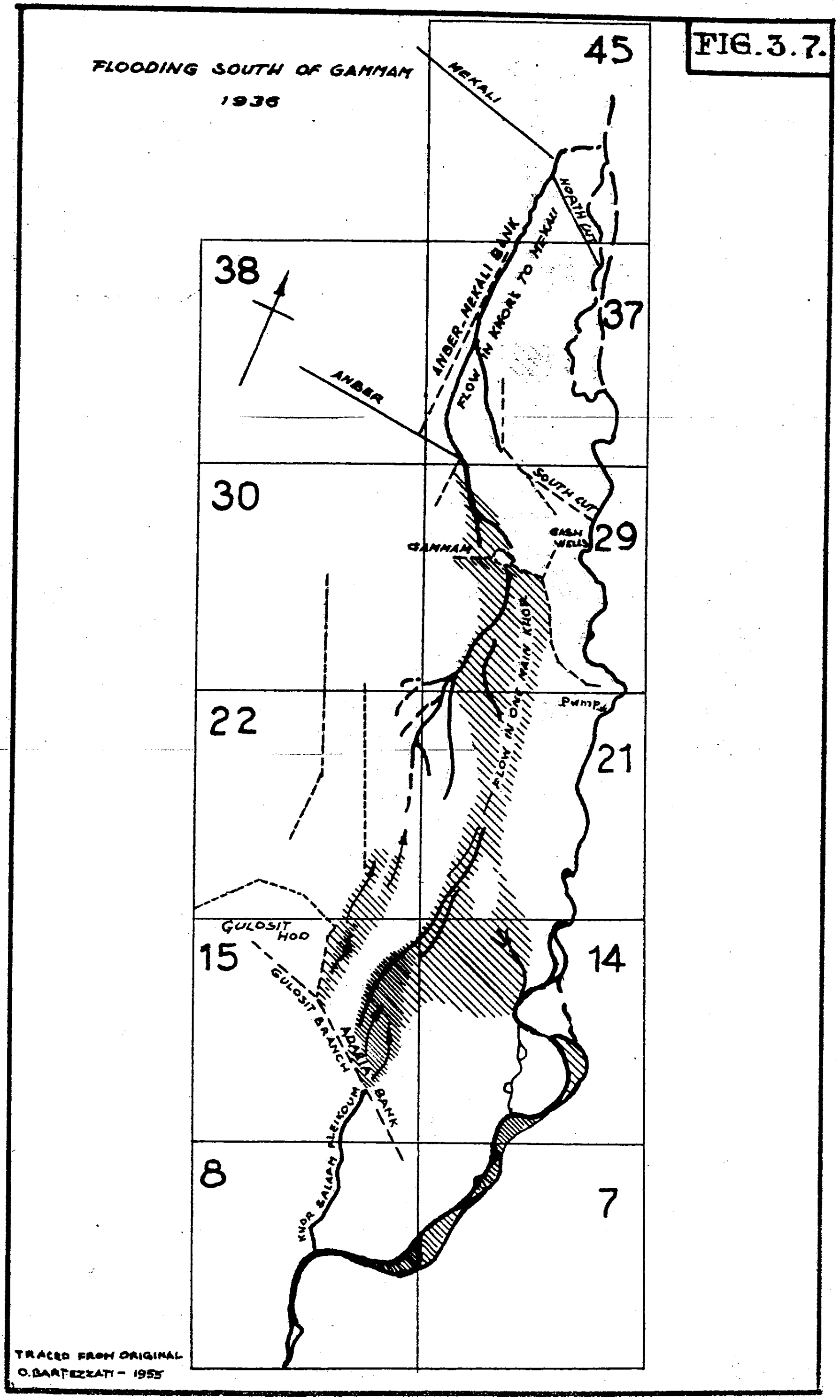

FLOODING SOUTH OF GAMMAM
1936
45
37
38
29
30
21
22
14
15
7
8
MEKALI
NORTH CUT
ANBER-MEKALI BANK
FLOW IN KHORS TO MEKALI
ANBER
SOUTH CUT
GASH WELLS
GAMMAM
FLOW IN ONE MAIN KHOR
Pump
GULOSIT HOD
GULOSIT BRANCH
ADARIAL BANK
KHOR SALAM ALEIKOUM
TRACED FROM ORIGINAL
O. BARTEZZATI - 1955

FIG. 3.8.

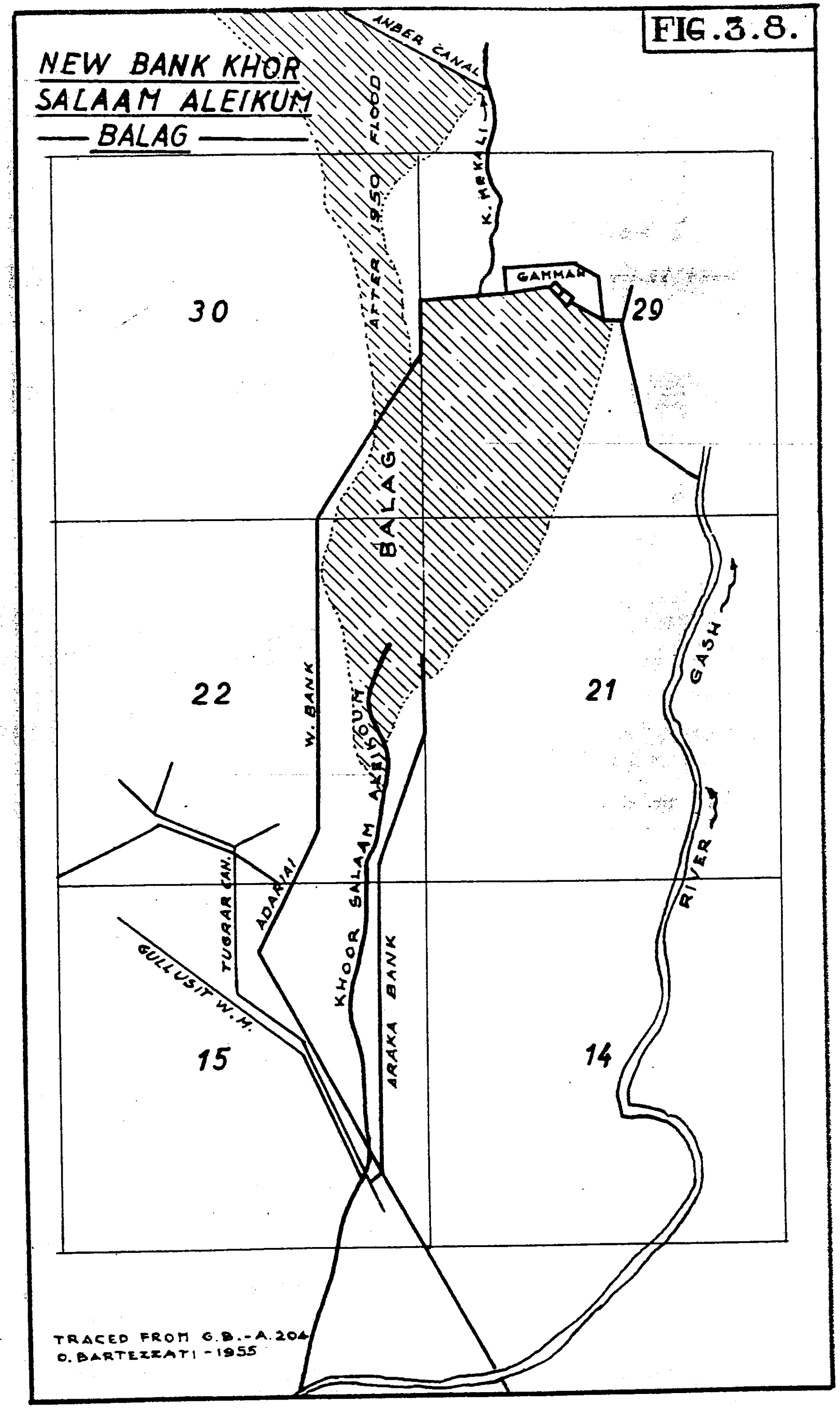
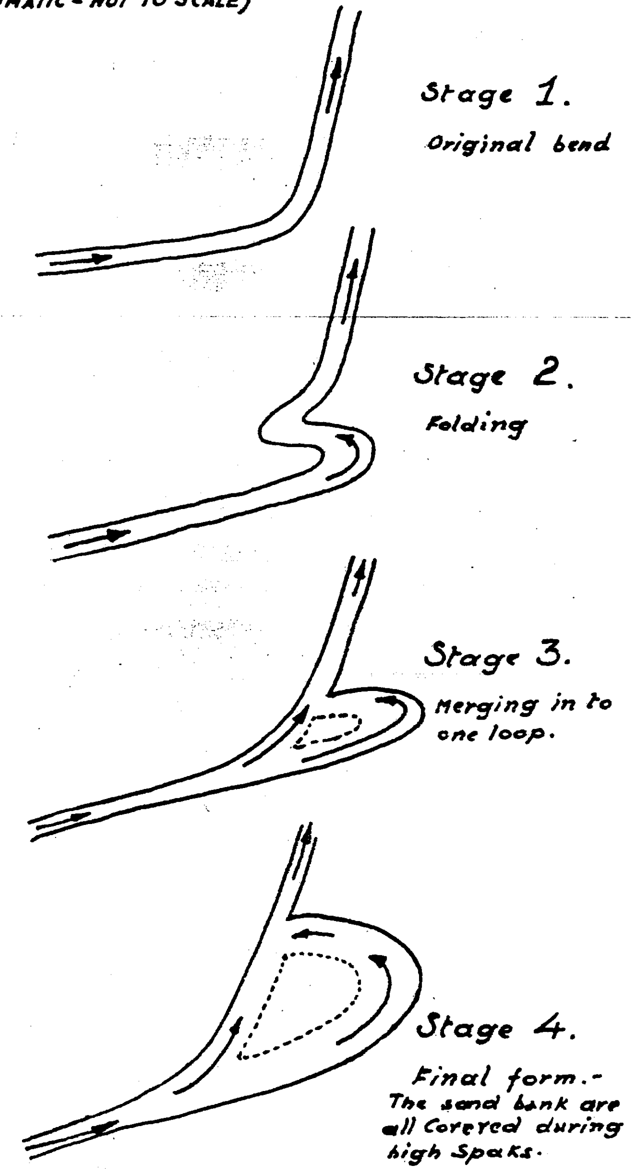

NEW BANK KHOR
SALAAM ALEIKUM
BALAG
ANBER CANAL
FLOOD
AFTER 1950
K. MEKALI
GAMMAR
29
30
BALAG
22
21
W. BANK
KHOOR SALAAM ALEIKOUM
GASH
RIVER
TUGRAR CAN.
ADARIAI
GULLUSIT W.M.
ARAKA BANK
15
14
TRACED FROM G.B.-A.204
O. BARTEZZATI - 1955

FIG.3.9.

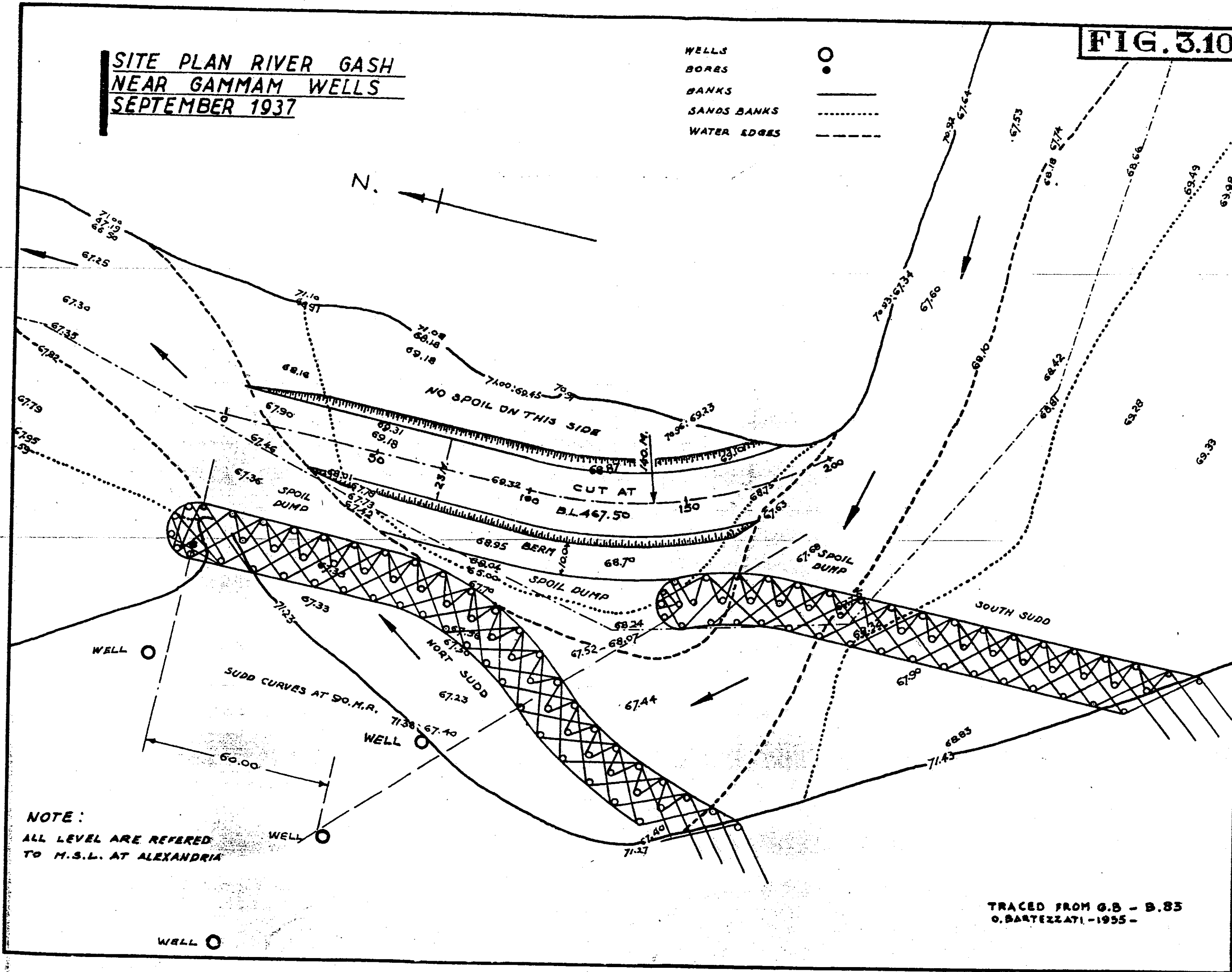
THE FORMATION OF BENDS IN THE DEBELAWEIT REACH

(DIAGRAMMATIC - NOT TO SCALE)



TRACED FROM SKETCH SWAN'S
D. BARTEZZATI - 1955 -

FIG. 3.10.


SITE PLAN RIVER GASH
NEAR GAMMAM WELLS
SEPTEMBER 1937
WELLS
BORES
BANKS
SANDS BANKS
WATER EDGES
N.
NO SPOIL ON THIS SIDE
CUT AT
B.L.467.50
BERM
SPOIL DUMP
SPOIL DUMP
NORT SUDD
SOUTH SUDD
SUDD CURVES AT 90.M.R.
WELL
WELL
WELL
WELL
60.00
NOTE:
ALL LEVEL ARE REFERED
TO M.S.L. AT ALEXANDRIA
TRACED FROM G.B - B.83
O.BARTEZZATI -1955-

SURVEY GASH U/S K.S. ALEIKUM
DURING THE FLOOD 1951

(TRACED FROM AIR PHOTOGRAPHS TAKEN SEPT. 1951)
(O. BARTEZZATI)

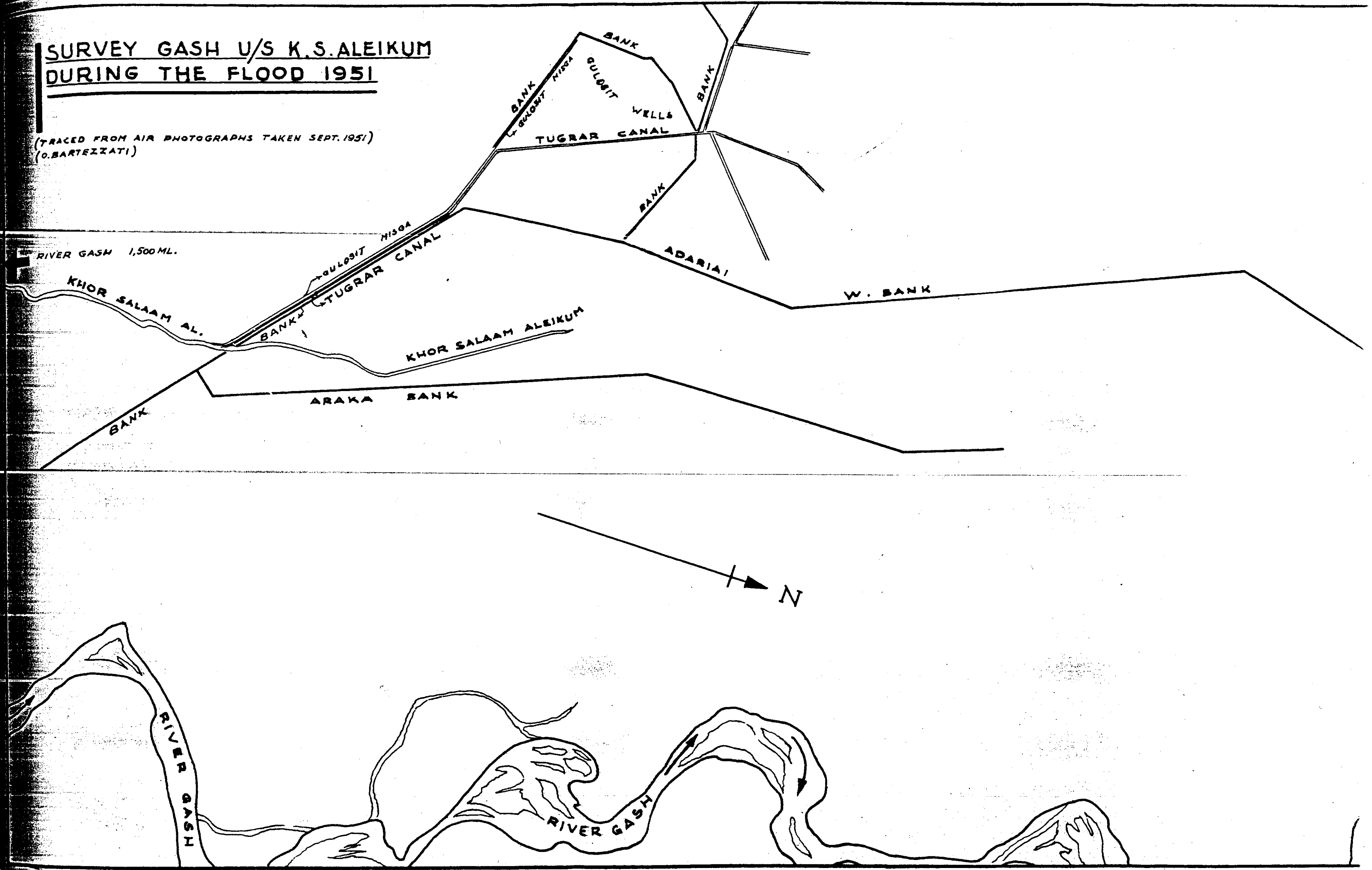
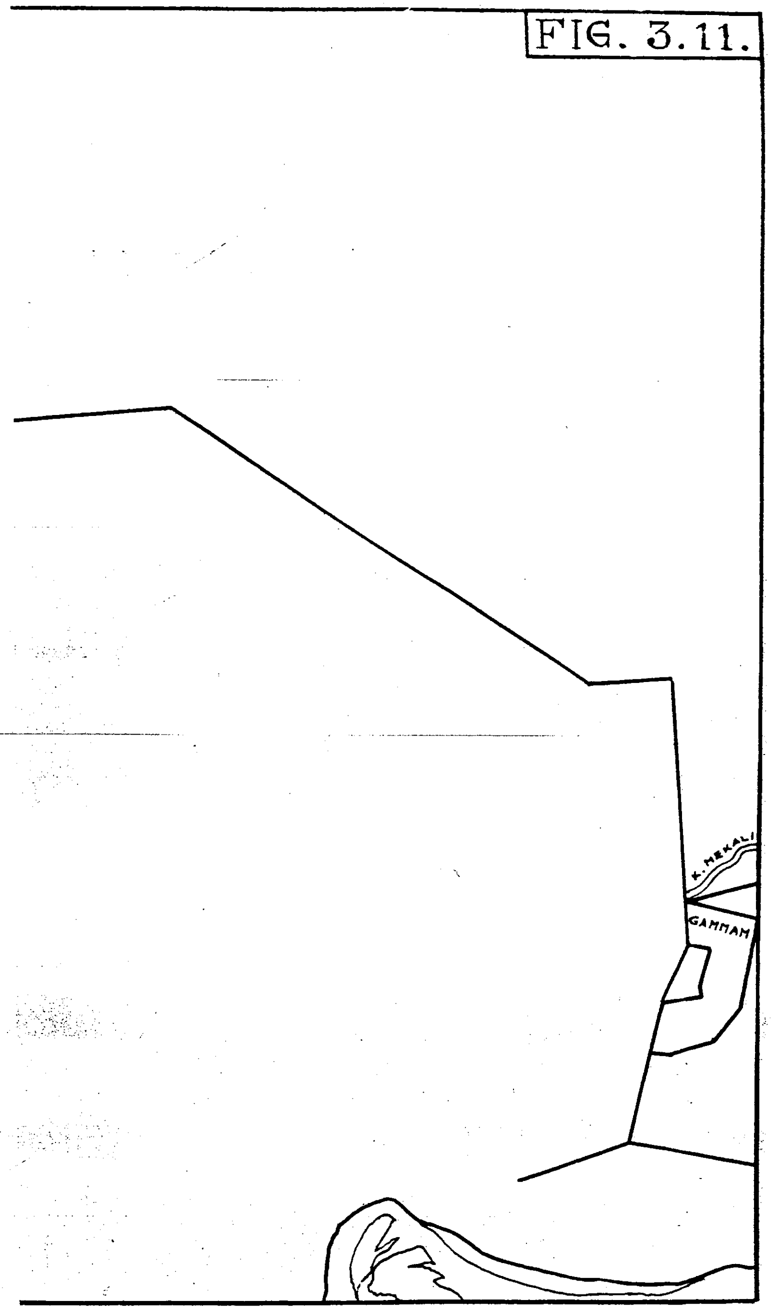


FIG. 3.11.



SECTION IV

GAMMAM TO MEKALI

1. Introduction

We shall discuss, in this section, the reach of the Gash from just below Gash Wells to what is known as the Haboba crossing, which is on a level with Mekali Wells, and with Khor Mekali from where it issues from Gammam balag down to Mekali canal offtake. In this section, also, we shall deal with Mekali canal, the most southerly of the major canals taking off the Gash.

The history of the reach and the history of Mekali canal are inextricably bound up, and it will not be possible to deal with each in a separate, water-tight compartment. Mekali canal has always been difficult to water; on the other hand it irrigates some of the most fertile soil which it is possible to reach by a major canal system in the present state of development of the delta. Efforts to find a suitable supply for the canal have been unremitting and have ranged from Khor Salaam Aleikum in the south to the present canal head in the north, a distance of twenty kilometres. It is proposed, therefore, to discuss the problem of an offtake for the canal, which will necessarily include following the history of the Gash Khor itself year by year. The canal below its offtake will be dealt with separately at the end.

2. Early History

Very little is known about the flow of the Eastern Gash before the cotton-growing scheme first started in 1923. Fig.1.1 shows that in 1922 the Eastern Gash was forming from the running together of a number of khors which drained the Gulosit-Gammam balag. Khor Madafarieib, which came from the Debelaweit area (and further upstream bore the name of Khor Debelaweit, though it should not be confused with the other khor which bore the same name in about 1930) was joined by Khor Gammam coming from west of Gammam just north of the well centre. These two were joined north of Mekali Wells by Khor Mekali, coming in from still further to the west. It seems probable that, of the three, Khor Mekali carried the greatest discharge; certainly a large number of "shaiyotes" watered from it.

In 1923 the Gash some distance south of the present Mekali head was described as being narrow and deep; there was no trace of the sand that characterized the Kassala reach and the general appearance indicated that the river was scouring its bed. It is not known precisely which channel is here described, but the description tallies well with what one might expect of any channel running out from a balag.

Mekali was one of the first of the major canals to be dug in the delta. A trial cut was made in 1923 taking off Khor Mekali. In Fig.4.1 it is marked as the "Old Cut" and it continued along the general line of Misga 1. This line must have given a very steep slope and by the following year, when a much larger area was being watered, the cut scoured to a slope of 1:1,100. In 1924 a new collecting bank was built to increase the flow from the Gammam balag into Khor Mekali; it is shown in Fig.4.1 in Hod 37.

In 1925 an existing "shaiyote" called Anber was developed by building a small catch bank in Gammam balag and opening a cut westwards. It was not a success that year because there was no head regulator.

3. Mekali Supply: 1926 to 1938

In 1926 a head regulator was built for Mekali canal. It was combined, at right angles, with a cross regulator on Khor Mekali. Both had two 2.5 m openings controlled by stop-logs. A number of these right-angle offtakes were built in the early days in the Gash; they are not a good hydraulic design, the flow through them at anything above a moderate discharge being far from streamline. An even more serious defect is that when it is the canal which takes off at right-angles, as it is at Mekali, the draw-down to one side attracts to a greater extent the slower moving flow near the bed which

causes silting in the canal. A non-hydraulic disadvantage is that drivers of vehicles wanting to cross both regulators in succession are forced to described a 270° loop between each part and thereby have to drive through a dense cloud of dust which they themselves have just raised.

The site chosen for the head was about one kilometre further downstream on Khor Mekali than the offtake of the original cut. This was to reduce the slope in the canal, which was causing scour. The head regulator is still in use; it is the structure which is referred to throughout this report as Mekali head. At the time of writing a new head is being built for Mekali canal taking off the main Gash; in order that there shall be no confusion, this new structure will always be referred to as the proposed new Mekali head.

In the same year a head regulator to Anber cut was built and a by-pass put in for the excess water. The structure was another of the right-angled offtakes just criticized. The 1926 flood was a big one and the regulator was quite inadequate to cope with the large volume of water from the balag. The canal was broken in several places, both above and below the regulator, which was short-circuited on the south side by a balag 300 to 400 m wide running alongside the canal for nearly two kilometres. The water, which broke through the canal, swept on to Mekali.

The new arrangements at Mekali worked very well until all control was lost on account of the flood from Anber; even then they prevented the damage from becoming a great deal worse than it actually was. It was evident that the system of collecting banks in Gammam balag which supplied both Anber and Mekali was more than adequate and in times of high spate sent more water down Khor Mekali than it could carry. Spill took place from both sides of the khor all the way down to Mekali head; that to the east proved an excellent safety escape back to the Gash, but that to the west broke into Mekali canal below the head regulator and added to the water which was breaking in lower down from Anber. It must have been quite an eventful July, as has happened so often in subsequent years. The Inspector's house and the village of Mekali were surrounded and, of course, Mekali canal was breached. There were two main breaks: the first was just downstream of Misga 3, whence the water swept on, breaking through the Badarir extension of Mekali canal and finally breaking into Magauda canal near Aroma; the second break, upstream of Misga 1, ran down Khor Halibeit and broke into Magauda canal near Misga 1 Magauda.

The most serious damage done in breaches of this kind, which are still all too frequent, is the flooding of land out of rotation, producing a strong weed growth involving heavy labour in cleaning the land afterwards and adversely affecting the next crop to be grown in the area. The damage to the channels and banks of the water distribution system is usually repaired much more quickly and cheaply.

Mekali head was of value during the flood, although outflanked, by closing up at least one source of flow from Khor Mekali. Indeed, at one time it was opened to pass the water in reverse, back from the canal to the khor !

To prevent a recurrence of such a flood banks were built from Mekali head to Anber, west of Khor Mekali, and from Anber canal to tie into the high ground west of Gammam wells. This is shown in Fig.4.1. Escapage was provided by demolishing the catch bank in Gammam forest for a length of 700 m opposite the offtake of Anber.

The 1927 flood was almost as big as that of 1926, but the new banking system proved quite adequate and full control was maintained over both Anber and Mekali canals throughout the watering season. At Anber the balag levels were higher than had been anticipated and rose to 30 cm above the deck of the regulator, but breaks were prevented by raising the banks and putting sand b... across the deck. At Mekali everything went smoothly.

Two points were noted after the flood: firstly that khors tending to drain balag water back to the Gash in the neighbourhood of Gammam were increasing and, secondly, that Khor Mekali was scouring deeply, particularly in its upper reaches. We have seen, in the previous section, that both these tendencies were related to the final drying out of the

balag. It is unfortunately, one of the features of river control, as with so many other activities, that it is much easier to detect tendencies and trends in retrospect than it is in anticipation; the historian has all the advantages over the would-be prophet !

Anber canal was not operated in 1928. The areas commanded were too heavily weeded and the problem of ensuring an even flow over them had not been solved. It was not brought back into use until 1944 because as time went on the supply of water was insufficient for Mekali canal alone, which gave no encouragement for other ventures in the same area; in addition command was lost due to scour in Khor Mekali and was not regained until the falls were built in 1944.

Mekali was successfully operated in 1928 but after the flood it was thought wise to extend the catch bank system in Gammam forest. Unfortunately the 1929 flood brought too much water and the Mekali-Anber bank was breached; the flood broke into Mekali canal below the head and all control was lost. It was lost on all canals that year.

It was not until 1932 that Mekali began to suffer from shortage of water as a result of the developments in the Gulosit-Gammam balag. Three small cuts were put in, before the 1933 flood, taking off the main flow of the Gash near the point where Khor Debelaweit was approaching it in Hod 14. These cuts only worked for the early part of the flood because, as we have seen, the main Gash khor cut back in 1933 and left the offtakes of the cuts well above maximum water level. Another attempt was the opening of a cut from the Gash near Gammam, called the South Cut, feeding into Khor Mekali. The cut followed along the line of the old catch bank and was not provided with a head. Its discharge does not seem to have been very great since altogether Mekali canal did very badly in 1933.

It was seen from the air, that year, that the Gash khor had bifurcated in Hod 37 and did not join back into one stream until just north of the prolongation of the line of Mekali canal.

In 1934 the enlargement and clearance of Khor Debelaweit was carried out to improve the supply through the balag, the South Cut was widened and deepened and a North Cut was dug from the westernmost of the two Gash khors, leading directly to Mekali head. The position of the North and South Cuts is shown in Fig.4.2.

The supply to Mekali was improved by all these measures, but by no means as much as had been hoped. Most of the water came from the Khor Debelaweit source, via Gammam balag, and from the South Cut, but both of these failed early in September. ~~The North Cut was not a success.~~ In the first place the branch of the Gash from which it took off was found only to run intermittently and, secondly, at times of high spate spill from further south ran through the forest and against the line of the cut, filling it almost to ground level with silt. As a result the North Cut only functioned at times of high spates and the water it supplied was heavily laden with silt; when the flood was slack it failed to augment the supply from other sources just when it was most needed.

On the whole Mekali supply was unsatisfactory in 1934 because, while in general it was deficient, at times of high spate it was excessive and heavily laden with silt. These violent fluctuations led to bad irrigation. It may be added that the Gash itself did not help; 32% of the entire discharge passed between 23rd and 30th August. Even for the Gash that is an unusually erratic flood.

Before the 1935 flood another offtake leading to Khor Debelaweit was cut. This was mainly intended for re-charging the well centre at Gammam, but it was hoped that Mekali would also benefit from it. The North Cut was not kept up and reliance was largely put on the South Cut. Unfortunately it silted up due to lack of command at its offtake; efforts were made to improve it by building a brushwood spur out into the river from the opposite side of the Gash. The spur was built (which must have been no mean feat when the Gash was running) but it had no effect on the South Cut offtake.

The branch leading to the North Cut had by now silted up, so that source brought no water except on one or two high spates.

The situation was serious since no water at all was reaching Mekali at anything less than a high Gash, so by mid-August the stop-bank at Gammam was cut and water from the Debelaweit source, which was operating well, was allowed to pass on down Khor Mekali. At that distance from its offtake it was but a small supply, but it was at least steady as a result of balag flow.

1936 saw the beginning of the Khor Salaam Aleikum project and the cutting off of the Debelaweit source. The supply was late in coming, after passing through the balag, but it was steady and was maintained right through to the end of the flood. Basing the estimate on the 1924 to 1926 records, a loss of 40% of the water had been allowed for in the balag. Actually the loss appeared to be greater than 50% (probably due to the fact that the balag had been dry for some years) and Mekali canal received only 70% of its designed supply. That, however, was a great improvement on the previous year.

Almost no water came in from the North and South Cuts. The former had been deserted by the river and the latter silted up.

Before the 1937 flood, the full Khor Salaam Aleikum scheme had been installed. From reading reports of the period it appears that by that time Khor Mekali had deteriorated badly and was no longer an effective water channel. It is not clear just when the deterioration started, but it was presumably some time after the Gulosit-Gammam balag dried out. In any case, by 1937 it was necessary to clear the bush along the route from Gammam to Mekali and to dig a shallow leading channel. Despite this work there was a considerable delay in getting water along it and it was not until 15 days after the opening of Khor Salaam Aleikum that an even moderate supply reached Mekali. In the end a very fair supply came down and Mekali did quite well. A number of useful flushes came down the North Cut; the main Gash khor had swung westwards until it was now only 30 m from the point where the original cut took off from the now silted branch of the river. The South Cut failed.

A lot of work was done before the 1938 flood to cut down the delay between Khor Salaam Aleikum and Mekali and to reduce transit losses. The building of the Araka bank in Gammam balag has been described; its main purpose was Mekali supply. From the end of it a clearing 30 to 50 m wide was made along the main flow line through the forest to Gammam. From there, Khor Mekali was remodelled into a fair channel. The magnitude of the task can best be appreciated from the following figures: it entailed 31,500 m3 of earthwork and the clearance of 60 feddans of forest along 8 Km of flow line ! In addition to this, a cut was made from the original offtake of the North Cut to the main Gash khor.

The 1938 flood was an erratic one with several high spates. This time the water took six days to come from Khor Salaam Aleikum head. The discharge was ample and the area of cotton grown was the best since 1930. The North Cut contributed strongly during high spates, although its new cut, direct from the Gash, failed. The South Cut, by now, was quite dead. The measure of acceleration effected by the works in the forest and Khor Mekali only became apparent later in the flood; by September the results of regulation at Khor Salaam Aleikum head were being felt at Mekali within 24 hours. The uncontrolled discharges from the North Cut were occasionally an embarrassment and reduction of flow could not be made from Khor Salaam Aleikum in time to accommodate them. In any case there was at that time no telephone at Khor Salaam Aleikum head.

It almost seemed as though a reliable supply for Mekali had been found at last; it was a great pity that the supply from Khor Salaam Aleikum started to get less from then on.

4. Mekali Supply: 1939 to 1954

In order to supplement the existing escape regulator at Mekali head, a new escape weir 8.10 m long was built there in 1939, facing Mekali canal regulator. Some minor clearance of the route through the forest was also carried out.

The flood was a very poor one indeed; the flow to Mekali varied between 40% and 70% of the full supply and at one period it failed completely. The new escape spillway remained dry and must have added an irritating note of irony to the depressing sight of a starved canal head.

During the 1940 flood Khor Salaam Aleikum regulator was in a forward area and only flying visits to it were possible. The resulting lack of control was reflected in poor supply to Mekali. This was made worse by a number of unrepaired breaches in the Adariai bank which let a lot of water escape into the forest and some, it is thought, back to the Gash.

The 1941 flood was a large one and, at first, there was a good supply down Khor Salaam Aleikum. The same early spates produced a flow in the North Cut which helped. The good supply at the start tailed off later on, but on the whole Mekali did not fare too badly. The same thing happened in 1942; after a fairly promising start the supply petered out and the second rotation almost failed.

This falling off in the supply called for special measures before the 1943 flood. Reference is made to Fig.4.3, from which it can be seen that there were two sources of supply, down Khor Mekali and from the khor marked EC and the North Cut. We have seen that this latter khor had silted up before 1935, but it seems to have yielded an intermittent supply in 1941 and 1942, possibly because of a rise in the Gash bed level at point E. The steps taken in 1943 included an extension of the North Cut to the main Gash (from C to D) as conditions there were favourable for an offtake; it will be noted that this was the second attempt, the first being in 1938 when the cut had failed. Next, the old line of the original 1923 Mekali cut was reopened. This is shown between G and H on the sketch; a pipe regulator was put in at G. The reason for this new approach was that in 1942 heavy erosion in the main Gash near point E had caused a large sand bank to be formed just off the khor offtake; as a result a lot of silt was carried in and deposited in the head reach of the canal between A and H. The idea was that if this happened again, as well it might, the canal could still be supplied through the new by-pass. Further work included straightening the escape channel from A to F, raising the head regulator by 1 m and building a new regulator with two 2.5 m openings at H. As a further precaution against trouble from silt in the canal, the watering arrangements were framed so that 70% of the area should be watered as first rotation and only 30% as second rotation.

During the 1943 flood the tendency in the Gash khor was undoubtedly to widen and to raise its bed. The river ran full to the banks and spill started just north of the North Cut. A good deal of change was taking place and it was feared that the satisfactory conditions at the offtake of the North Cut might not last.

The new arrangements for the supply to the canal worked excellently. The new offtake for the North Cut was fairly silt selective; some silt was brought in to the canal but there was sufficient clear balag water coming from Gammam to carry it away. The by-pass was never used.

At the end of 1943 an interesting review of the whole subject of Mekali supply was written by Mr. J.F. Glennie. He stressed the excellence of the soil watered from the canal, pointing out that some areas had yielded as much as 6 to 7 kantars of cotton per feddan after as many days watering. A feature of the soil is a very high absorption rate; it has already been remarked that irrigation water at Mekali is normally supplied at 2 m3 per second per 500 feddans of area - twice the rate for the canals further north - and the suggestion was now put forward that the rate be further increased to 3 m3. I do not believe that this suggestion was ever adopted as a design criterion (it certainly is not in use today) but the writer was rightly stressing the importance of a continuous, high rate of supply. If the supply fails when watering soils as permeable as they are in Mekali, the land rapidly dries out and weeds start growing; it is often difficult afterwards to carry on watering from where it was left off.

Dealing with the existing sources of supply, the review points out that the North Cut could yield a full canal at little more than average Gash. Although the present offtake was unlikely to remain satisfactory, the presence of the old khor (EC on the sketch) quite close to the Gash for some kilometres and running into the North Cut, made it unlikely that the task of developing a new offtake would be very costly. The other source, from Khor Salaam Aleikum, had deteriorated so much that an average Gash gave only 30 cm depth of water over the cill of the Khor Salaam Aleikum regulator, which was half what was required.

A large number of possibilities were examined and the conclusion was reached that the present supply system was satisfactory but unlikely to last and the final solution would probably be some form of river training at Khor Salaam Aleikum. The possibility of fluming the river there was mentioned. A separate new Mekali head taking directly off the Gash was rejected as too risky in so unstable a part of the river.

The increased discharge in Khor Mekali of the previous few years, together with the steep slope of the land, were causing serious erosion of the channel, and a series of five falls was decided upon to control the retrogression before it affected Gammam pumping station. Fig.4.4 shows the progressive erosion and the measure of control effected by the falls. The first two were installed in 1944 and the lower of them was sited at Anber head so that the canal could once more be commanded.

During the 1944 flood Mekali supply was again satisfactory and 500 feddans were watered off Anber. Conditions at the North Cut offtake were still propitious. The remaining three falls in Khor Mekali were installed in 1945 and the whole series worked most satisfactorily, as can be seen from the longitudinal section. It was just as well that Khor Mekali was so put in order because it had to carry the bulk of the supply during the 1945 flood. At the offtake to the North Cut a large sand bank had been formed; this was thought to have been caused by a projection in the west bank some 300 m upstream which was diverting the main stream to the east. The river was fairly stable for two kilometres upstream of this point, but still further up it was not so. One embayment had almost reached the old South Cut. Fortunately the natural khors and artificial cuts that by this time ran almost continuously through Gammam balag had greatly improved the flow from that source and although Mekali canal ran at full supply for only a short period, it did not fare too badly and the final cotton area was not much below estimate.

The South Cut was revived before the 1946 flood and a control consisting of a pipe regulator in an earthen bank was put in at the head. The word "control" here is used in a relative sense; actually the offtake was without regulation -

just open pipes behind an earthen dam so that once the dam was broken to start watering there was no further control. The flood, a big one, was marked by some high spates very early on, at the beginning of July. One of the first of these blew out the pipes on the South Cut and the resultant deluge breached the banks of Khor Mekali and Mekali canal; it also caused several breaks along the banks of the North Cut. When river levels fell the pipes were reinstated, only to blow out once more almost immediately. This time it was not possible to repair; eventually the South Cut was blocked right off and put out of commission. All this was quite disastrous for Mekali canal. With the Anber-Mekali bank broken, water was running right across the canal between Misgas 1 and 2. It could not be repaired until the middle of August. By then, of course, the supply was insufficient and the North Cut, which might at least have diverted some balag water into the canal, had been breached and could not be repaired. Mekali only watered just over half the estimated area. Despite the large flood there was little change in the Gash, though the sand bank in front of the North Cut became larger. The failure was yet another demonstration of the fact, already shown at Khor Salaam Aleikum, that an earth bank is not strong enough to resist the Gash at a canal offtake.

In 1947 a new control regulator was built in the South Cut. This time it consisted of four pipes laid on a concrete bed. Again they were buried in an earth bank, but it was pitched both upstream and down. Two sets of stop logs were installed, each set covering two pipes. As it took off an unstable reach, liable to erosion, the regulator was sited 100 m down the channel from the offtake. Such siting has two disadvantages: firstly the regulator can never be completely closed for fear of silting up the inlet channel and, secondly, at time of high spate the inlet tends to get choked with timber and floating debris. The whole subject of the siting of offtakes is of interest and is dealt with more fully later in this report. At the same time the left bank of Khor Mekali was enlarged to form a Gash balag bank because the Mekali-Anber bank had been a source of trouble at times of high Gash. This was probably because rising balag levels had left it too far down the slope down from the river.

The 1947 flood was a poor one. The North Cut soon silted up at the mouth and the supply from Khor Salaam Aleikum was meagre; most of the water, which was sufficient to water only 62% of the designed cotton area, came from the South Cut. To add to the general gloom it seemed that even the South Cut was unlikely to last much longer. We have seen that it took off an embayment; on the other side of the Gash there was, as usual, a deposit of silt and in 1947 the Gash cut a minor channel across this deposit and gave every indication of an impending cut-off. At the North Cut the promontory upstream the offtake was cut away before the flood and conditions there became much smoother.

Although no major work was done before the 1948 flood, and although as a flood it was even worse than in 1947, the supply to Mekali showed a surprising improvement. It seems that besides its normal pastime of thwarting the best laid schemes for control and exploitation, the Gash can, on occasion, reverse its tactics and co-operate when least expected. In the first place, as we have seen, Khor Salaam Aleikum offtake improved in 1948, and the supply from that source was quite fair. Then, at the South Cut, the Gash did not cut off as had been feared (although the threat remained) and a very satisfactory supply was maintained. Finally, conditions at the North Cut took a turn for the better. The sand bank which had veiled the offtake moved off into mid-stream and the cut remained in operation throughout the season. As a result Mekali canal did very well and exceeded its estimated cotton area.

Both North and South Cuts continued to flow during the even poorer 1949 flood. The supply from Khor Salaam Aleikum that year was negligible and the main source of supply was still the South Cut. The area watered was just above estimate; a remarkable achievement under the circumstances.

In 1950 a new masonry head was built on to the South Cut. It consisted of two 2 m openings controlled by stop logs. The Gash, repenting of its previous attitude of co-operation, promptly deserted it. It was a very high flood and, on account of damage further north, the Khor Salaam Aleikum regulator was fully opened to act as an escape relief.

[The] discharge, added to that of the South Cut before the Gash [le]ft it, breached the Mekali-Anber bank and ran into Mekali [c]anal. Mekali escape overflowed and enlarged an already [la]rge balag caused by Gash spill from near the Haboba crossing. [Th]is balag finally broke into Magauda canal. The second [ro]tation in Mekali was poor because of the loss of the South [C]ut and because a new extension to Misga 1 (called Gubba North) [w]as overrun by the balag and could not be operated properly. [I]n addition to this the supply from Khor Salaam Aleikum [d]eteriorated with time and in the end only the North Cut was [o]perating.

The 1951 flood was a weak one and Mekali canal did [v]ery poorly on a supply which came mostly from the North Cut.

Before the 1952 flood the Khor Salaam Aleikum weir was built and, in connection with it, Khor Mekali was enlarged so that it would be able to take the entire supply for Mekali canal. This work was followed by two very large floods in [1]952 and 1953; in both years Mekali canal did well but in both years the main supply was from the North Cut operating well on high spates, which were frequent. The supply from Khor Salaam Aleikum was disappointing and from the South Cut very slight. In 1954 it became clear that the weir at Khor Salaam Aleikum had not solved the problem of Mekali supply. It was a year of poor flood and with almost no spates of any size; under these conditions the North Cut did not operate, the South Cut was completely deserted by the Gash and the supply from Khor Salaam Aleikum was utterly inadequate. It was clear that yet another attempt must be made to secure a supply for Mekali canal.

5. Recent Developments in the Gash Khor

Before discussing the proposed new arrangements for Mekali supply it is necessary to go back a little and study the developments of the river. Fig.4.5 shows the 1939 outline of the Gash from the South Cut to Haboba. It can only be approximate because it is enlarged from a very high altitude aerial mosaic, but it gives the general idea well enough. Fig.4.6 shows the change over twelve years; the general run

and direction of the river has not changed so much as might have been expected. Major bends are still recognizable. What jumps immediately to the eye is the great widening and instability of the river near the South Cut and the apparently increased stability near the North Cut, where the river is running in a smooth, well defined channel. Finally, Fig.4.7 shows the position by 1954. Here the instability downstream the South Cut has increased and a major bend has cut off. The reach near the North Cut is still stable.

The decision to make a new offtake for Mekali on the Gash was made because, in the first place the land served was so good that it was imperative to get a supply from somewhere and, despite all improvements, Khor Salaam Aleikum had been shown incapable of meeting all its upstream commitments (Gammam, Tugarar and Gulosit) and still provide an adequate supply for Mekali in years of less than average flood. The position of the offtake site, shown in Fig.4.7 was not difficult to pick upon because it is the lowest point on the Gash from which Mekali canal can, at all stages, be commanded (the North Cut does not command Mekali at low river). It can be seen that the further upstream one goes the less stable the river becomes and it so happens that at the point chosen there is, at present, a suitable curve for an offtake. The risk was therefore accepted and a new masonry regulator is, at the time of writing, in course of construction. It is not expected to be permanent, but the hope is that by means of river training in future the offtake will at least serve for some years to come. The regulator has five 2.5 m openings controlled by stop logs and is, in general design, rather similar to the regulator at Khor Salaam Aleikum, though considerably higher. It feeds a new canal, three kilometres long, which runs into Khor Mekali about a kilometre above Mekali head.

6. Mekali Canal

The line of the original Mekali cut in 1923 has been shown. Very little is known about it except that it took a total discharge of 6 million m3 during the season, so it must have served only a small area on what is now Misga 1.

The present line of the canal was started in 1924 when Misgas 1, 2, 3 and 4 were put in with pipe regulators set in light masonry head walls and stone pitching, and Misga 5 was put in with a 2 m masonry opening.

In 1925 a pipe cross-regulator was built in the canal downstream of M.2 to reduce scour. The next year, after the building of the head regulator, three falls were put in the canal at K.7.4, K.9.0 and K.10.4 and two bridges were built over it at K.1.4 and K.4.4. Misgas 6, 7, 8 and 9 were put in with pipe regulators and the regulator at M.1 was converted to an open masonry head 2 m wide. The canal was completed down to K.17.4 with a steady bed slope of 1:3,000.

In 1927 Misgas 10, 11, 14 and 15 were brought into service, the first three with pipe regulators and the last, being at the tail, without headworks. Misgas 12 and 13 were put in with pipe regulators in 1928. The Gubba South misga, taking off Misga 1, was dug in 1932 and Gubba North misga in 1950.

Since 1942 an annual programme has been carried out of converting misga offtakes from pipes to open masonry structures. The latter are more efficient because the discharge increases more rapidly with a rising canal level and so allows advantage to be taken of spates when big flushes can be let out on to the land. In this connection, see the remarks in the Preliminary Section of this report. The programme has affected Mekali as follows :-

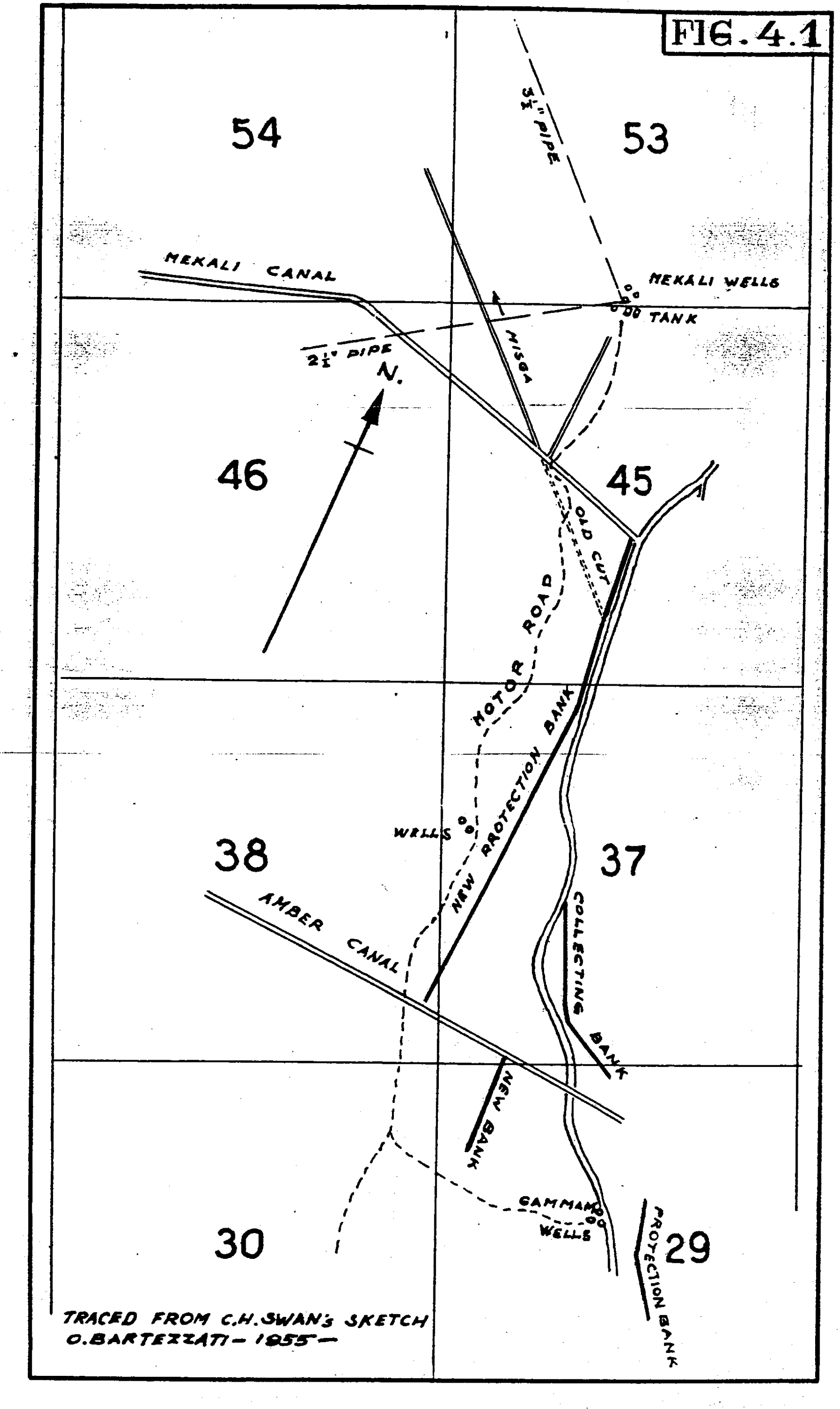
M.8 and M.9	in	1943
M.13	in	1944
M.2	in	1947
M.3 and M.6	in	1948
M.10	in	1949
M.1 (supplementary to existing head)	in	1950
M.12	in	1954

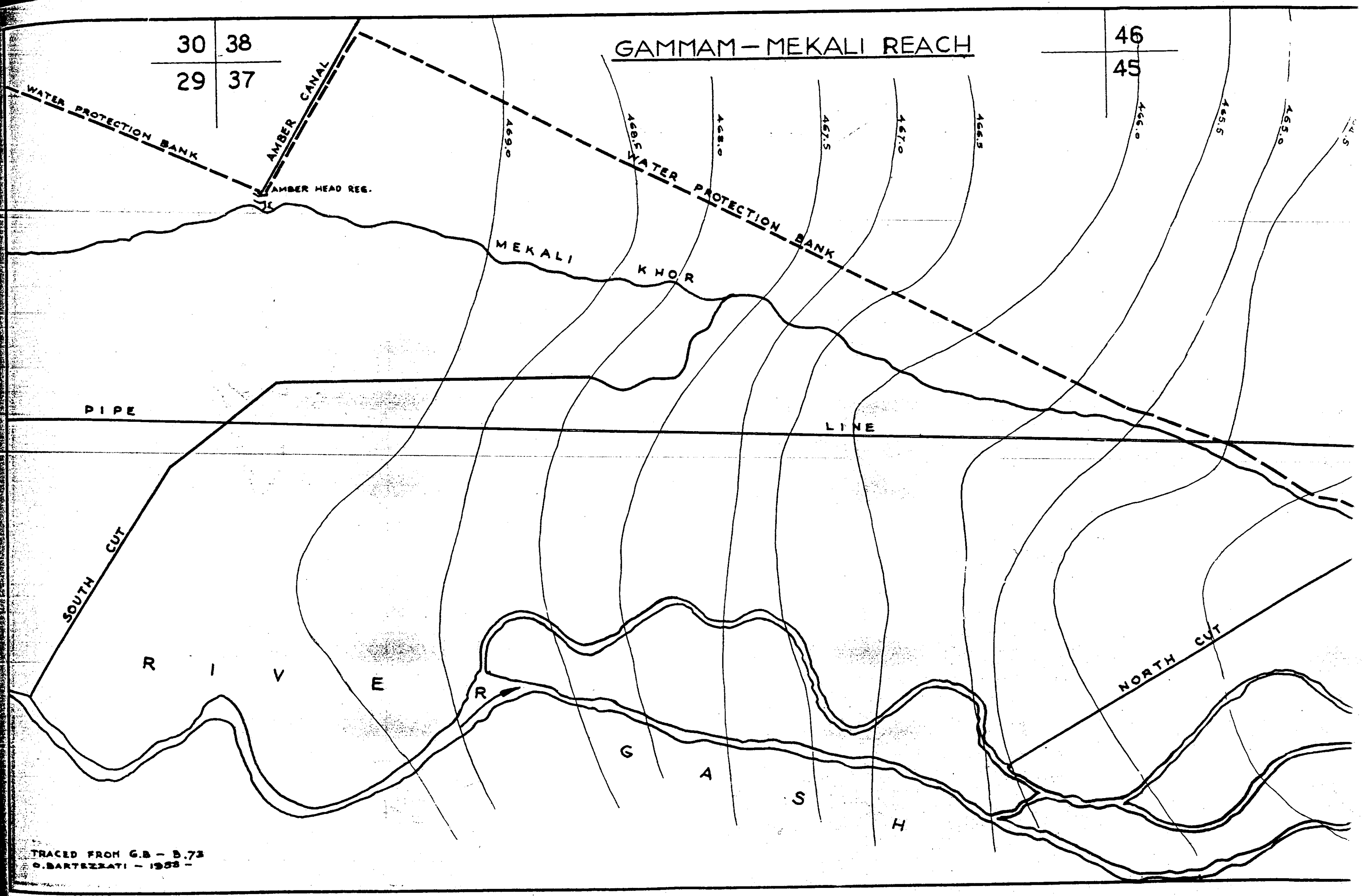
A new misga was dug in 1954 taking off the escape at Mekali head. The main intention was to wet the Mekali-Magauda bank before the flood and this aspect of it will be dealt with

in the next section. In addition, however, it was intended to serve an area to the east of the Gubba North misga; this has not yet been brought into use.

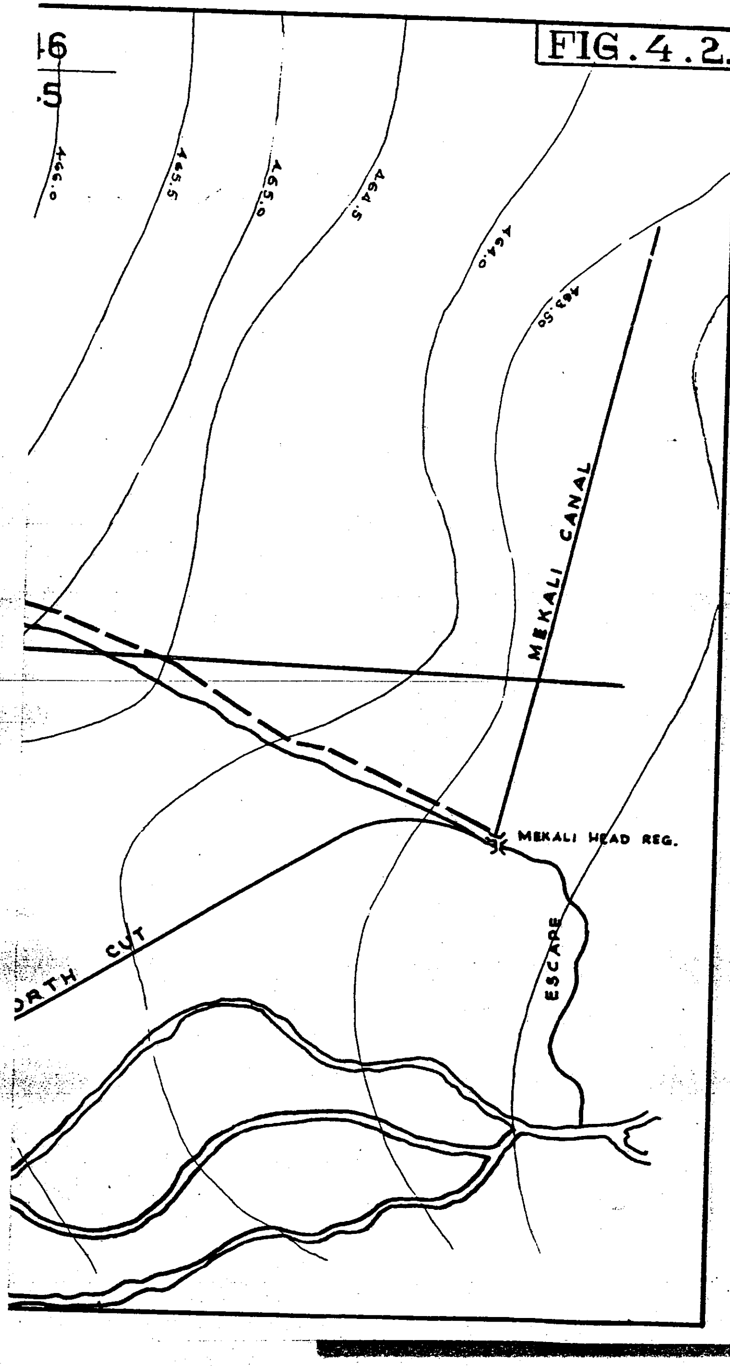
Mekali canal has never really established a steady regime and needs clearance nearly every year. This can hardly be wondered at when it is considered what a variation there is in its supply; sometimes it has been drawing relatively clean water from Gammam balag and at others the very heavily silted discharge from the North Cut; sometimes it has drawn off its full supply of nearly 20 m3/sec and at others merely a miserable and intermittent trickle. Since it was first dug at a slope of 1:3,000 it has been gradually remodelled to 1:2,500, which it shows every indication of preferring. The bed width varies from about 8 m in the head reach to a fairly steady 4 m below K.6 and the depth is designed at between 1.6 m and 1.85 m. Like all the Gash canals (except the most northerly) it has adopted an almost rectangular cross-section with a flat, sandy bed and almost vertical side slopes built up from much finer silt whose clayey nature tends to keep them firm.

FIG. 4.1


54
53
46
45
38
37
30
29
MEKALI CANAL
MEKALI WELLS
TANK
3½" PIPE
2½" PIPE
MISGA
N.
OLD CUT
MOTOR ROAD
NEW PROTECTION BANK
WELLS
AMBER CANAL
COLLECTING BANK
NEW BANK
GAMMAMO WELLS
PROTECTION BANK
TRACED FROM C.H. SWAN's SKETCH
O. BARTEZZATI – 1955 –



GAMMAM – MEKALI REACH
30
38
29
37
46
45
WATER PROTECTION BANK
AMBER CANAL
AMBER HEAD REG.
WATER PROTECTION BANK
MEKALI KHOR
PIPE LINE
SOUTH CUT
NORTH CUT
RIVER GASH
469.0
468.5
468.0
467.5
467.0
466.5
466.0
465.5
465.0
TRACED FROM G.B – B.73
O. BARTEZZATI – 1958 –

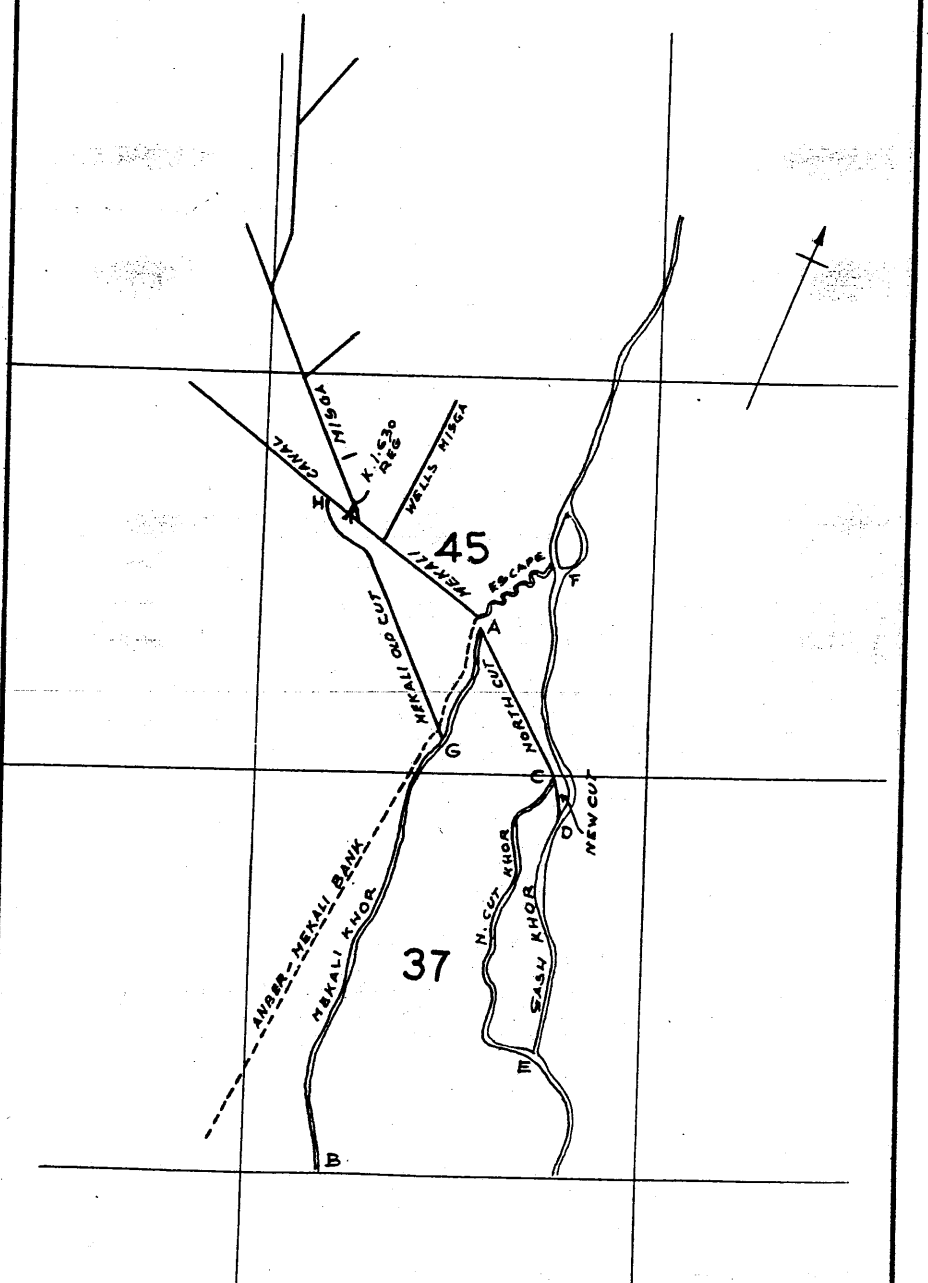


46
5
466.0
465.5
465.0
464.5
464.0
463.50
MEKALI CANAL
MEKALI HEAD REG.
ESCAPE
ORTH CUT

FIG. 4.2.

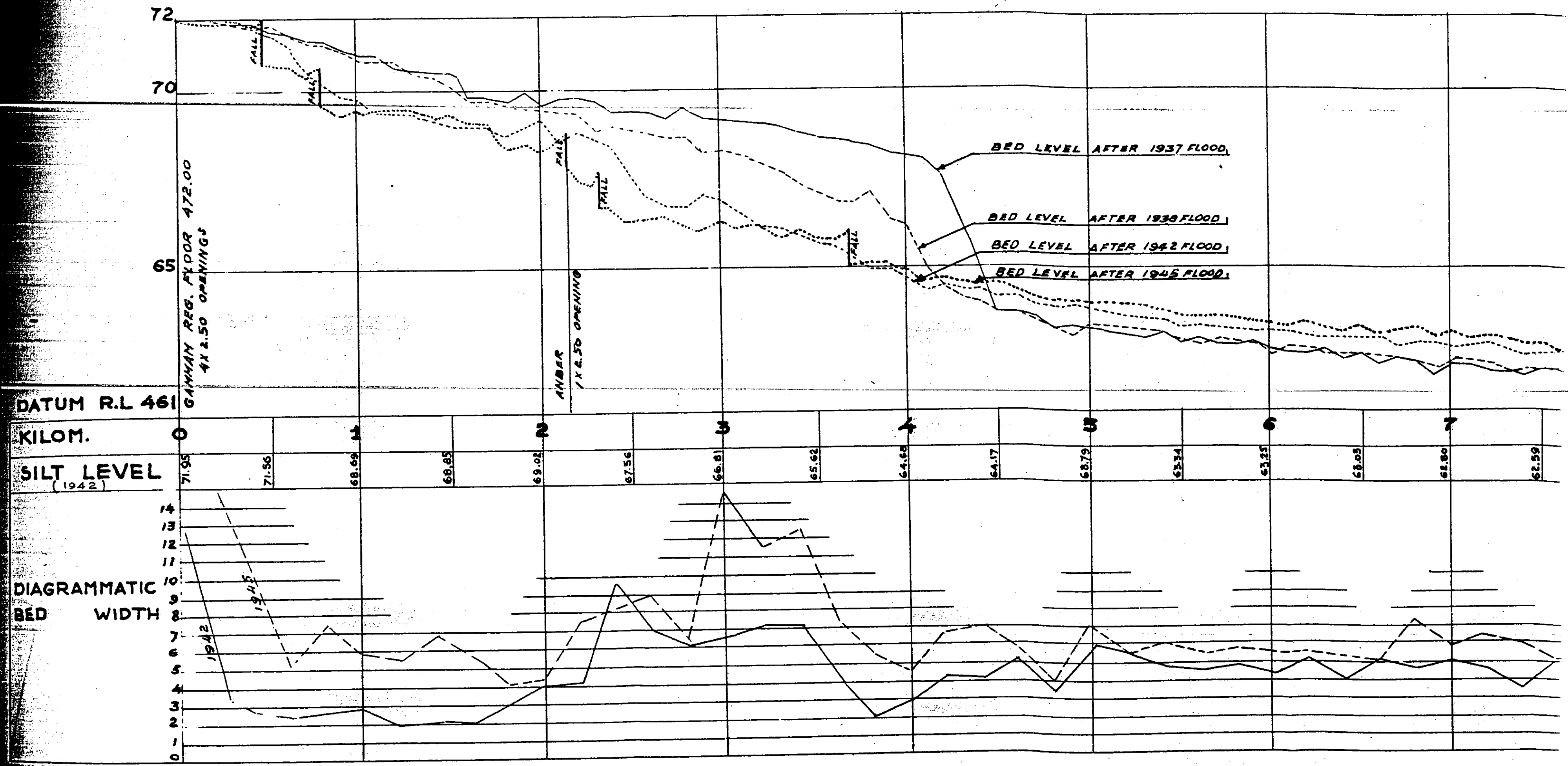
MEKALI SUPPLY SYSTEM

FIG. 4.3.



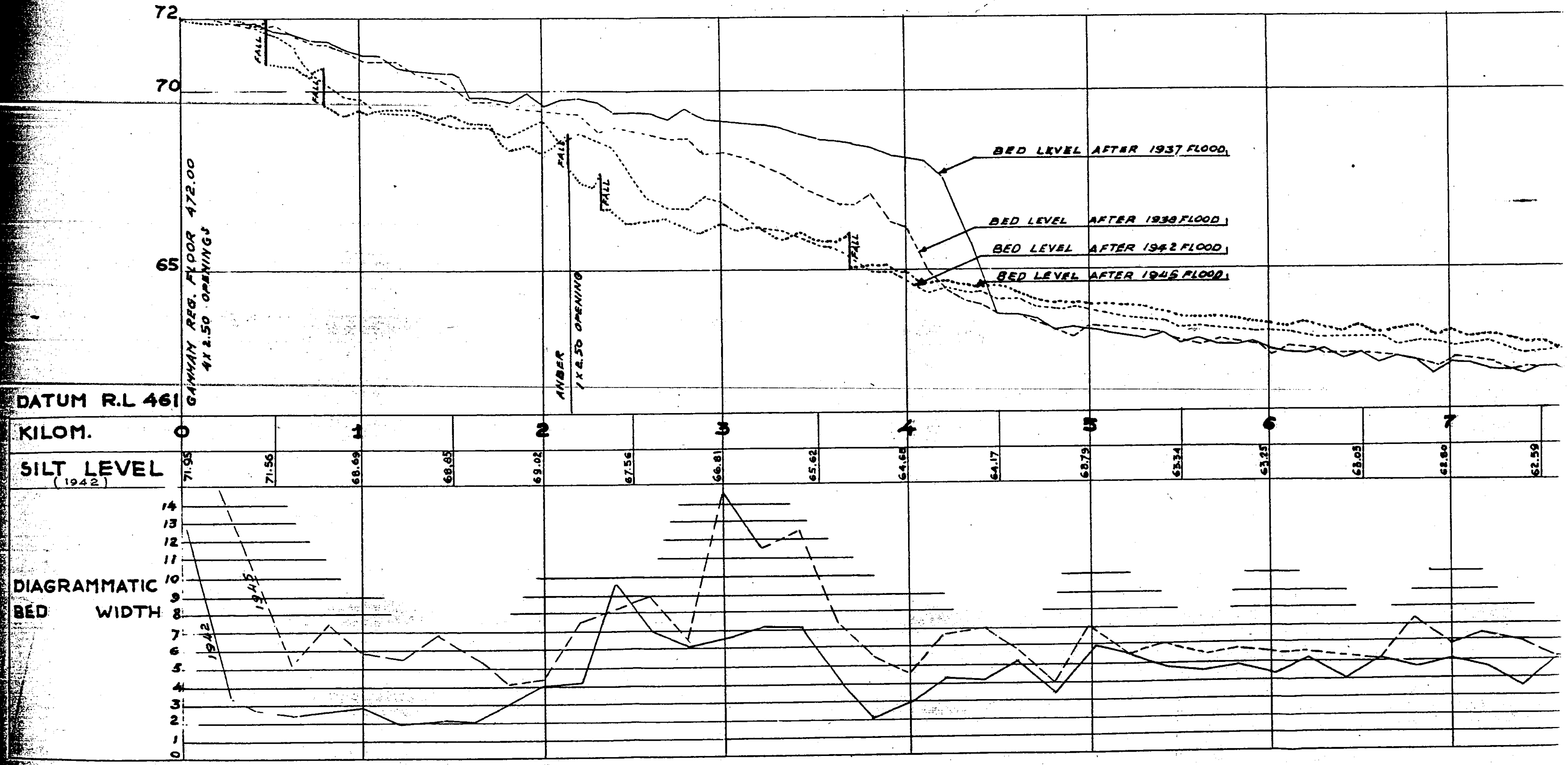
TRACED FROM ORIGINAL
O.B. 1955

GAMMAM/MEKALI KHOR



TRACED FROM G.B.- B.107/120
O.BARTEZZATI - 1955

GAMMAM/MEKALI KHOR



TRACED FROM G.B.- B.107/120
O.BARTEZZATI - 1955

FIG. 4.4.

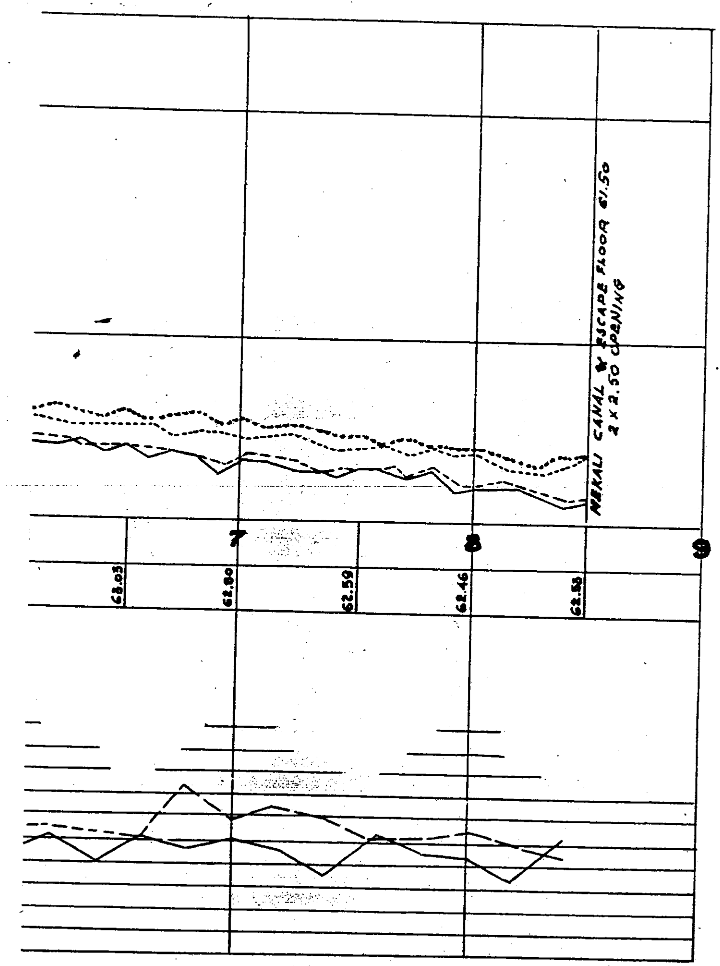
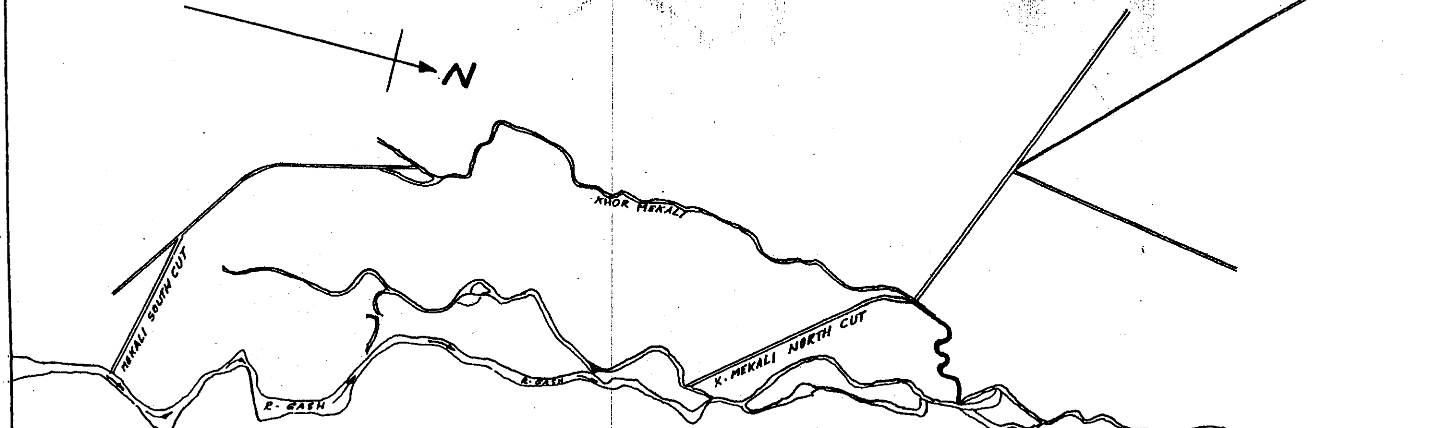

NEKALI CANAL ℄ ESCAPE FLOOR 61.50
2 X 2.50 OPENING
7
8
9
63.05
62.80
62.59
62.46
62.55

FIG. 4-5



SURVEY GASH NEAR MEKALI
CANAL DURING THE FLOOD 1939
TRACED FROM AIR PHOTOGRAPH TAKEN 1939
NEG. Nº A7G 686

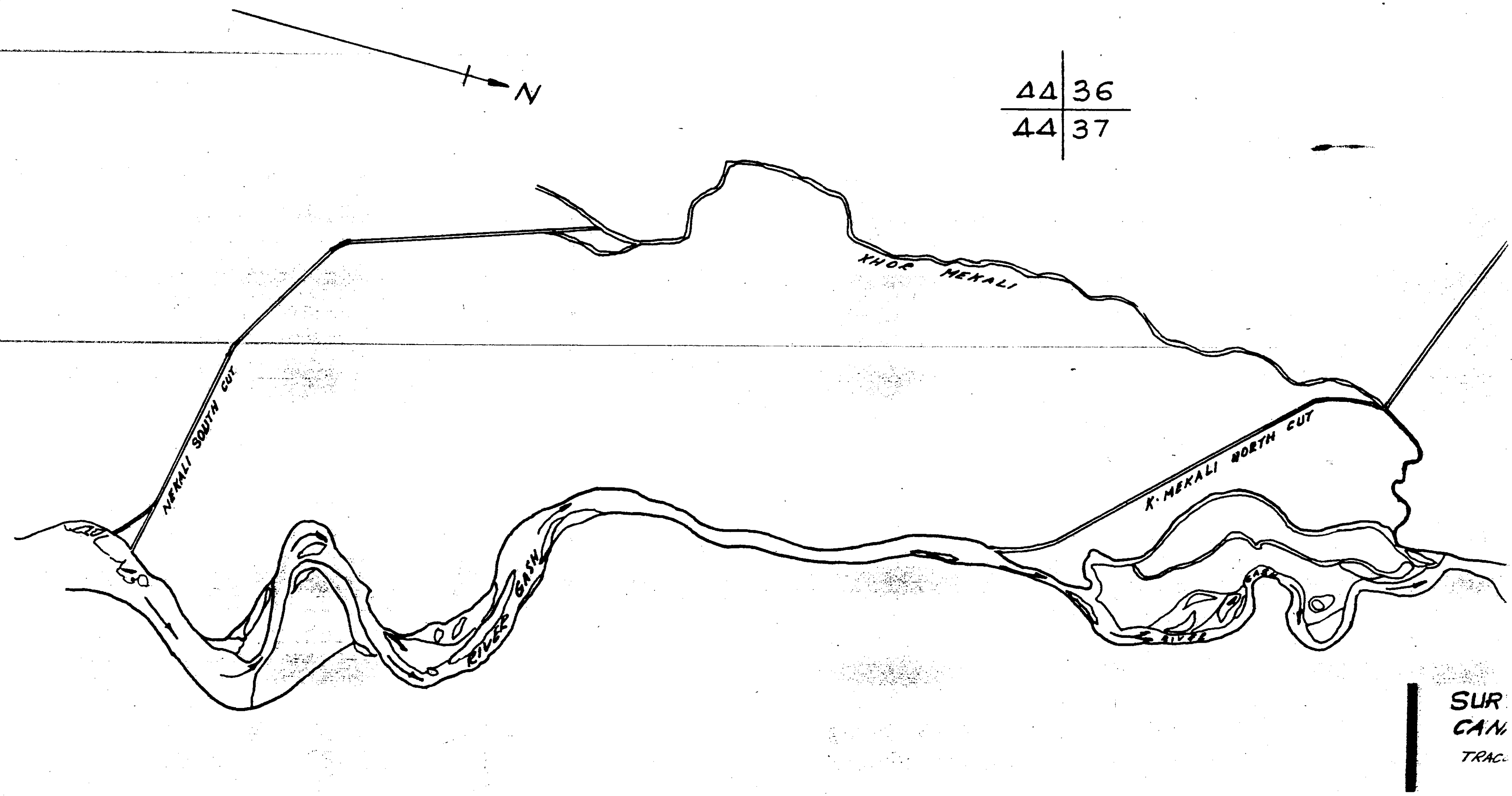
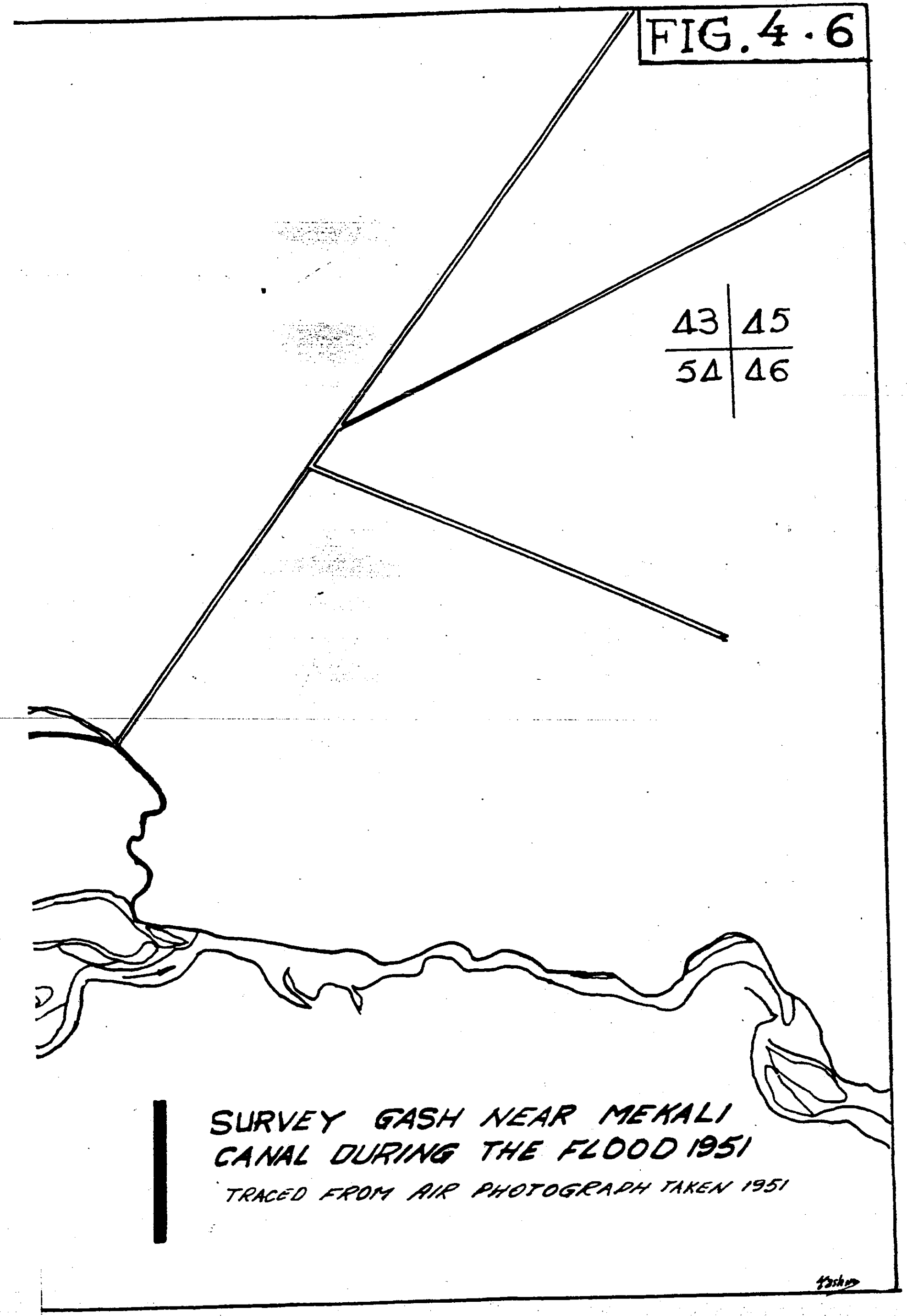

N
44 | 36
44 | 37
KHOR MEKALI
MEKALI SOUTH CUT
K. MEKALI NORTH CUT
RIVER GASH
RIVER
SUR
CAN
TRAC

FIG. 4·6



SURVEY GASH NEAR MEKALI CANAL DURING THE FLOOD 1951

TRACED FROM AIR PHOTOGRAPH TAKEN 1951

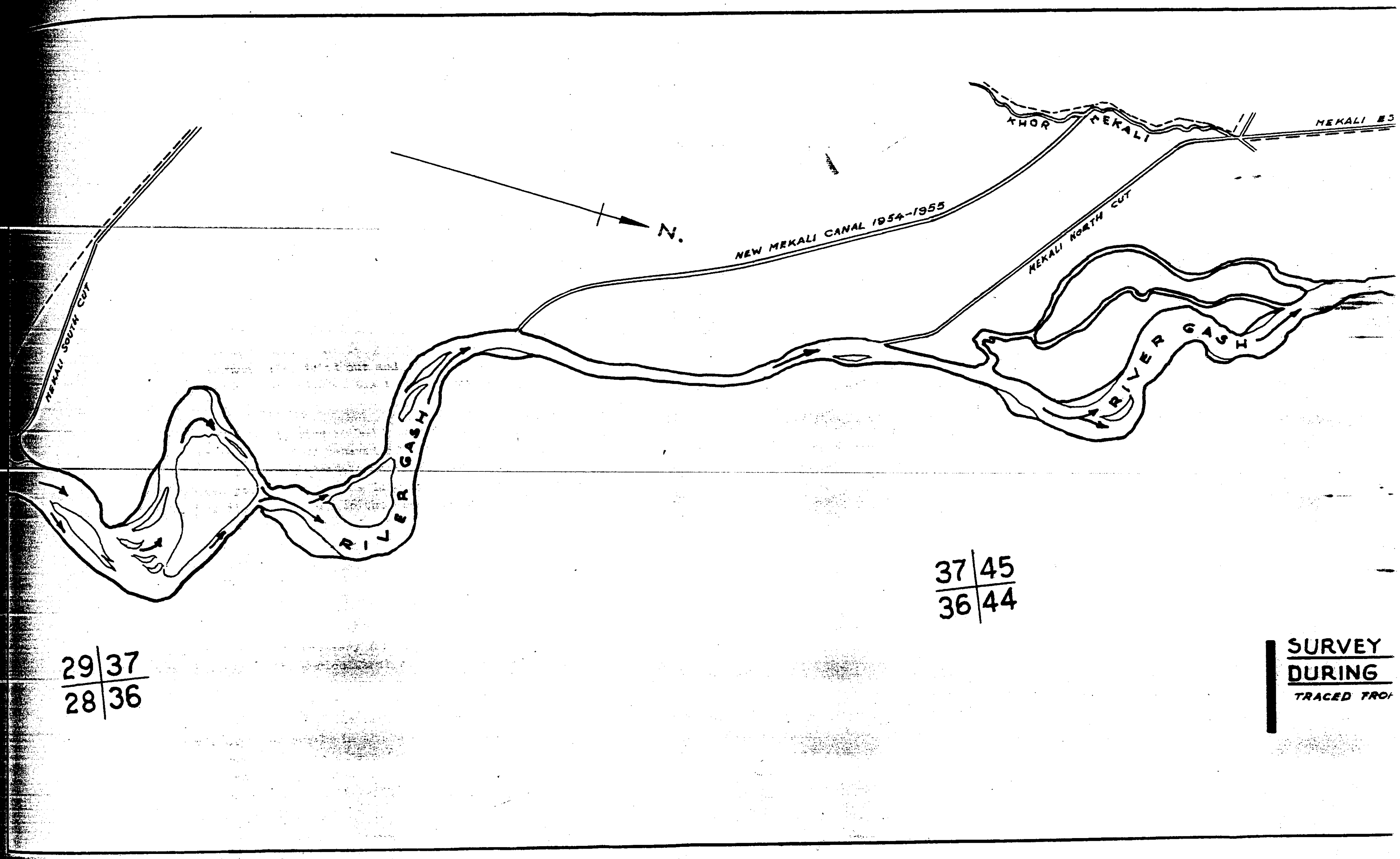
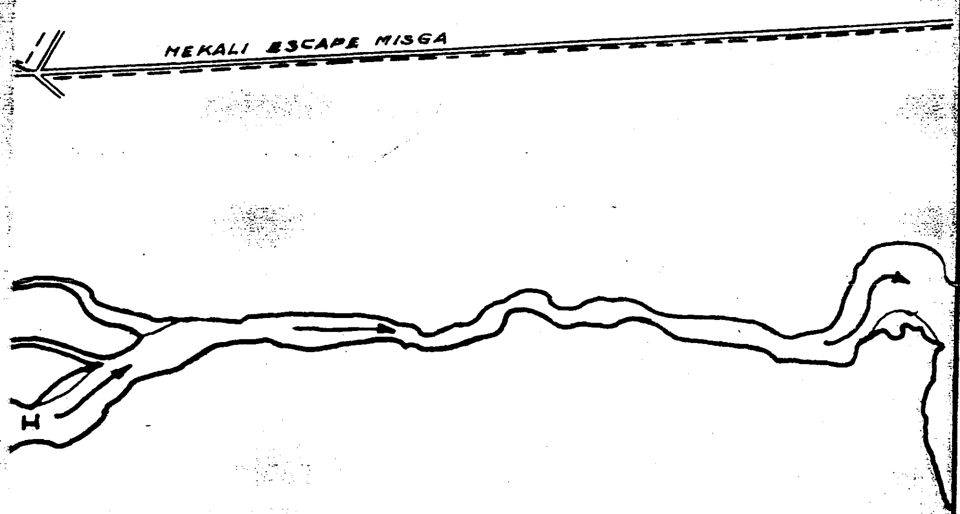

MEKALI SOUTH CUT
N.
NEW MEKALI CANAL 1954-1955
KHOR MEKALI
MEKALI NORTH CUT
RIVER GASH
RIVER GASH
29|37
28|36
37|45
36|44
SURVEY
DURING
TRACED FRO

FIG. 4.7.



SURVEY GASH NEAR MEKALI CANAL
DURING THE FLOOD 1954

TRACED FROM AIR PHOTOGRAPH TAKEN 1954 AND G.B.-B.148

O. BARTEZZATI - 1956 -

SECTION V

MEKALI TO MAGAUDA

1. Introduction

This section deals with the Gash from the Haboba crossing, just below Mekali, to the original offtake of Magauda canal; it also deals with the supply to Magauda canal and with the canal itself. This time it is not a story of constant battle and change. The river has run as a moderately stable khor ever since records begin; it was well to the north of the great areas of balag round Gulosit and Gammam in the early days and well to the south of the balags that formed in the north later on. This does not mean that it is a "safe" reach; levels have been rising ever since the Gulosit-Gammam balag dried out and sooner or later it is bound to give trouble. So far its troubles have only been little ones !

Again, Magauda canal, once it had got over its teething troubles, has been quite the best behaved of all the Gash canals. For years it has run steadily and well, even when the floods have been poorest. This is largely due to the excellent siting of its offtake and to the measures which have been taken to preserve the general condition of the river in its neighbourhood. Magauda offtake is a model one and has remained so for years, so it will be instructive to study it with some care and at the same time to discuss the whole subject of the location and design of head regulators on the Gash.

A word of warning is necessary for those who are not familiar with the Gash. The agricultural station which has its headquarters on Magauda canal is near the village of Degein and is therefore known as Degein Station. Unfortunately the name is often also applied to the canal, so Magauda canal is another example of those canals in the Gash which have two names (c.f. Ankora canal with its alternative of Rabakassa). Only the name of Magauda will be used in this report, but the caution is needed for when reference is made to other documents or maps.

Once past Mekali, the Gash leaves the tamarisk forest behind it and energes into more open country. The river itself, running in a well defined channel, is lined on either side by a narrow fringe of tamarisk, beyond which there is a flood plain covered with a fairly dense growth of bush, mostly "kurmut", "tundub" and "ushur". The latter is known in English as the "Sodom apple" (Calotropis procera Ait). The flood plain is nowadays bounded on the west by banking and on the east by high land. Beyond, there is only the sparse vegetation of the delta on the one hand and poor grazing land on the other.

In passing, some reference should be made to the "ushur" bush, mentioned above. It is the bush "par excellence" for brushwood revetment in the Gash; it grows profusely and very rapidly in the flood plains and on sand banks in the bed of the river itself so it is nearly always to hand when needed. Its large, pulpy leaves and thick, pliable branches give excellent protection and the fact that quite big branches, and even the main trunks of the smaller bushes, can be cut through with one blow of a hatchet means that it can be brought into use with the least possible delay and without excessive labour. A minor advantage of this excellent plant is that it carries big, bright green pods which make easily seen (and expendible) floats for gauging discharges by the surface float method. All in all the plant is a God-send in the Gash area; the only pity is that it is not a little more decorative.

2. Magauda Canal and Supply: Up to 1934

The first description of the area left to us was written in 1923. After describing the Mekali reach, this report goes on to say: "Further on the channel becomes more regular, its appearance suggests stability and the depth decreases until at a distance of about 25 miles north of Kassala the water begins to overflow the banks and to flood a gradually widening area of land. It is somewhere about this point that the conditions are most favourable for the offtake of an irrigation channel. The water should be comparatively free from silt, the channel is stable, and there is a large area of land suitable for irrigation which can be commanded

from this point by a channel taking off from the left bank". The present Magauda canal offtake is, in fact, approximately 25 miles north of Kassala.

The following year the canal was dug. It was taken right through to K.17.7 and twenty-four misgas were built, each with pipe regulator, brick head and tail-walls and stone pitching. A cross regulator was built at K.12. The head reach of the canal was extremely hard digging (in 1935, in the same area, explosives had to be used) but when wetted the side slopes collapsed and reduced the capacity of the canal by nearly 50%. The head regulator was the first to be built in the Gash delta. It had three 2.5 m openings spanned by brick arches; the stop logs were raised ~~and~~ lowered by block and tackle operating from a gantry. The regulator and canal took off the Gash at right-angles just below a bend, as shown in outline in Fig.5.1.

The first year was disappointing. The capacity of the canal had been reduced by the banks slipping, which had left a deposit averaging 0.5 m deep in the bed of the canal. A still greater loss was due to intermittent flow in the Gash; the canal was not able to draw sufficient water at low river. After the flood the first of these troubles was met by pitching the side slopes of the canal for the first 2.7 Km downstream of the head and the second by increasing the bed width of the channel from 5.8 m to 12.0 m. A concrete apron was added to the head regulator.

This treatment was successful and in 1925 the canal ran well. There was no silting; on the contrary there was scour in the bed over the first eight kilometres of the canal. This gives some idea of the effect of the Gulosit-Gammam balag in filtering out silt: the canal was scouring at a bed slope of 1:3,000 whereas today it is in regime at 1:2,200.

In 1926 the canal was extended out to K.23.2. It now had 36 misgas; the new ones were built with single 90 cm diameter pipes and many of the original ones which had been put in with 75 cm pipes were also changed over to 90 cm pipes. The slope of the canal was continued at 1:3,000. During the flood the canal ran well and watered an area of 12,500 feddans which gave 9,500 feddans of cotton. It is interesting, nowadays, to note that out of the total of 36 misgas, 31 watered that year. The scour in the head reach did not recur although the canal was frequently forced to carry a discharge greater than it was designed for. This was caused by the delays in regulation against high spates due to the difficulty in handling unwieldy stop logs.

Stop logs are still the main means of control in the Gash delta. They have their inherent disadvantages; they are liable to get jammed, are not easy to handle and demand the greatest attention to the maintenance of the grooves in which they rest. On the other hand they are simple, and in an area like the Gash where distances are relatively great, roads non-existent and where all transport is immobilized during and for many hours after rain simplicity is an overwhelming advantage. A further advantage is that stop logs give an over-fall supply into the canal, thus excluding the bed load of the river. Actually, despite the difficulty of handling, regulator staffs become remarkably skilled and delays in regulation do not occur nowadays except when jams or breakage occurs, which is not at all frequently. Many improvements in the design of detail have been introduced since the early difficulties but no better means than stops logs has yet been found.

Before the 1927 flood emergency doors were fitted in the head regulator at Magauda behind the stop logs. During the flood the canal ran well and the new gates on the regulator worked excellently. Only 21 misgas were allotted for watering and the area of cotton was consequently considerably less. The canal remained quite stable but a slight silting was noticed towards the tail. No extensions were built that year, but a bridge was built at Aroma to carry water under the railway to Tombai wells.

In 1928 still fewer misgas were watered, this time only 16 in all, but none the less a good area was achieved and the canal ran well. It was reported that the Gash near the head regulator and the canal were both very stable, but a certain amount of silting, this time in the head reach, was also noted.

The 1929 flood was the exceptionally big one that did a lot of damage all the way down the line. In general Magauda stood up to it very well and control was maintained throughout the flood except for just over a week at the beginning of August when water from the Gash balag broke in from the south side and breached the canal near M.7. To ease the pressure Misgas 1 to 10, which had been closed, were re-opened. There was no damage done to the regulators, nor was there excessive silting. Partly as a result of balags due to the flood, a very large area of cotton was achieved that year.

It was in 1930 that the canal began to silt badly. Unfortunately we have no surveys of the Gash near the offtake to show what was happening there, but it is virtually certain that the trouble was caused by a deterioration of conditions at the offtake (this will be discussed later) although it is stated that the Gash appeared to be very stable.

In 1931 the silting became far worse. The accumulation totalled 60,000 m^3 in the canal, and was over a metre deep at the head. There were other troubles as well; since the opening of the canal and the watering of the various misgas (nearly all of them at first, as we have seen) the available land had become heavily grassed, particularly with sedge. Heavy rains and intermittent watering in 1931 intensified the trouble. The canal was closed down early and the area watered was much smaller than usual owing to lack of clean ground for cultivation. Even so 2,500 feddans of the 5,700 watered were considered unfit for cotton cultivation. The price of cotton was low at the time and so it was decided that only clean land should be watered in 1932 since it was uneconomic to cultivate the grassed areas. Accordingly Magauda canal was not opened in 1932. This pusillanimous agricultural policy has been described as "The Flight from Weed". It was noted, during the flood, that the head regulator was topped during a spate for the first time.

In 1933 it was intended to leave Magauda closed again; unfortunately Mekali canal failed. Arrangements had been made to water the important well centres north and west of Aroma from Mekali canal, but this was not possible and Magauda had to be opened up for that specific purpose. As the canal had to be opened up for the wells it seemed worth while to water three misgas at the tail and a small area of cotton was grown. The western wells are of particular importance as they are the only ones between the Gash delta and the Atbara river; when they have a good supply it keeps thousands of animals, grazing on the grass lands to the west, from having to come into the delta for water with subsequent inevitable damage to the crops.

It was noted in 1933 that the bed of the Gash opposite Magauda regulator rose 60 cm during the flood. By 1934 it seemed proper to open the canal once again. The result was most depressing. 90 cm of silt were deposited in the head reach during the first ten days. The canal finally closed itself completely in early September.

So much for the recorded facts. We have seen a canal, dug in 1924 and functioning exceptionally well for the first few years, gradually drawing more and more silt, until ten years later it virtually fails completely. The same canal, unmodified in channel section, slope or headworks, shows scour in the head reach in 1925, apparent regime flow in 1926 and 1927, increased silting thereafter, until in 1931 over a metre of silt is deposited in the head reach and by 1934 the canal becomes completely stopped, having deposited 90 cm of the silt in the head reach in ten days ! It will be of considerable interest to find out why this should be.

The first point to note is that the channel design and headworks were unaltered. The variables which remain are discharge, silt load and river conditions above the head. The discharge in the canal cannot be seriously taken into account; it is always highly variable, dependent on the stage of the river, and the fact that the area in 1934 fell below estimate indicates that the canal was probably run to the fullest discharge which it would carry for as long periods as possible, exactly as it was in 1926 when 12,500 feddans were watered. It is noteworthy that when the area was reduced in 1931 the reduction was effected by early closure rather than by throttling down the discharge at the head; this is the usual practice in the Gash.

As regards silt load, clearly there was a progressive change. In 1924 and for several years afterwards the water had passed through the Gulosit-Gammam balag. As we have seen, the balag dried up between 1930 and 1933 and the filtering effect was lost. Silt samples were taken from the river in 1926 and in 1939. As the Gulosit-Gammam balag was finally cut through in 1933, it seems reasonable to take the 1939 figures as being representative of 1934. The figures given are averages of a number of samples :

Station	Parts per million total solids August 1926	 August 1939
Kassala	6751	4144
Magauda	4229	6510
Change	37% loss	57% gain

Unfortunately the gauge readings at the time of sampling are not given and cannot now be traced. All that can be done is to see how the silt at Magauda varied in comparison with that at Kassala. The variations between individual samples is so great that these figures should be treated with reserve. But two general conclusions may be drawn, that before 1930 the silt load in the Gash was being dropped in the Gulosit-Gammam balag and that by 1934 erosion somewhere in that region was increasing the silt in the reach downstream. An annual series of cross-sections were made in the Gash at Magauda head from 1929 to 1939 and they show a steady rise in bed level averaging 20 cm per year throughout the period. The 60 cm rise in 1933, mentioned earlier, must have been purely local and does not indicate the general trend which was surprisingly steady. From this it is clear that for all its stable appearance, the Gash was undergoing a fundamental change.

The third variable, the river conditions at the offtake, is rather more difficult to assess precisely, though the general picture is clear enough. The only sources of information are the 1924 survey shown in Fig.5.1, a survey made after the 1937 flood and reproduced in Fig.5.2, which is some time after the period we are discussing, and an aerial oblique taken in 1934. The best approach is to compare the two surveys and then, by studying the oblique, to assess how much of the change between 1924 and 1937 had taken place before 1934.

The first thing to note is that the bed of the Gash had widened by 1937 to nearly twice what it was in 1924, but that its actual channel in the bed was about the same width. Secondly, that whereas there was, in 1924, a right-hand bend about fifty metres above the offtake, by 1937 there was a left-hand bend at the offtake and right-hand bends 250 m upstream and 150 m downstream of it. An elementary knowledge of the behaviour of meandering streams suffices to lead to the conclusion that the right-hand bend, which favoured the offtake in 1924 and just after, had moved two hundred metres downstream by 1937. As this was half the length of the meander, the favourable conditions of 1924 had been almost exactly reversed. In passing, it is of interest to note that after a further 13-year period, that is in 1950, there was again a right-hand bend at the offtake site.

The oblique photograph taken in 1934 shows that in that year the point of contraflexure was about fifty metres above the regulator. The movement of the bend downstream was causing marked erosion on the west bank below the regulator (it actually carried away 20 m of pitching there) and the photograph gives the impression that, but for the interference of the regulator structure, the point of contraflexure would be at or even below the offtake. In this connection, a quotation from the 1934 Annual Report is of interest : "at Magauda the river showed a tendency to swing to the east about 500 m upstream the headworks, and to throw up a bar of silt just opposite the upstream gate. This was countered by fixing brushwood spurs in the new embayment with wire ropes. The results were entirely satisfactory". If this effect was correctly observed, and there is no reason to suppose it was not, it means that material eroded from the outside of a curve was being deposited, not as is usually the case, on the inside of the next bend, but a full meander further downstream; it is interesting to note that, even so, the silt is still deposited on the same side as that from which it was eroded. To have formed a silt bar opposite the regulator, the silt must have been dropped at the very beginning of the right-hand bend, since we have shown that the point of contraflexure was only fifty metres further up.

It is clear, then, that the offtake, from being just below a favourable right-hand bend which was gradually eroding towards it in 1924, was at a point of contraflexure in 1934, with silt deposition probably taking place on both sides alternately (silting in the canal and, in the same year, on the opposite side of the river); further, the general situation was rapidly deteriorating as the unfavourable left-hand bend came nearer.

3. Magauda Canal and Supply: 1935 to date

In 1935 a new head for Magauda was built. The site of the offtake was about one and a half kilometres above the old head; the new head is now known as Magauda South head or just Magauda head, while the old regulator is known as Magauda North head. No survey remains of the site at the time the head built and no aerial photography of it is available before that made in 1937. However the latter is probably not a bad representation of conditions as they were in 1935 and so is reproduced in Fig.5.3. It must be mentioned, however, that the figure is enlarged from a very high altitude photograph and can be regarded as only approximately accurate.

It can be seen that the new offtake was at the downstream end of a big right-hand bend. Since no drawing of the headworks remains we have no information about the angle of offtake, but there is every reason to believe that, like the structure that followed it, it took off radially to the curve, that is to say at right-angles to the tangent to the bank at the point of offtake.

The new cut was 1.5 Km long and had a slope of 1:2,500; it led into the old Magauda canal. The digging was extraordinarily hard and in the end gelignite and black powder had to be used. Temporary headworks consisting of two six-foot diameter "Armco" pipes set in an earth bank with a brick facing were tried out.

The results were excellent. There was some collapsing of the side slopes, though not to the same extent as in 1924. In any case this had been foreseen in the design of the channel.

The early part of the 1935 flood was an anxious time, as it started very late and it was not possible to open Magauda canal until mid-August. Once opened, the south cut settled into a regime and gave a good discharge whenever Gash levels were even moderate.

There was no silting except in two local spots, along the whole length of the canal.

Silt gave trouble, however, in the misgas. It has been seen that Magauda was provided with no less than thirty-six misgas at that period. It had been realized for some time past that large numbers of small misgas were not the best way of watering in the area and so for the following year it was decided to run a number of contiguous misgas together as one group. This proved effective and is still the method of watering normally adopted on Magauda canal.

Before the 1936 flood the "Armco" pipes of the head regulator were dug out and re-laid to level and the brick facing was raised. The banks of the south cut were revetted with brushwood for the first kilometre on both sides in an attempt to control the erosion of the previous year.

Early in August the head blew out during a high spate. The river topped the brick facing but not the earth bank. However, it rapidly washed away the earth fill and exposed the pipe culverts which soon followed suit. It seems probable that the trouble was caused by the refilling over the pipes which had been made up anew only two months previously and also to leakage along the sides between the fill and the original earth. The canal was breached in eight places between K.3 and K.11, and this, together with the natural safety valve of spill southwards into the balag, prevented damage further west. The brushwood revetment near the head was washed away and became a great nuisance by blocking the misga offtakes further downstream. This is yet another example of the danger of relying on earth banks at offtake sites on the Gash.

At the regulator the head-wall still stood. One culvert had been completely removed but some ten metres length of the other one remained. The sides were built out again

and strongly protected by sand-bags and brushwood and the gap reduced to three or four metres. By this means, partial control was maintained until the end of the flood and, though there were difficulties, the canal ran, on the whole, very well.

The trial of grouped misgas, 23-24-25 and 26-27-28 was successful and the two groups together watered an area 40% greater than had been expected.

In 1937 Magauda South head was rebuilt. This time it consisted of three 72-inch diameter "Armco" pipes set in mass concrete, with strong head and tail walls and substantial pitching upstream. Control was effected by stop logs. The structure forms the basis of the present head. The design is shown in Fig.5.4; this drawing shows, above the pipes, the additions made in 1943 and 1951. A site plan, made after the 1936 flood, shows that the offtake was more or less radial, see Fig.5.5.

More grouping of misgas was done that year, this time 7-8-9, 32-33-34 and 35-36.

The new regulator functioned very well indeed right through the flood and showed up its great "forte" of being able to draw good supplies from a low river. This it has done ever since and, today, Magauda South head carries this ability to the extreme of being able to draw the entire flow of the river when it is very low !

The grouping of the misgas was again very successful and the total cotton area was the second highest on record although the flood was only a moderate one.

During the 1937 flood the upstream pitching of the regulator had been topped by a spate, so before the 1938 flood it was raised to the same height as the head-wall. Even so, it was again topped in 1938, although sand-bagging prevented any serious damage. This flood was a very erratic one, producing some very high and sudden spates. There was a good deal of westerly spill (mentioned for the first time) from the Gash khor between Mekali and Magauda, and balag water broke into the canal near the head; fortunately no damage was done.

Further grouping of misgas, 1-2 and 29-30-31, was again successful and again the canal ran very well, drawing adequate supplies when other canals were short of water.

Again, before the 1939 flood, the pitching and, this time, the head-wall as well had to be raised by 50 cm, and yet again, despite the raising, the stone-work was topped, although no damage was done. The flood was a miserably poor one, but Magauda canal was never short of water; in this it was unique in the delta that year. A high spate at the end of July broke through a short protection bank south of the regulator and again broke into the canal near the head. This time the canal was already very full and a breach occurred. It was soon repaired. A site plan and sketch made in 1939 is reproduced in Fig.5.6 and shows the pitching as then existing.

In 1940 the canal ran well, although the cotton area was not up to the usual standard on account of heavy weed and grass. In 1941 and 1942 there was little trouble, and in the latter year a new area west of the railway, Misga 37, was watered. At the head, the downstream pitching was extended. The river levels were again higher in 1942, and it appears from annual cross-sections taken at Magauda South head that the Gash bed level had been steadily rising there between 1936 and 1942 at an average rate of 11 cm per year. This should be compared with the rate of 20 cm per year observed at the North head from 1929 to 1939.

Owing to the rising river levels, regulation at Magauda South head was becoming rather difficult, so in 1943 the structure was remodelled to provide regulation by clear fall over stop logs. Piers were built on above the pipes, leaving three 1.90 m openings. The work can be seen in Fig.5.4. Thus heightened, the regulator provided much easier control.

There is nothing to say about the canal offtake between 1943 and 1946. It simply continued to work most efficiently and with no trouble. However, in the latter year erosion took place on the left bank of the Gash about 300 m above the regulator. The embayment so caused threatened completely to spoil the flow conditions at the head. It is shown in

Fig.5.7. During the same flood some of the Gash bank pitching downstream of the regulator was washed out and an embayment formed. This is also shown in the figure, which shows up another feature; the changes in the khor at the offtake site, though slight in themselves, have converted the Magauda South head into an oblique offtake. During the flood the regulator was topped several times.

Before the 1947 flood a projection on the east bank of the Gash about 450 m above the regulator, and thought to be the cause of the embayment on the west side, was cut away. At the head itself, the downstream pitching on the Gash bank was reinstated to conform with the existing bank, and all the pitching was raised one metre. Despite the removal of the offending promontory and considerable brushwood revetment, the embayment was enlarged still further during the flood.

Before the 1948 flood, a further attempt was made at straightening the Gash upstream of Magauda. This time a leading cut was intended in the bed of the river; the Gash easily foiled this move by coming down in an early spate about a month before it was expected. The cut was not completed and the embayment got still worse. It must be noted, at this point, that although the embayment constituted a threat to Magauda supply, it did not actually affect it and the canal was still running excellently all through this period.

In 1948 the embayment was completely sealed off by a pitched bank. The lay-out is shown in Fig.5.8. The bank was curved to lead on to the head regulator. Pipes were put through the bank so that the area behind could silt up. Actually the bank was completely submerged on one occasion; nearly two metres depth of silt were deposited behind. This bank has been a complete success and it is very interesting to compare it with the pitching put in above Khor Salaam Aleikum regulator in the same year, described in Section II of this report. These are both very similar works, yet one was completely successful and the other, if anything, made matters worse. It can be seen that the pitching at Magauda led in a continuous curve, admittedly of reduced curvature, to the head, while that at Khor Salaam Aleikum, also curved at first, led thereafter in a straight line to the head.

It is probable that this was the factor which made the difference between them.

In 1951 Magauda South head was raised yet again; the decking was removed and another metre built on to the piers and abutments as shown in Fig.5.4. At the same time a vertical parapet wall, one metre high, was built along the top of the pitching. The earth banks flanking the regulator were raised to conform.

Since 1951 there have been no further developments and ~~Magauda canal has maintained its good record.~~ As might have been expected, the continued raising of the pitching was finally too much for it and the downstream Gash bank pitching collapsed in 1953. It was rebuilt in cement mortar to its previous design with the important modification that this time a gravel backing was laid behind the pitching.

Further extensions of the watering to the west of the railway have been made from time to time, right out as far as Tombai. In the course of the programme of building masonry misga offtakes the following have been converted: M.36 in 1944 and two double heads at the tail of the canal 500 m below the railway bridge, in 1951. These latter two serve to distribute water to the various well centres and the more recent misgas west of the railway.

4. The Siting of Offtakes on the Gash

The two Magauda regulators are very instructive. We have discussed the North regulator and the reasons for its failure and we have seen that the South regulator has served well and steadily for the last twenty years. Clearly the siting of offtakes is of pre-eminent importance; so much is evident from the behaviour of the two regulators. The whole question was first discussed in a paper by Mr. H.A.W. Morrice written in 1939 (Sudan Engineering Society, 1945-46). Fig.5.6 is taken from that paper; it shows how, at Magauda, the main current sets directly against the convex curve of the pitching just below the regulator. This convex curve of pitching which, it must be remembered, slopes down at

approximately $1\frac{1}{2}:1$, is known in Arabic as a "dawran". There is no English equivalent and the word is freely used in the Gash by English speaking officials; it will be used in future in this report.

Morrice adduces conditions at a number of other regulators in support of his conclusions, but Magauda is typical. He points out that an ideal head should draw maximum possible supplies at low stage, but should never take in excess silt, and he goes further to say that if a canal is silting heavily due to a defective head, there is little hope of curing the trouble by alterations of canal design. On the evidence, he concludes that a canal head should be inset on the outside of a curve of fairly large radius and should point slightly upstream when viewed from the canal, in such a manner that the main current in the river strikes the downstream "dawran" from which it rebounds into the canal.

This basis for design has been followed since the paper was written and nothing has occurred to shake its validity. There are two points, however, which have been brought out since that time. It has been seen that, at Khor Salaam Aleikum, the supply was much improved by building the "dawran" a metre further out into the stream and by cutting back the upstream bank. From this it would seem that in the wider reaches, where the main current may be some distance from the bank, the head should not be too far inset into the bank and it may even prove more effective to make at least part of the structure project into the river. This is being done on the new Mekali head, and it should be interesting to see the result. The other point is the curvature of the bank. It has been brought out that this must be continuous right up to the head (and indeed this was stated in the original paper where it was specified that the head must be on the outside of a curve); it seems probable that, if it can be arranged, a slight increase in curvature as the head is approached would be advantageous.

It is, of course, better to build a regulator at the downstream end of a curve in an unstable river. Meanders move downstream and it is clear that the further down a favourable curve the offtake is, the longer will the site remain on the outside of the bend as it moves downstream.

The action of the "dawran" is not yet fully understood and is, in any case, probably extremely complex. To say that the water rebounds off it into the canal is almost certainly an over-simplification. When the water impinges on that part of the "dawran" that is normal to its line of flow (in plan) it appears to run up the slope and roll right over itself in a breaking wave, the mass of water falling off to right and left, clear of the masonry. The turbulence set up prevents the formation of silt bars across the entrance to the regulator, but why this form of regulator should be silt selective, as it certainly is, is not clear.

It is not proposed to discuss here the problem of drawing supplies off balags. It will be dealt with later but here all that is necessary is to point out that there is no general solution and each case needs to be dealt with as an individual problem.

The fact that, ideally, a regulator should be sited on a narrow and deep reach of the river which is stable is evident, but in the Gash such a state of affairs is becoming more and more infrequent, as the river gets steadily wider in the south and as the balags of the north move steadily southwards. The small part of the river that satisfies these ideal conditions is already, probably, fully exploited. Perhaps at some time in the future such conditions may return over a great part of the river but for the time being it has become necessary to rely on offtakes from wide and, ipso facto, relatively unstable reaches. It seems probable, given the present trends of the river, that this will become increasingly the case in the foreseeable future, and if the problem can be satisfactorily solved developments in the rich southern part of the delta can be carried much further than at present. The present approach is to build the same sort of head as has proved so effective in the narrow, stable reaches and to rely on river training to maintain favourable river conditions at the offtake. Two obvious precautions can be taken in the design of the regulator: firstly to put the cill well below river bed level and, secondly, to make the total width of the regulator greater than the existing hydraulic conditions indicate. These precautions will give some security against erosion in the river. Silting of the river bed should be

guarded against by building piers and retaining walls to a section which can be heightened in case of need.

The writer is of the opinion that some better form of offtake from wide and unstable reaches may possibly be evolved in the future; it has been seen, in the case of the present Magauda regulator, how it has been possible to evolve the design over the years once granted the original excellent siting. It seems more probable, however, that there is no general solution and that each case must be designed independently, basing the design on previous experience. So far, the only experience on a big scale is at Khor Salaam Aleikum; another attempt is now being made at Mekali which should be of great interest, and further attempts will almost certainly have to be made in the future.

Finally, to summarize, the following points have been brought out :

i) The problem of offtakes from stable, narrow reaches has been largely solved, but such reaches are becoming increasingly rare.

ii) Offtakes from balags do not permit generalized treatment.

iii) The problem of offtakes from wide, unstable reaches has not been solved. The richest and least developed areas in the Gash are commanded by such reaches and efforts must be made in the future to get suitable offtakes from them. The fact that such efforts may involve expensive failures must be accepted.

As is natural a number of engineers have considered attacking these problems by means of hydraulic models and a model of the Khor Salaam Aleikum reach has in fact been made. Sir Claud Inglis, on his visit to the Gash in 1953, was asked to advise particularly on the subject and he was shown the model which had been made. He gave it as his opinion that the technique of such models was such as to require, for really successful results, the services of a properly equipped Hydraulic Research Station and that small models of the size which it was practicable to make in the field (that is to say in the Gash delta) were unlikely to yield much valuable information. He suggested that a more useful line of research would be the methodical investigation of past records of the river itself. This is the original "raison d'etre" of this report.

5. The Gash Khor and Protection

Although the reach between Mekali and Magauda has been the most stable in the course of the Gash it has not been without change. We have seen that at Magauda North head the bed level of the Gash rose an average of 20 cm per year between 1929 and 1939. Since then, the avulsions further north have slowed this tendency down, but still the bed had risen another metre between 1939 and 1954. At Magauda South head the silting has been slower; it averaged 11 cm per year from 1936 to 1942, by 1948 it had risen another 60 cm and yet another 40 cm by 1954. These figures can be no more than approximate; they can be taken to mean that the Gash bed has been rising about 10 cm per year for the last twenty years and there is some slight indication that the rate of silting is a little less now than it was earlier on. The position is rather more obscure at the other end of the reach. There has been no permanent offtake from the Gash, so no regular observations of Gash bed levels have been made. Those that have been made indicate silting of about a metre between 1937 and 1942 and another half metre between 1942 and 1954. Some bed levels as much as 70 cm higher than the 1954 figure were recorded between 1950 and 1952, but it is thought that these represent average bed levels; all the other figures are minimum bed levels and, as such, are a better basis for comparison. In general, it seems that the Gash bed at Mekali silted at about 20 cm per year soon after the Gulosit-Gammam balag dried out, but is now silting far more slowly, if at all. The slope of the river bed is about 0.80 m/Km over the whole reach, but is rather irregular locally.

The first mention of westerly spill from the Mekali-Magauda reach was in 1938. It can be seen from the general map of the delta that such spill is likely to run into Khor Halibeit and lie against Magauda canal on the south side; thence it breaks into the canal

In 1939 a bank was built from Magauda South to Magauda North head. By this time the Mekali-Magauda reach was more tortuous and was getting wider, but it was a slow process. It was not until 1946 that serious spill started from north of the Haboba crossing. This increased the balag near the river, but most of it ran back into the Gash further north.

Until 1946 Gash discharges were measured downstream of Magauda South head where there was a well defined, stable reach yielding a fair gauge-discharge relationship. Measurements were made by surface float. By 1949, however, some erosion had been taking place on the west bank, as we have seen, and some silting on the east; the site became unsuitable and a better one was found upstream of Tendelai head.

There was a big spill near Haboba crossing during the 1950 flood. It over-ran most of the Gubba North misga, interfering with the proper watering of the area, and some of it broke into Magauda canal. The rest of it poured back into the Gash just south of Magauda South head, and did slight damage to the new pitching cutting off the embayment there. In 1951 a new bank was made, now known as the Mekali-Magauda bank, running from the Mekali wells basin to Magauda South head.

During the 1953 flood there was again heavy spill from the neighbourhood of a big double bend north of the Haboba crossing. This time it breached the Mekali-Magauda bank and ran up to Magauda canal. The resultant balag swept westwards along the canal, surrounded the Inspector's house at Degein and gave rise to some concern for Aroma, though it never reached that far. A sketch, showing the extent of the flooding, is reproduced in Fig.5.9.

The trouble was largely due to the fact that the Mekali-Magauda bank was built on "badobe" soil, the black cotton soil which is fairly common in the delta. During the dry weather this soil cracks deeply and any bank founded upon it is subject to failure by water running underneath it in these cracks. Once the soil is thoroughly wet the cracks seal up and the banks become sound enough, as wet "badobe" is highly impermeable, but all too often the flood strikes against a bank before any reasonable amount of rain has fallen and in such cases breaches are almost inevitable. The best protection is to make arrangements to wet the area of ground near the bank artificially before heavy spill begins.

A striking example of this quality of earth banks founded on "badobe" occurred during the 1952 flood on the Magauda-Tendelai bank. It was known from the gauge readings that spilling from the Gash was likely to occur. The Chief Engineer was on the bank when water began to reach it across the balag from the Gash some 500 m away. Almost immediately a small gush of water began welling up out of the ground some five metres from the outer toe of the bank, that is on the far side from the Gash. Men were sent into the water to try to locate the hole on its upstream side. Soon its position was revealed by the whirlpool generated by the water entering the hole; it was about five metres from the inner toe of the bank. Attempts were then made to staunch it with sacks of earth, but the sacks were sucked into the hole and blown out on the downstream side. Then the grass roof of one of the workmen's shelters was carried into the water and dropped complete into the whirlpool. This also was sucked in and its remains cast out on the downstream side. Finally the lower part of the bank collapsed into the hole leaving an earth bridge over which a man could walk until this also collapsed leaving a breach about three metres wide in the bank with a strong stream flowing through it. The bank at this point was two metres high above ground level on the upstream side; it had a four metre top width and 1:1 side slopes. The level of the ground on the downstream side was considerably lower than that on the upstream side. In due course the Gash subsided and the breach was repaired.

"Lebad" soil does not crack in the same way as "badobe". Shrinkage does take place as the soil dries out but instead of producing a network of cracks relatively close together it tends to produce enormous cracks several hundreds of metres apart; sometimes these cracks are as much as a metre across and at least five metres deep. It occasionally happens that these cracks do not extend right up to the surface and the line of the crack is only indicated by a line of pot-holes

several metres apart which lead down into the main crack below. Whichever form the crack takes it makes motoring in the vicinity, particularly at night, exceedingly dangerous. Banks built on such soil, however, are fairly safe; if such a crack occurred near the bank it would be detected and blocked off.

To return to Mekali, it was decided to remedy the trouble caused by cracking soil by producing an artificial wetting of the area before the high spates arrived. A new misga was taken off from the escape at Mekali head and three watering basins were built along the Mekali-Magauda bank at the section most liable to attack. The idea was that these basins should be filled with the first water to come to Mekali head, and before the Gash had built up any high levels. The bank was strengthened throughout. The whole scheme is shown in Fig.5.10; it was not put to the test by the small 1954 flood, which produced no spill along the entire course of the Gash.

The Gash from Mekali to Magauda is still fairly stable, but it is widening, particularly on the bends, some of which are beginning to show signs of developing along the lines shown in Fig.3.9. Bed levels are still rising, though at a reduced rate, and it seems probable that the stability of the reach will not last for very much longer.

6. Magauda Canal

Magauda canal is in almost perfect regime. No major silt clearance has been necessary for some years now and it seems almost the perfect example of a canal running in regime flow in its own alluvium. The head reach is designed to carry a discharge of rather over 10 m3/sec. It has taken up a slope of 1:2,200, with an average bed width of nine metres and a depth of 1.2 m. It is almost rectangular in cross-section with a smooth, flat bed of sand and nearly vertical side slopes of very fine silt. The lower reaches of the canal show a tendency to get narrower by a deposit on the berms and for the section to compensate itself by scouring the bed; the result is a very narrow, deep canal. Much of the length of the canal is lined with tamarisk trees and almost the only annual attention it needs is the cutting back of the trees to clear the water-way. Trees and bushes along canal banks in the Gash delta are never cleared right away because, apart from their attractive appearance, they serve a very useful purpose in keeping down the accumulations of wind-blown sand in the channels during the dry weather.

7. Recent Developments at Magauda North Head

Of recent years an embayment has threatened to cut in behind Magauda North head. This would have seriously imperilled the whole system of river defences in the area and particularly in the next reach downstream. A first attempt to control the embayment was a light stone impregnable head, shown dotted in Fig.5.11. This was put in before the 1954 flood, but the Gash did not react as had been hoped. Instead of cutting off the bend on the east side, it increased its water-way by digging a deep channel along the head, which was undermined and shown to be not so impregnable after all; it was entirely carried away. The position was held by sand bags and stone but considerably more of the bank (joining Magauda South and North heads) was lost.

A further attempt is being made at the time of writing. This is also shown in the drawing. The old head-works structure itself is being adapted to form a second, and more retired, head and the connecting shanks are being retired to conform. The foundations of the structure go down 4.5 m below the present Gash bed and so it is hoped that undermining will not take place this time and that the head will be more impregnable (if impregnability can be regarded as a relative quality, as it must in the Gash !) than its predecessor.

FIG.5.1.

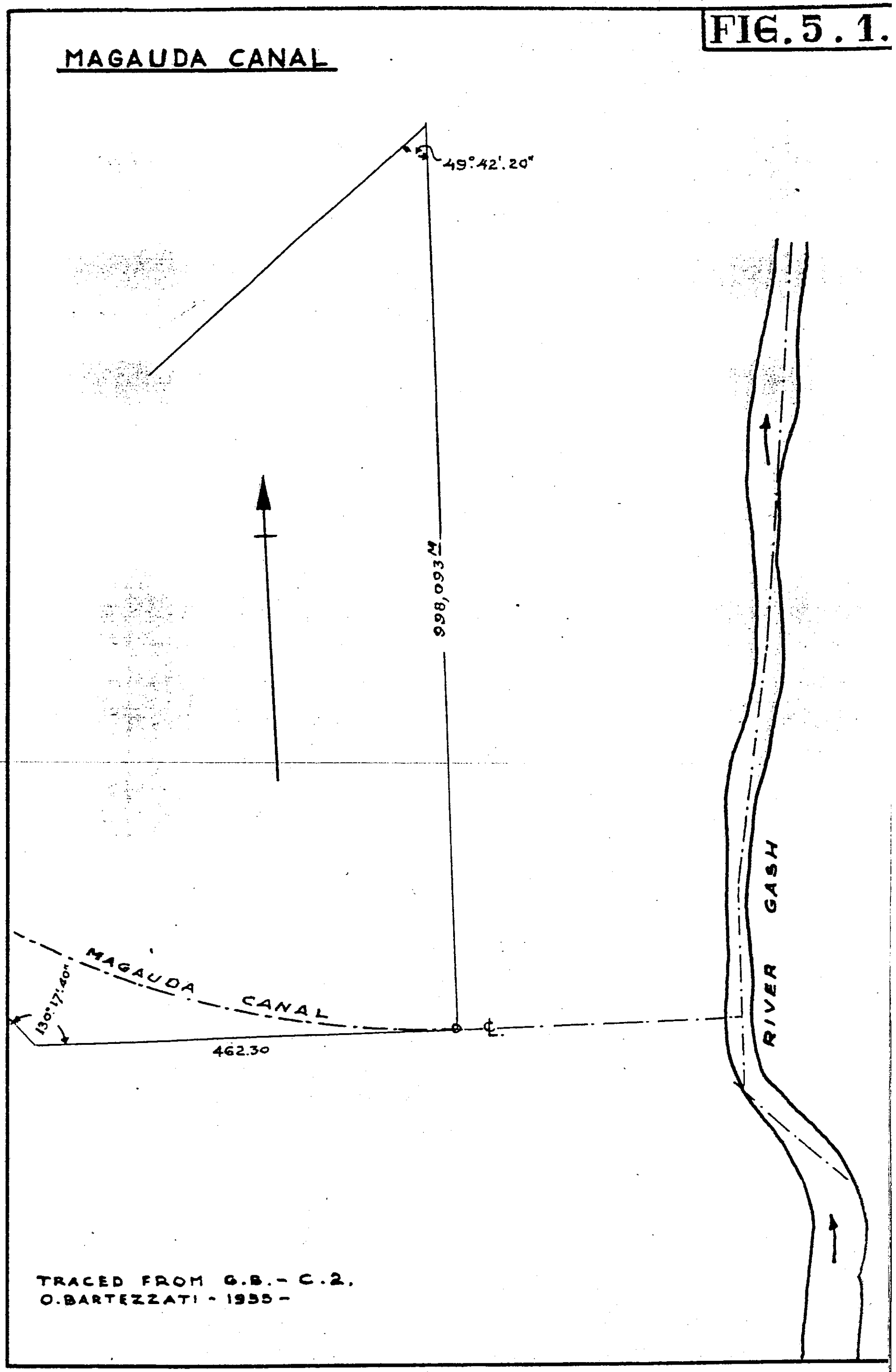


FIG. 5.2.

GASH PLAN U/S. MAGAUDA N.E.1938

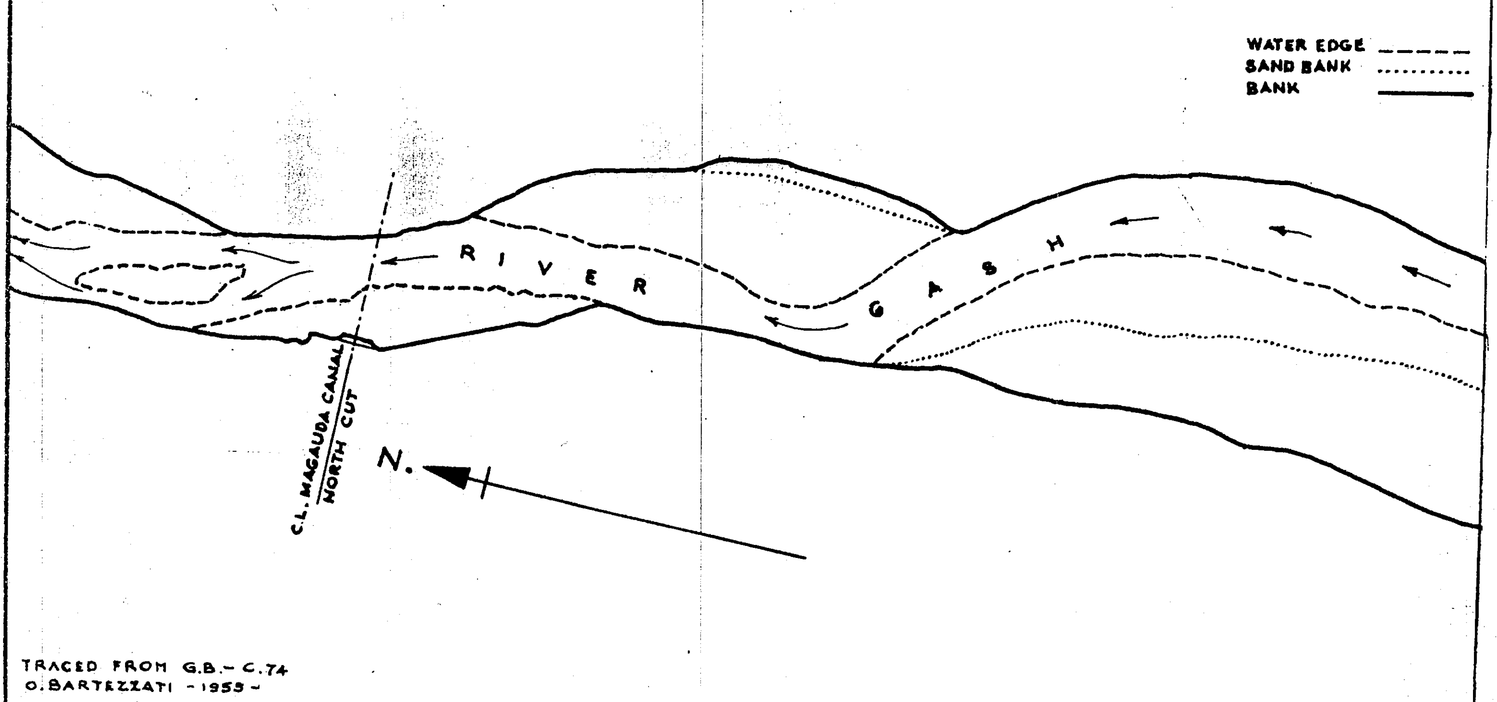
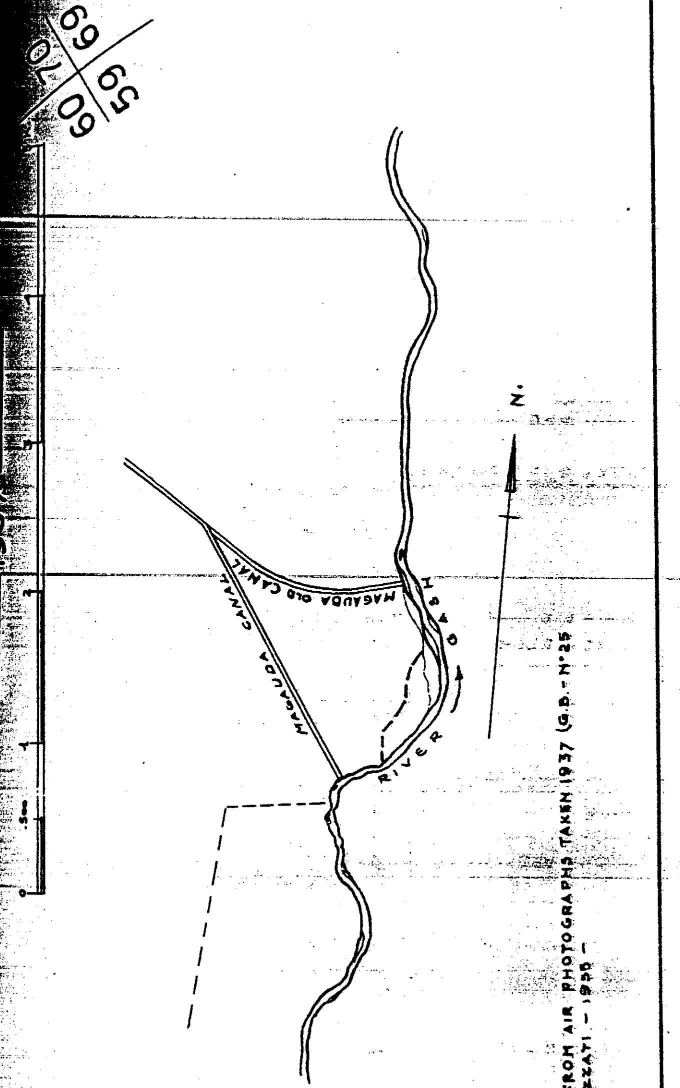
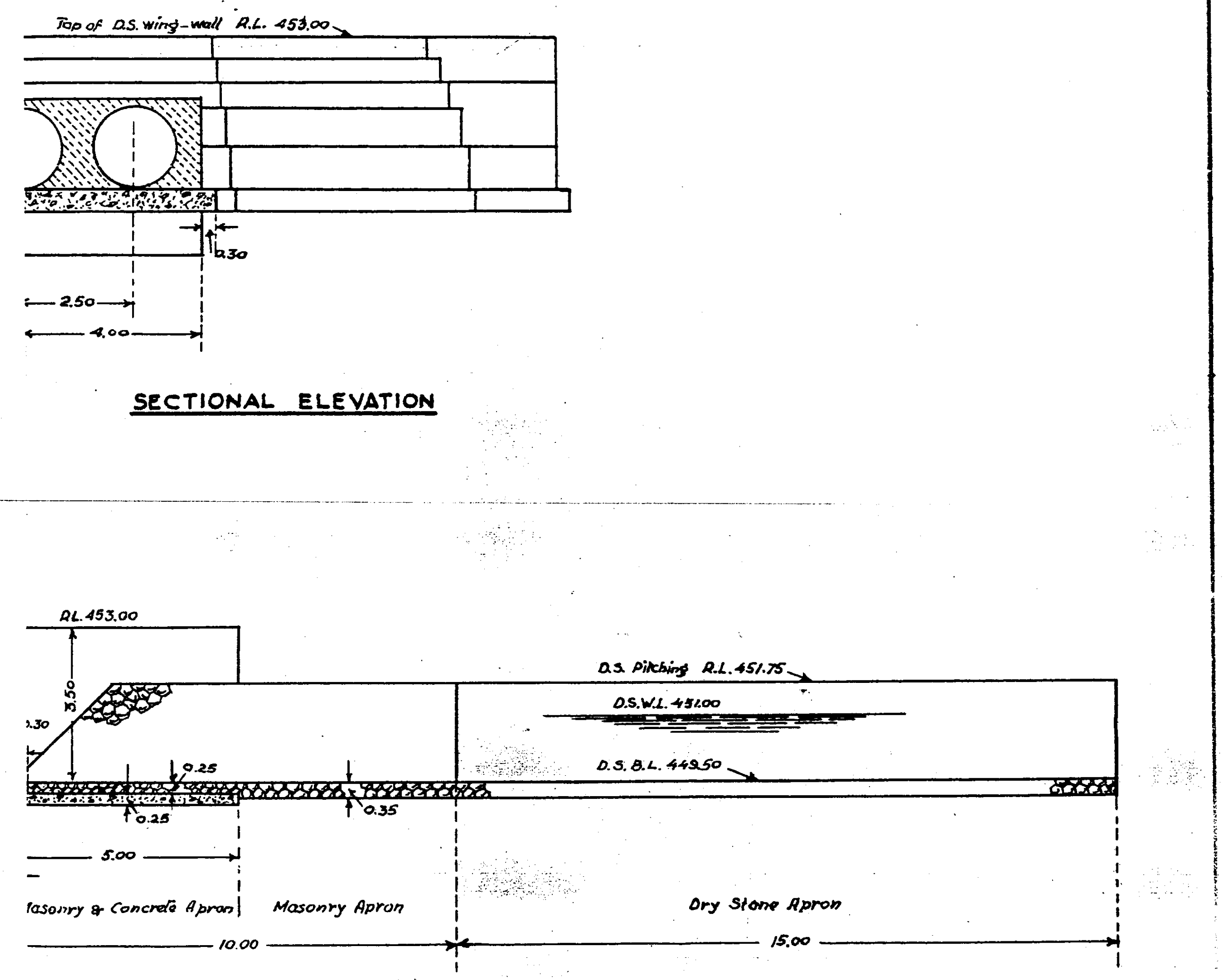


FIG.5.4.



TRACED FROM AIR PHOTOGRAPHS TAKEN 1937 (G.B.-N°25
O. BARTEZZATI - 1955 -

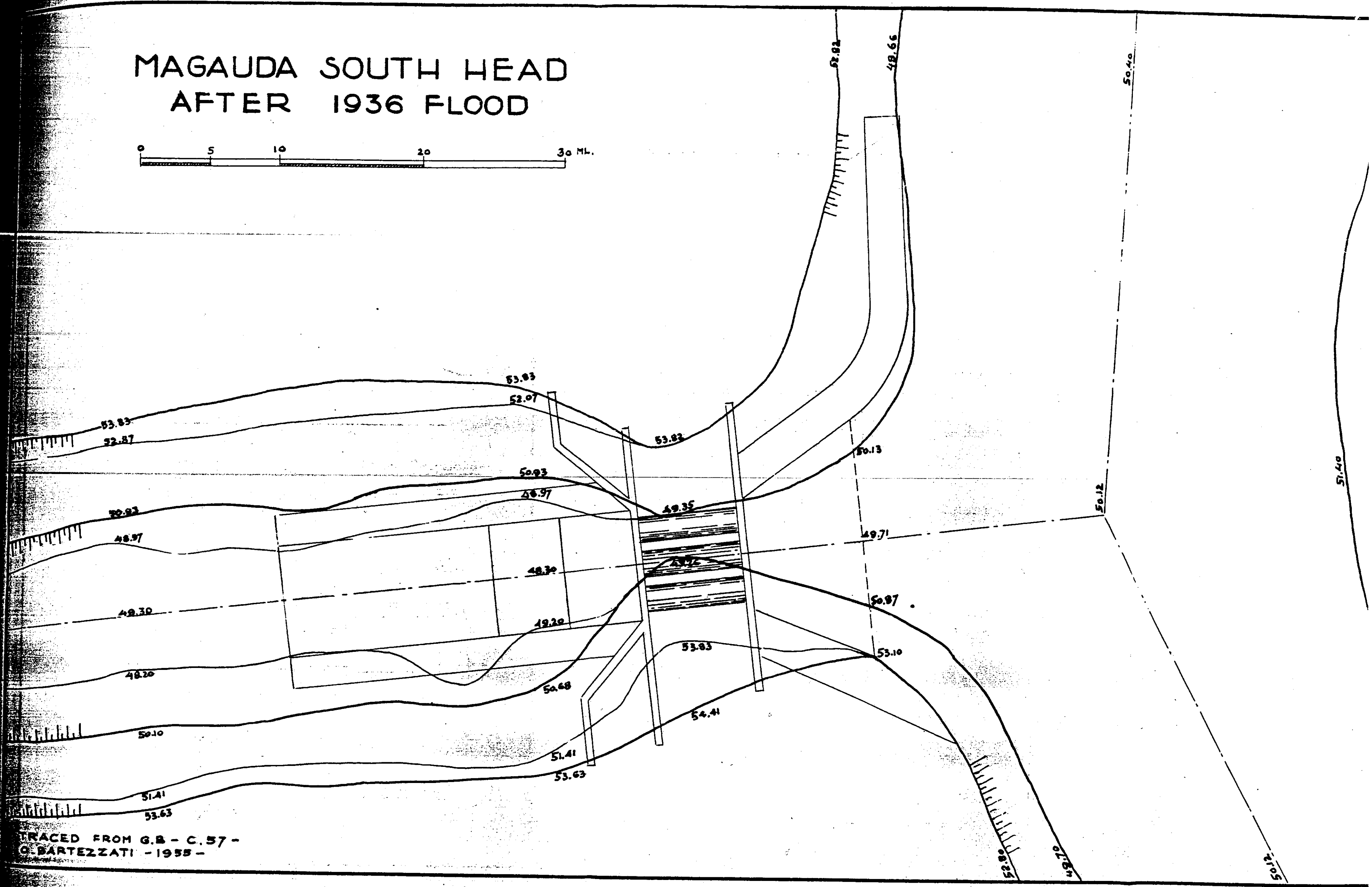
OUTH-HEAD REGULATOR



TION BETWEEN PIPES

TRACED FROM G.B.-C.56.A.
O. BARTEZZATI - 1955 -

MAGAUDA SOUTH HEAD AFTER 1936 FLOOD



TRACED FROM G.B - C.57 -
O. BARTEZZATI - 1955 -

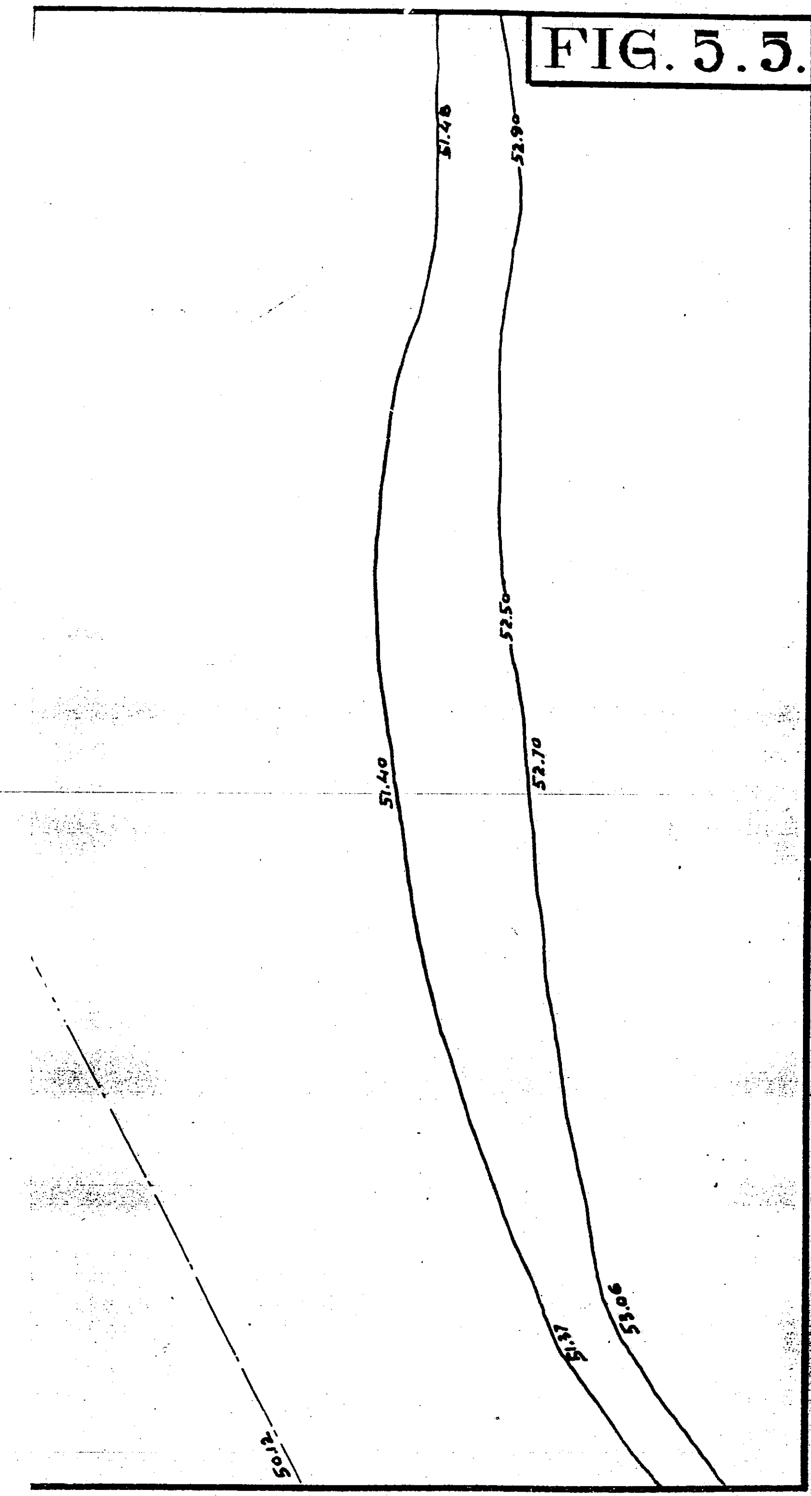


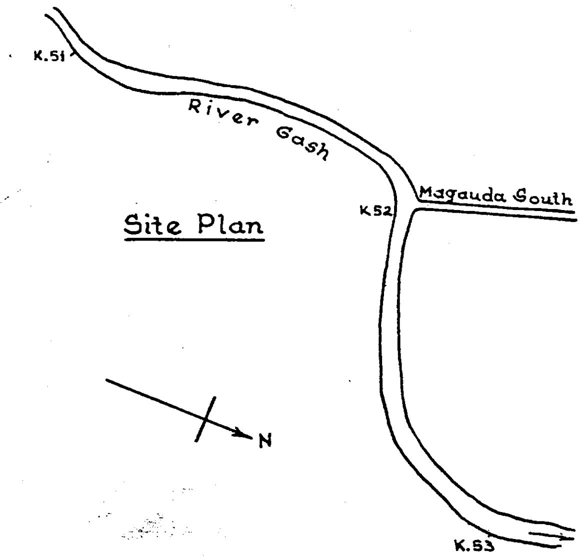
FIG. 5.5.

FIG. 5.6.

MAGAUDA SOUTH

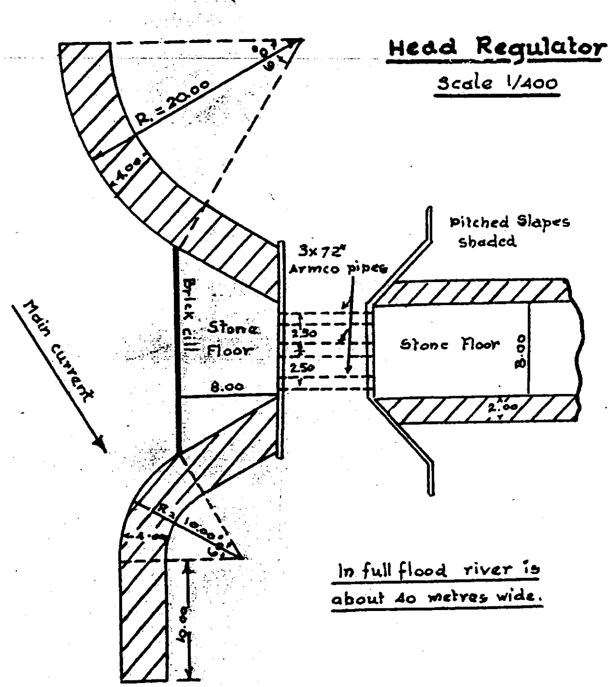
-1939-

Site Plan



Head Regulator

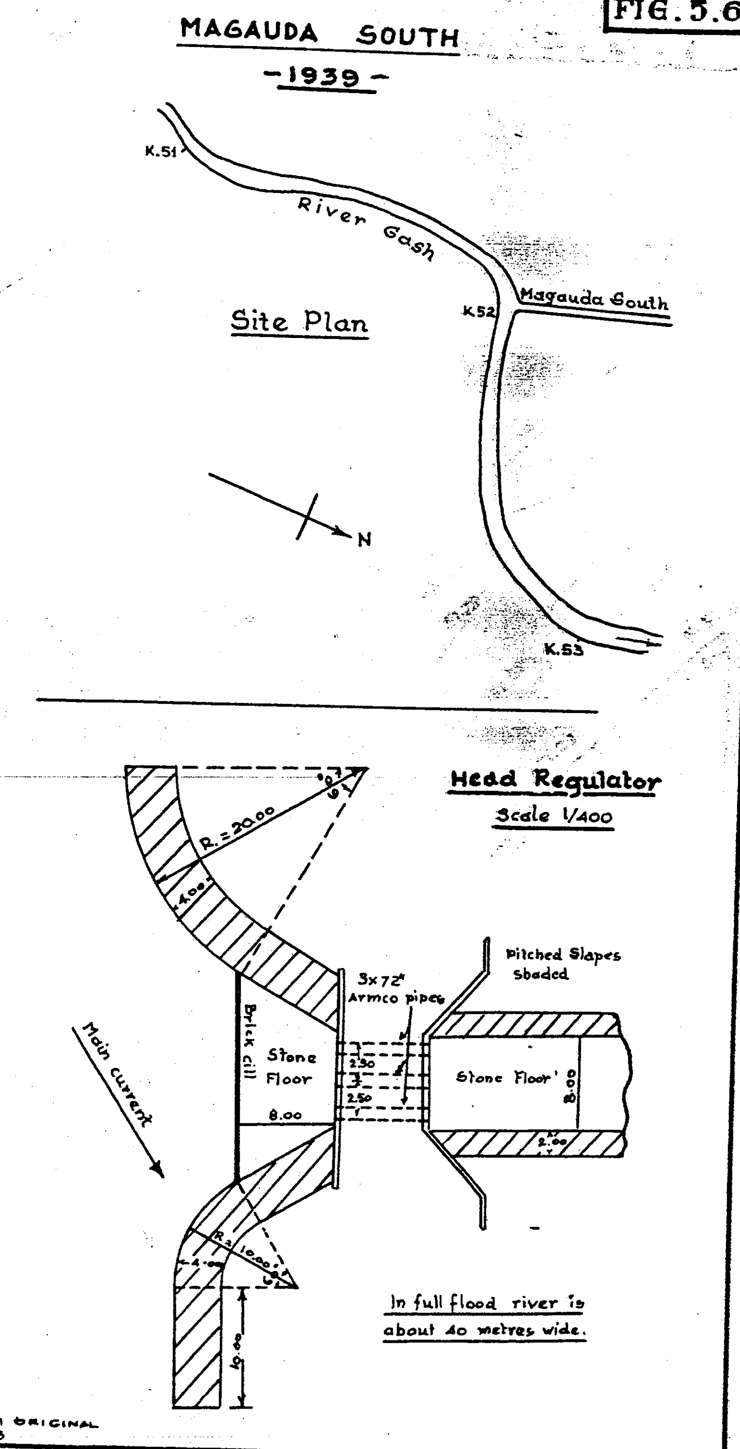
Scale 1/400



In full flood river is about 40 metres wide.

TRACED FROM ORIGINAL O.B. - 1958

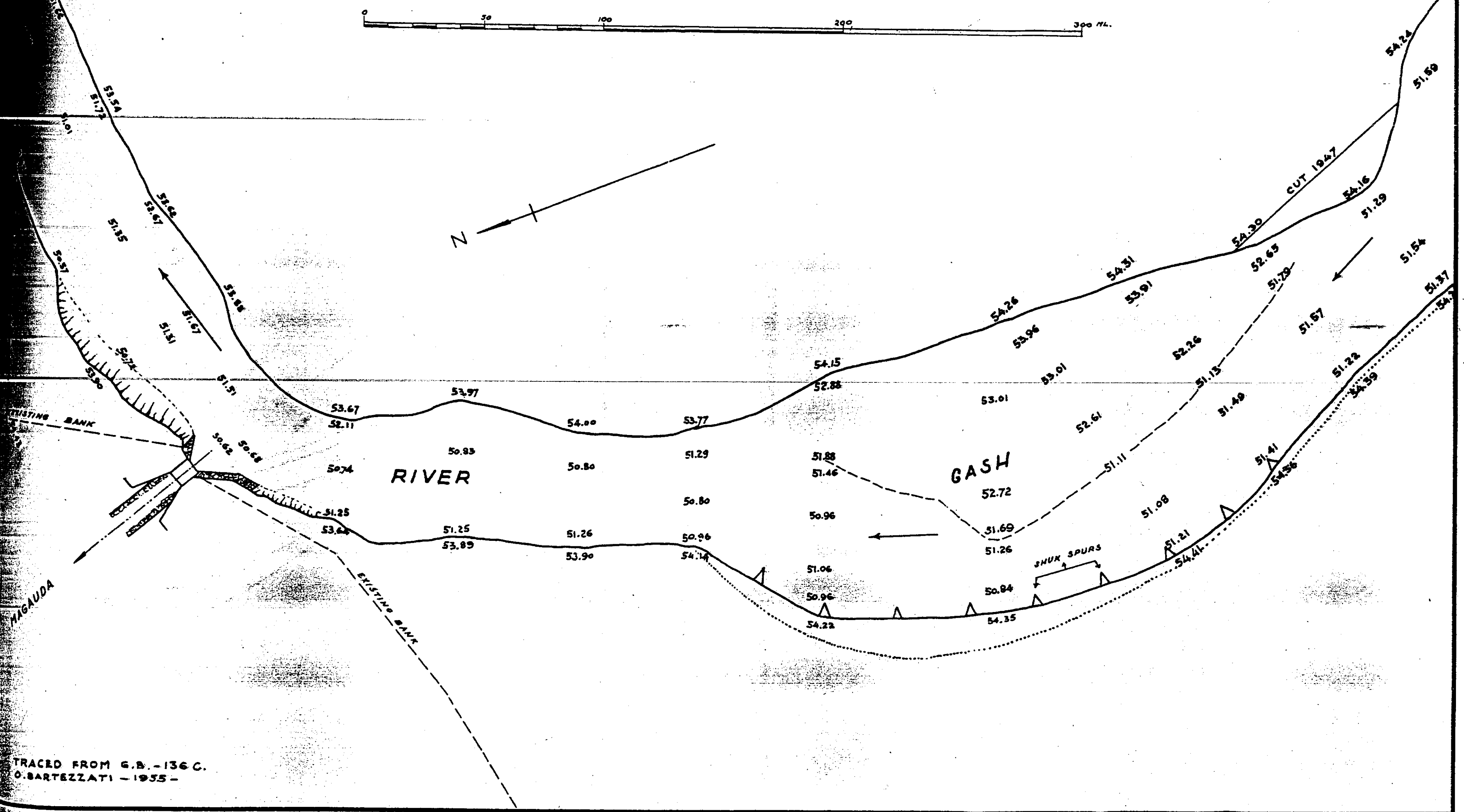
FIG. 5.6.



MAGAUDA SOUTH
-1939-
K.51
River Gash
K.52
Magauda South
Site Plan
N
K.53
Head Regulator
Scale 1/400
R.=20.00
4.00
3x72"
Armco pipes
Pitched Slapes Shaded
Brick cill
Stone Floor
2.50
2.50
8.00
Stone Floor
8.00
2.00
Main current
R.=10.00
4.00
In full flood river is about 40 metres wide.
TRACED FROM ORIGINAL
O.B - 1958

FIG. 5.7.

PLAN OF RIVER GASH AT MAGAUDA S. Hd.



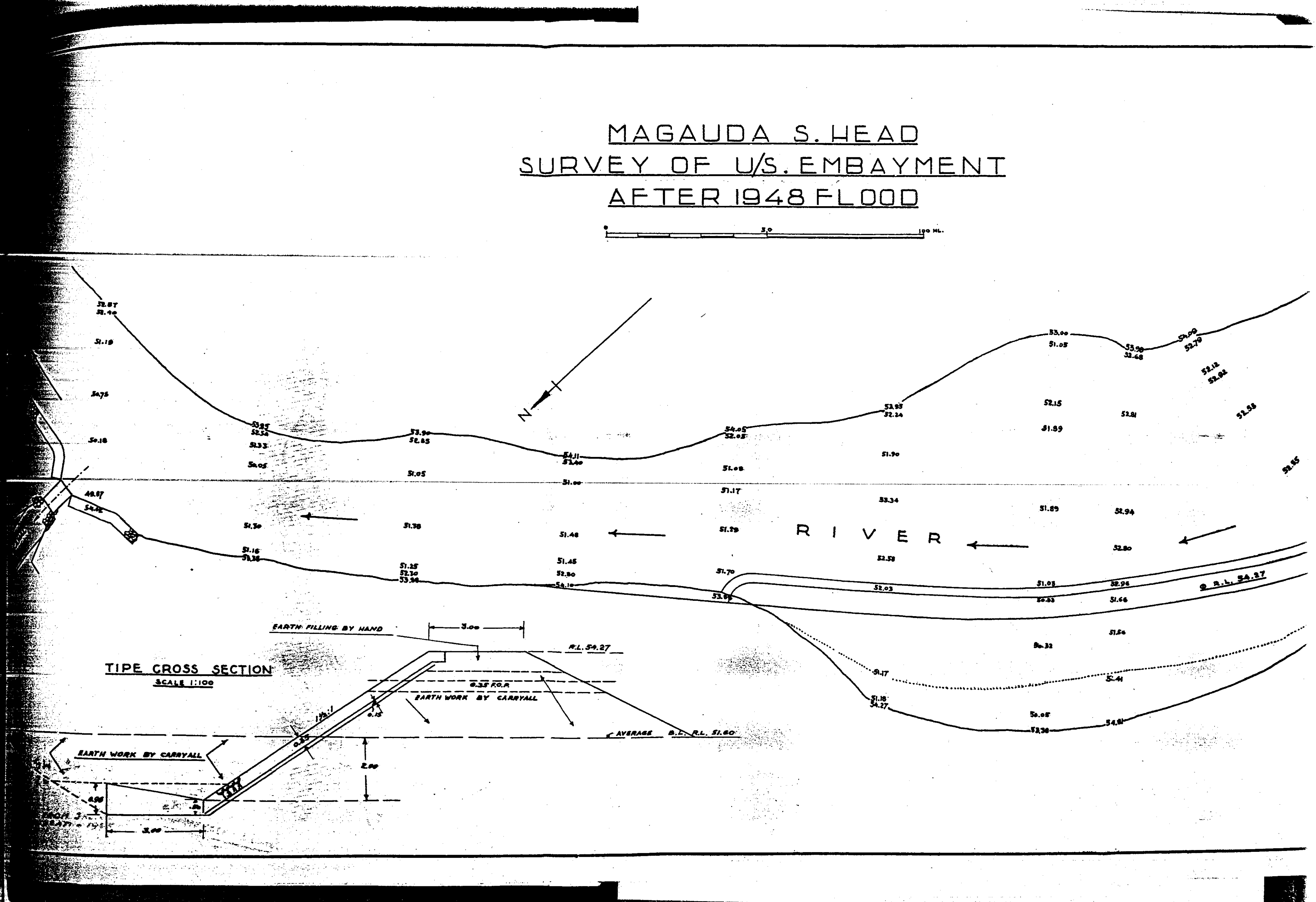

MAGAUDA S. HEAD
SURVEY OF U/S. EMBAYMENT
AFTER 1948 FLOOD
RIVER
N
TIPE CROSS SECTION
SCALE 1:100
EARTH FILLING BY HAND
3.00
R.L. 54.27
0.35 F.O.R.
EARTH WORK BY CARRYALL
AVERAGE B.L. R.L. 51.60
EARTH WORK BY CARRYALL
2.00

FIG. 5.8.

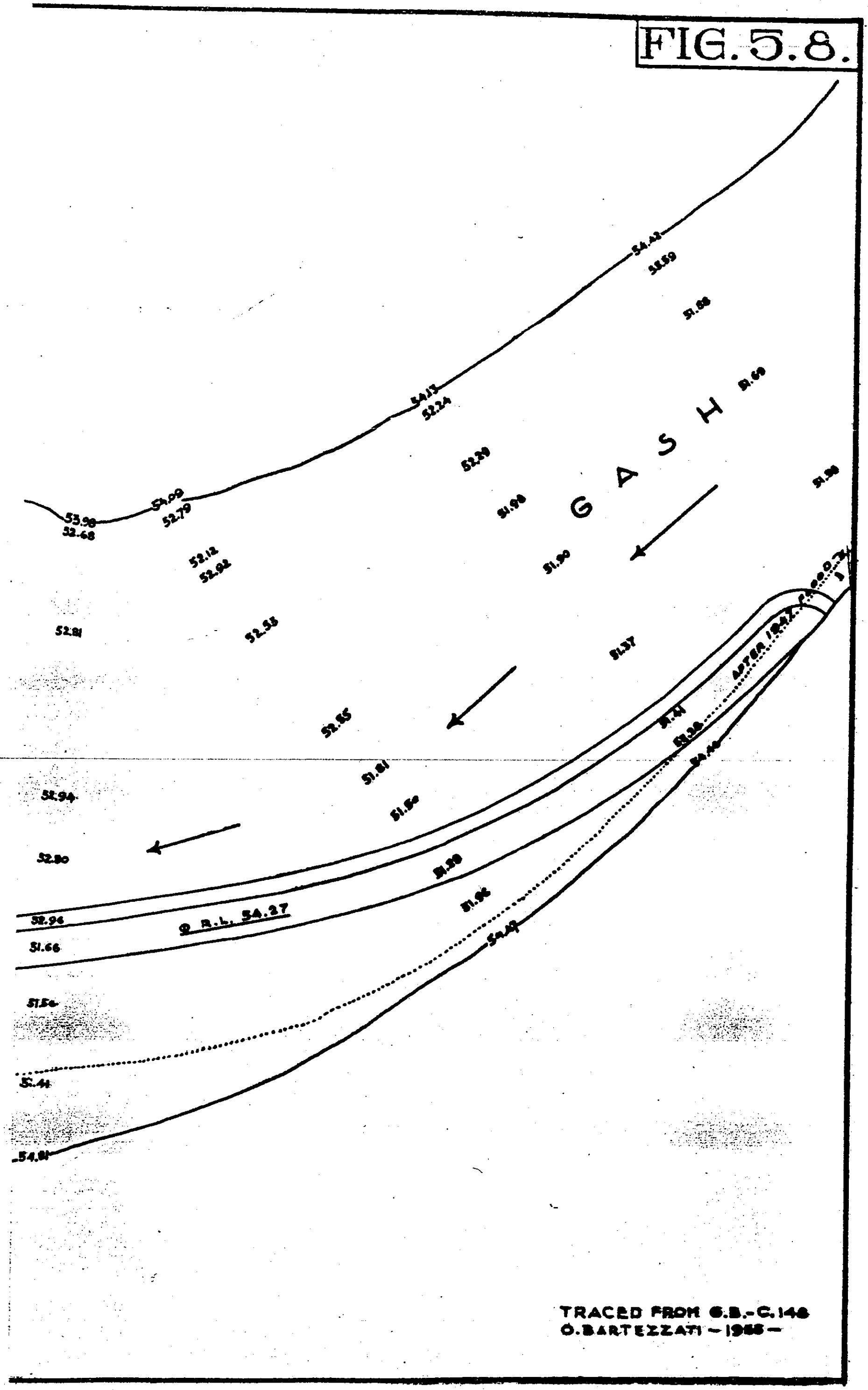
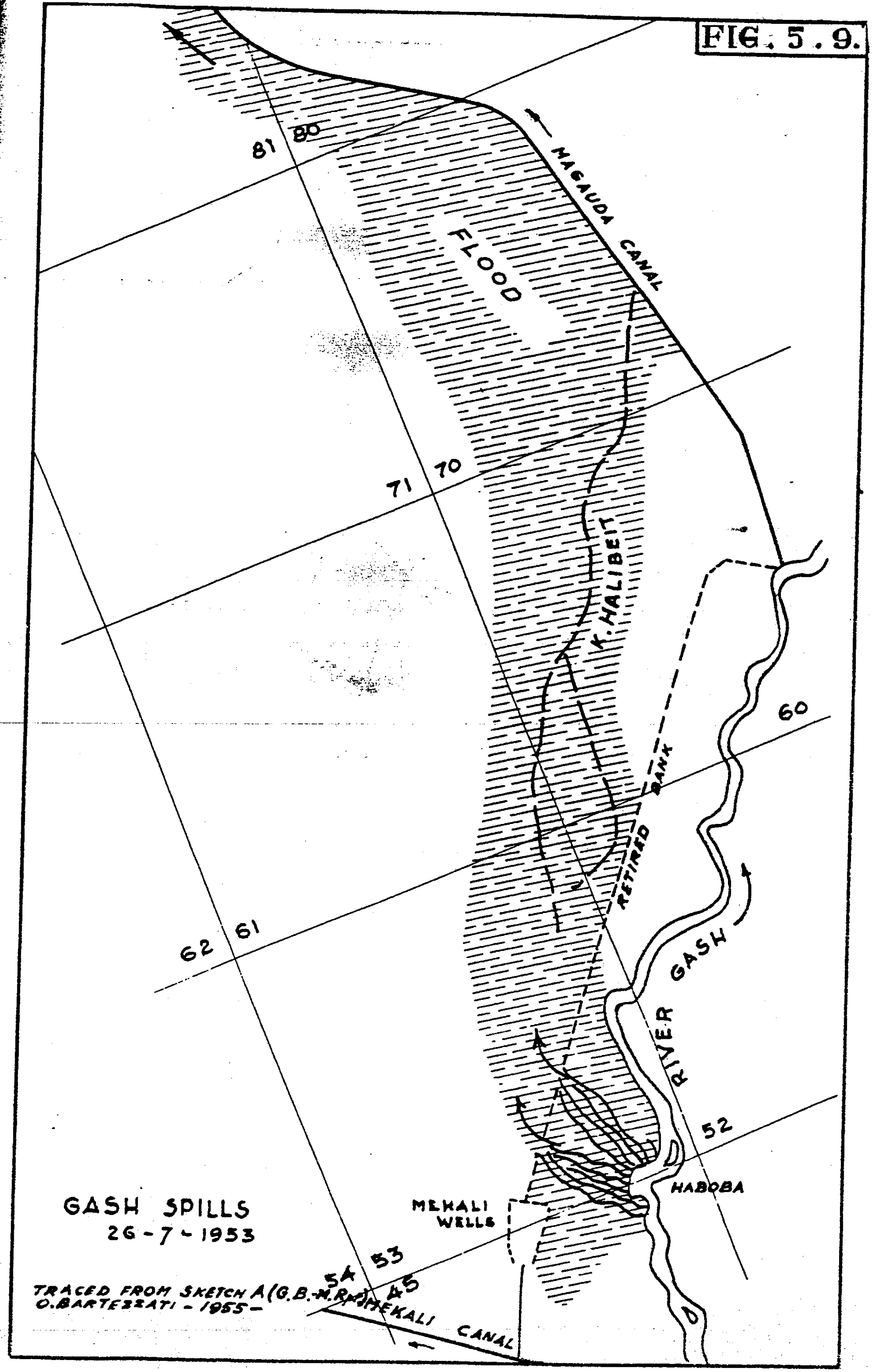

GASH
AFTER 1944 FLOOD
R.L. 54.27
54.42
52.59
54.13
52.24
54.09
52.79
53.98
52.68
52.81
52.94
52.80
52.94
51.66
51.54
51.44
54.81
TRACED FROM G.B.-C.146
O. BARTEZZATI — 1955 —

FIG. 5.9.


MAGAUDA CANAL
FLOOD
K. HALIBEIT
RETIRED BANK
RIVER GASH
HABOBA
MEHALI WELLS
MEHALI CANAL
81
80
71
70
62
61
60
54
53
52
45
GASH SPILLS
26-7-1953
TRACED FROM SKETCH A (G.B.-M.R.)
O. BARTEZZATI - 1955 -

NEW MISGA OF MEKALI ESCAPE

PLAN

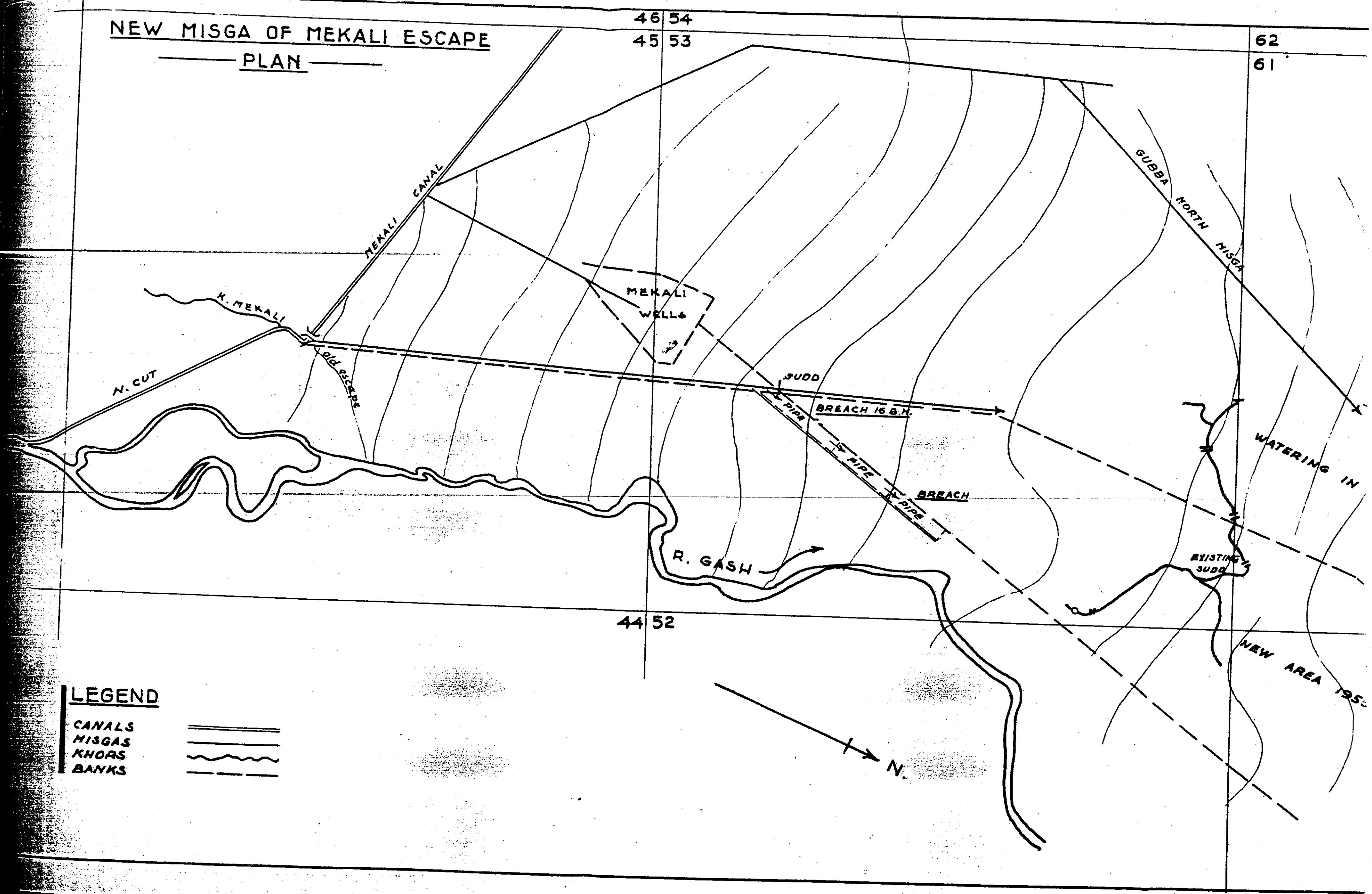
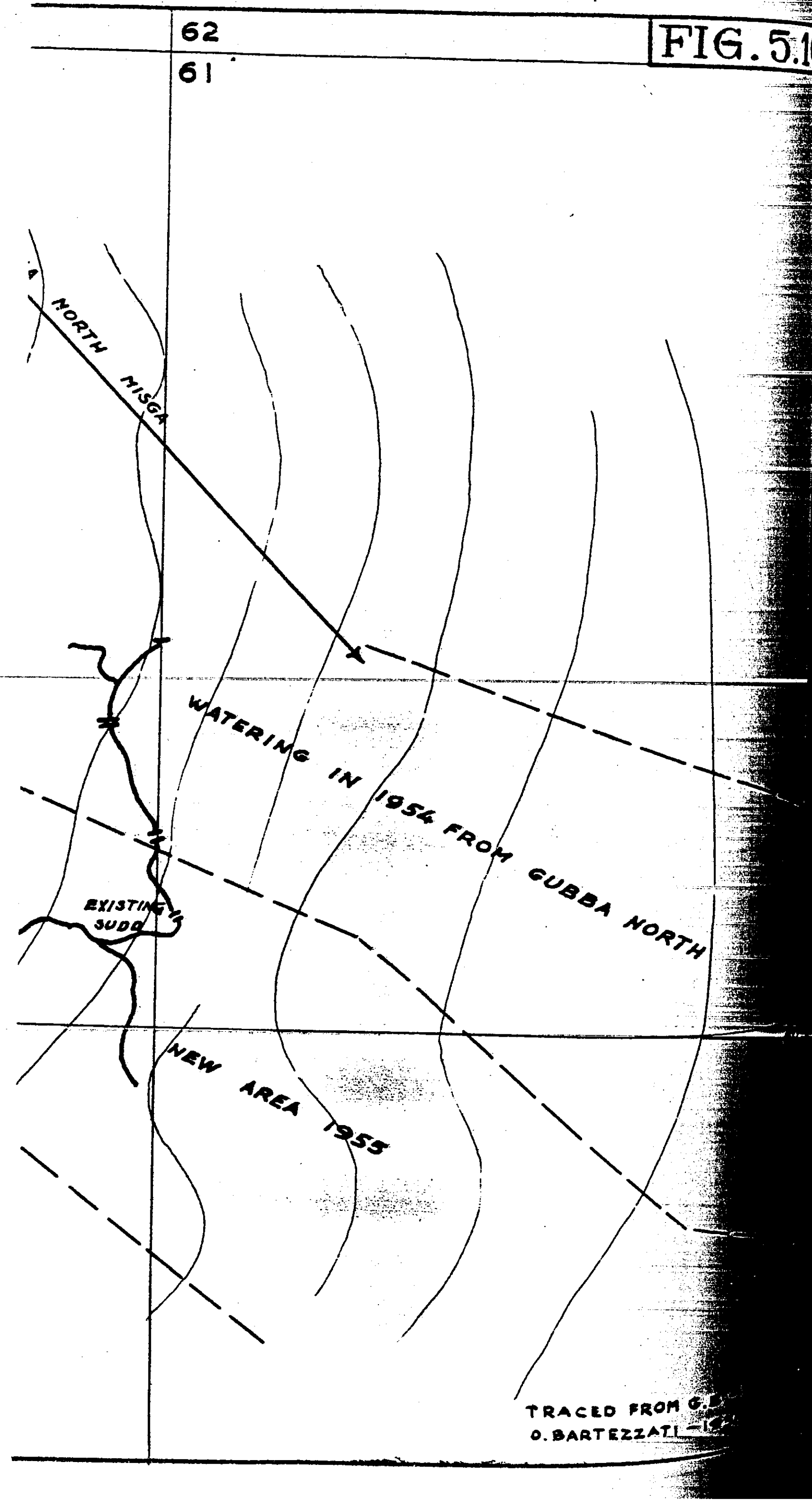


FIG. 5.10


62
61
NORTH MISGA
WATERING IN 1954 FROM GUBBA NORTH
EXISTING SUDD
NEW AREA 1955
TRACED FROM G.
O. BARTEZZATI

MAGAUDA OLD HEAD
PROPOSED CONTROL WORKS 1954-1955

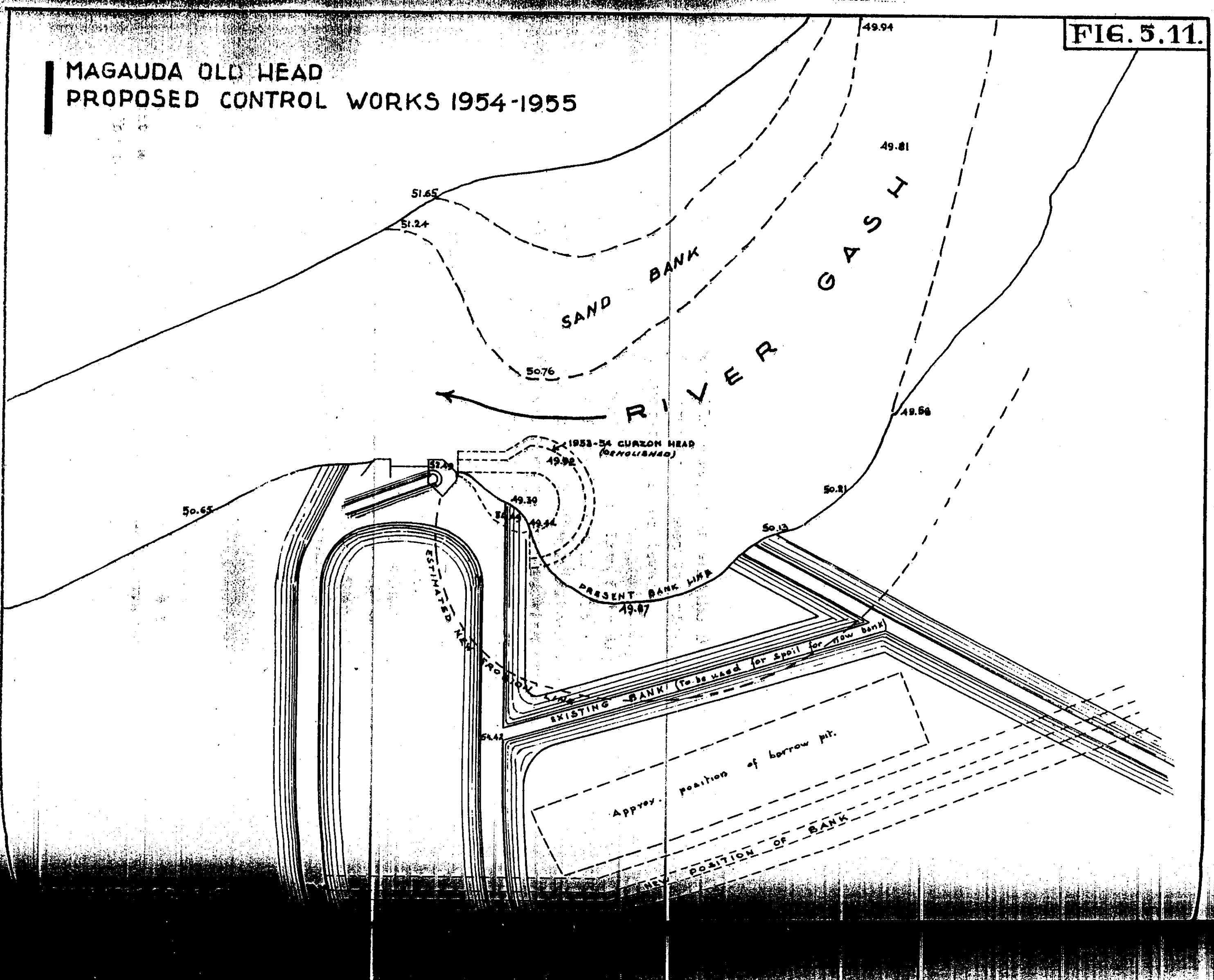


FIG. 5.11.

SECTION VI

MAGAUDA TO TENDELAI

1. Introduction

In the Tendelai reach we first come across the sweeping changes which have been taking place in the lower part of the delta. Once the Gulosit-Gammam balag dried out, the silty water ran on northwards to start building up new balags further downstream. At the time of writing, this process is taking place from Tendelai northwards and it is in the reach we are now dealing with that the Gash khor really comes to an end. After Tendelai the flow becomes a series of more or less interconnected balags.

This has only recently come about and the reach has been the scene of an epic struggle to keep the river within its banks in the face of ever-rising bed levels.

This section will deal with the Gash from Magauda North head to the original line of Tendelai canal. It will also discuss the question of the supply for Tendelai canal which has had almost as many vicissitudes as Mekali, with offtakes being tried out at both ends of the reach and, finally, in the middle.

Most of the reach, with the exception of the downstream end, has been (and still is) relatively stable. The river is narrow and fairly deep and its course is tortuous. It is lined with tamarisk trees on both sides and, as spill has been frequent, the belt of trees is rather deeper than it is further upstream. Beyond the present Tendelai head the river runs into such dense bush that it could almost be called forest again.

2. Tendelai Canal Supply: 1927 to 1937

Tendelai was the last of the main canals to be dug; it was not put in until 1927 and even then it was not completed. The head regulator was built with four openings of 2.5 m and took off the river at right-angles. No contemporary plan of the offtake site remains. The reach was described at the time as being "a stable part of the Gash where (the) canal has call on the whole of the Gash water; (it has the) disadvantages of (requiring) deep cutting before command of the ground is obtained and heavy spates (forming) balag to east and west at (the) head regulator; the cross-section of the Gash here is smaller than at Magauda and therefore we have the advantage of a greater depth of water available here than at Magauda for a given quantity of water in the Gash". It would seem, from the general sense of the above quotation, that the word "cross-section" has been used where "width" is intended.

A good idea of the conditions at the offtake can be got from an aerial photograph taken in 1932. This was five years after the head was put in, but there is no doubt that it gives a fair indication of conditions as they were in 1927; it is immediately clear that the Gash was indeed stable and it can be seen, from the size of the trees growing on the banks, that there had been little change in the preceding few years. A trace of the outline from the photograph is shown in Fig.6.1. The canal is seen to take off at right-angles from an almost perfectly straight reach of the river. It is known that this was intentional as such siting was, at that time, considered to be correct. Subsequent experience, including Tendelai itself, has shown that it is not. The Gash at the offtake is only about 25 m wide and appears to be slightly constricted just above the head; there is a left-hand (or adverse) bend just under 300 m upstream.

For the first year the canal was excavated only as far as K.9. The bed slope was set at 1:4,000. No misgas were put in because it was intended to water only from the end of the canal in one large area. Profiting from earlier experience, it was intended to dispense with misgas altogether in Tendelai and to run the water out into a total of four large "farms" - two to be run each year. Although this original intention has subsequently been modified, Tendelai canal still preserves few, but large, misgas; the principle is a good one and makes for easier watering.

During the first season there was a heavy silt deposit in the canal just below the regulator and a lesser one at the tail, otherwise the canal behaved well. The canal had not been dug out to full section for the first year and this was thought, at the time, to be the cause of the silting; looking back after the passage of years, it can be seen that it almost certainly was not, and that the trouble was a badly sited offtake.

Protection banks had been built up along the Gash, but it is not now clear to what extent. The idea was prevent westerly spill which was tending to cause balag near the canal. The banks were breached in one or two places during the first season.

Sections were taken of the Gash near Tendelai head every year from 1926 to 1941 and they show a remarkably steady rise in bed level throughout the whole period, averaging 20 cm per year. It is very interesting that this tendency should be observed as early as 1926 when, it must be remembered, the Gulosit-Gammam balag was operating. There does not seem to have been any change in the rate of silting when the balag was finally cut through. The practice of taking annual cross-sections at specified points along the course of the Gash has been dropped of recent years. As a result of the study of the river which the writing of this report has necessitated, this is shown to be a great pity and it is most strongly suggested that the practice be re-instituted.

Before the 1928 flood, Tendelai canal was enlarged to full section (to carry 12 m3/sec) from the head to K.6.6. At this point a misga with a masonry head, known as No.1, was taken off; it was designed to carry 6 m3/sec and led into Khor Halibeit. The water ran down the khor for some distance to a point where the latter was blocked off and a cut was made leading to an area suitable for cultivation. In addition the area watered the year before from K.9 was watered again. The supply was adequate until the end of August, but by then the head reach of the canal silted so seriously (to a maximum depth of 70 cm) that it was unable to carry its full discharge. By this time the bed level of the Gash was 25 cm above canal bed level.

After the flood, the canal was extended to K.15.5 and a cross regulator was built at Misga 1. The 1929 flood was the all-time record flood and a good deal of damage was done. The Gash banks had been extended, before the flood, so that they were continuous from Tendelai head to Magauda head, but they breached almost immediately and the water swept into Tendelai canal below the head regulator. All control was lost from 1st July onwards and at the end of July the north bank of the canal was breached in three places between K.1 and K.4. Large quantities of water continued to pour through these breaches until the end of the flood. Despite all this there was ample water in the canal and the distribution was good that year. The first six kilometres of the canal were again heavily silted.

At the time it was thought that the silting was due to the fact that Gash bed levels were so high above canal levels and, accordingly, the floor level of the regulator was raised before the 1930 flood and the design of the first six kilometres of the canal was adjusted to conform. Subsequent experience leads one to believe that this was a fallacy; at Magauda, for example, the canal bed is, at the time of writing, about 17 cm below average Gash bed level at the offtake. That is why Magauda canal can take the full discharge of the Gash at low stage and it certainly does not lead to silting there. In any case the bottom few stop logs are always left in place, except at very lowest river, in order to exclude the bed load. The fact that raising the floor of the regulator also made the head reach of the canal steeper may have been to some extent helpful, but it appears to have been regarded at the time as a secondary consideration.

Misgas 2, 3 and 4 were dug that year and were provided with open masonry head regulators. At K.15 a double cross regulator (of the right-angled type) was built; one part of this led into a khor which was developed into Tendelai Northern Extension and the other, the one at right-angles, was for a future westerly extension. The Northern Extension runs along a pronounced ridge, about the only place in the Gash Delta where the slope of the land is actually apparent to the naked eye. The ridge runs northwards and the land falls away sharply to east and west on either side; it ends abruptly

forming a rounded nose of land pointing towards Matateib. It may be surmized that the khor which ran along it was once a branch of the Gash, carrying a heavy load of silt. In 1930 the Northern Extension was run without misgas.

In 1931 only the Northern Extension was run (in conformity with the policy of watering only clean land) and three misgas, Nos.5, 6 and 7A, were taken from it. Actually Misga No.5 takes off just below the Tendelai Western Extension regulator, but the extension had not by that time been put in.

Measurement of discharge in the Gash during the flood of 1931 indicated heavy losses of water (nearly 30% of the total flow above Magauda) before Tendelai was reached. This was partly accounted for by several breaks in the Gash banks on the west, but much more so by spill to the east forming a large balag on that side. This easterly spill was all eventually collected by Khor Fillik and did not rejoin the Gash.

The 1932 flood was a very big one. To quote from the Annual Report for that year: "The Gash no longer runs in stable regime north of Magauda head regulator. The main stream has changed its course in no less than six places, eroding new channels and throwing up silt deposits in the old ones. Two serious break-aways to the west were made by sharp swings in the river and quickly formed themselves into khors drawing off considerable amounts of water. These combined waters fell away slightly to the north-west and, after breaching Tendelai canal at K.2 and K.4, eventually fell into Metateib canal".

All this is clear from an aerial photograph taken during the flood. Another fact that emerges from the photograph is that by this time the North Collector bank had been built and that it too had been breached. No reference can be found to the building of this bank and its date is not known, but it looks fairly new in the photograph and I think we may assume that it had been not long built. Its position can be seen in Fig.6.2. Its purpose is quite clear; to return the balag water into the Gash.

In the same year, 1932, the Tendelai Western Extension was put in. The channel was designed to carry 6 m3/sec, though this was exceeded even in the first season. Four misgas took off the extension, No.5 (which had already watered with the Northern Extension), Nos.9, 10 and 11. The latter was west of the railway. Misgas 10 and 11 were put in without regulators. Road bridges were built at the agricultural station and beside the railway; in addition a railway bridge was built. Although control of the canal was lost in mid-August due to the Gash breaches, the new area watered very satisfactorily.

By the end of the 1932 flood the Gash bed level at the head of the canal was one metre higher than it had been in 1927. This rise had been accompanied by a corresponding rise in berm levels.

Before the 1933 flood, the South Collector bank was also built, see Fig.6.2. It can be seen from photographs that both these collector banks had continuous borrow-pits on the east side to lead the water back to the river. The head regulator of the canal, which had been topped by 40 cm during the 1932 flood, was raised a further 45 cm. In the canal itself the Western Extension was produced to form Misga No.12 and the Northern Extension was remodelled and extended by dividing Misga No.7 into two branches, east and west. The canal, though still silting, ran well. After the flood, continuously rising Gash levels made it necessary to redesign the canal; the new design was carried through from the head right down to K.15. The water slope was increased from 1:4,000 to 1:2,780; the depth varied uniformly in the head reach from 1.10 m at the head to 1.60 m at K.6, thus the bed slope in this section was actually 1:2,260. Misga No.1 was raised to suit the new canal level. This redesigning to steeper slope would, it was hoped, reduce the silting. It did not.

The 1934 flood was marked by a very poor supply in July, so Tendelai canal was not opened until August. By the middle of the month it became clear that it was silting badly. Careful records of silt levels just below the head were maintained during the flood and it transpired that the most rapid deposition took place when the canal was run below design discharge. The clearance after the flood amounted to 24,000 m3; a serious matter.

A masonry regulator was built for Misga No.10 that year.

In the Gash khor bed levels were rising steadily and berm levels were following them. This was made clear by a study of the river gauges. At that time it was not until below Magauda that serious spill started, but thereafter large quantities of water were lost to the east on high spates; spill was confined by artificial banking on the west. It might be expected, therefore, that rising levels at Kassala would produce corresponding rising levels at Tendelai and downstream, up to the point at which spill began and that thereafter there would be very little further rise whatever the increase at Kassala. This was in fact the case, but these "maximum gauge readings" were increasing year by year (20 cm annually at Tendelai) as the river berms were built up.

A record area was watered during the 1935 flood but the behaviour of the canal was most unsatisfactory. No less than 65,000 m3 of silt were deposited in the head reach. Just below the head the deposit was 1.35 m deep and it diminished to an average of 0.40 m deep downstream of K.8. The head regulator was topped on several occasions on high spates.

Before the 1936 flood the head reach of the canal was remodelled to give a deeper and narrower section. The channel was cut on the right-hand side of the bed and the spoil bank on the left-hand side was lined with brushwood for 3.9 Km downstream the head to prevent it slipping back into the new excavation. Escape pipes were put into the north bank at K.0.9 in the hope of scouring the silt from the head reach.

It is about this time that the first mention is made of silting basins; no record now remains of exactly when they were put in. A bank was built northwards from the North Collector bank about 300 m from the Gash. Other banks joined this bank to the Gash protection banks along the river, and it was hoped to flood the basins so formed with silty water and in that way raise land levels generally in the basins.

The 1936 flood was marked by several high spates. The Gash was becoming more sinuous and there was a good deal of westerly spill between the South and North Collector banks which breached the latter about a kilometre from the Gash. The south silting basin was not filled, but the north one was flooded and breached. All this water ran on and lay against Tendelai canal, breaking into it at K.4. Just south of Tendelai head the increased sinuosity was particularly noticeable. There was little spill to the east.

The canal ran very badly. In the first place, the escape pipes were found to have been badly sited and silt blocked the outfall. After this failure an attempt was made to clear the silt by blowing it out with a big discharge during a spate; unfortunately canal levels rose too high and the water went over the top of the revetment on the left-hand bank and the loose spoil bank there slipped along the first 200 m of the canal. The depth of silt downstream the head jumped from 70 cm to 150 cm overnight. Further downstream, both the Western and the Northern Extensions had been blocked with wind-blown sand just before opening up irrigation and both had to be cleared at the last moment. The total area watered was little more than half that of 1935 and the silt deposit amounted to 40,000 m3.

The water, mentioned above, which broke into the canal from the balag at the end of August was a great help. It was very clear and enabled the Northern Extension to be watered after the supply from the head had more or less failed. It was decided to exploit the supply by putting pipes in the Gash bank to feed the balag and allowing the water to enter Tendelai canal over a weir at K.4.

Before the 1937 flood, the head reach of the canal was pitched with stone for a length of 500 m. A new scouring escape was made at K.1.5; it consisted of four 42-inch "Armco" pipes, with masonry head and core walls and dry stone pitching downstream. The auxiliary supply system is shown in Fig.6.2. Four pairs of 42-inch "Armco" pipes were built in with head and core walls and with pitching upstream and downstream; they led out from the north silting basin into the balag. The water was admitted to Tendelai canal at K.4.140 over a masonry weir with a crest width of 30 m. At the canal head two curtain joists were removed and a silt

excluding weir was built at each gate, to adjust conditions to the rising river bed levels.

During the flood there was again a lot of spill to the west from near the South Collector bank northwards. Again the North Collector bank was breached just over a kilometre from the Gash. The water passed into Tendelai canal over the weir. Curiously enough, the expected supply from the pipes in the silting basin did not get through; the basin itself did not fill except on high spates, behaving quite differently from the way it had behaved the previous two years.

The breach, which was entirely uncontrolled, provided altogether too much water. During one very high spate there was more than a metre of water over the crest of the weir which was three times the designed depth. The canal was able to carry the discharge, running 90 cm above full supply level, but the big inflow at the weir resulted in the supply from the canal head being backed up and the first kilometre of the canal became completely plugged with silt. Over four hundred men were turned out to cut a channel through the deposit to the escape and a great deal of silt was blown out that way, but not enough to clear an adequate water-way in the canal. For the rest of the flood only occasional flushes came down from the head and reliance had to be placed on the uncontrolled supply over the weir. It is interesting to note that the silting escape channel itself became heavily silted although it had been dug with a bed slope of 1:500.

The total silt deposit in the canal was 25,000 m3. That was some reduction compared with the previous two years, but it was small consolation because the improvement was only in the deposit below K.1. To some extent the continuous failure in Tendelai was due to accident: the slipping of the banks in 1936 and the uncontrolled discharge over the weir in 1937. There was no doubt, though, that the fundamental trouble was at the head. The early history of Tendelai canal gives strong support to the thesis that when a canal silts heavily because of a faulty offtake, there is little hope of remedy in re-design of the channel or other measures downstream of the head itself. There was now no alternative but to seek some other offtake. It is unfortunate that the site picked on had a record no better than Tendelai head itself; it was Magauda North head !

3. Tendelai Canal Supply: 1938 to 1942

The proposal was to dig a new channel from Magauda North head to the end of the North Collector bank where the water would spill into the balag. A new bank, the Weir Guide bank, would be built from there to the weir to confine the balag on the west. The collector banks were extended back to the new cut. The advantages of the scheme were obvious: no new regulator was necessary; the east bank of the new cut, with water flowing behind it, would form an excellent protection bank; and the filtering effect of the balag on the water entering Tendelai canal.

The site at Magauda North head was improved by cutting back the west bank of the Gash upstream of it and the curtain joists in the regulator were removed. As a "just in case" measure the head reach of the original Tendelai canal was cleared to its full section and the silt escape dug out again. The inlet weir was provided with a cistern floor and the built stone pitching on the opposite side of the canal was strengthened. A light foot bridge was built across the new cut from Magauda North head to provide access to the protection banks during the flood.

Westward spill from the Gash occurred in the 1938 flood from as far south as Magauda North head. It became worse and worse as one went north and at one point it started to develop a khor leading straight from a sharp bend in the river towards the North Collector bank. From the silting basins northward there was a lot of spill to the east which was heaviest and most concentrated about 1.5 Km south of Tendelai head.

The watering of Tendelai canal was impeded by a succession of disasters. Magauda North head was opened in mid-July. The water did not follow the guide bank, although a continuous borrow-pit had been adopted to induce it to do so; instead it swung east and ran against the canal at about K.1.

It then followed the south bank of the canal to the weir. There was a delay of four days from opening Magauda to the arrival of the water at the weir. The head reach of the new cut silted at a distressing rate and a metre depth of silt was deposited in the first few days. This might have been because of the poor supply from the Gash in July and so it was decided to try and clear a channel through the deposit and make a fresh start. Accordingly Magauda North head was closed and the original Tendelai head opened and work started. The head reach of Tendelai silted to a depth of 80 cm in four days. By this time it was mid-August and the next disaster was due; this took the form of a high spate in the Gash which breached both collector banks. The resulting flood is shown in Fig.6.3. In preparation for it Tendelai head was closed, Misgas 1 and 2 and the scour escape were opened and the guide bank was cut near the weir to allow water to escape to the balag south of the canal. It was not enough; the regulator group at Misga No.1 blew out and the canal breached at K.4, just above the weir. This last break drained all the water from the weir and the canal ran dry.

The Misga No.1 and the K.4 breaks were mended after a six day struggle but it was not possible to mend the collector banks because there was no dry spoil near enough to the breaks. Instead, the worst of the spill was partly closed off on the Gash banks themselves by double banks of brushwood.

Towards the end of August Tendelai head was re-opened, followed three days later by Magauda North. At this point, after so much costly work, the Gash played its trump card. The flood failed and all command was lost early in September. It was a great pity that there was no chance to test the newly cleared cut properly before the end of the season, because some doubt remained as to whether the original silting was due to intermittent and poor supply from the river or to other reasons more fundamental. This led to the decision to try it out once again in 1939 and to that extent delayed the solution to the problem of Tendelai supply.

Before the 1939 flood a big programme of banking work was carried out. It can be seen in Fig.6.4; this drawing also shows work carried out in 1940. The main protection line was from Tendelai head to the silting basins along the bank of the river, then along the North Collector bank and the east bank of the Magauda-Tendelai cut; this was strengthened throughout. A new Middle Collector bank was built and all three were provided with drains along the east side to carry the water back to the river after spates. A retired bank was run from the silting basins to Tendelai canal at K.1.5, with four diagonal spreading banks. It was intended to run water into this area from the draw-pipes in the existing silting basins, so as to form a new silting area. Surplus water could be discharged into the balag above the weir through a culvert in the banks.

A leading cut 10 m wide and with an average depth of just over a metre was dug in the bed of the Gash for three kilometres south from Tendelai head. It is difficult to say what effect this had because the following flood was so poor that no serious spill occurred in the reach anyway.

Both Tendelai canal and the Magauda-Tendelai cut were cleared and groynes were built in the latter where it was tending to widen. A steel plate weir was erected in front of Magauda North head to keep out the bed silt. Vegetation in the balag was burned before the flood to cut down the time lag between Magauda and the weir. Finally, a dragline excavator (a novelty, at that time, in the Gash) was stationed on the Magauda-Tendelai cut during the flood.

The 1939 flood was no real test for the banking system; it was such a poor flood that there was almost no spill. The original silting basins remained dry and almost no water reached the new silting area north of them. Low river levels made it impossible to open up until the beginning of August, when a start was made from Magauda. A deposit of 40 cm of silt immediately formed, but did not increase beyond that depth. It was found by trial that the canal would carry 60 cm depth of water without further silting; any greater depth started it off again. The designed depth in the canal was one metre. Again the water took four days to reach the weir and the 60 cm depth in the canal produced about 15 cm over the weir; this was only about half the necessary supply, not a cheerful prospect after a late start to the flood which was delayed

still further in the balag. The risk of taking a supply from Tendelai head had to be accepted, and it was opened a week after Magauda. The head reach started silting immediately, but it seemed for a short while as though the main canal could still be kept going with a reduced supply from each source. However, it was not to be and by the end of August the Tendelai head reach was completely plugged with two metres of silt. A small supply was kept flowing from Magauda, but by mid-September the flood failed and that stopped too.

This failure, in 1939, was not entirely due to the poor offtakes; it was a year of wretchedly poor flood in the Gash. It was, however, the fourth lean year in succession at Tendelai and the tenants were, not unnaturally, getting despondant. By this time considerable experience of the siting of offtakes had been gained and it was decided to build a new head. The principle of feeding into the balag first and then into the canal over the weir was accepted as a good one which prevented silting in the channel and so a site was sought well to the south of the original Tendelai head. It is shown in Fig.6.4. The new head consisted of ten 42-inch diameter "Armco" pipes with "Calco" gates, set in a masonry head wall; this design was adopted because the pipes happened to be available and not because it was considered to be superior to the more usual open head. The site was the first to be chosen in accordance with the principles discussed in the last section: it was inset from the river on the outside of a curve in the way specified and the pitching was arranged to provide a "dawran" downstream of the head. A site plan, showing the arrangement is reproduced in Fig.6.5. The Magauda-Tendelai cut was retained as a reserve supply but the original Tendelai canal head reach was not cleared again.

A protection bank was built from the new head to join the Magauda-Tendelai cut east bank and, in the balag area, a new bank was built parallel to, and two hundred metres east of the Weir Guide bank. The bank ran for 3.25 Km, about half way to the weir; it was intended to confine the spread in the balag and so cut down the delay between the channel outlet and the weir. In case the bank broke, an alternative flow line was cleared through the balag to the east, following the best defined of many previous flow lines round to the weir again.

A spur was built out from the new bank as shown on the drawing and was intended to guide the alternative flow. All this work is shown in Fig.6.4.

In 1940 the Gash eroded its left bank about a kilometre north of Magauda North head; the old protection bank by the river was eaten away and heavy spill occurred. It ran against the right bank of the Magauda-Tendelai cut and the new Tendelai head protection bank and breached them both. Fortunately emergency measures were successful in restoring the situation. The soil in this area is a badly cracked "badobe" and even today banks founded on it seem to melt away at the very thought of water; it is impossible to rely on any defences there until the whole zone is thoroughly wet.

The new head was a complete success and Tendelai enjoyed a steady and good supply throughout the flood. The early, uncontrolled floods broke into the original Tendelai canal above the weir and this was allowed to run. The double banking in the balag greatly accelerated the passage of water to the weir, although the extra weight of water against the Weir Guide bank caused it to breach in several places.

Before the 1941 flood a new bank was built along the river from Magauda North regulator to the new Tendelai head. A series of large, triangular brushwood spurs was placed in the eroded bay whence the main part of the silt of the previous year had emanated; these were successful and a useful deposit of silt was built up. Although the river ran above ground level during spates the banks held, except for one breach in the first few days which was soon repaired. The new head at Tendelai was again most successful; the only trouble was from occasional accumulations of drift-wood against the gates.

In 1942 the bank from the new head to the Magauda-Tendelai cut was considerably strengthened and was extended across the cut to block it off completely. It was then possible to flood the zone thus bounded by bank and cut with a controlled flow of water through pipes in the extension of the bank. During the flood the banking near the pipes gave way but was soon repaired. In any case the flow was not very strong and was held by the retired banks. At the point

where the supply channel opened out into the balag there was a heavy silt deposit and the canal head was closed for a week, early in the flood, to allow an extension to the channel to be dug, taking it over to the east side of the east balag bank built in 1940. There were then no further difficulties.

4. The 1943 Avulsion

Before the 1943 flood, a sharp bend opposite the draw pipes to the silting basins south of the old Tendelai head was cut off by an artificial channel and a spill channel to the east some distance further north was blocked off.

During the flood the silting of the old Magauda-Tendelai cut upstream of the stop bank was completed. At Tendelai new head silty water was passed through a pipe from the Gash into the area bounded by the supply channel, the old Magauda-Tendelai cut and the protection bank joining it to the head. Thus a continuous retired protection was achieved from Magauda North to Tendelai new head.

The avulsion took place on the 3rd August about 500 m north of the artificial cut-off, though it would not seem that the two were connected. The forward Gash bank had been threatened in 1940 at this point and a loop-bank had been built behind it, but the space between the two had not yet been filled up with silt. The inner bank was topped by a sudden spate and the outer bank was breached almost immediately. The results can be seen in Fig.6.6.

Within the first twenty-four hours it became clear that it would be impossible to close the actual break-out from the river and all labour was therefore wisely switched on to guiding the flood northwards. The flood quickly spread along the original Tendelai canal and broke into it at a number of places; over a metre of water was pouring over the weir and the Weir Guide bank was swept away as other water ran on along the south bank of the canal. The north bank of the canal was breached about 300 m east of the weir; this was a convenient outlet and so the south bank was broken opposite to it to help.

Two further breaks were then made; the second by the old scour escape and the third between the first and the second. These were sufficient and within forty-eight hours of the original break-out, the entire flood was passing through them to the north and the supply to Tendelai canal over the weir had ceased. The course of the flood to the northward will be dealt with in subsequent sections of this report.

The next problem was to get the supply to Tendelai going again. This was done by breaking the Weir Guide bank at the tail of the supply channel from Tendelai new head. The water in the channel was diverted to the west of the guide bank, down which it ran along a route it had followed by accident on several previous occasions, to break into Tendelai canal to the west of the weir. A few days elapsed before the new arrangements settled down, but thereafter they worked well and the canal was kept fully supplied to the end of the flood. Altogether, the avulsion caused an interruption of only three days in the watering at Tendelai. When the magnitude of the event is taken into consideration the resumption of watering after such a short delay must be accounted a remarkable feat.

5. Tendelai Canal Supply: 1944 to date

The main results of the avulsion were felt further to the north and curiously enough it had little effect in the section of the river under discussion, where it actually broke out.

All that was necessary before the 1944 flood was to block off the old channel of the Gash and, by redesigning the bank system, to reinstate the balag supply for Tendelai.

The new balag was contained by banks to the west of its original position. The old Balag East bank was retained and carried right up to the weir. This was now called the Inner bank. Another bank, the Outer bank, was built parallel to it and one kilometre to the west. Both banks were protected with spurs. The supply channel fed into the balag between them.

The arrangement is shown in Fig.6.7. The free-board of the regulator was increased by building up the pitching on the upstream side. The flood was rather featureless and the supply to the canal was satisfactory; it was noted, however, that the Gash banking from Magauda North to Tendelai South (i.e. new) head was not sufficiently strong.

In 1945 a new retired bank was built on a line running about half-way between the Gash and the Magauda-Tendelai cut. It was taken from the South Protection bank near Tendelai South head almost, but not quite, as far as the line of the old Magauda canal where the Magauda-Tendelai cut took off. The river was allowed to spill along this reach and a good deposit of silt was achieved between it and the new bank. Unfortunately the bank breached at one point and the area between it and the Magauda-Tendelai cut became filled up with almost silt-free water, thus defeating any attempt to introduce silt there as well.

From Tendelai South head to the end of the South Collector bank the Gash, though exceedingly tortuous, did not appear to be eroding its banks severely. Opposite the South Collector bank an artificial cut was made across a "hair-pin" bend in the river which was threatening to erode westwards and remove part of the Gash banking. The cut eroded to the full section of the Gash and the bend silted up almost to ground level. The supply to the canal was again satisfactory. The Outer balag bank breached because of high levels due to silt and bush but there was little loss of water.

Several khors led the water northward from the avulsion point. The original Gash khor itself, though blocked off, still carried some water; it was heavily silted, however, and was not expected to flow for much longer.

The 1946 flood brought some very high spates and did a lot of damage. Both Inner and Outer banks of the Tendelai supply balag were breached, as were also the inner and outer protection banks between Magauda North and Tendelai South heads. As a result of these breaks a great deal of uncontrolled water poured into Tendelai canal below the weir and operation was difficult. Much of the excess water ran along the south side of the canal and flooded the agricultural station at Tendelai.

Before the 1947 flood the retired protection bank between Magauda North and Tendelai South heads was strengthened and was extended to tie into the line of the original Magauda canal; three spurs were built from it to deflect the Gash balag back towards the river. All the banks in the system were raised 50 cm higher than the observed maximum water levels.

Although the flood was a poor one, even higher water levels occurred and the banks were breached near Tendelai South head. Uncontrolled water ran into the supply channel. Further downstream, the flow in the supply balag developed a ~~wide meander and attacked the Inner bank,~~ normally a Gash bank and protected by spurs on the east side only. It was breached on several occasions and the head had to be closed while repairs were made. A breach of this bank, of course, meant a permanent loss of water back to the Gash; breaches in the Outer bank were not so serious as the water would eventually break into Tendelai canal below the weir.

The banking system between Magauda North and Tendelai South heads was again reinforced in 1948. The main retired bank was extended to join Tendelai supply canal and it was widened and raised throughout its length. A new spur, No.4, was added. The complex as then existing is shown in Fig.6.8. This drawing also shows some work carried out in later years. Five discharge pipes were put in the main bank in order to flood the area between it and the Magauda-Tendelai cut. In order to protect the supply balag Inner bank from attack on the west side twelve small spurs were built along it.

The Gash itself seemed a little easier during the flood. Two sharp bends between the Middle and North Collector banks had been artificially cut off - this, it was thought, would reduce the tendency to spill. The strain on the protecting banking did, indeed, seem less and the new works were effective. Beyond the avulsion point the Gash was by this time running in a single, well-defined channel as far as the line of the original Tendelai canal.

Bends in the Gash have been cut off artificially in the past apparently for two reasons: firstly to prevent a bend from eroding into and cutting the protection bank; this had

often proved successful; secondly bends have been cut off to "ease the flow". Unfortunately there is insufficient concrete evidence to show whether this was ever more than fleetingly effective. Reports (such as those quoted above) give the impression that it was, but this is quite out of keeping with what one would expect from the normal behaviour of the Gash, which is to restore its slope as quickly as possible whenever it is interfered with. In the case of a cut-off one would expect further meandering immediately to follow leaving the final state of affairs very much what it was before.

No new works were carried out in 1949 and the flood that year calls for little comment. The general level at the upper end of the supply balag had been raised somewhat by silt, so the supply channel was extended through it for a short distance in the form of a shallow leading cut. It was found possible to take a discharge of as much as 20 m3/sec in the supply channel during spates. This was more than the canal proper could carry but there was some storage ~~in~~ the balag and Misga 1 was used as an escape for any excess water that could not be carried. The storage effect compensated to some extent for the fact that the head could not be relied upon for a full supply at low river.

In order to improve this defect the first five kilometres of the supply channel were deepened and the slope was increased. The Gash bed near the head was still rising and the masonry cill in front of the pipes was raised to keep out the silt. The 1950 flood started off with some very high spates. One of the first of these penetrated a crack in the earth fill over the pipes at Tendelai South head. The bank was quickly washed away but fortunately, when the spate had passed, it was found that the masonry head wall and the pipes were undamaged. Within twelve hours the bank had been reinstated and its upstream face reinforced by five layers of sand-bags. Two days later the Gash broke out about 500 m downstream Magauda North head; it breached the main retired bank in five places, the spurs in four places and the line of the Magauda-Tendelai cut in two places. The flow divided into two, part breaking into Tendelai Supply canal near the head regulator and part running down west of the supply balag. When the Gash levels fell again the breaches were repaired but ten days later, on another spate, the river broke in again at the same place as before and made four new breaks in the retired banks.

It was not possible again to close the main retired bank and two openings were left in it at the Magauda end. The original breach from the Gash was blocked off with brushwood, only to open again further downstream on the next spate. This process was repeated several times and it had, at least, the advantage of preventing the formation of a major spill channel.

Most of the water poured into the supply channel. Misga 1 was used as an escape and fortunately the right bank of Tendelai canal held. When watering was finished the Inner bank was breached and the water escaped back to the Gash. As a result of the breaks Tendelai station had such a watering as it had never had before, no less than 25,330 feddans being wetted !

A big programme of works was carried out before the 1951 flood. First of all a new regulator was built on the site of the existing pipe regulator. It consisted of four 2.5 m openings, 5.5 m high from floor to roadway. It has occasionally been necessary to close this regulator completely during a high spate; under such circumstances it carries a head of nearly 5 m. The regulator gave a much more flexible supply to Tendelai and has worked very satisfactorily until the present time. Then the main retired bank from Magauda North hoad to Tendelai Supply canal was remade with a four metre top width and an estimated 60 cm free-board. The space between this bank and the old Magauda-Tendelai cut was divided into four basins by cross banks and an arrangement was made to flood them one after another by a pipe in Magauda North head and by having a masonry spill-way in each cross bank to pass the water on to the next basin as each one was filled to the required level. This is shown in Fig.6.8.

In all this work, the immense advantage of using a tractor-drawn scraper for bank work was most clearly shown. The scraper not only builds a well consolidated bank but it leaves it in the form of a raised motorable road. This results

in far greater ease of inspection and has, over the past few years, greatly improved communications during the flood in the danger zones near the river.

The 1951 flood was a very poor one and there was never enough water to fill all the basins from Magauda North head. As it happens, it did not matter because there was no spill and the balag area in front of the main retired bank remained dry throughout the flood. The canal supply was as good as could be expected on so small a flood.

There were no major developments before the 1952 flood, and the flood itself, though big, did no damage. In 1953 the main retired bank from Magauda North to Tendelai head was modified by digging a trench in the upstream toe of the bank and filling it with Gash silt. This means of stabilizing banks built on sub-soils liable to cracking is helpful but has been found seldom to be fully effective because of the great depth to which some of the cracks go. During the 1952 flood the channel immediately downstream Magauda North head had silted up even with the small discharges required to fill the basins behind the retired bank. To overcome this a cut was made from Magauda canal just below Magauda South head, leading directly to the first basin. This cut was not successful during the 1953 flood; there was insufficient head. However, the whole area between the present Magauda canal and the Magauda-Tendelai cut was flooded through a breach in the bank between the Magauda North and South heads and this water provided sufficient head at the pipes into the first basin to flood the first two basins. The main retired bank was breached before the basins were filled, but was quickly repaired and no further damage took place.

There was no spill during the 1954 flood and it was not possible to fill the basins. It so happened that it did not matter as there was no attack on the banks. At the time of writing the problem of wetting the Magauda-Tendelai banking system has not been properly solved; it seems that the basins are rather too large to fill on the first flush of the Gash, which is when the banks should be wetted. It is of the utmost importance that a suitable scheme be put into operation without delay and the solution seems to be a supply direct from the

Gash and a confining of the wetted area in the basins, at least during the first wetting.

6. Recent Developments in Tendelai Canal

In 1938 a branch misga, No.10A, was put in to help water the area between Misga 10 and the railway, and in 1939 a branch was dug off Misga 3 to assist in the watering of Misga 4. Masonry regulators were built at Misga 6A and Misga 7E in 1943 and a pipe regulator was put in for Misga 6B in the same year. This latter was a new misga built that year (making Misga 6 into Misgas 6, 6A and 6B). Another new misga put in the same year was Misga 8N, between Misga 8 and Misga 7W; it was not provided a regulator.

Misga 7W was provided with a masonry head in 1945 and and Misga 6 in 1946; a similar head for Misga 8N was built in 1949 and in 1950 a new misga with a masonry head was built between the weir and Misga 1. This is known as the Weir Misga. Masonry regulators were built at Misga 10 in 1953 and at Misga 8 in 1954.

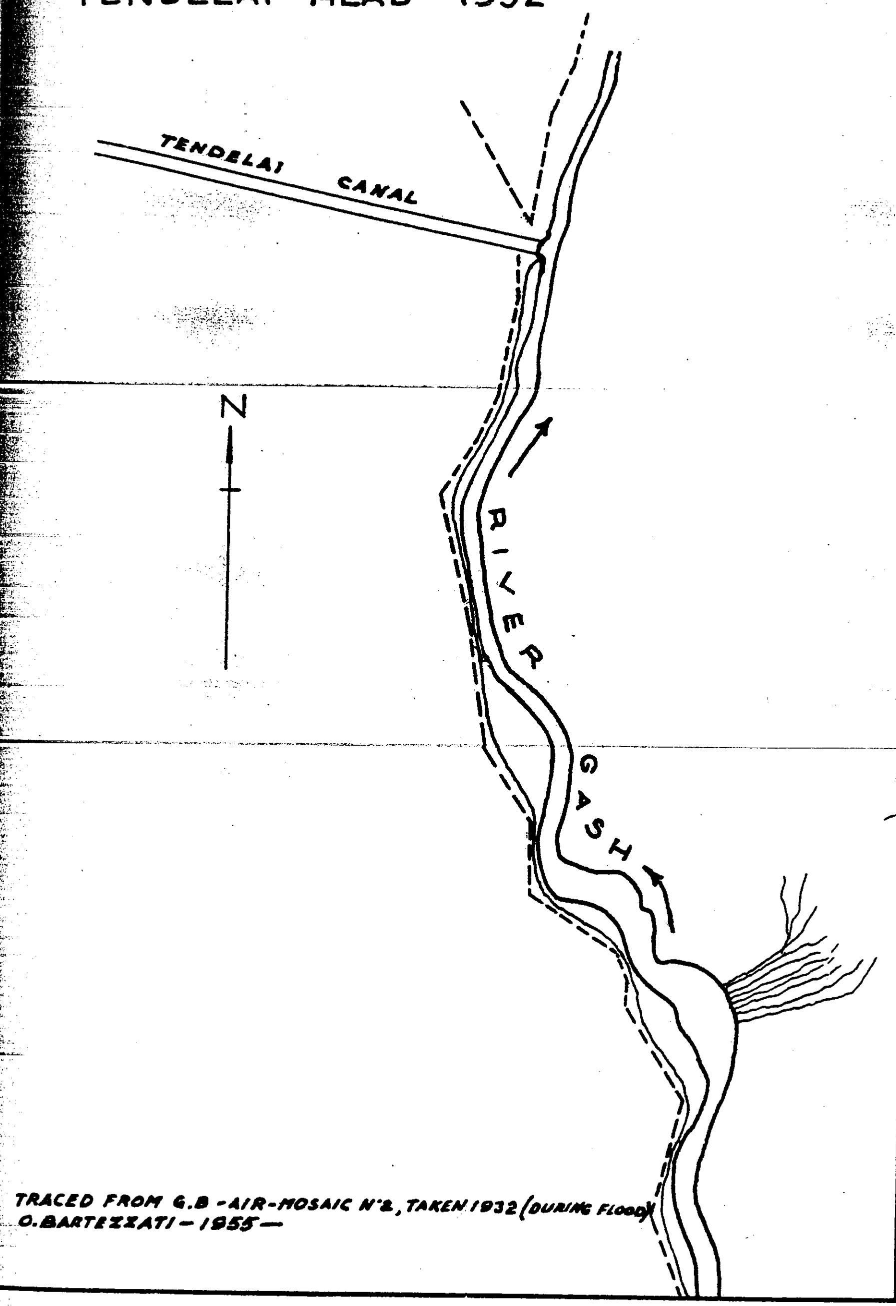
The cut through the supply balag has been gradually extended further and further in, until in 1954 it was cut through to join a natural khor cutting back from the weir. There is now a continuous channel through the balag area, and the whole of the space between the Inner and Outer banks has been filled with silt, forming a protection bank a full kilometre wide ! The weir itself is in process of silting over and will shortly disappear as the canal is now designed to have a continuous slope from the head to below the weir. This may result in increased silt deposit, but the whole system has been in a state of transition since the supply balag was cut through and it is difficult, at the time of writing, to detect the tendency; in any case it is not serious; silt has not yet reached the new design bed level.

7. The Gash Khor

Since 1950 annual cross-sections have been taken at Tendelai South head where the present discharge gauging site is located. At first there was a little scour, but on the whole the bed level there has been steady for the past five years. It would appear that some stability has been reached after years of rising bed levels. It seems likely, however, that silting will start again as balag levels further downstream start building up and the reach must be regarded as a dangerous one.

FIG. 6.1.

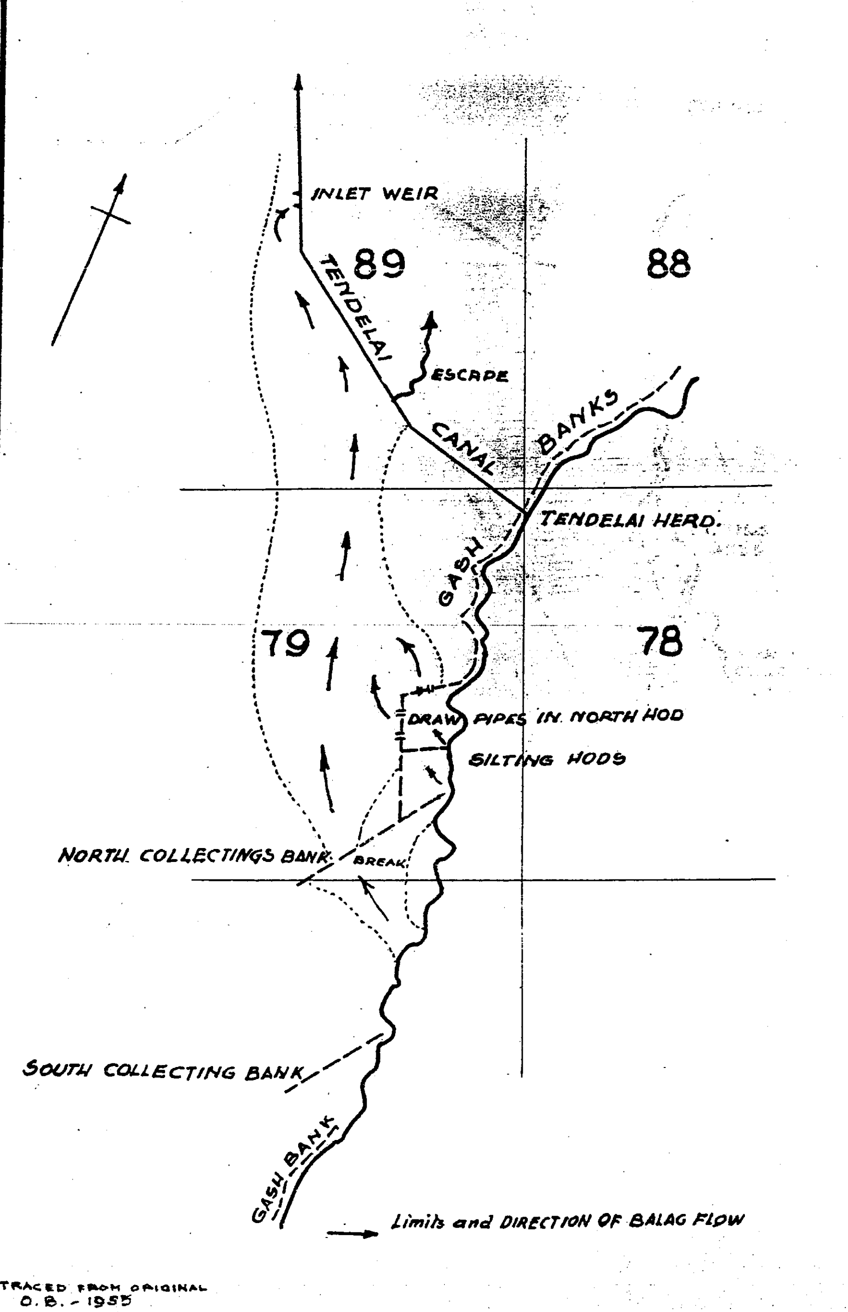
TENDELAI HEAD - 1932



TRACED FROM G.B - AIR-MOSAIC N°2, TAKEN 1932 (DURING FLOOD)
O. BARTEZZATI - 1955 -

FIG. 6.2.

SKETCH PLAN ILLUSTRATING
SUPPLY ARRANGEMENTS TO
TENDELAI CANAL



TRACED FROM ORIGINAL
O. B. - 1955

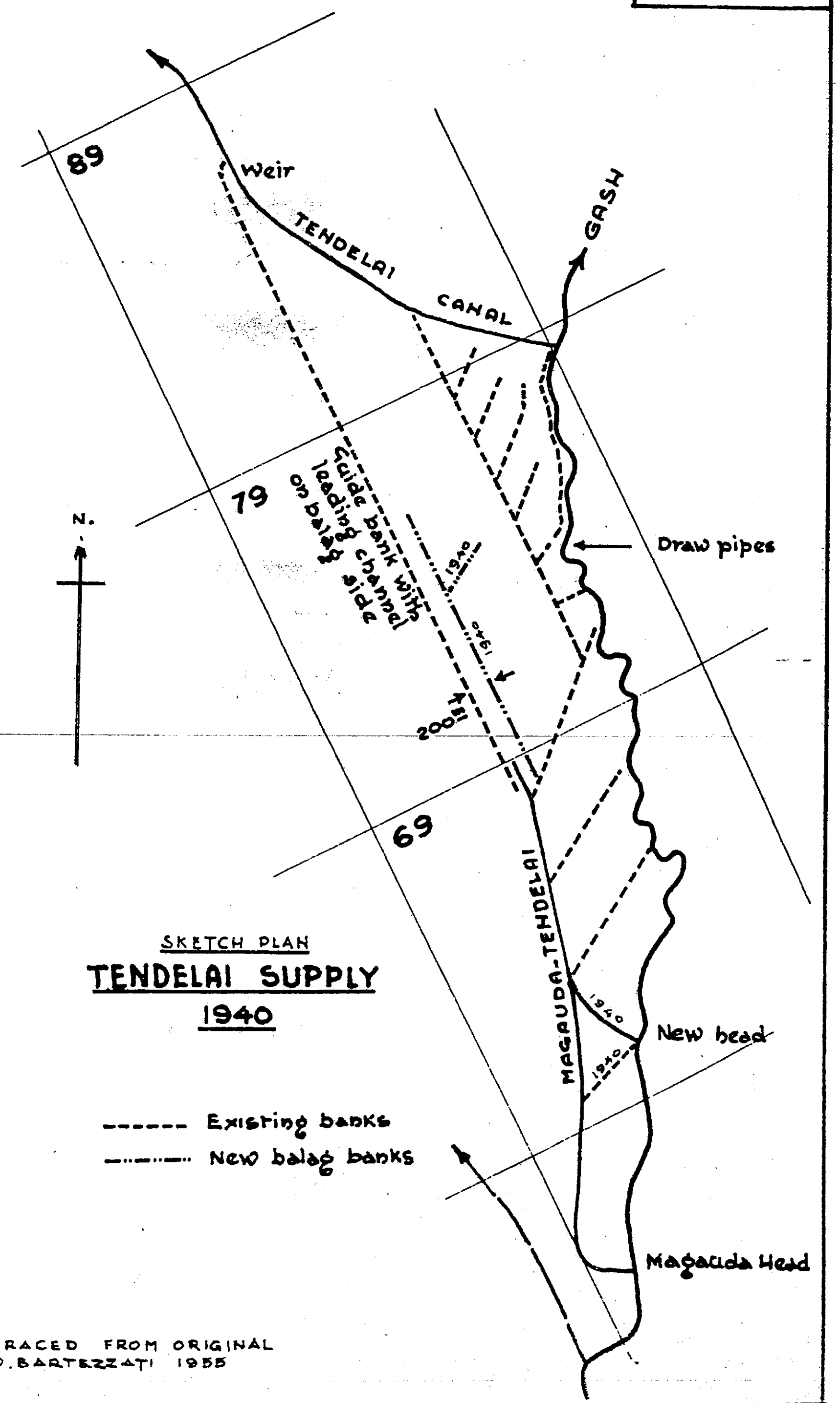
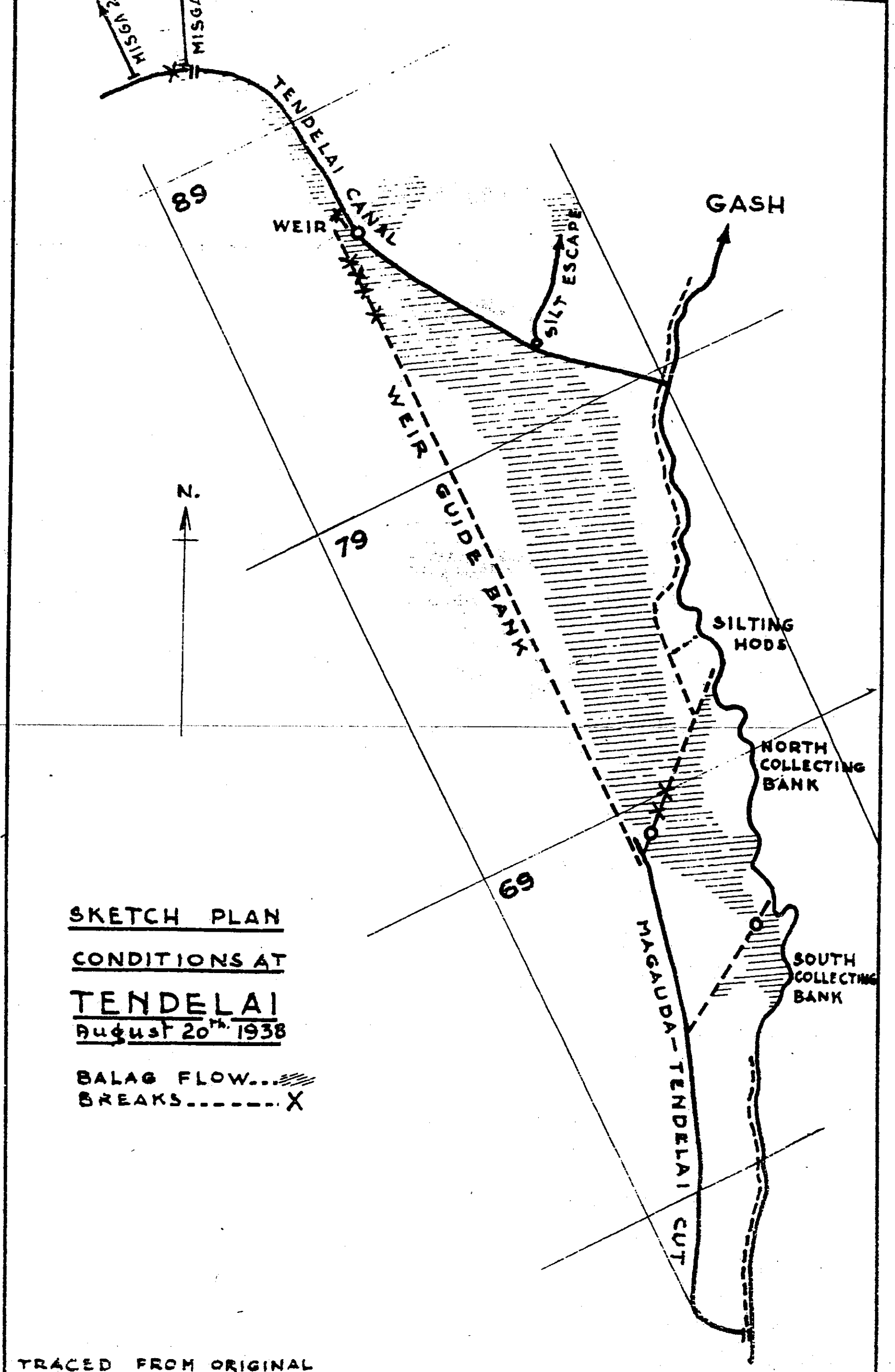

89
79
69
Weir
TENDELAI CANAL
GASH
Draw pipes
Guide bank with leading channel on balag side
1940
200
MAGAUDA-TENDELAI
New head
Magauda Head
N.
SKETCH PLAN
TENDELAI SUPPLY
1940
Existing banks
New balag banks
TRACED FROM ORIGINAL
O. BARTEZZATI 1955

FIG. 6.4.

FIG.6.3.



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O. BARTEZZATI 1955

FIG. 6.5.

TENDELAI SOUTH HEAD 1940

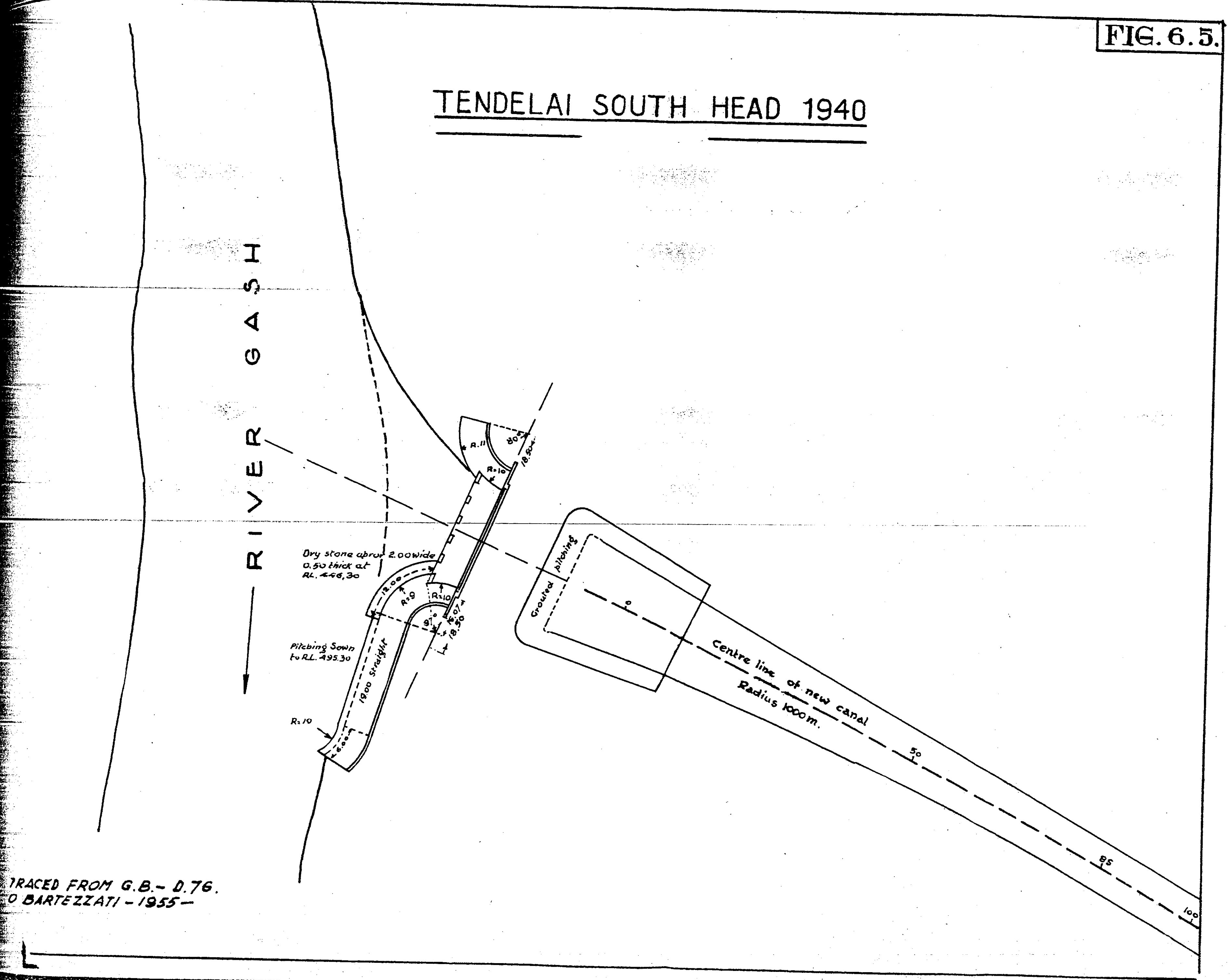
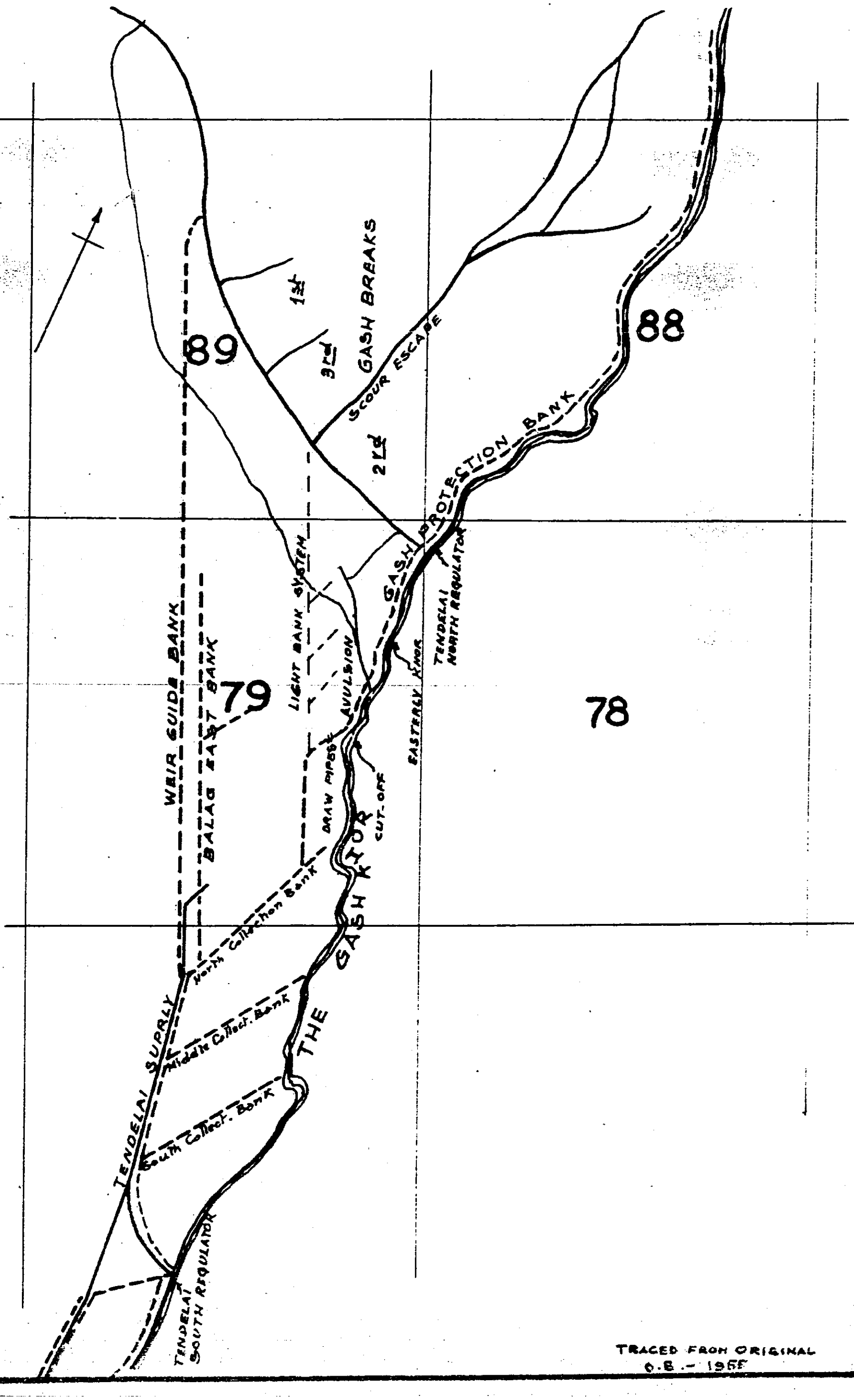


FIG. 6.6.

1943
GASH AVULSION
TENDELAI AREA



TRACED FROM ORIGINAL
G.B. - 1955

FIG.6.7.

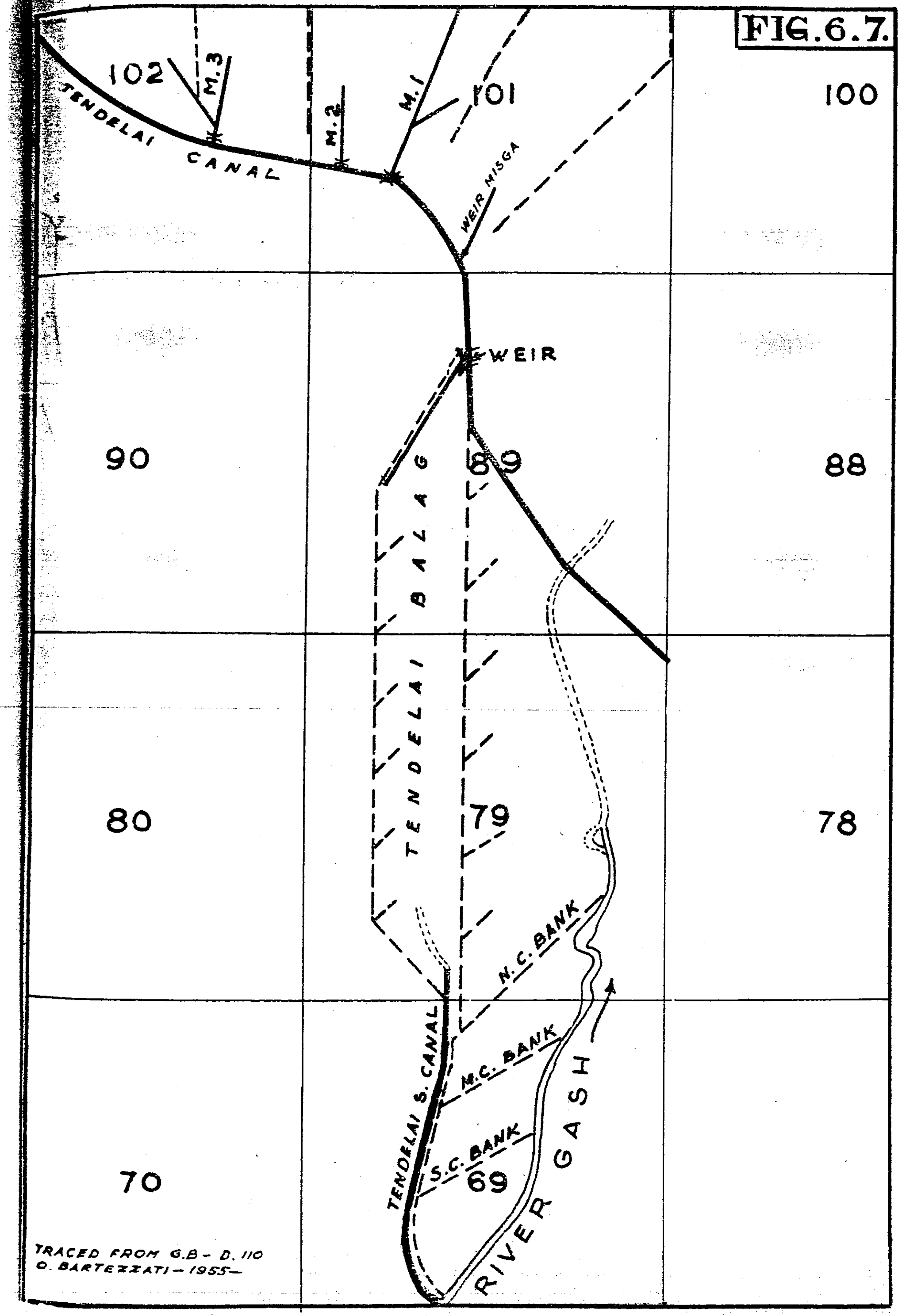
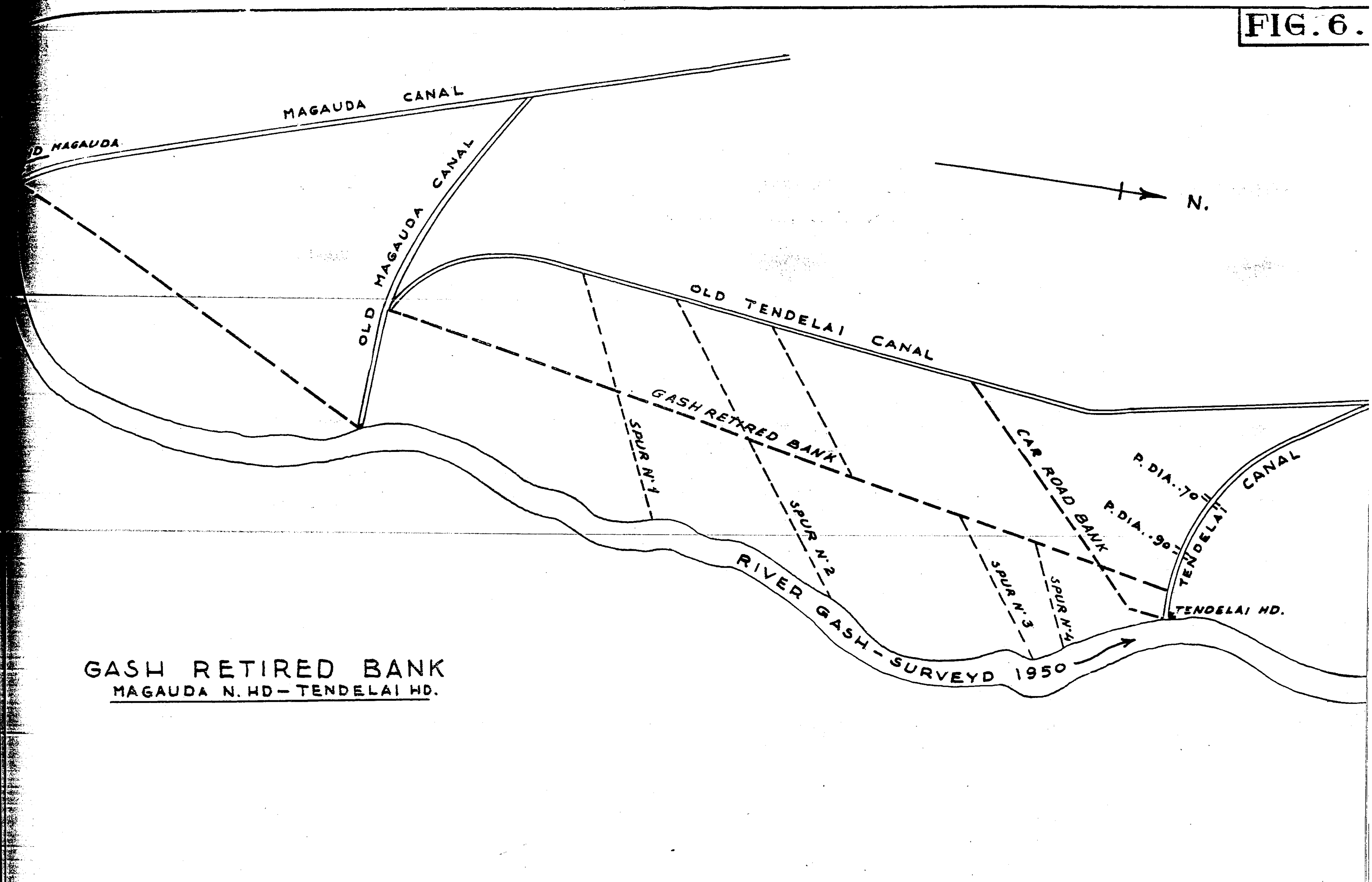

100
101
102
M.1
M.2
M.3
TENDELAI CANAL
WEIR MISGA
WEIR
90
89
88
TENDELAI BALAG
80
79
78
N.C. BANK
M.C. BANK
S.C. BANK
TENDELAI S. CANAL
70
69
RIVER GASH
TRACED FROM G.B - D. 110
O. BARTEZZATI - 1955 -

FIG. 6.



GASH RETIRED BANK
MAGAUDA N. HD - TENDELAI HD.

TRACED FROM G.B - C.152
O. BARTEZZATI - 1955 -

SECTION VII

TENDELAI TO METATEIB

1. Introduction

North of Tendelai we come to what are now the big areas of balag from which both Metateib and the Hadaliya canal systems are fed. It has never been an easy stretch to control nor from which to irrigate; when it ran as a khor the difficulties due to rising bed levels were even more pronounced than they were south of Tendelai and, since balag conditions have existed, there have also been a number of vicissitudes as the flow pattern in the balag varied from year to year.

Tendelai is about the northern limit of the tamarisk trees, perhaps because of rapidly decreasing annual rainfall from south to north in the delta or perhaps because of changed soil conditions. From here on the balag forests are made up of a diversity of thorny trees, most of them Acacia varieties, but one, the "sidr" (Ziziphus spina-christi Lam.), is particularly noticeable, not so much because of its profusion as on account of the ruthless efficiency of its thorn system. To fall into the middle of a barbed-wire entanglement would be a mere inconvenience compared with the disaster that befalls a rider whose mount decides to walk under a "sidr" bush, which is armed with both straight spines and small curving hooks. As a result of this tree in particular and the others in general, the forest and bush covered areas of the northern balags are absolutely impenetrable without deliberate clearance.

Large areas of the balags have been cultivated since the start and have thereby been kept clear of bush. Cotton cultivation on balag areas has the disadvantage that the crop cannot be sown until all Gash flow has ceased, often late in October. This delays the whole process of growing, and picking must continue until well into May, so there is then a very short close season left before the water comes down again. As a result pests are carried on from year to year and affect the cotton in the whole delta. The balags are too valuable to leave uncultivated and at the moment experiments are being made to find some other suitable crop for balag cultivation. From the engineer's point of view the cultivation has an advantage; it keeps the area clear of bush so that it is far easier to detect the flow in the balag from the air or from the banks. There is thus less danger from sudden surprises.

2. Metateib Canal Supply: 1925 to 1937

No site plan of the original Metateib head now remains. The structure was a right-angled offtake of two 2.5 m openings and appears to have been sited on the outside of a gentle right-hand bend in the river. It was not intended to supply the whole of the discharge required in the canal; the head reach of the canal was really only a collecting bank and was not carried right through to the Gash. The intention was to draw water from the balag, which was fed partly by natural spill and partly by a cut leading from the head regulator. The collecting bank was parallel to and five hundred metres north of the cut from the head.

In the first year, 1925, the canal was built as far as K.22 to supply the first fourteen misgas. There was only a small flow of water from the natural balag and almost all the supply came from the head regulator. This was not sufficient and, possibly because of the small discharge, there was considerable silting, particularly in the misgas.

There were no modifications made to the system in 1926. Just before the flood a number of the very severe dust storms, known as "haboobs", to which the Gash delta is particularly prone, deposited large quantities of wind-blown material in the canal; in some places the whole section of the canal was filled from bank to bank. The last statement is no figure of speech; photographs of the damage still exist and it is only too clear that "from bank to bank" was the literal truth. Another feature brought out by the photographs is the great degree of protection afforded by even a small amount of vegetation; where leafless and widely spaced cotton stalks were left upwind of the channel the quantity of wind-blown sand was greatly reduced. This is because the dust which does the damage is not that carried aloft by the wind, but that rolling along the

surface of the ground, analogous to the bed-load in a water channel. With the passage of years most of the Gash canals have become lined with vegetation of some sort and usually there is a wide balag area on the south side (whence the dust laden wind normally blows) which affords considerable protection. Though the problem of wind-blown sand still arises, it does so on nothing like the scale it did in the early days. One of the worst features of the "haboobs" from an irrigation point of view is that they are most frequent in June, leaving very little time for canal clearance before the watering season begins; volumes could no doubt be written about their inconveniences from the personal point of view !

In 1926 the deposits in the canal interfered with the watering until some high spates came down, when it was possible to over-charge the canal and blow them out into the misgas. The natural balag supply to the canal was even less than the previous year and only supplied the full discharge for two days. The reason for the failing balag supply was scour in the Gash bed; after the 1926 flood bed levels were seen to be 60 cm lower than before the 1925 flood. It was clear that the supply must be made independent of the balag and so in 1927 a new head regulator was built.

Metateib South head, as the new offtake was called, was sited on a moderately straight reach of the river two hundred metres upstream of the original North head. A similar design was adopted, the regulator being flush with the river bank. The supply channel was parallel to the channel from the North head and this meant that it was not quite at right angles to the head-wall of its head regulator but actually faced slightly downstream when looking from the canal to the Gash; the angle of offtake was 98°. The new head also fed into the balag and did not connect directly with the canal. The canal was extended to Misga 18 at K.25. The intervening misgas were not put in until the following year.

There was more "haboob" trouble before the 1927 flood when it was estimated that no less than 70,000 m3 of dust drifted into the canal and the misgas which were due to water that season. With the two heads in operation a very good, steady discharge was achieved throughout the season and the wind-blown deposits were soon scoured away. The idea of building the South head was to make the canal independent of the failing natural balag supply. In its own characteristic way the Gash upset the calculation by flooding the balag for nearly a month in September, just when watering had finished and it was time to close off the canal. If the misgas had been re-opened irreparable damage to the crop would have ensued; fortunately the canal was able to carry the entire flow and discharge it at the tail. A large balag was formed along the south side of the canal and against the railway embankment.

When the South head was built, the floor level was set 60 cm lower than the floor at the North head because it was the practice to build the floor at the level of the Gash bed and that, as we have seen, had scoured 60 cm since 1925. By the end of the flood, the cut from the South head had silted to a depth of one metre whilst that from the North head was quite clean. This was interpreted as meaning that a regulator with its cill above the bed of the Gash does not draw the heavy bed load into the supply channel behind it and so it was decided to build the bottom joists of the South head into position so as to form a permanent weir. While there was a certain amount of truth in this deduction and the action taken was a proper one, the fact remains that the North head also was originally built at the level of the Gash bed and there is no record of its silting even at the outset - note that we are only discussing the channel just downstream of the head. Moreover, despite the building of an artificial silt weir at the South head, that supply cut continued to silt up in future years. Fig.7.1 is traced from an air photograph taken several years later, in 1935. Still, it probably gives a fair indication of river conditions in 1927, since the Gash looks very stable at the offtake sites and appears to be lined with sizeable trees. From the figure it is evident that, in the light of our present thesis on the location of regulators, the North head is well sited and the South head badly sited. It seems far more probable, therefore, that this was the true reason for the difference in behaviour of the two heads.

It is interesting to note that the main canal itself was dug at a slope of 1:3,000 and was tending to scour,

furthermore it was even capable of clearing itself of wind-blown sand at that slope.

In 1928 a protection bank was built along the west side of the Gash from Tendelai to Metateib, eliminating the natural balag flow which had caused difficulties in 1927. Misgas 15, 16 and 17 were dug, requiring no extension of the canal. By this time all the misgas in Metateib canal were provided with double 90 cm diameter pipes at the head. During the flood the canal ran well except for the cut leading from the South head which silted. This time the silting was attributed to insufficient slope in the channel, which was accordingly steepened the following year.

Before the 1929 flood the canal was extended west of the railway to K.30. Road and railway bridges were built at K.27. At the same time the decking at both heads was widened to take motor cars and the bridge formed by the cross regulator at K.19 was provided with a suitable decking. (It is not known now whether this cross regulator was built at the same time as the canal or later; the first reference to it is in 1929).

The great 1929 flood has been commented on before. Between Tendelai and Metateib it breached the Gash banking in several places and the balag supply was more than the canal could carry with both regulators closed. Breaches occurred at K.4 and K.8, the former being kept open as an escape for the rest of the flood. Both head regulator channels silted up but perhaps the most serious trouble was the flooding of land out of rotation with its consequent heavy grass growth.

It was noted at about this time that the tendency of the Gash to scour its bed near the Metateib regulators had reversed and the river had started silting. This trend continued; by 1935 bed levels had risen over a metre and ground levels in the balag where it was confined by the protection bank had risen by the same amount.

Two new misgas were dug near the tail of the canal in 1930. These were Misgas 19 and 20 and they were provided with open masonry heads, the first to be so provided on the canal. The canal ran full throughout the flood and remained under good control.

In 1931 the canal was extended to K.36 and five new misgas were dug. These were Misgas 21 to 25, and all except Misga 25 were provided with masonry heads.

The Gash banks were again breached during the 1931 flood and control of the canal was lost. The canal north bank was cut at several places to avoid water running on to the new misgas at the tail which had already received their quota and were partly sown.

In 1932 the canal ran satisfactorily until mid-August when water from the breaches in Tendelai canal, mentioned in the previous section, fell into Metateib canal and control was lost. An escape channel had been built in time to deal with this excess water and so no damage was done and no agricultural land was excessively flooded.

It was in the same year that the first aerial reconnaissance was made over the Gash. This made it possible to see what a big draw-off there was to the east between Tendelai and Metateib. That the loss of water was serious had already been realized from comparative discharge measurements, and from the air it could be seen that three khors were taking off the Gash north of Tendelai head regulator. They were caught up by khor Filik to form a stream between one and two kilometres east of the Gash and was as big in carrying capacity as the Gash itself at Metateib. Khor Filik does not rejoin the main stream.

By 1934 Gash bed levels had risen to such an extent that both head regulators had to be raised 40 cm and the main canal was regraded to a steeper slope in conformity. Despite this both regulators had to be raised again in 1935, the South head by 20 cm and the North by 50 cm. By this time the small balag zone between the cuts leading from the regulators and the main canal had almost disappeared. A photograph taken during the 1935 flood (Fig.7.1) shows that the north cut was within two hundred metres of the collector channel and the south cut within fifty metres of it, though spill was taking place in both cuts before the tail was reached. All this time the canal was running very well.

Although both regulators had been raised in 1934 and again in 1935, the first flush of the 1936 flood topped them,

though it did no damage. The balag finally disappeared and water from the cuts ran in khors down to the canal.

Before the 1937 flood both regulators were stripped down to the foundations and rebuilt stronger and higher - the North by 85 cm and the South by 90 cm. Silt excluding weirs were built across both with cills set at Gash bed level. There was some silting in the canal during the flood; the filtration effect of the balag had been lost.

3. The 1938 Avulsion

The Gash bed level at the Metateib offtakes had risen about one and a half metres in the last ten years and was still rising. Curiously enough the cross-sections taken at the time indicate that conditions were steady in 1936 and 1937, but this was clearly a local effect only - the rising water levels at the regulators prove that. Sooner or later a break-out was inevitable.

It occurred on the night of the 19th July, 1938. This was before Metateib canal had been opened up. The Gash broke through about 400 m above the South head at a point where the main Gash bank had been reinforced some years previously by a loop bank built on the side remote from the river. This is exactly what happened at Tendelai in 1943 and emphasizes that such loop banks, though attractive at first sight, give a sense of security which is entirely false. By day-break on the 20th July nearly half the Gash flood was pouring through the breach and within thirty hours of the original break, the whole river had been diverted. Although the Gash was still very much in spate the water surface at the breach was thirty or forty centimetres below the bed level of the original channel further downstream.

Clearly not much could be done about stopping a breach of those dimensions and all efforts were turned to diverting the flood north towards Hadaliya and to stabilizing the supply to Metateib canal. These efforts can best be followed in Fig.7.2.

As it came out of the break the flood tended to split in two; part directed towards the angle of the south cut and part running west into the canal balag. The first of these flows was encouraged by breaking it into the south cut, whence it passed into the head reach of Metateib canal to be released through a break in the north bank at K.3.5 towards the Eagir balag; when things had settled down this diversion was able to take 60 to 70% of normal floods.

The flow running west into the canal balag was more difficult to deal with. A site for a stop bank was found at about K.5.5 Metateib where the spread of water was narrowed by higher ground to the south. The bank had to be built across five hundred metres of running water 80 cm deep. Work started from both ends, rough bridges being thrown across the canal to carry bags of earth from the north side. As the gap narrowed the only way to extend the banks was by filling cotton sacks with earth when they were in position, stone being unavailable. Progress was slow because all the spoil had to be carried along the length of the completed bank. Successive spates in the river gave a lot of trouble and the bank had repeatedly to be extended back southwards to avoid outflanking. At the end of the flood it was 1,300 m long ! This bank formed the basis of what is known today as the Morrice bank.

Upstream of the stop-bank a temporary pipe control was made for Metateib canal supply. This, and a protection bank in front of it blew out during a spate before the stop-bank was finished. They were not replaced. The stop-bank itself was nearly topped and destroyed by the same spate and was only saved by the fact that a safety gap had been left in it, by being outflanked to the south and by another large break in Metateib canal at K.4.5, which also led out to Eagir balag. After this no attempt was made to close the stop-bank completely; an eight-metre opening was left with rail, timber and sack abutments. It was spanned by a rough foot-bridge and Metateib canal was supplied through it. The gap gave a great deal of trouble and scoured heavily during spates; probably this would have been prevented if a brushwood mattress had been laid down when the gap had been reduced to, say, about thirty metres and the abutments built over it. This is the Dutch method of closing breaches in dikes; it was not known in the Gash at that time. The flood fed the south balag and ran westward,

surrounding Metateib agricultural station and eventually cutting the railway line.

The results of the season were that a good area was watered and that, except for a rather battered south bank, Metateib canal was improved by the scouring it had received. The two head regulators were high and dry. The scouring of the Gash due to the break had made a marked improvement in conditions in the khor which could be seen as far back as Tendelai.

It has been seen that the avulsion had become inevitable. This poses the question that if it should be necessary to design irrigation works from the start under similar conditions (a distinct possibility) would it be possible, in the light of past experience, to design them so that such a situation did not recur ? It seems that the best answer to the problem would be on the lines of Tendelai where there is a supply balag running parallel to the Gash and some distance to the west of it. If each canal could be so supplied, and as we have seen the system has its inherent advantages, an almost continuous line of supply balags would be produced which would provide a most reliable basis for defence and would finally build up land levels to such a point that a westward avulsion would become most unlikely. Whatever the approach to the problem, however, it is not a straightforward one because of irregularities in ground formation.

4. <u>Metateib Canal Supply: 1939 to 1943</u>

After the avulsion the two Metateib heads were abandoned. The bed level of the khor below the break was above the level of the ground to the west, while the river upstream the break had scoured its bed nearly a metre and a half. Moreover the new flow had the advantage that the Gash now discharged into Eagir balag and the supply to Hadaliya was fairly free of silt.

A good site for a new head was found about a kilometre south of the old South head. Fig.7.3 gives a site plan and also a lay-out plan of the actual structure. It can be seen that it is sited and designed in accordance with the same principles which had led to effective offtakes elsewhere. The result was excellent and once again a regulator was produced which could draw the entire flow of the Gash at low stage.

A very heavy banking programme was undertaken to prevent the river from breaking out westwards along Metateib canal, and the old cuts together with their banks and the head reach of the original main canal were levelled to allow free passage of the water to the north. All this is shown in Fig.7.4. A feature of the canal now was that, due to the rising levels of the previous years, the head reach sloped at about 1:1,200 for the first four kilometres; thereafter the original slope of 1:3,000 was retained. The new arrangement had been fitted to these slopes. A light road bridge was built at K.3.

Before the 1939 flood the bank along the Gash from Tendelai to Metateib was strengthened and at four danger points, where the Gash was cutting in westwards on the outside of a bend, the re-entrant bay was filled with brushwood and faced with widely spaced planks bolted to stakes made of 2½-inch diameter pipes. One bend north of the new head was artificially cut off. During the flood there was almost no spill to the east between Tendelai and Metateib, no doubt mainly because of the scouring of the bed after the avulsion. The protection at the danger points worked well and solid plugs of silt and brushwood were left after the flood. The new arrangements at Metateib were highly satisfactory; the Gash ran north towards Eagir balag just as it was supposed to and the canal drew very well indeed.

The general lowering of river levels caused by the avulsion was to be short lived. Annual cross-sections taken 75 m above the new head show that between 1938 and 1942 the bed level there rose at an average rate of 25 cm per year. The reach was rapidly becoming dangerous again. All went well in 1940 both in the Gash and in Metateib canal but by 1941 a good deal of work was necessary to prevent further break-aways. It had been found that as the solid plugs of silt and brushwood which had been formed in the bends increased in weight, the

pipe and plank facing tended to collapse. It was therefore replaced by more expendible wooden stakes and as subsidence took place between spates more brushwood was piled on top and more stakes were driven as necessary. The pitching on the Gash bank downstream Metateib head was extended that year and the canal ran well again.

By 1942 the Tendelai-Metateib reach of the Gash had become the most serious problem in the delta. A full, detailed survey of the reach (which is reproduced on a reduced scale in Fig.7.5) was made and danger points were carefully recorded. Two experimental silting basin systems were built. The first consisted of a bank approximately parallel to the Gash and running two kilometres north from the old line of Tendelai canal with cross banks at the mid-point and end; arrangements were made to supply water to the basins from the old Tendelai head. This was moderately successful, the upper basin silting to a maximum depth of one metre but the lower one not at all. Further north a large semi-circular bank was built out from the protection bank, and, after preliminary soaking, was connected to the Gash by a 90 cm diameter pipe. No useful quantity of silt was deposited and it was concluded that a much larger water-way was needed to give free access of Gash water to the basin; any such large water-way would not be without its dangers.

Metateib canal again ran satisfactorily but the river broke through the banking just north of the old Metateib supply cuts in a way that might have led to a major change of course, had it not been checked in time. The incident is illustrated in Fig.7.6.

5. Effects of the Tendelai Avulsion of 1943

Before the 1943 flood steps were taken to ensure the northward flow of the Gash past Metateib. The work, which is shown in Fig.7.7, consisted of a cut one and a half kilometres long to carry the Gash through a silt deposit which had formed, together with retired banking built upon and extended from the line of the old bank; the banking was protected by a number of short spurs. Water courses leading west, which had formed in 1942, were stopped up. A lot more work was done on the danger points in the Gash khor between Tendelai and Metateib. The latter canal had been silting slowly for some years past and the water-section had been maintained by raising levels. By 1942, however, the canal was spilling over into the south balag in the head reach and defeating efforts to get any large flow downstream. It was due for a major clearance and got it.

The avulsion upstream Tendelai head in early August had far more serious consequences on Metateib supply than it had on Tendelai. The way in which the flood was escaped through three big breaks in Tendelai canal between the head and the weir has already been described. The flood followed roughly the line of the old scour escape; at first it headed for the old course of the river, but as it approached Metateib it swung away again. It made for Tambarassai, at about K.5 on Metateib canal, and plans were made to break it northwards across Metateib canal at that point. Unfortunately the Morrice bank broke in several places. This bank was a development of the stop bank built to control the south balag after the 1938 avulsion; it is shown in Fig.7.7. A rush of water swept westwards along the south side of Metateib canal and it seemed as though the railway would be cut again.

The next few hours must have been a very anxious time, watching which way the Gash would go. Luckily it was the breaks through the canal to the northward which scoured most deeply and were soon carrying the greater part of the flood. A few days later a period of low river made it possible to reinstate Morrice bank.

A less satisfactory feature of the flood was that the cuts across the canal scoured out far below canal bed level, and a ridge of hard clay prevented the small flow in the canal from cutting back a channel into the balag. A lot of work was done by way of hand excavation and brushwood spurs and a tolerable supply was obtained for the second rotation. In general, however, the supply to the canal suffered badly, but it was with a sigh of relief that the engineers realized that they would no longer have to deal with the old Gash khor north of Tendelai.

Three head regulators to Metateib canal now stood on the far side of the Gash, so yet a fourth had to be built. It should be noted here that although the 1939 head only lasted for four years it was an economically sound investment and paid for itself in that period - this sort of thing is perhaps not immediately apparent to those who are unfamiliar with the Gash and accounts for some of the seeming risks that are taken. The engineers now faced an extremely difficult problem. In general the Gash from Tendelai to Metateib was running in an ill-defined balag and had by no means settled down to any particular pattern. As a result of the war no aerial reconnaissance was possible. It was thought probable that eventually the river would scour a new channel for itself; so far it has never done so, but that fact could hardly have been foreseen at the time. The state of affairs was, literally and metaphorically, fluid and the building of a head regulator that functioned satisfactorily for many was a very creditable achievement - and a very bold one !

The possibility of the flow in the Metateib area completing the cycle and returning to channel flow at some date in the future, in the same way as Debelaweit, must always be borne in mind. The cycle can no longer operate in a natural way as there has been so much artificial interference with the balag.

6. Balag Control and Metateib Canal Supply: 1944 to date

The new regulator was built in the Morrice bank, feeding a cut leading into Metateib canal. The general lay-out is shown in Fig.7.8. The regulator consisted of four 2.5 m openings and a leading channel led directly to it from the balag. Escapage for excess water was provided by a breach in the line of the original Metateib canal. For the first year the balag flow, which was very wide just south of Metateib canal, tended to approach this breach from the east somewhat to the detriment of the canal draw-off since most of the water ran away to escape before it reached the canal head. Even so a moderately good supply was obtained.

In 1945 the supply was improved by a diversion bank along the line of the leading cut from the balag. A fall was built in the canal downstream Misga 6, and at the same time a masonry head to the misga was built. It greatly improved the watering of Misga 4, 5 and 6 but was insufficient to prevent heavy scour in the head reach. It will be remembered that the canal had to be cleared in 1943; the scour was a new development caused by the change in the nature of the supply from khor flow to clear balag water. The trouble was partly cured by a cross-weir built downstream Misga 2 in 1946.

During the 1945 flood a general westward tendency had been noted in the balag south of Metateib and water had escaped round the upper end of Morrice bank. In 1946, therefore, the bank was extended a kilometre further south to the western boundary of Hod 113. A survey carried out before the flood indicated that the Gash had now settled down into one well defined channel from the avulsion point to the line of the old Tendelai canal, but that thereafter it broke up into a large number of small khors; of these the two largest ran down a natural depression which, if followed further, would lead to Metateib canal at about Misga 8. Actually these khors were blocked by the southward extension of the Morrice bank, but the flow reached the end of the new work. It was decided to extend the Morrice bank further south along the hod line separating Hods 113 and 114 until it joined the east boundary bank of Tendelai Weir misga, see Fig.7.8. The bank was protected by eight short spurs.

Despite the new cross-weir at Misga 2, the canal was still scouring (which was leading to loss of command) so in 1947 the cross-weir was raised a further 30 cm and another fall was incorporated at the downstream end of the pitching below the head regulator with a fall of 50 cm. These two works reduced the slope in the head reach from 1:1,500 to 1:3,000.

In 1947 the westward movement of the balag became even more pronounced. After crossing the line of Tendelai canal the flow swung sharply west and ran along parallel to the old canal nearly to the weir. Then it turned off to meet the Weir Misga boundary bank, now incorporated into Morrice bank, at a point only 600 m from Tendelai canal. The flow followed

Morrice bank for the rest of the way to Metateib head. Levels at Metateib were higher than before and the Morrice bank was breached. It was towards the end of the 1947 flood that the first post-war aerial reconnaissance took place; it must have been very frustrating to try and analyse complicated balag flow before that time. Metateib canal ran well in 1947 although there was still some scour downstream Misga 6.

In 1948 the Morrice bank was extended south as far as Tendelai canal. Again the flow in the balag clung to the bank almost until it reached Metateib. The flow in the canal was most satisfactory, it was the steadiest in the delta on account of the storage in the balag from which it was supplied. There was no further scour in the bed.

In 1949 the Morrice bank was greatly strengthened to give a uniform cover of 70 cm. Two more spurs were added. Again the balag water lay up against the bank for its entire length; the pressure at the south end, near Tendelai canal, was considerable and led to the building of the Weir Spur in 1950. Metateib canal again ran exceptionally well; it was, in effect, drawing from a lake and maintained a full supply under all conditions.

The Weir Spur, which was built in 1950, ran from the Tendelai weir northwards for one kilometre. Its object was to deflect a khor which was approaching Morrice bank and was increasing year by year. It can be seen in Fig.7.9. It was breached early in the 1950 flood but still kept a great deal of pressure away from the main Morrice bank. During the course of the flood there was a great deal of silt deposited in the area and water levels rose higher and higher. The Morrice bank held until early September, when it broke in two places. Then there was no holding it. Khors quickly eroded back into larger khors; very large quantities of water poured out, over-running Misga 1 of Tendelai, surrounding the agricultural station at Metateib and pouring into Metateib canal. The Gash flood died away before the railway was threatened. The break so late in the season and so far north was not very serious in itself, but its implications shadowed the future. The canal ran very well; two new misgas at the tail, No.19 East and No.19 West, gave exceptionally good areas. Some restriction to flow was caused by the railway bridge.

In 1951 Morrice bank was again greatly strengthened, this time by scraper which gave it a four metre top width suitable for motor traffic. A number of leading cuts were dug and lines of brushwood built to divert the water away from the line of the bank. These measures were successful and the small 1951 flood left Morrice bank almost dry yet still maintained a good, steady supply to Metateib head, running straight down the leading cut. An excellent watering was achieved on one of the poorest Gash floods for many years.

There were no major developments in 1952. Silt had built up almost to the level of the bank crest between the Weir Spur and Morrice bank. In July, during one of the early spates, the banking broke. Every effort was made to close the breach; the first spur was broken to encourage the flow northward and banks of sand bags screened by brushwood were pushed southward from the north side of the break. By the evening of the next day the gap had been narrowed to three metres, but it was impossible to close it completely and by next morning the breach had widened again to thirty metres. Fortunately there was a heavy deposit of silt laid down just beyond the breach which slowed down the flow. The flood swept on towards Metateib canal, see Fig.7.10, which it reached four days after the original break. The canal was blocked off downstream Misga 5 and again at the fall downstream Misga 6. Water entered the canal between these two points and was discharged through Misga 6. Misgas 4 and 5 were fed from Metateib head. A bank was quickly built from the bridge at the agricultural station to join one of the Tendelai inter-misga banks. Later the flood was broken into the canal upstream Misga 9 and Misgas 8, 9, 10 and 11 were opened. Still later the canal was breached at K.16 and K.18 (the agricultural station is at K.19). In this way a precarious equilibrium was maintained which was not upset until the end of the flood when a heavy rain storm on the Tendelai misgas flooded into the already over-full Metateib canal and the railway line was broken. The watering of Metateib canal was hardly interfered with at all throughout all these troubles and even the breaches ran out on to land from

which a good crop was raised; the handling of the flood can only be described as a "tour de force". No less than 13,714 feddans of cotton were grown on Metateib station !

In 1953 the Morrice bank system at the Tendelai end was reinstated. The Morrice bank itself was re-aligned over the first 2.3 Km, to run parallel to and 100 m east of its original line. This was to take advantage of higher land. The Weir Spur was extended for 1.3 Km. During the first part of the flood the pressure on the new banking and on the first two spurs was very great and it was only by dint of unceasing vigilance and labour that a repetition of 1952 was avoided. The supply to Metateib was moderate at first and not so good as one might have expected from the pressure on the Morrice bank. It seemed that Spur No.1 had pushed the flow over too far to the east; it was supposed to do so, but this was excessive. Pipes were therefore laid under the spur and all the succeeding spurs were breached in order to encourage a flow down the west side of the balag to Metateib. This was fairly effective while it lasted. Then, quite suddenly, at the end of August the high levels which had been lapping the crest of the upstream part of Morrice bank fell away completely overnight leaving an expanse of silt although the river was still in spate further upstream. Aerial reconnaissance showed that the flow had disintegrated as it passed the line of the old Tendelai canal; much of the water ran down the east side of the balag towards the three old Metateib heads while only a minor part continued down the west side to supply the canal. In general, Metateib canal suffered from a shortage of water in 1953.

In 1954 a new cut was made from Metateib head into the balag with a catch bank behind it. It was intended to catch the now more easterly flow in the balag and can be seen in Fig.7.11. The catch bank was provided with a 100 m wide uncontrolled spill-way at its upper end and a smaller spillway controlled by stop logs down by Metateib head.

The 1954 flood was a very poor one. There appeared to be very little water in the balag for the first few days and what was coming down was just missing the end of the new bank. From the air it was immediately clear what had happened; it is shown in Fig.7.11. The general eastward move that had been detected in 1953 had been completed and a complete avulsion had taken place at the point where the Gash crosses the old Tendelai canal. In the sketch the 1953 flow is shown in interrupted line and the 1954 flow by arrows. Another feature, visible from the air, was that there was a large part of the flood being caught up by the old Metateib canal and running down it to within 1,300 m of the existing canal before breaking out to the north. Machine power was used to open up the intervening section and a tolerable supply for Metateib was passed through four pipes into the canal at the angle below the head.

Cross-sections of the Hademeib balag (as the balag upstream of Metateib offtake is called) revealed that levels were considerably lower on the east side, where the water was now running, than on the west near Morrice bank. The sequence of events, fairly clearly, was that several years of flow along the Morrice bank had built up a ridge of silt there. In 1952 the flood fell off the ridge to the west, but before the 1953 flood the bank was reinstated yet higher up the ridge and, with an effort, held against the westward pressure of water. The alternative was for the flow to fall off to the east and this it started to do in 1953 and completed in 1954. Land levels indicate that the flow is likely to remain where it is for a year or two because it is running along the lower side of the balag and the old line of the Gash khor forms a high barrier to the east. In future, cross-sections of the balag should be taken annually because sooner or later the east side of the balag will silt up and then the flow will probably fall back to the west with considerable violence.

In 1955 the catch bank for Metateib is being extended right across the balag to the high ground on the east. The scheme is shown in Fig.7.12. In addition to the existing 100 m spillway, a new 250 m spillway is to be added and another controlled cross-regulator is to be built across the supply cut to maintain some control of the balag water level and thus of the discharge over the spillways. The whole design is based on an assumed maximum discharge of 300 m3/sec in the Gash which must be safely passed over the spillways. This is the first

time a control bank had been built right across the Gash flow and the results should prove most interesting.

7. <u>Recent Developments in Metateib Canal</u>

Since the regular programme of building open masonry misga heads started the following have been built in Metateib canal :-

Misgas 4 and 5	in	1942
Misga 15	in	1946
Misgas 1 and 18	in	1947
Misgas 9 and 10	in	1955

(N.B. Misga 1 head also serves Misga 2)

Misgas 9 and 10 heads are replacements of temporary open structures built of corrugated iron and steel oil drums. These structures were never very satisfactory and were only intended to last over a period of shortage of supply. In fact they have lasted long enough to lend support to the dictum that "there is nothing half so permanent as a temporary structure" ! It has already been noted that Misga 6 and Misgas 19 to 24 inclusive are provided with masonry heads.

Metateib canal is not in regime. It silted heavily in 1952 and scoured in 1953. In 1954 it was not affected much either way. Clearly it all depends on the provenance of its supply, whether through the balag forest as in 1953 and 1954, or whether mostly down a series of khors in the balag as in 1952. At present it is designed to carry a discharge of 13 m3/sec. The head reach has a slope of 1:2,500 as far as the weir at Misga 6, thereafter the slope is 1:3,000. The fall at Misga 2 is at present silted over but it was effective in limiting the scour in 1953. The bed width is 6 m and the depth 1.5 m. Like most of the Gash canals it has an almost rectangular cross-section with a flat bed of coarse silt and almost vertical sides of very fine material.

FIG. 7.1.

METATEIB HEADS - 1935 -

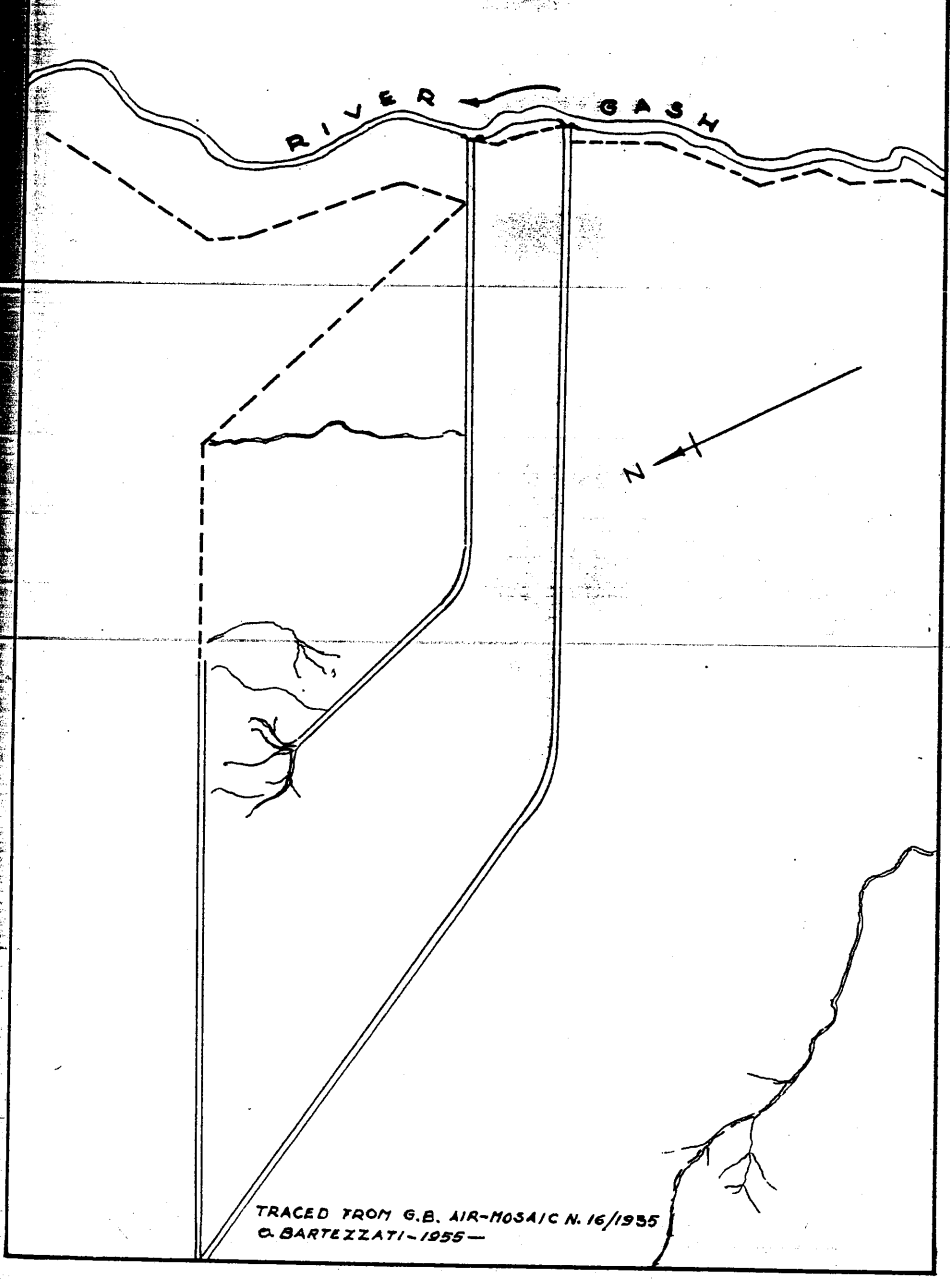


FIG. 7.2.

SKETCHES ILLUSTRATING BREAK-AWAY OF GASH AT MITATEIB - 1938

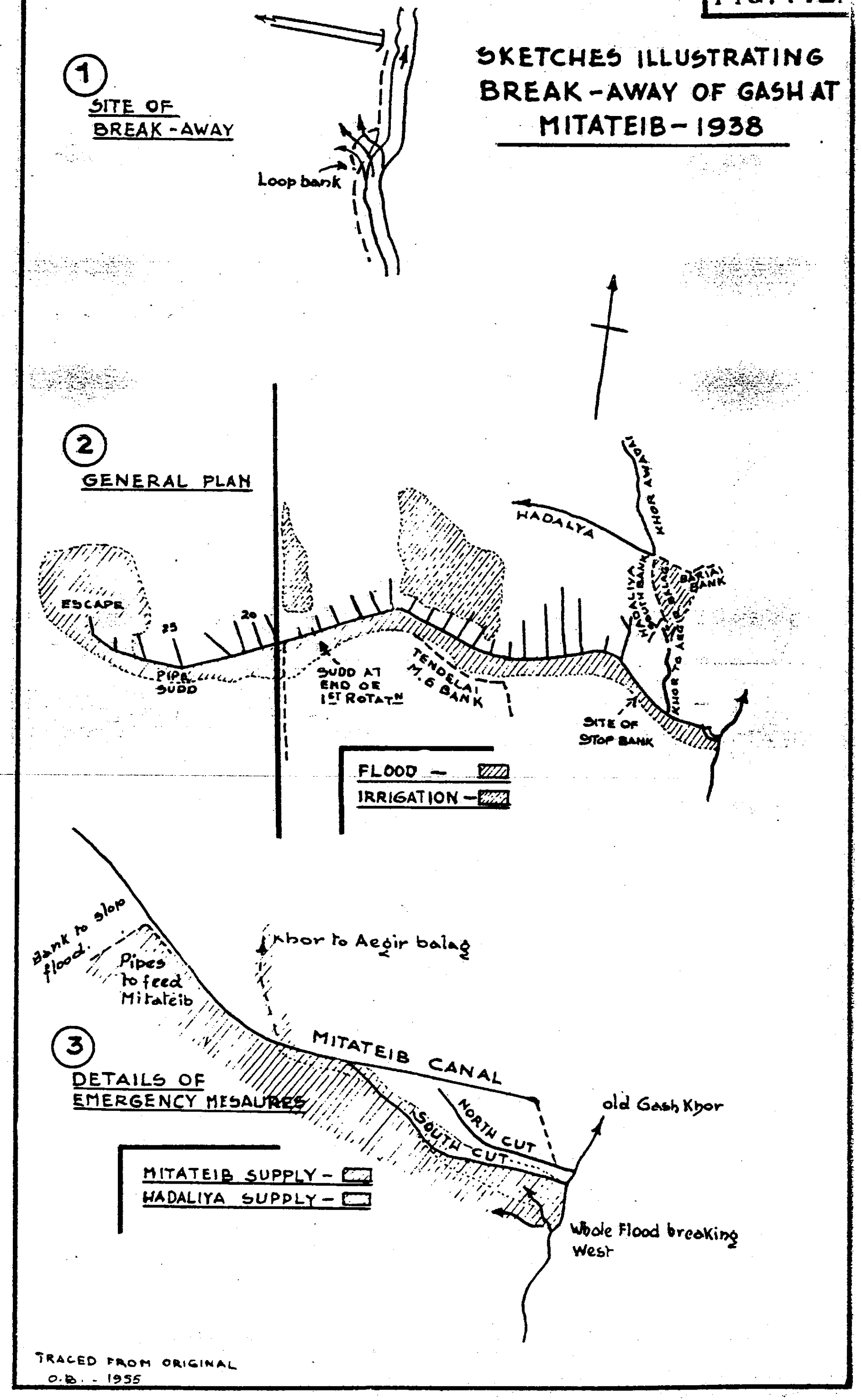


FIG. 7.3

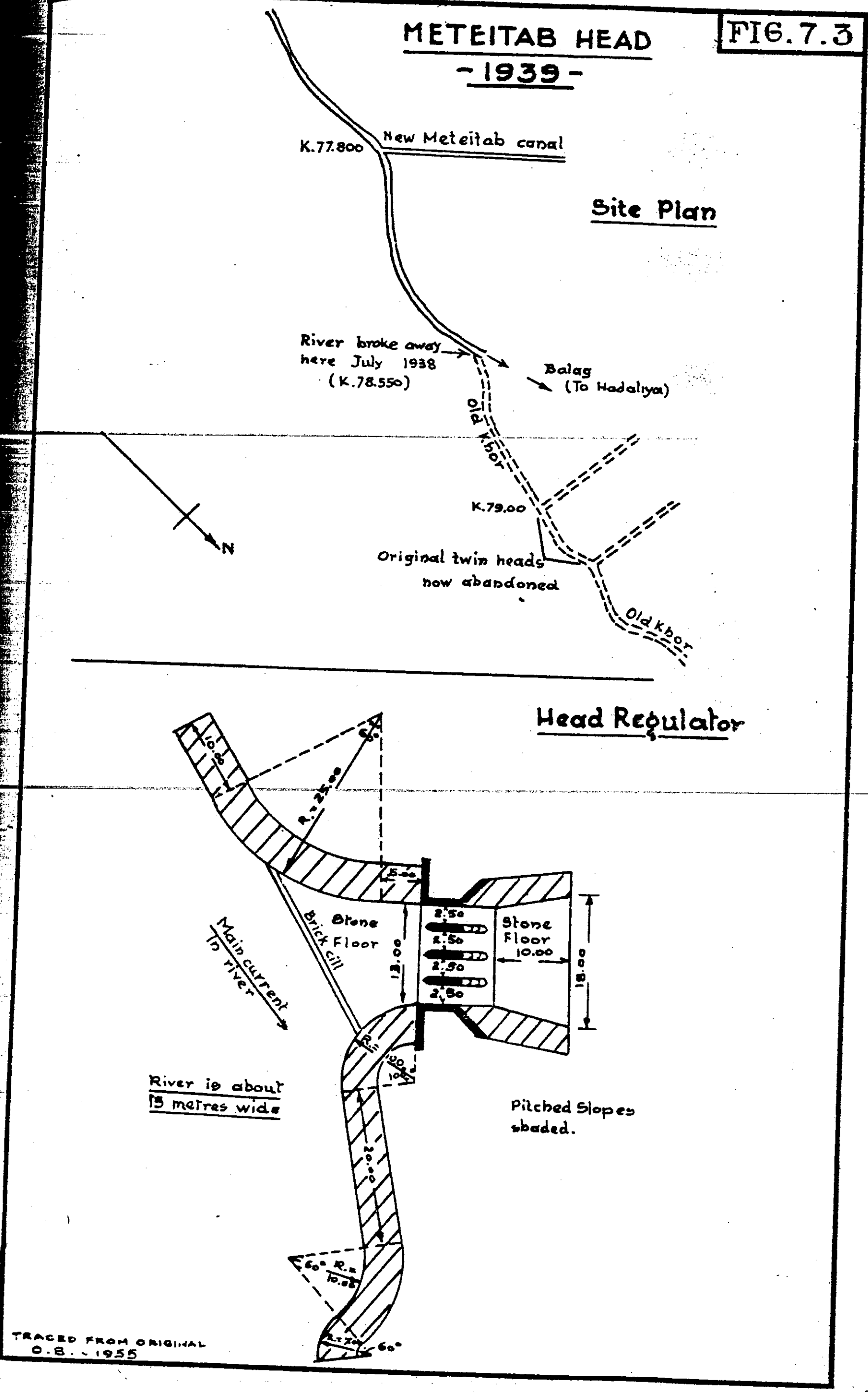
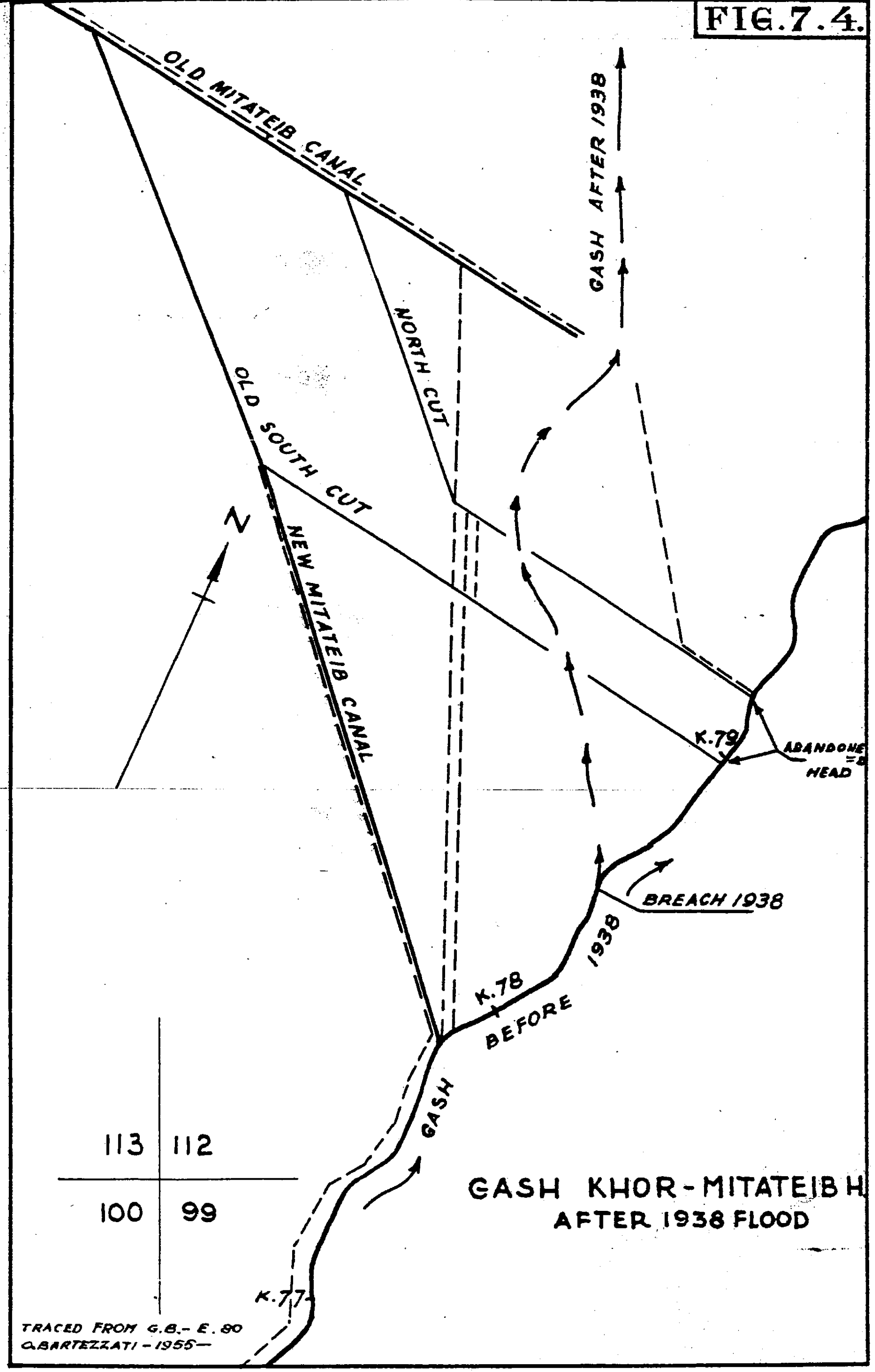
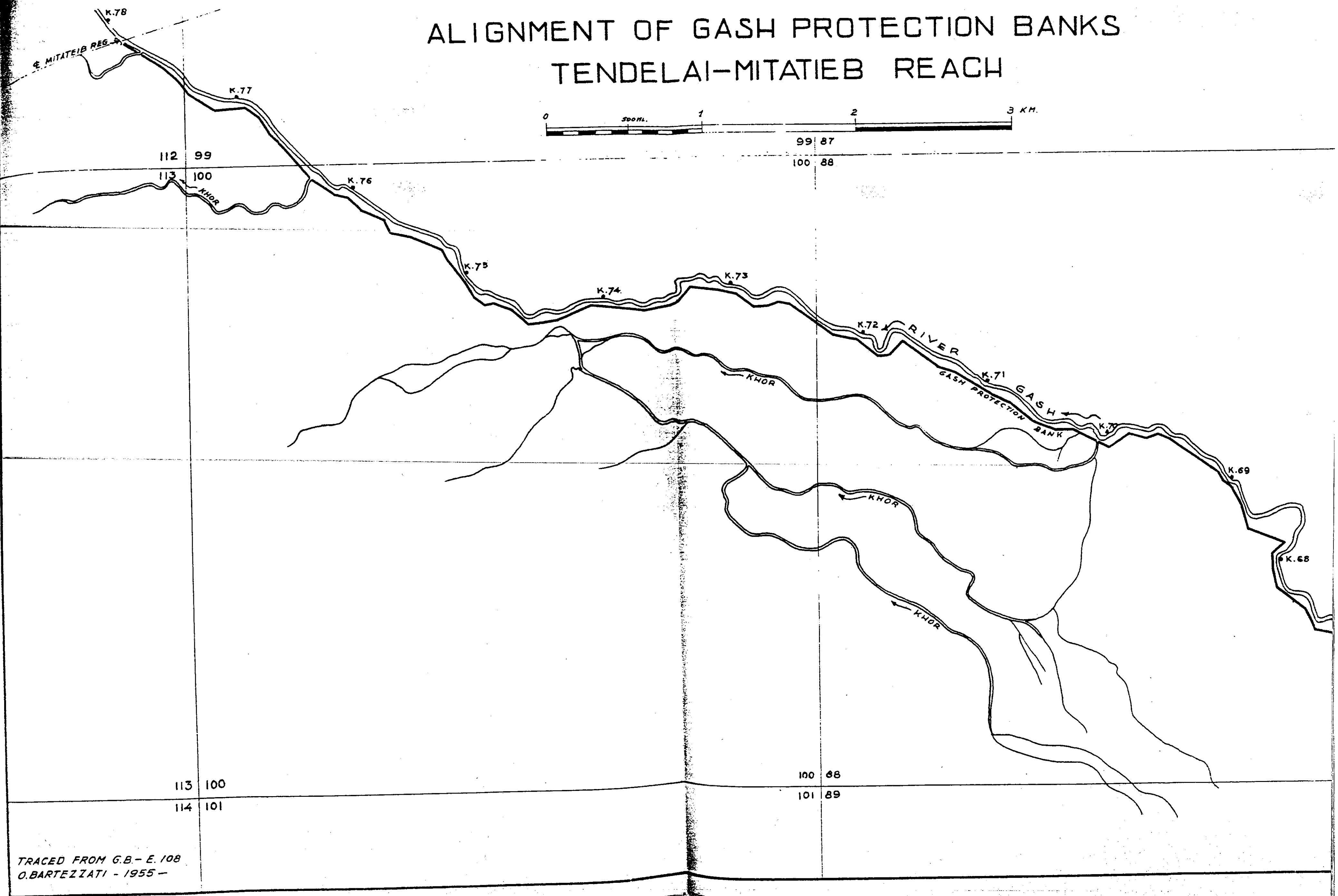

METEITAB HEAD
-1939-
K.77.800
New Meteitab canal
Site Plan
River broke away here July 1938 (K.78.550)
Balag (To Hadaliya)
Old Khor
K.79.00
Original twin heads now abandoned
Old Khor
N
Head Regulator
Stone Floor
Brick cill
Stone Floor
10.00
18.00
Main current in river
River is about 15 metres wide
Pitched Slopes shaded.
20.00
TRACED FROM ORIGINAL O.B. - 1955

FIG. 7.4.


OLD MITATEIB CANAL
GASH AFTER 1938
NORTH CUT
OLD SOUTH CUT
NEW MITATEIB CANAL
N
K.79
ABANDONED HEAD
BREACH 1938
1938
K.78
BEFORE
GASH
113
112
100
99
K.77
GASH KHOR - MITATEIB H
AFTER 1938 FLOOD
TRACED FROM G.B.- E. 80
G.BARTEZZATI - 1955 -

ALIGNMENT OF GASH PROTECTION BANKS
TENDELAI–MITATIEB REACH



TRACED FROM G.B.– E.108
O.BARTEZZATI – 1955 –

FIG. 7.5.

ALIGNMENT OF GASH PROTECTION BANKS
TENDELAI–MITATIEB REACH

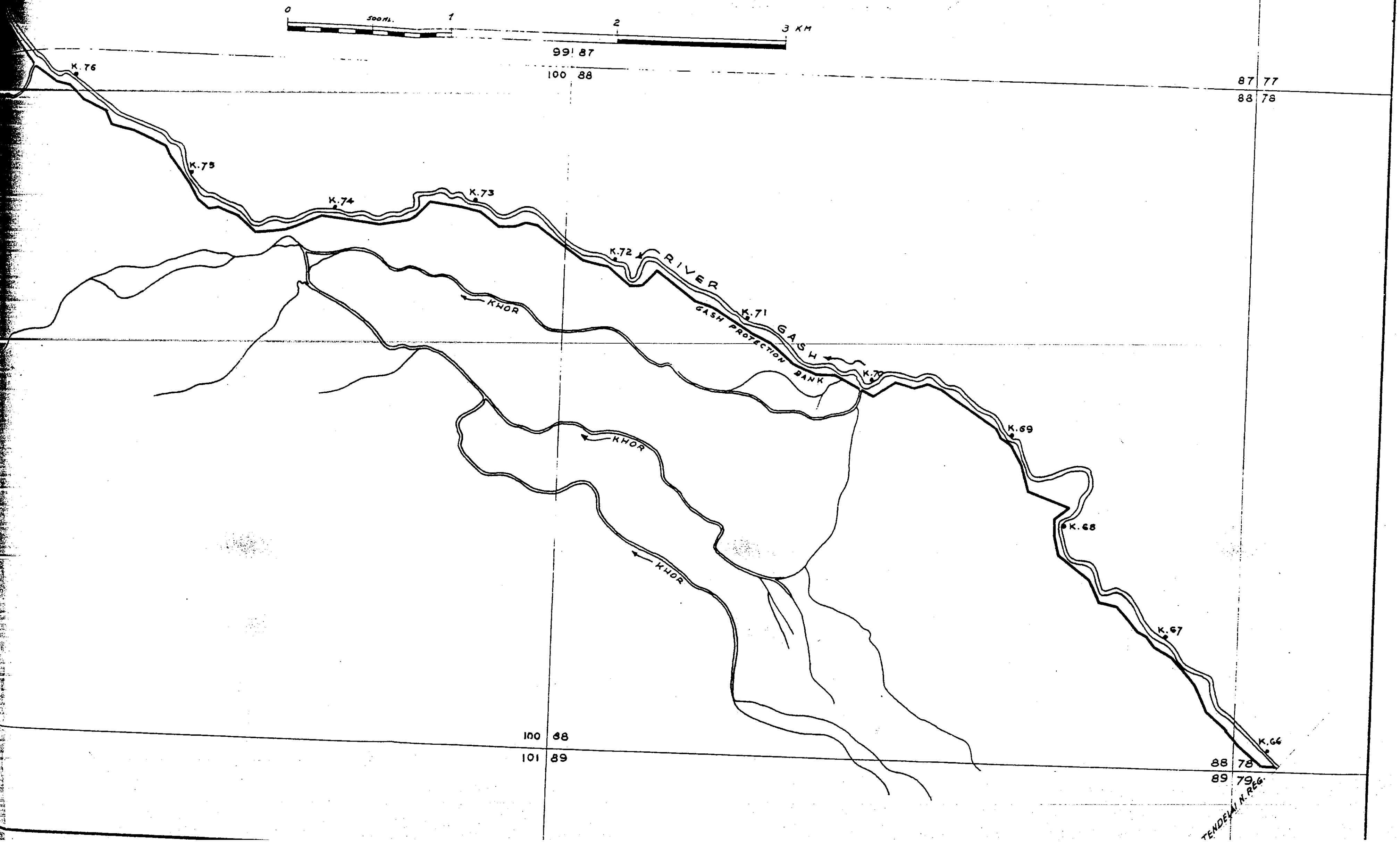


FIG. 7. 6.

THE GASH KHOR AT METATEIB

SKETCH 1942 - G.B.- MONTHLY Rpt

NOT SCALE

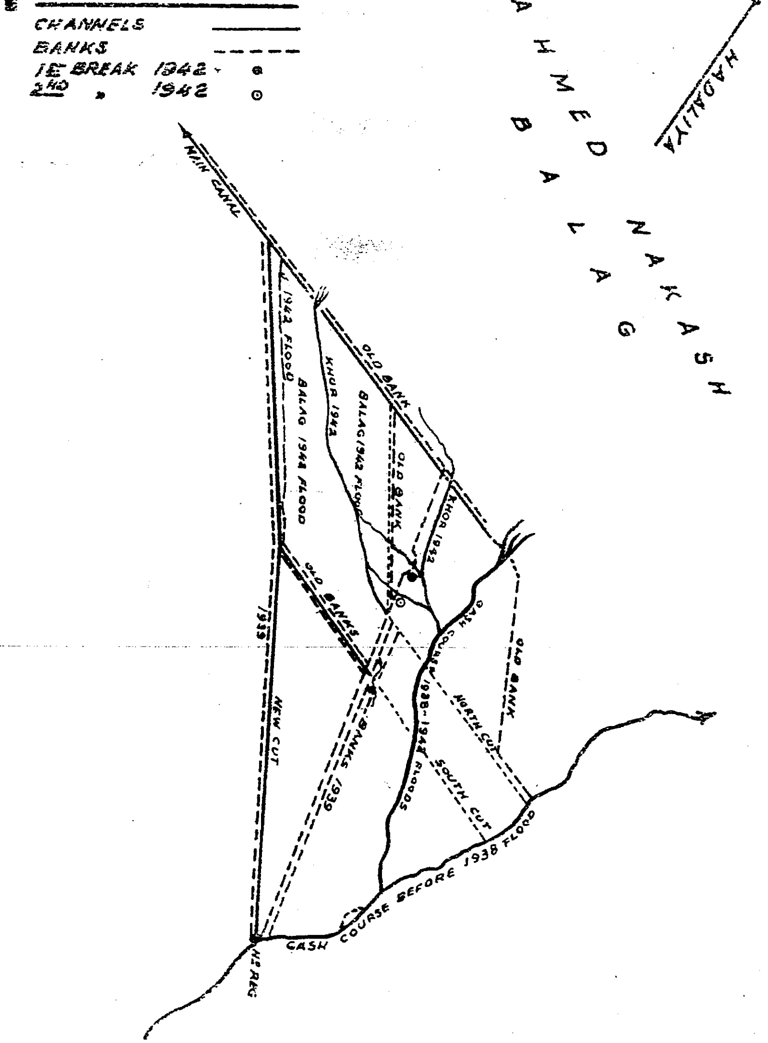


FIG. 7. 7.

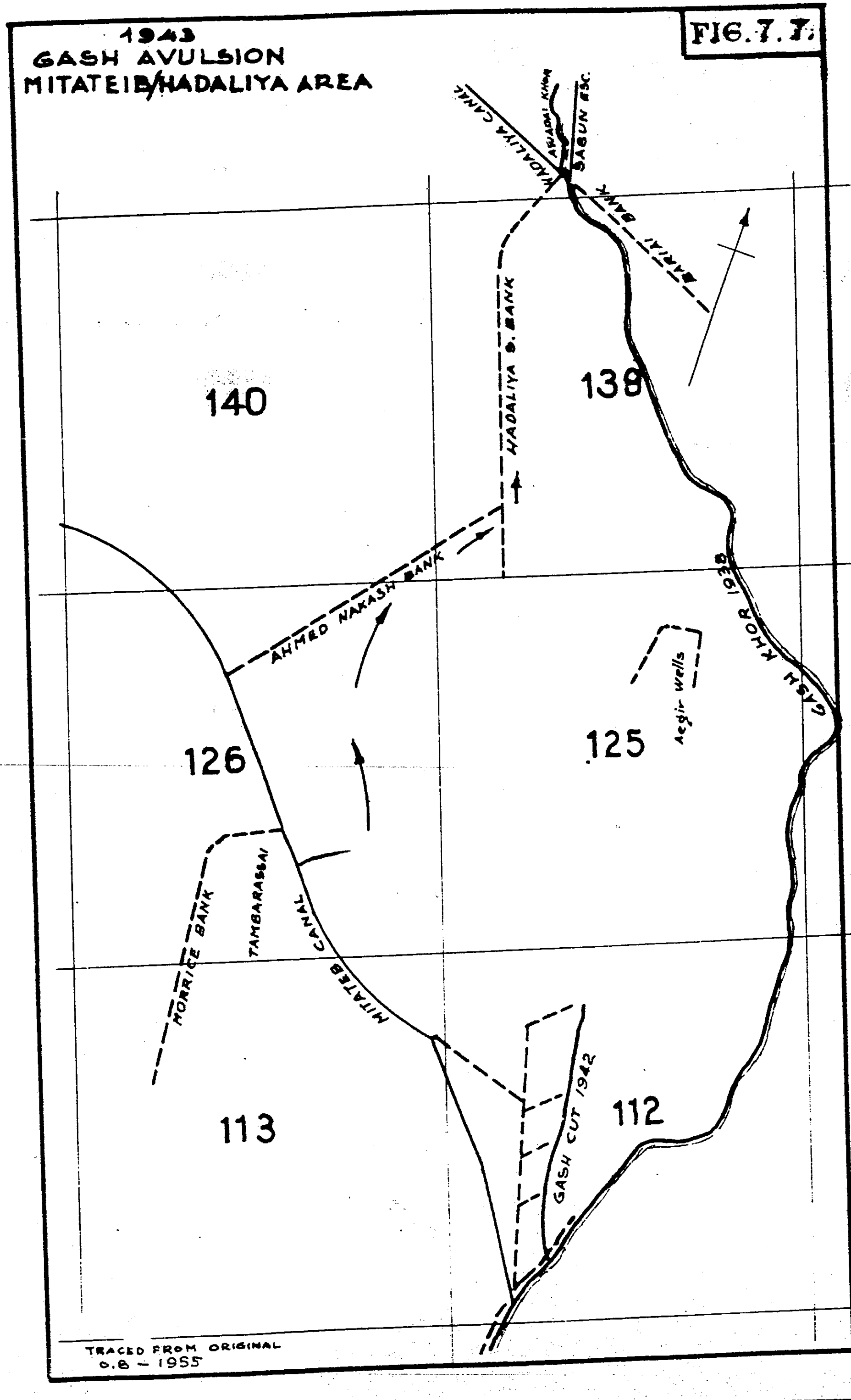

1943
GASH AVULSION
MITATEIB/HADALIYA AREA
HADALIYA CANAL
AWADAI KHOR
SABUN ESC.
BARIAI BANK
HADALIYA S. BANK
140
138
AHMED NAKASH BANK
GASH KHOR 1938
Aegir wells
126
125
TAMBARASSAI
MORRICE BANK
MITATEB CANAL
GASH CUT 1942
113
112
TRACED FROM ORIGINAL
0.8 – 1955

FIG. 7.8.

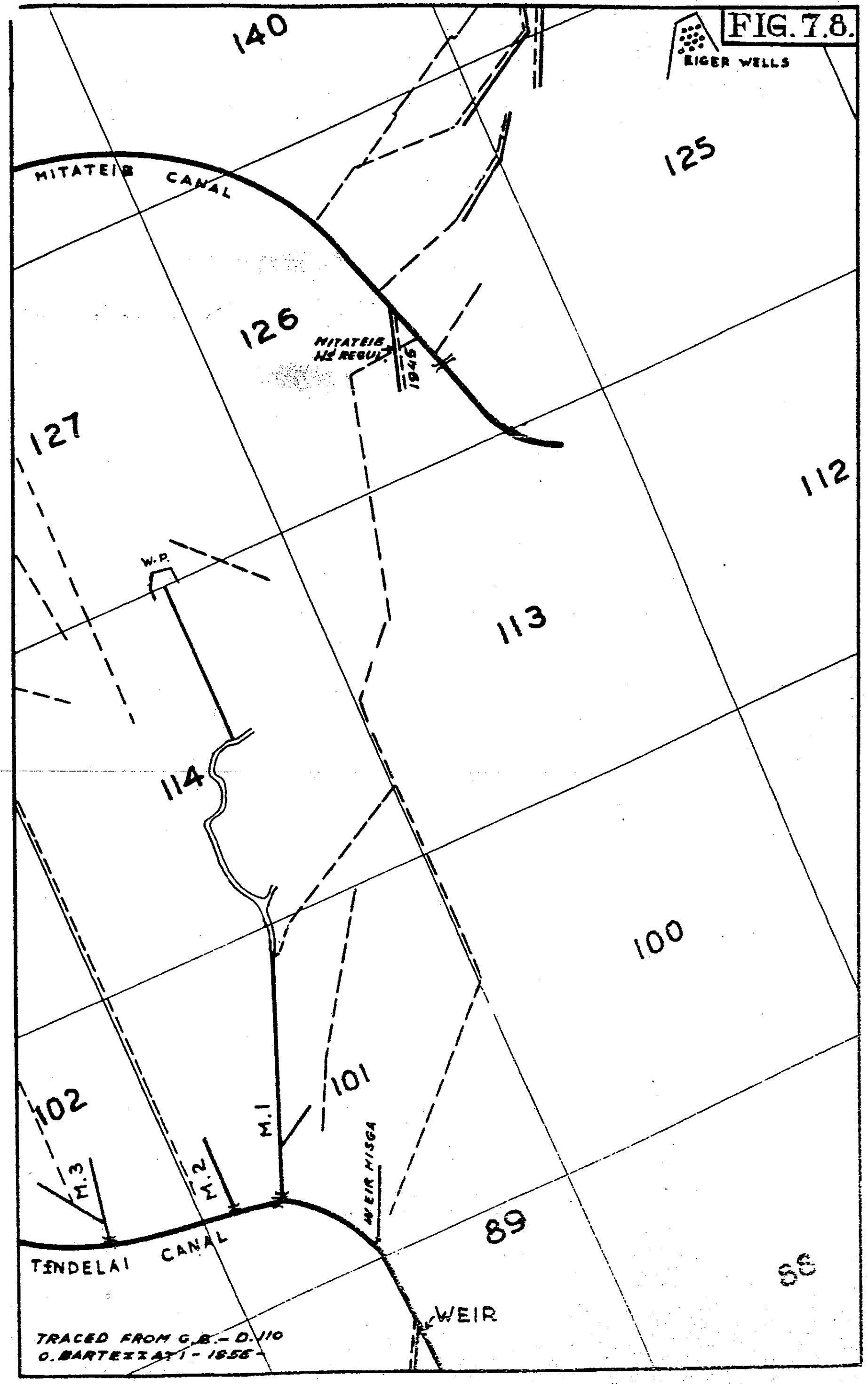

EIGER WELLS
140
125
126
127
112
113
114
100
101
102
89
88
MITATEIB CANAL
MITATEIB H.R. REGUL.
1945
W.P.
M.1
M.2
M.3
WEIR MISGA
WEIR
TENDELAI CANAL
TRACED FROM G.B. - D. 110
O. BARTEZZATI - 1956 -

FIG 7-9

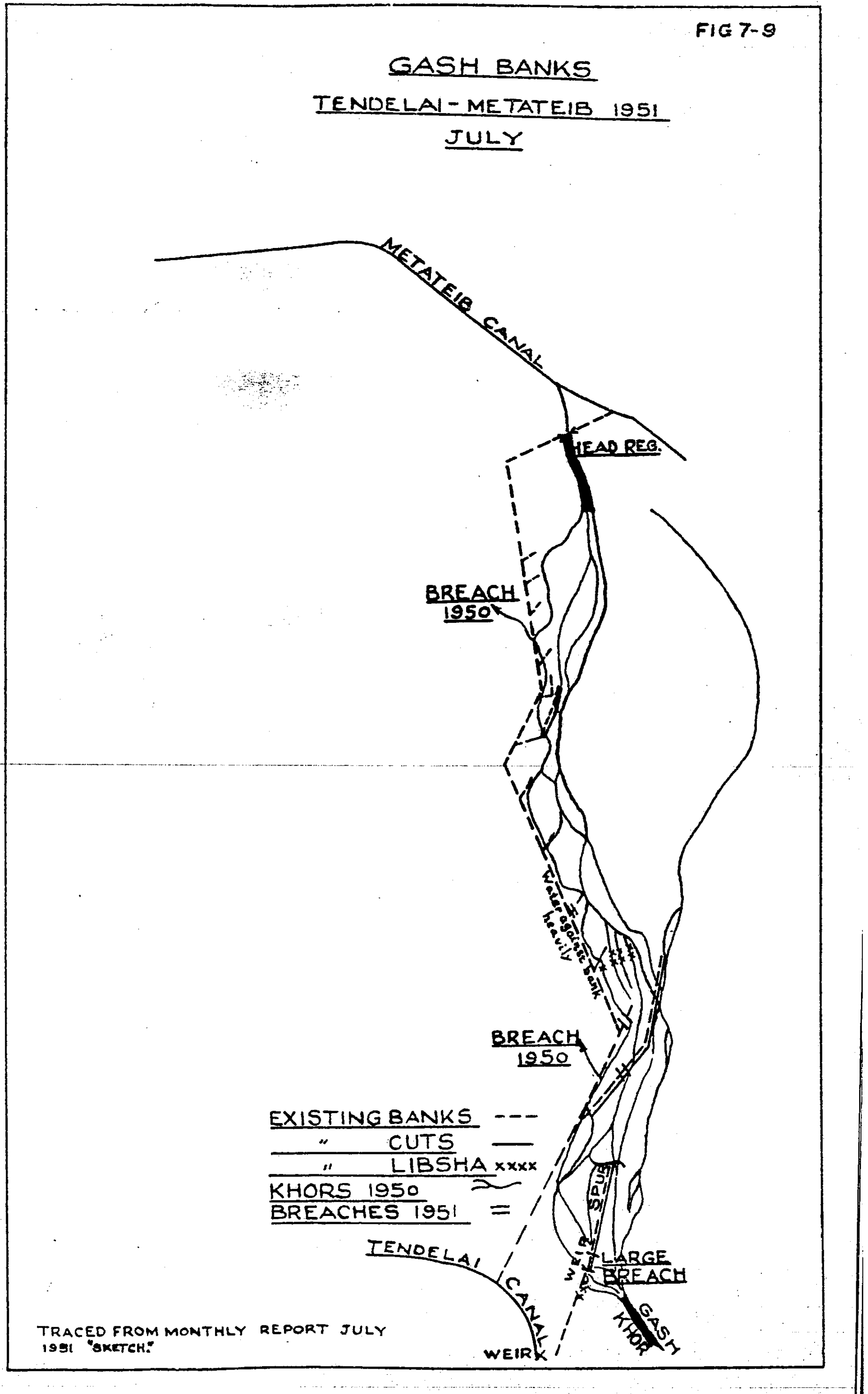
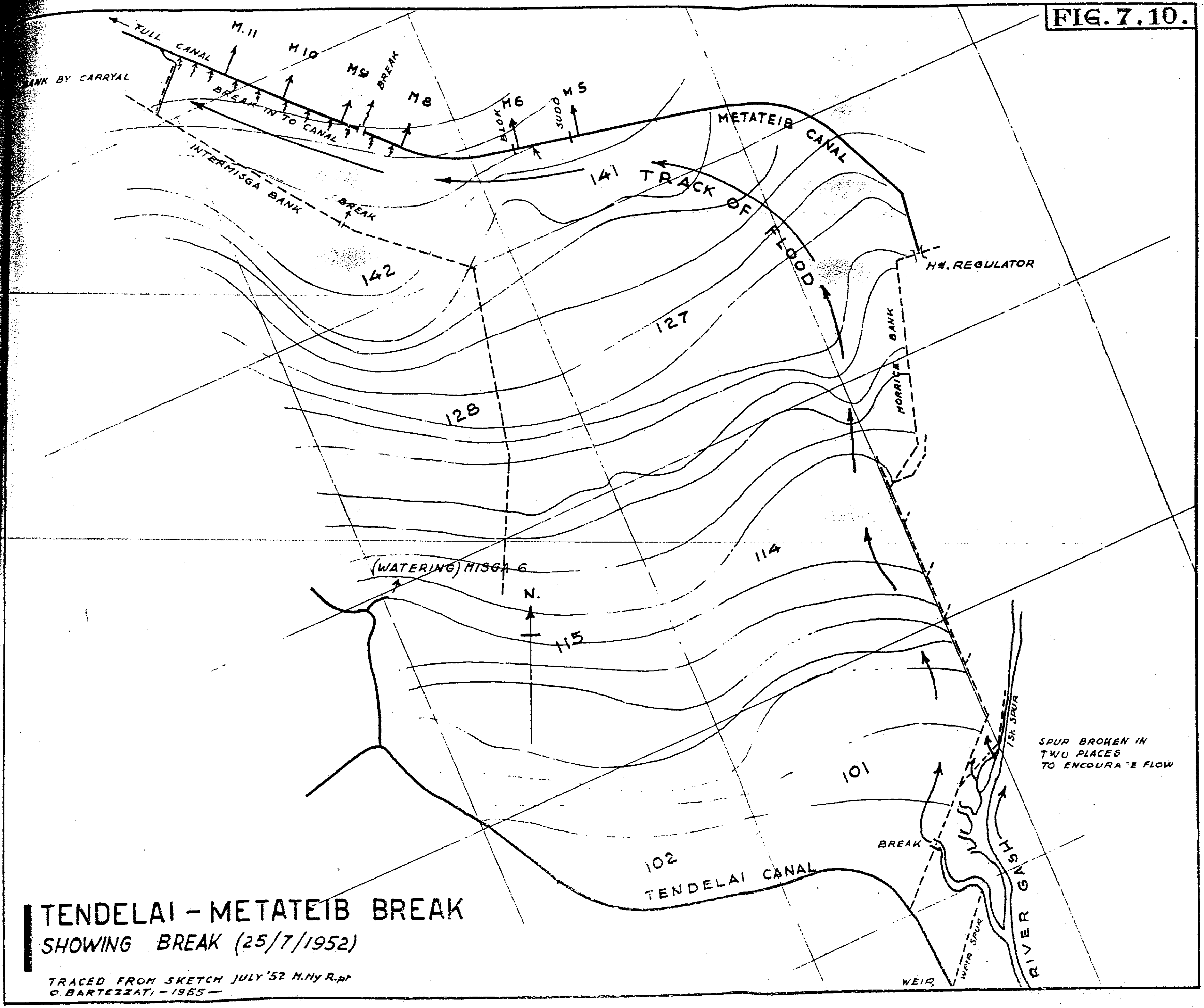

GASH BANKS
TENDELAI - METATEIB 1951
JULY
METATEIB CANAL
HEAD REG.
BREACH 1950
Water against bank heavily
BREACH 1950
EXISTING BANKS ---
" CUTS ——
" LIBSHA xxxx
KHORS 1950
BREACHES 1951 =
TENDELAI CANAL
WEIR
SPUR
LARGE BREACH
GASH KHOR
WEIR
TRACED FROM MONTHLY REPORT JULY 1951 "SKETCH."

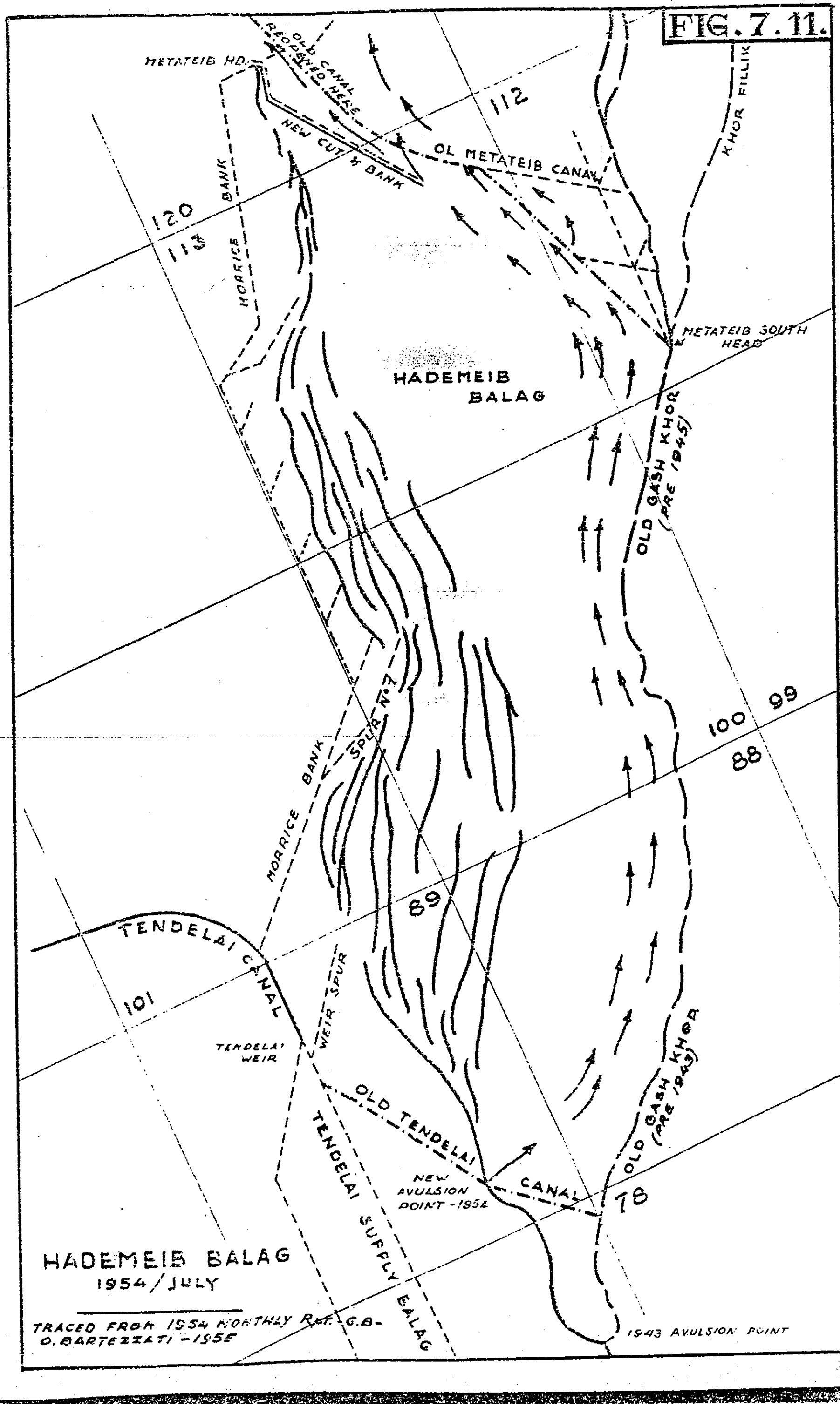
FIG. 7.10.



TENDELAI - METATEIB BREAK
SHOWING BREAK (25/7/1952)

TRACED FROM SKETCH JULY '52 M.Hy R.pt
O. BARTEZZATI - 1965 -

FIG. 7.11.

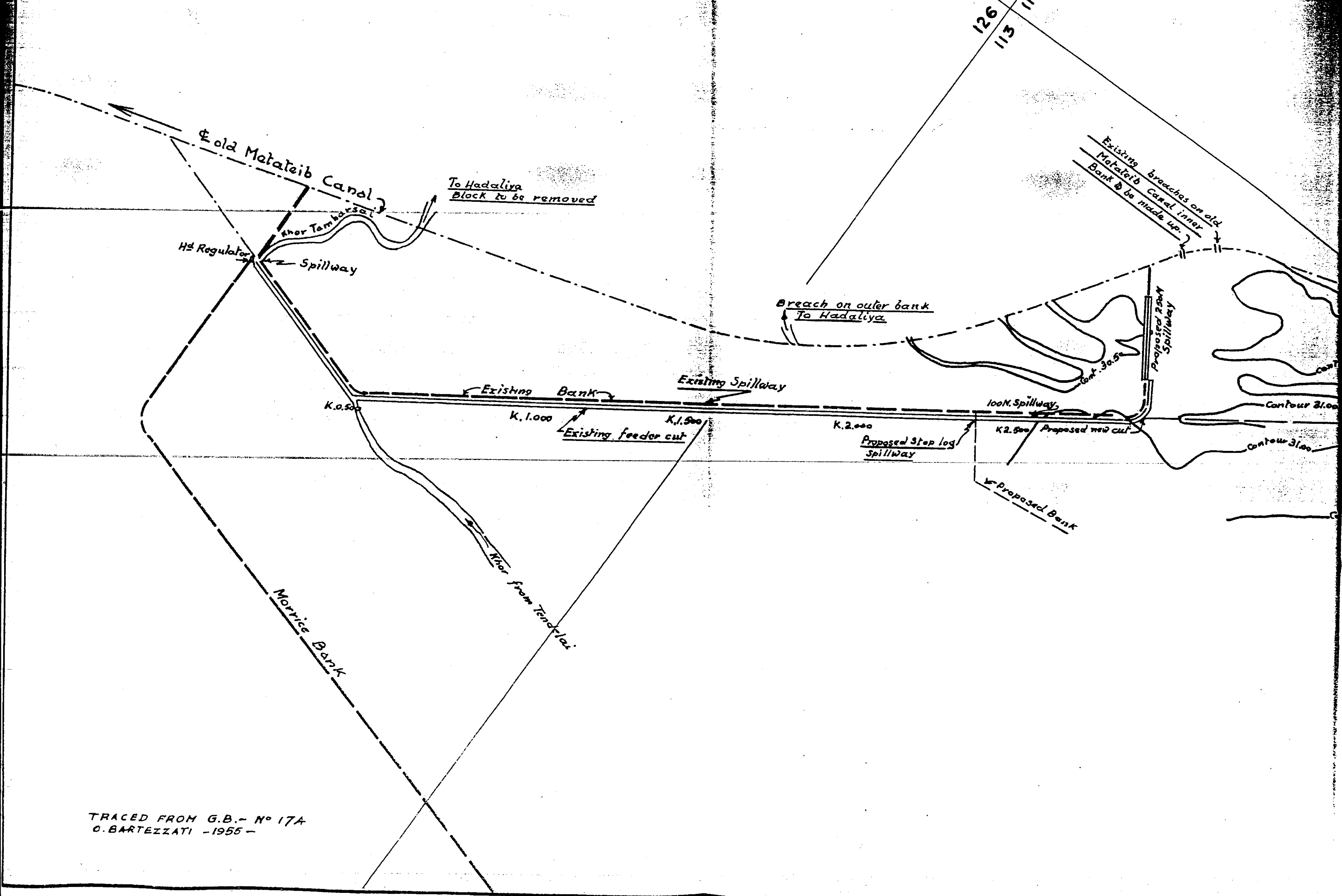


HADEMEIB BALAG
1954/JULY

TRACED FROM 1954 MONTHLY Rpt. G.B-
O. BARTEZZATI - 1955

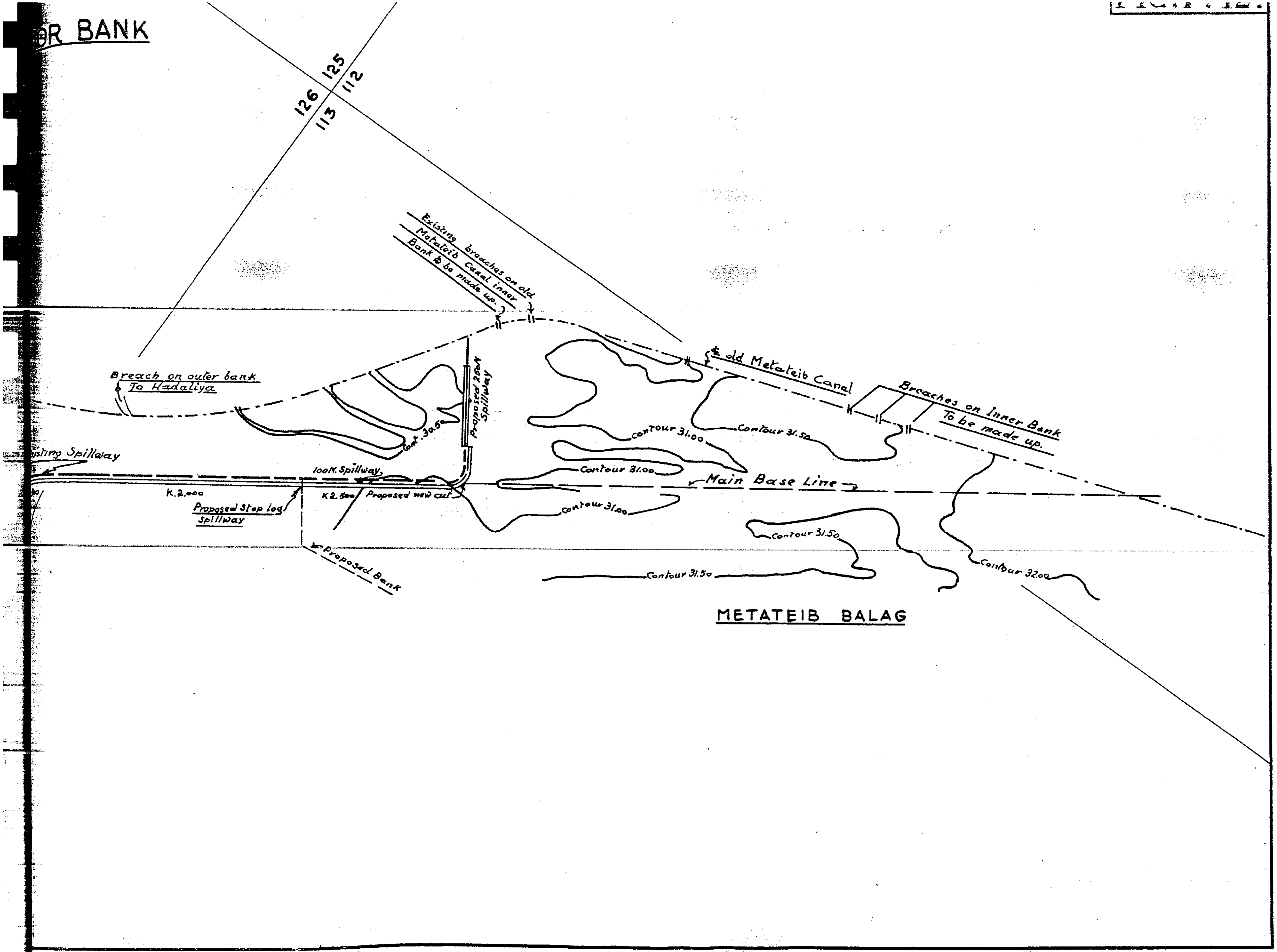
METATEIB CANAL SUPPLY - COLLECTOR BANK

PLAN OF METATEIB BALAG



TRACED FROM G.B.- Nº 17A
O. BARTEZZATI -1955-

...R BANK



METATEIB BALAG

SECTION VIII

NORTH OF METATEIB

1. <u>Introduction</u>

Four masonry head regulators have been built at different times to serve Metateib canal and today even the most recent of them is serving more as a cross regulator below the offtake than as a proper head regulator. In contrast to such a chequered career, Hadaliya canal is still drawing excellent supplies from its original head built in 1925 ! Many of the difficulties which exist further upstream do not apply at Hadaliya; the water is relatively silt-free, violent fluctuations of level do not occur and the discharge of the river is much reduced by the time it gets so far north. Major changes of flow have occurred; but always within such limits that the existing arrangements at Hadaliya head have worked well enough after relatively minor modifications.

Because of this easier irrigation and because of the rather indeterminate flow in the balag, the section of the Gash between Metateib and Hadaliya is but indifferently documented, and north of Hadaliya it is hardly documented at all. The flow has generally been in a series of khors with overflow into balag and the course of the river is marked by a belt of impenetrable thorn forest several kilometres wide. The forest stretches nearly up to the latitude of Amm Adam railway station; this is as far as the water reaches in a year of moderate Gash or less. In years of greater floods the water flows northwards in a sheet several kilometres wide until north of Eriba railway station, then it swings to the west and passes under the railway, finally to reach, in years of really high flood, a place called Gashdai; here there is a basin where the water spreads out over a large area of land. There is no evidence that the water from the Gash has ever passed Gashdai to flow on into the Atbara. In bumper years great crops of millet are raised by the Hadendowa in the northern course of the Gash and in Gashdai. In bad years it is the object of all good irrigators to prevent a drop more water than necessary passing north in the Gash khors beyond Hadaliya head; sometimes this object has been achieved absolutely.

The land is not particularly good in the northern part of the delta. It is largely "badobe" or black cracking clay unmixed with the rich silt of the southern delta. "Badobe" is far less permeable than silt and so absorbs water more slowly when flooded for some time, although it may absorb great quantities of water initially until the cracks are sealed by the swelling of the soil. On the other hand the flooding is ~~much easier at Hadaliya than it is further south;~~ there are fewer natural water courses (due to rain or earlier Gash flows) to hamper the spread of the water over the land and the supply from the head has usually been fairly reliable. There is always, therefore, a temptation to expand and flood more and more land in the north; When this is done to make use of surplus water it is excellent, but it should never be done at the expense of the southern delta. The policy has always been, and must continue to be, to water as much land as possible in the south and only then to use up the remaining water in the north.

2. Hadaliya Canal Supply: Up to 1929

No record is left of conditions in the north before the first Hadaliya cut was dug. This was in 1923 when, with the Mekali cut, it formed one of the first two trial cuts in the Gash delta. North from Metateib the Gash ran in a series of khors; the easternmost of these was Khor Filik, rather separated from the rest, and the westernmost was Khor Awadai. Subsequently Khor Awadai assumed a greater significance and is often called the Gash, the title Khor Awadai being reserved for that part of it below Hadaliya offtake. It is difficult to say whether the upper part of Khor Awadai is rightly called the Gash or not, but it certainly was not in the early days and so to avoid confusion only the name Khor Awadai will be used in this report for the parts both above and below the regulator. Hadaliya cut was taken off a convenient angle of Khor Awadai. Very little is now known about the working of that season except that about 4,000 feddans were watered.

In 1924 the cut was eight kilometres long. There was still no head regulator and supplies were obtained by blocking Khor Awadai; the earth dam was broken when watering was complete. About 6,000 feddans were watered. The main feature of the flood was reported as being the steadying effect of the balag which kept the gauge reading at a practically constant level. It is not immediately clear to which balag this refers, but as the effect is not mentioned at Magauda, it may be assumed to be the Eagir balag, just to the south of Hadaliya offtake.

In 1925 a head regulator was built for Hadaliya canal. It was another of those structures consisting of two pairs of 2.5 m openings set at right-angles to each other, which have been unfavourably commented upon earlier in this report. The worst evils of this system were avoided at Hadaliya by having the supply to the canal pass straight ahead, and the surplus flow down Khor Awadai taking off at right angles to the right. This at least avoids drawing the majority of the silt into the canal. Perhaps it were more prudent, on the whole, not to be too disparaging about Hadaliya head; the 1925 structure is still serving admirably today, thirty years after it was built.

In that year the canal was extended to K.10 and arrangements were made to water breaches at K.3, K.5 and K.6.5 and from the tail at K.10. The channel was blocked at the breaches to assist the flow. Unfortunately the first two earth dams blew out immediately on opening up and only K.6.5 and the tail watered. Even these were handicapped because the canal was only half completed. It is in this year that the first mention of a catch bank is made. It was then some 300 m long and extended eastwards from the head into the balag; this bank is now known as the Bariai bank. Only about 40% of the water passing Metateib was reaching Hadaliya head regulator; it was realised that most of it was being lost in balag to the east and that the loss could be reduced either by prolonging Bariai bank or by enlarging the water-way of Khor Awadai.

In 1926 the canal was completed to K.20 and sixteen misgas were constructed with double 90 cm diameter pipe regulators. A bridge was built at K.4 and a cross-regulator was put in near the agricultural colony at K.13. The system ran very well although Khor Awadai, which supplied it, silted up completely. All the water came from the balag and a great part of the flood was lost to the north.

Khor Awadai was cleared in 1927 for six kilometres upstream of Hadaliya head. At the same time Bariai bank was extended eastwards, though it is not now clear how far; a 25 m break was left in the bank near the canal head to dispose of any surplus water. The result was excellent and a large and steady supply for the canal was maintained. Nearly 7,000 feddans were watered. A certain amount of silt was deposited in the head reach of the canal due to the cutting of Khor Awadai back through the balag. It is not clear whether the gap left in Bariai bank was protected or not; if it was not it was lucky that the arrangements worked satisfactorily. Unprotected gaps in banks are almost always troublesome either through bed scour or abutment erosion.

The canal ran well in 1928 and in 1929 although in the latter year control was lost because the balag flow caused by that great flood broke into the canal downstream of the head regulator. The canal did not breach and the excess water was disposed of as end spill. That year the railway was carried away north of Eriba station and communications were not restored for six weeks. A large area of cotton was watered off Khor Awadai to the north of Hadaliya offtake: this was in the Illibilli area, later to be served by a canal. Yet another area was watered by the balag to the east of Khor Awadai. This was a windfall, but it was resolved to incorporate it in a future scheme.

3. Development of Illibilli Canal: 1930 to 1936

In 1930 the next six and a half kilometres of Khor Awadai below Hadaliya head were canalized. At the tail a group of three regulators was built; that leading straight ahead was Illibilli, to the left Bahabini and to the right an escape called Shabash from which was watered, later on, the area mentioned at the end of the last paragraph. In the first year Illibilli and Bahabini canals were run in succession, each taking the full discharge of Khor Awadai. Illibilli

canal was excavated as far as K.6; the offtake of Misga 2 and the head regulator of Misga 1 at K.3 together with a cross-regulator and fall, were built. Another fall was incorporated in Illibilli head regulator. Bahabini canal was dug as far as Misga 1 and again a fall was combined with the head regulator. Illibilli Misga 1 and 2 were run together. Between them the two canals watered an area of more than 8,000 feddans. A further 1,800 feddans were watered by Shabash escape. Hadaliya canal was only used for wells and Misga 10 acted as an escape.

During the same year investigations were made into the possibility of exploiting the water collected by Khor Filik. Discharge observations made during the flood showed that it was not practicable. The precise reason is not recorded but it seems reasonable to suppose that since Khor Filik was mainly fed by spill from the main Gash its discharge would be intermittent and subject to rapid fluctuations. In any case, it was found that the area it was proposed to water from Khor Filik could be commanded by an extension of Illibilli canal.

The marked feature of the season's large extensions was the ease of irrigation, attributed to the large discharges at the outlets and the even distribution of the water possible on these northern areas.

In 1931 Illibilli canal was extended to K.9 where Misga 3 was taken off without headworks. Bahabini was extended to Misga 2. Again the policy was adopted of running only two misgas, one in each rotation, and these two new misgas were run that year. Again they were spectacularly successful, Illibilli Misga 3 watering nearly 7,000 feddans in thirty days. The masonry of Hadaliya canal and Khor Awadai regulator group had to be raised that year. Misga 2, Hadaliya, was run and canal end spill served to relieve pressure on Khor Awadai. Even so the pressure was too great and Bariai bank had to be broken.

Before the 1932 flood Illibilli canal was extended to K.17.5 (Misga 4) and it was intended to water from this new misga. Unfortunately the fall downstream Misga 3 was not completed in time. This left the station with a very restricted area for watering. Shabash escape had been designed to deal with the excessive discharges which could not be passed down Illibilli and Bahabini canals; it could not cope with the entire discharge of Khor Awadai and consequently formed a bottle neck which silted Khor Awadai badly.

1933 saw a return to the pattern of 1930. Illibilli canal was blocked downstream Misga 2 and Misgas 1 and 2 ran together, with Bahabini Misga 1 running in the other rotation. Hadaliya canal was only run for wells.

The regulator and fall at K.9 Illibilli together with a masonry head for Misga 3 were finally constructed in 1934 and in the same year an escape head, known as the Sabun escape, was built in the Bariai bank close by Hadaliya head regulator. From here an escape channel was run out northwards into the forest, with a branch to ensure the watering of Sabun wells. In Illibilli canal, Misga 3 was run in 1934 and, the fall being completed, it was possible to run Misga 4 in 1935. The last stage in the development was in 1936 when a westward extension of Misga 4 was run as Misga 5. All these misgas ran excellently. There were no difficulties; both Illibilli and Bahabini canals run below ground level and are virtually impossible to breach. The slope in Illibilli was fixed by the falls at 1:3,000 but was tending to silt into a slightly steeper slope.

One claim to fame must be accorded to Illibilli canal which comes neither under the heading of irrigation nor agriculture: it once won a newspaper competition for the longest single-word-palindrome submitted !

4. Hadaliya Station up to 1937

By 1934 Khor Awadai upstream of the Hadaliya offtake was silting heavily and the fact that balag levels were also rising was revealed by a 50 cm rise in "maximum" gauge readings (after which spill absorbed most of the increased discharge) during the 1934 flood. Sabun escape was very helpful that year, making for ease of regulation.

In 1935 a new type of misga was tried out. This was Misga 10A, Hadaliya, which was designed to bring fresh land into cultivation since all the old areas were by now too fouled

by weed growth to be economic at that time. Misga 10A was run above ground level between high banks and was carried right out to Hod 197 before dispersal was permitted. No head was provided as the misga took the full discharge of the canal. The misga was rather troublesome at first, the old story of banks built on cracked "badobe", but once thoroughly soaked it went well and over 6,000 feddans were watered.

During the 1935 aerial reconnaissance it was observed that there was no longer any connection between Khor Filik and the main Gash khors north of Metateib. Khor Filik was entirely supplied by eastward spill from the Gash south of Metateib. Compared with the Gash it seemed insignificant but that this was not so was evident from the extent of the flooding it had produced further north.

It is in 1935 that the first mention is made of Hadaliya South protection bank. Clearly it was built earlier, possibly after the 1929 flooding, because it is recorded as being "strengthened and extended".

Bariai bank was strengthened and Hadaliya South bank again strengthened and extended in 1936, while at the south end of the reach the Gash banking north of Metateib North head was also strengthened and extended. A small sketch made after the 1936 flood shows the lay-out of banking and the method of watering Eagir wells; it is reproduced in Fig.8.1. There was considerable change during the 1936 flood. Due, no doubt, to silting in the channel, there was a great deal of spill to the west between one and three kilometres north of Metateib. The balag so formed passed west of Eagir wells and was joined by further spill breaking out some five kilometres south of Hadaliya head. Almost the whole of Hod 139 was flooded; Hadaliya South bank was outflanked and breached and the flood ran along the south side of Hadaliya canal, eventually to round the tail and run parallel to the railway until it passed Hadaliya railway station. The agricultural station was surrounded. The pressure on Bariai bank was only light and an attempt to relieve Hadaliya South bank by breaking Bariai was unavailing.

The same year, 1936, a new misga was taken off Hadaliya Misga 10A to water an area north and west of 10A; this was called Misga 10B. The results were satisfactory. There seems to have been rather more silting that year, particularly in the escapes.

In 1937 Hadaliya South bank was again strengthened and extended to trap the Eagir balag and at the same time Khor Awadai was widened and cleared for three kilometres upstream Hadaliya head. This was completely successful in controlling the balag and although the khor at Hadaliya again silted to former bed levels, it was left with a far wider and freer water-way.

The Hadaliya South bank breached immediately the water reached it, but was repaired quickly and then gave no more trouble. This bank has much in common with the banking near Magauda, already described; it is built on cracked clay soil and disintegrates at the first sign of water. Most of the supply to Hadaliya came from the balag that year, 1937, and the main embarrassment was too much water. Levels were remarkably steady.

5. Hadaliya Station: 1938 to 1942

Before the 1938 flood Hadaliya South bank was greatly strengthened and for the first 700 m above Hadaliya head it was widened to road width so as to provide flood communication between Metateib and Hadaliya. Even so the first spate breached it about 500 m from the head and water poured into Hadaliya canal and had to be escaped out on to the areas of Misga 10A and 10B. The bank was repaired just before the avulsion took place at Metateib.

The immediate effect of the avulsion was the complete failure of supplies to Hadaliya. It will be remembered that one part of the flood at Metateib headed north into Eagir balag from a breach in Metateib canal at K.3.5 and that this flow was encouraged until finally it was taking 60 to 70% of normal floods. This, then, became the supply for Hadaliya. It started to reach the regulator two days after the avulsion

but was meagre for the next week. Then it arrived in quantity, so much so that Sabun escape had to be operated and later a breach had to be made in Bariai bank.

In 1939 the banking at Hadaliya was even further strengthened. Over the first 700 m (the road width section) a guard bank was built parallel to the main bank and about forty metres from it. The remainder of Hadaliya South bank was protected by a series of seven small deflector spurs. From the south end of this bank a new tie bank, now known as the Ahmed Nakash bank, was run across to the north bank of Metateib canal. In the Bariai bank yet another escape spillway was built. This is now called the Bariai West escape and is situated about 90 m above the Hadaliya group of regulators.

The balag flow in 1939 just included Eagir wells basin in its eastern fringe and just reached the southern section of Hadaliya South bank on its western fringe. In other words it was exactly where it was intended to be. It did not touch Hadaliya South bank again until it reached the 700 m stretch near the regulator. Here, in spite of the new guard bank (which did no good at all) the first real spate breached the bank in ten places ! The water broke into Hadaliya canal and seriously upset the watering programme. Fortunately a few days of low river followed and the bank was repaired, to give no more trouble for the rest of the flood. The new Bariai spillway proved its value repeatedly, carrying away the early flushes. It was noted, that year, that although the supply came from Eagir balag, there was no reservoir effect. Spates were to some extent damped out, but that was all. The reason was probably the fact that Eagir balag then, as now, consisted of a large number of minor khors and the balag was merely spill from them. The desilting effect of it was, none the less, marked.

In 1940 Hadaliya South bank was provided with a deep key trench near the toe which was filled with sand from the khor bed. It was remarked that strangely enough no cracks in the earth were visible when digging the trench although the soil was fully dried out. This is a feature of the cracking clay which is difficult to understand, but which is nevertheless quite usual. It makes it impossible to judge to what depth key trenches should be taken and may well explain the reason why so many banks thus protected have subsequently failed.

Despite this key trench and some silting basins built against the bank further south, Hadaliya South bank again breached badly on the arrival of the first big flush of the 1940 flood. Water poured along the south side of the canal and again Hadaliya agricultural station was surrounded. Once again a convenient lull allowed the bank to be repaired and for the rest of the flood there was no more trouble. It was noticed that at the northern end of the Eagir balag the water was tending to drain into the old course of Khor Awadai about half a kilometre above the head regulator.

There was little to note during the next two years. In 1941 the position of the balag was slightly further west than before and looked as if it were going to leave Eagir well centre aside; special arrangements had to be made to flood the basin. In 1942 scour in Hadaliya canal had so lowered general water levels that it was difficult to water Misgas 1 and 2; accordingly a weir was built across the canal just below the offtake of Misga 2.

6. <u>Eagir Balag and Hadaliya Supply: 1943 to date</u>

The works designed to carry the flood north from Metateib in 1943 have already been described in the previous section. Early in the flood Hadaliya South bank was again breached but, as before, a lull allowed it to be repaired and there was no more trouble until the avulsion took place at Tendelai. As can be seen from Fig.7.7, the main body of water from this flood crossed the line of Metateib canal at about K.5. From there it ran along the Ahmed Nakash bank, which broke in two places. The flood then followed Hadaliya South bank (on the wrong side) and broke into Hadaliya canal.

A few days later a period of low river allowed the breaks in Ahmed Nakash bank to be repaired. There was very little cover, and about three weeks later the bank broke again. Previously the flood discharges had been passed into Hadaliya misgas (after some re-arrangement of the watering programme)

but this new flood was too much and the canal broke between Misgas 4 and 5 and flooded nearly 3,000 feddans of land that it had not been possible to command and irrigate for many years. "It's an ill wind ....". By this time it was September when there is never any spare labour in the Gash since everybody is busy sowing the crop and hoeing it. In any case Ahmed Nakash bank had been flooded on both sides so there was no dry spoil. The flow was therefore allowed to run on until the end of the flood.

The north-westerly course the water had taken after breaching Ahmed Nakash bank was the natural course dictated by the contours and its new point of departure at about K.5 on the old line of Metateib canal. Such a course, however, would leave the upper part of Hadaliya canal and the whole of the irrigation system fed by the lower part of Khor Awadai completely to one side. It was therefore necessary to embark, in 1944, on a heavy programme of banking and leading cuts in the Eagir balag area to hold the water to the east of the general line of Hadaliya South and Ahmed Nakash banks. The scheme can be seen in Fig.8.2. The principle adopted was that of an interrupted guide bank made up of a series of curved, inclined spurs with their heads parallel to the desired line of flow. Wide and shallow leading cuts were dug through the balag along the same general line and others led in from the balag to Hadaliya head. This arrangement did all that was asked of it, except for some ponding against the northern end of Hadaliya South bank near the regulators. The bank, of course, promptly broke as it always does, but the breaks were kept under control and later repaired.

Downstream of the Hadaliya group of regulators heavy bank erosion was taking place in Khor Awadai and threatened to eat right through the intervening strip of land between it and the Sabun escape channel. Subsequent developments lead strongly to the conclusion that the basic trouble was too steep a slope in the channel, but this is being wise, if at all, after the event ! The treatment decided upon was the pitching of both banks of Khor Awadai below the head. This was carried out in two stages; in 1946 43.5 m of the right bank and 30 m of the left bank were pitched and the job was completed with 28 m on the right bank and 24 m on the left bank in 1947.

In 1946 the flow in the balag swung sharply left after passing Spur No.3, the most northerly of the three spurs constructed in 1944 (see Fig.8.2). The water set against the junction between Hadaliya South and Ahmed Nakash banks, which was a dangerous place where a break-out would run far to the west and nullify the entire purpose of the 1944 banking system. In 1947, therefore, Spur No.3 was extended 300 m further north and the leading cut beside it was extended to conform. This carried the water past the danger point that year. Hadaliya South bank was, in fact, breached during the flood, but much further north, one kilometre from the head regulator, where it was possible to maintain some measure of control.

Before the 1948 flood Spur No.3 was again extended and Hadaliya South bank strengthened still further. There were no mishaps that year. Due, no doubt, to the increased formation of khors through the balag, the water arriving at Hadaliya seemed rather more silty than in previous years. This was welcomed because some concern had been felt about scour in the canal and also in the khor above the regulator. The scouring tendency was checked by this extra silt.

There is an interesting description of the flow in the balag in 1949. The flood crossed the line of the old Metateib canal at two points. Of these the westerly flow followed the spurs until past the junction of Hadaliya South and Ahmed Nakash banks. Then it disappeared into the forest, to emerge in the leading cuts at Hadaliya head. The easterly flow was more difficult to trace; it crossed the old Metateib canal at Tambarassai wells and ran into the forest. It appears at some point to have been collected by the old pre-1938 course of Khor Awadai which brought it up to Hadaliya head on a line roughly parallel to Bariai bank. A good deal of this flow passed through breaches in Bariai bank.

During the 1948 flood the downstream cistern of Khor Awadai head had been almost entirely destroyed and the floor of the regulator had been damaged. Fortunately the main structure was not cracked. In 1949 extensive repairs were carried out; the floor was opened up and grouted and a

notched cill and stilling cistern were rebuilt downstream. A new cut-off wall was built to a depth of two metres on the downstream side of the main foundations.

All this was not enough. Erosion in the khor downstream was eating back inexorably and during the 1949 flood cill and cistern were destroyed and the pitching again damaged. Though in imminent danger of complete collapse, the main structure survived undamaged. A very ugly and worrying situation had arisen; the regulator was perched high above a great scour hole and seemed to be within inches of toppling over into it. The failure of this regulator would have had disastrous results on the whole station and it is very lucky that it held.

In 1950 a concrete notched fall of one metre was built 150 m downstream Khor Awadai head and the channel between the two was pitched. This has completely overcome the danger and no more trouble has occurred since. In the same year Bariai bank was made up again and another spillway was built into it, this time 400 m east of Bariai West spillway. It is now called Bariai Centre spillway. A leading cut ran along the south side of the bank to take water to Hadaliya head. These new arrangements worked well in 1950 and were not modified in the next year.

In 1951 an extensive new balag appeared to the east of the old line of Khor Awadai. It outflanked Bariai bank. The flood was a very poor one and in addition to the outflanking of Bariai bank, there were a number of troublesome, though not dangerous, breaches in Hadaliya South and Ahmed Nakash banks. Hadaliya station fared but poorly that year.

In 1952 a leading cut 2.2 Km long was dug along the south side of Bariai bank and the spoil was used to strengthen the bank. In the same year a combined bank and raised road, leading from the bridge at K.13 Hadaliya, was heightened and lengthened and a light masonry spillway was built in the canal just upstream of it, to return the balag water to the canal.

Water from the 1952 break in Morrice bank, after passing Metateib canal broke into Hadaliya canal at K.12 and various points to the west. It was discharged through

Misgas 10 and 16, which were watering, and the head regulator was opened when required to make up a full canal. Excess water was discharged into Tementai well centre. No damage ensued and a very large area of land was watered.

In 1953 there was a still further eastward movement in the balag and Bariai bank was outflanked again; it was also breached at points one and two kilometres from Hadaliya. Owing to the heavy flood enormous quantities of water were coming down and the further breach proved impossible to close. It widened out to over 100 m across and was estimated to be passing over 100 m3/sec. A little later Ahmed Nakash bank broke at the junction with Hadaliya South; it was repaired once but breached again. Even so, with all these breaches running there was very little margin of sagety at Hadaliya head. There was never any shortage of water.

The eastward shift in the balag had focussed attention on Bariai bank and Hadaliya South became of less importance. Before the 1954 flood a 100 m masonry spillway was built at a point 2.2 Km along Bariai bank from Hadaliya head, and the leading cut was enlarged. A sand-filled key trench was built along the toe of Ahmed Nakash bank where it had breached near the junction and an arrangement was made to bring controlled water through a pipe in Spur No.3 to wet the bank before the arrival of the main flood.

The easterly shift which took place in 1954 in Hademeib balag south of Metateib accentuated even further the eastward tendency of the water in Eagir balag. The new wetting arrangements at Ahmed Nakash bank worked quite satisfactorily, but as that flow was the only water to reach the bank during the whole flood, the success was of rather academic interest. On the other hand the arrangements at Bariai worked excellently and the whole of Hadaliya station had a steady and ample supply throughout the poor 1954 flood.

The new 100 m spillway, called Bariai East escape, was designed to pass exceptional floods without danger to the bank. The 1954 flood was exceptional, but because of its meagre supply rather than otherwise. For such a flood the spillway crest was rather low and tended to pass too much water

to the north, where it was lost. To combat this the crest was built up by sand bags held in position by pickets and timber rails, though there was a measure of risk in this; it might have been troublesome had a sudden spate come down. The risk was a calculated one and in fact paid dividends because thereafter almost no water was lost.

This arrangement produced excellent supplies for Hadaliya but the cill level at the weir could not be left permanently raised because of the danger during spates. The first suggestion was a row of stop-logs across the crest of the spillway; this was rejected because of the difficulty of handling bulky stop-logs over such a wide weir. There is relatively no silt problem so far north so the idea of vertical "needles" was adopted. These can be lighter and narrower than stop-logs and are much more easily handled. A narrow gantry is being built across the weir to carry them. "Needles" cannot be used elsewhere in the delta because regulation is always of the over-flow type to avoid bed load being drawn into the system. In order to facilitate control, Bariai bank is being widened to carry light vehicles and the bridges over Bariai East and Centre escapes are being strengthened for the same purpose.

It appeared, in 1954, as though the entire flow of the Gash which was only small, was approaching Bariai bank along the line of the old Khor Awadai with some slight balag on either side. The artificial cuts near the head carried nothing and the balag there was dry. This eastward movement, as has been seen, has been going on for some years now. The reason is probably the same as in Hademeib balag. For years the westward pressure was held back along an artificial line and the flow naturally lay against the banking. Here it dropped its silt, much more slowly than in Hademeib because the water is so much clearer, but over a longer period of years. It built up a ridge of higher land and, still constrained to the west, fell off to the east. This movement was undoubtedly helped by the eastward movement in Hademeib balag which shifted further east the points from which the water enters Eagir balag. The removal of the pressure on Hadaliya South and Ahmed Nakash banks, even if it is to be only temporary, is a relief; Bariai bank seems far more capable to stand the pressure.

7. Developments in Hadaliya Station

Two new misgas were added in 1937. They were at K.1 and K.3 Hadaliya and were called Salalat 1 and 2. After an interval of several years they are being brought back into use in 1935.

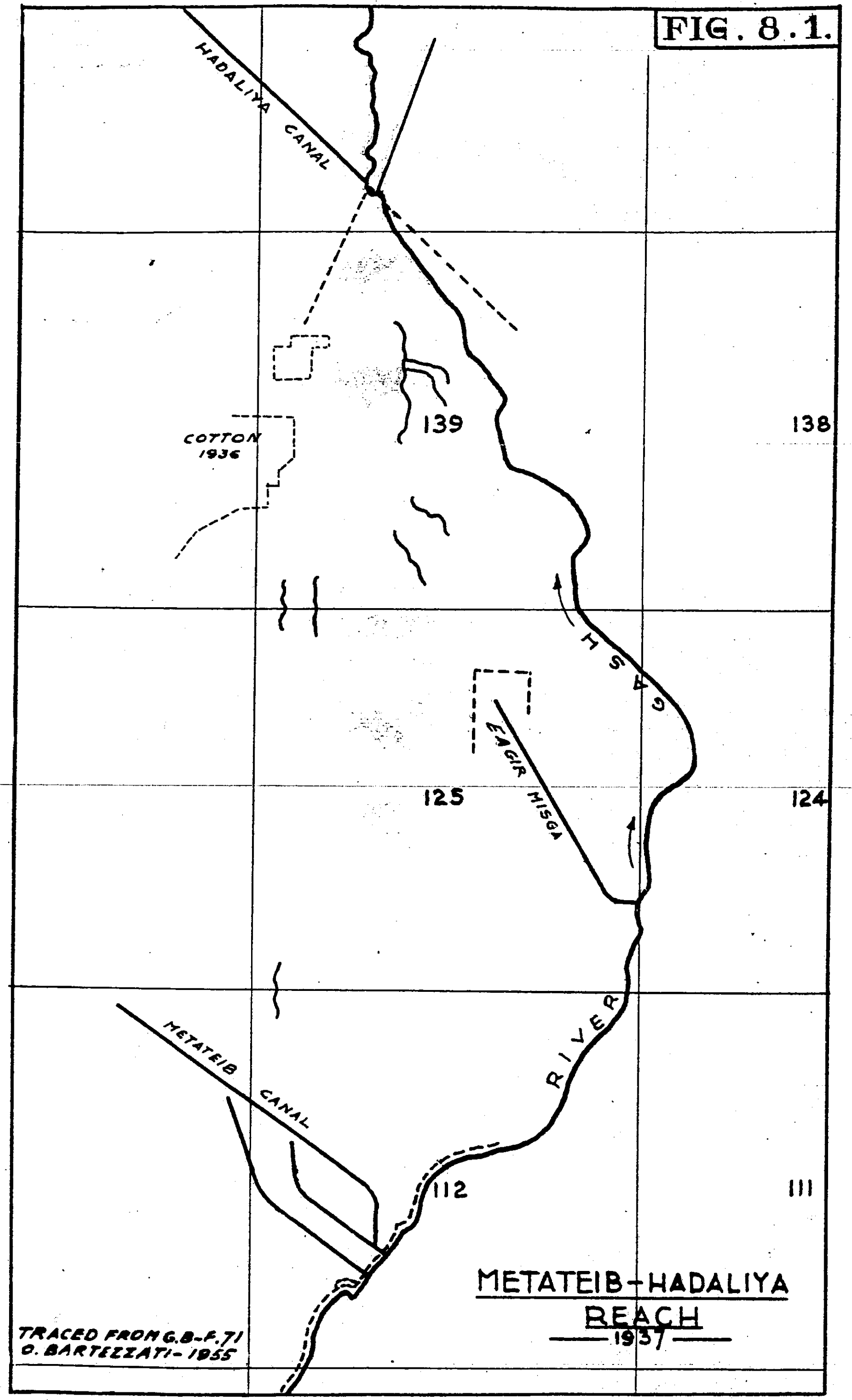
The following masonry misga heads have been built :-

Salalat 1 and Hadaliya 13	in	1945
Hadaliya 2	in	1946
Hadaliya 10A	in	1952

The canal seldom requires clearance but it is fundamentally different from other canals in the delta. There is a complete absence of coarse silt which usually forms the flat bed of the normal Gash canal. It runs in its own very fine silt and is very deep and narrow, having a 3.5 m bed width and a designed water depth of 2 m. The head reach slopes at 1:5,000 and the canal is designed to carry about 10 m3/sec. Below K.6 the slope is increased to 1:3,500, but the canal is still narrow with a 3 m bed width and a depth varying from 1.6 m at K.6 to half a metre at the tail. The side slopes are steep, but the typical rectangular section of the other Gash canals has given way to a more elliptical cross-section throughout.

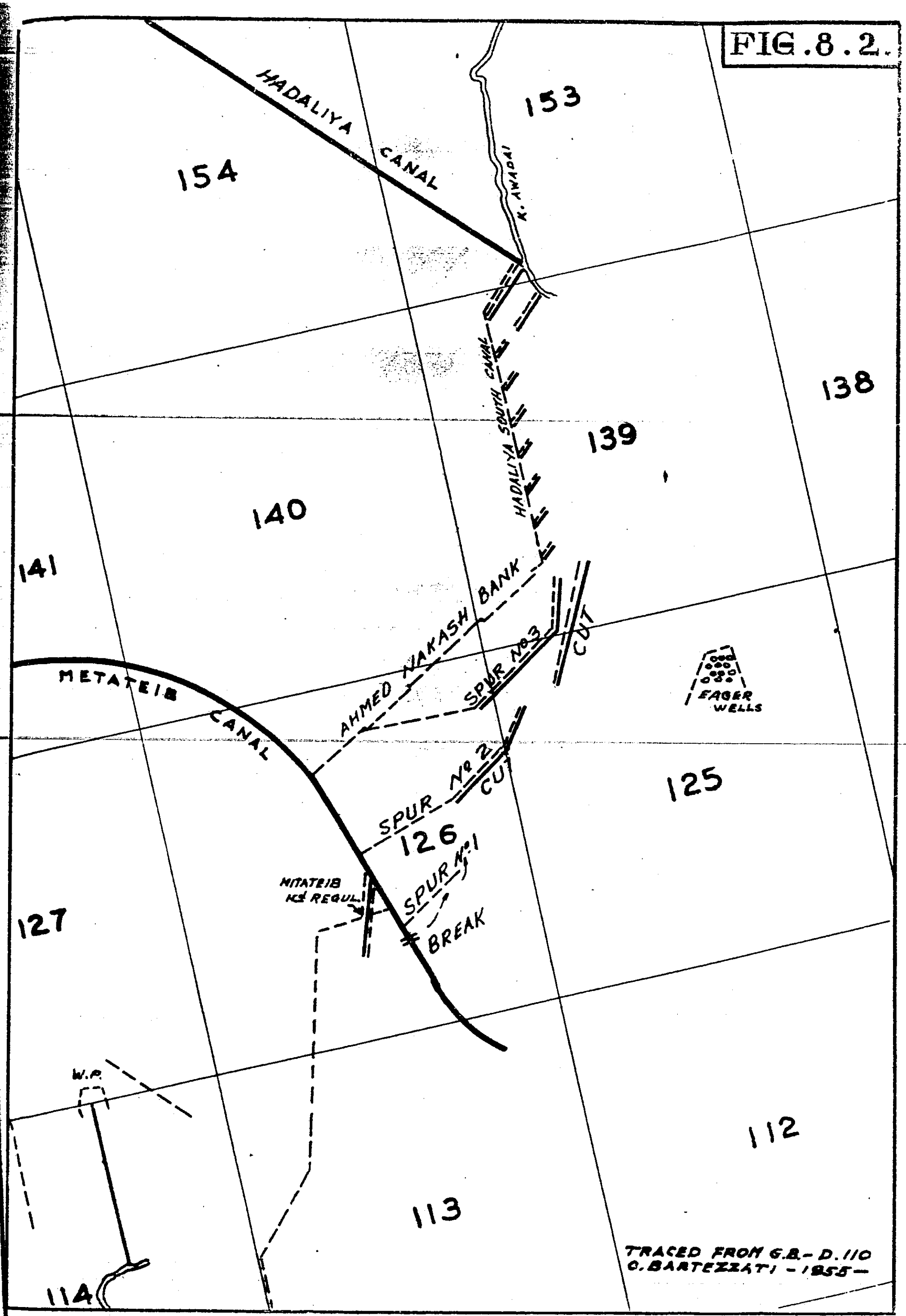
Illibilli canal is rather similar. The slope is 1:3,000 as far as K.9 and thereafter increases to 1:2,500. The head reach to K.3 has a bed width of 3 m and a depth of 1.8 m. It is designed to carry about 10 m3/sec. Lower down the bed width increases and the water depth gets less. Again there is not usually much trouble from silt in this canal, which has been little changed since it was completed in 1936.

FIG. 8.1.



METATEIB-HADALIYA REACH 1937

FIG. 8.2.



APPENDIX

A NOTE ON WATER SUPPLY

1. **Original Supply from Mekali**

The first piped water supply system in the Gash delta was installed in 1925. The supply was drawn from Mekali well centre and pipe lines were laid to Mekali and Degein agricultural stations, and to Aroma.

The open wells were dug about 8 m deep. Pearn triple-ram pumps, each of about 30 gallons per minute capacity, were driven by Pelapone paraffin engines; they fed into a 12,000 gallon elevated tank. From here a 3½-inch diameter main led to the neighbourhood of Badarir, about twelve kilometres away; thence seven kilometres of 2½-inch diameter main led to Degein and nine and a half kilometres of 2½-inch main led to Aroma. At both these points a 7,000 gallon tank was erected. Another 2½-inch diameter main led direct from Mekali wells to Mekali agricultural station. The maximum capacity of the pipe line was 40,000 gallons per day.

It was found that there were two quite distinct aquifers at Mekali; one from 1.5 to 7.5 m deep and one from 14 to 20 m deep. In 1927 one of the wells was sunk deeper to tap the lower aquifer.

2. **Gammam Scheme**

As early as 1926 drilling was started to try to find a better supply. A Star No.22 well boring rig was obtained and an experienced driller came out to operate it. Work started at Mekali with four bores at the wells and one at the agricultural colony (the latter carried down to 76 m) but without any useful result. In 1927 the search shifted to Gammam. At first the borings gave some misgivings; the strata were irregular and yields varied enormously. Work was carried on continuously until June 1929, except for the flood periods when all equipment had to be withdrawn. After twenty-four borings had been made six were found which together would yield 10,000 gallons per hour, so in 1930 the Gammam scheme was put under way. It was completed in 1931.

The scheme was designed to pass the whole of the maximum daily supply of 100,000 gallons to the delta in 21 hours, allowing a margin of 3 hours to cover any decreased flow due to future deterioration of the pipe line.

The water is drawn from the tube wells by $4\frac{3}{4}$-inch bronze "Dando" bore-hole pumps operated by jerker lines composed of a series of steel rods connected together and supported about half a metre above the ground by tie rods hung from raised supports. The tie rods swing backwards and forwards with the motion of the jerker lines. The jerker lines are operated by an eccentric mounted on an enormous horizontal fly-wheel eighteen feet in diameter which rotates at about 15 r.p.m. The sight of the slowly oscillating jerker lines radiating in all directions from the pump house is an astonishing spectacle and the very large wheel has, on occasion, given rise to some merriment amongst the ungodly. However, the system works. The prime movers are two 20 h.p. Ruston Type 5M oil engines, one of which is a stand-by; the fly-wheel is belt driven from the prime movers.

3. Distribution System

The water is pumped into two 76,800-gallon raised tanks. Thence a 6-inch diameter main leads to Mekali where the original installation with its 12,000-gallon tank is still in use as a stand-by; from here a $2\frac{1}{2}$-inch diameter branch leads to Mekali agricultural colony. The 6-inch diameter leads to Degein. Half-way between Mekali and Degein a 4-inch diameter branch takes off to a water point a Badarir with a 7,200-gallon tank. From there the branch leads to Aroma where there is a 9,600-gallon tank. For the last few kilometres this branch is reduced to a 3-inch diameter pipe.

Owing to the expansion of Aroma colony and to increased supplies being passed to the town, this branch is at the time of writing one of the tightest features of the water supply system and Aroma is but poorly served.

There is a 7,200-gallon tank at Degein and from there a 5-inch diameter main leads to Tendelai where there is a 12,000 gallon tank as well as a watering point taking directly off the main pipe line. From Tendelai to Metateib there is a 4-inch diameter main; about three kilometres short of Metateib a 3-inch diameter branch takes off to a 9,600-gallon at Oleib. At Metateib itself there is a 7,200-gallon tank. From Metateib, a 3-inch diameter main leads to a 9,600-gallon tank at Misga 18, Metateib canal, and a 3-inch diameter branch, reducing to $2\frac{1}{2}$-inch, leads to Hadaliya colony.

The tanks serve water points consisting of a number of taps fixed in a pipe about a metre above the ground. Tenants are allowed to draw quantities of water from these points on a scale commensurate with their land holdings. A much improved form of water point has been introduced recently. The pipe is elevated at least two metres above the ground; donkeys bearing water skins (the universal mode of transport) are driven underneath between control railings rather like the ticket offices in a large Underground station. Hoses hang from the raised pipe and these are fitted with nozzle valves of the type used in petrol pumps. Water is supplied directly into the water skins. This improved system is gradually taking the place of the older type.

In addition to the water points, piped water is laid on to most of the more senior staff houses. In Aroma the houses are connected to a colony ring main which incorporates a balance tank to damp down the extreme fluctuations of demand on the main line.

4. Development at Gammam

The problem of recharging the aquifers at Gammam has already been dealt with in Section 3 of this report and will not be discussed here. There were a number of teething troubles at the outset of the scheme. At first the jerker lines gave trouble on account of snatch at the eccentrics; this was cured by careful adjustment. Another trouble was excess pressure produced by the delivery stroke of the pumps. A steadier flow was obtained by fitting air vessels, which also ironed out the instantaneous pressure. The water was hard, containing 0.64 lb of calcium bicarbonate and 0.24 lb of magnesium bicarbonate per 100 gallons, giving a hardness of about 40°. Both the above salts are almost completely precipitated when the water is boiled. This caused trouble with car radiators etc., until a water softener was obtained. As a result of the deposition, no really satisfactory type of water metre has ever been found for the water supply system and air valves cause endless trouble. With the recharging of the aquifers at Gammam the hardness of the water has since been much reduced.

A serious cause of trouble was the clogging of the screens in the bores. To some extent the mesh was filled with sand, but there was also a deposition of iron and lime owing to the acidity of the water. The screens were of brass pressed into a steel tubing; this set up an electric couple which led to corrosion and deposition of ferric hydroxide which rapidly cemented together any sand in the mesh. There was no option but to draw the bores, clean the screens and then re-sink them.

By 1934 concern was being felt about supplies at Gammam and a trial bore was made at Gash Wells, which found water. Accordingly in 1933 a brick lined open well was dug there. In the same year, as a trial, a similar brick lined open well was dug at Gammam. Next year an attempt was made to recharge the aquifer at Gammam by flooding down the open well. This was a mistake; silt enters with the water and clogs the strata round the well and ruins it. The open well at Gash Wells had given an excellent supply until early January, so in 1936 two more open wells were sunk nearby, to be followed by a fourth in 1937. In the latter year yet another open well was sunk at Gammam. It seems that these open wells are more suited to the formations to be found in a typical delta well centre; the aquifers are thin and lenticular and so there is unlikely to be any effective draw down when pumping takes place. The increased surface area inside the limits of the aquifer provided by an open well is therefore advantageous. A narrow diameter bore also stands a greater risk of missing the sand lenses which contain the water. The water is drawn from the open wells by Pearn triple-ram pumps driven by Lister engines.

5. The Present Position

For many years the water supply in the delta has been a hand-to-mouth affair. First there was Mekali, which was inadequate from the start. Then Gammam which gave rise to concern within a few years of installation. The supply there was bolstered first by use of open wells at Gash Wells and at Gammam and later by more and more effective recharging of the aquifer. It has, however, been a perpetual head-ache. More recently alternative methods of supply have been developed; great attention has been paid to the improvement of native well centres and latterly large ponds, known as "haffirs", have been excavated. These "haffirs", which involve 30,000 cubic metres of excavation, are six metres deep and can be topped up by pumping to two metres above ground level. They then contain about 45,000 cubic metres (or tons) of water; they are filled each year by gravity from the nearest canal and then topped up. Supplies are drawn from a well sunk at one side into which water from the "haffir" passes through a filtering device. Most of these "haffirs" last out from one flood to the next; one that did not was sealed by a soil stabilization process which proved very satisfactory.

Despite all this, the shortage of water became more and more serious. Plans were put forward and approved by the Gash Board for a new supply system based on Kassala (where ample water was known to exist) as far back as 1951. The scheme was held up by the Sudan Government financial authorities until it could be proved that no supply nearer than Kassala could be found. Geo-physical investigation and a number of trial bores in various places occupied the next few years; much that was doubtless of great scientific interest was brought to light but this did not, unfortunately, include any water. Meanwhile, as had been foreseen by the Board, great developments were taking place in the delta without the necessary expansion of the water supply system.

As a result of the delays, the new scheme will not now be brought into operation until 1956. Until then conditions of stringent shortage will continue. Bores at Kassala have been completed and ample supplies obtained. The new distribution system aims at delivering 300,000 gallons per day of 21 hours; the pipe will run from Kassala to Aroma along the railway and thence to Tendelai and the north. Mekali, Badarir and Degein are to be supplied from the existing scheme at Gammam. An emergency connection from the Gammam system at Badarir to the new system at Aroma will be retained. Asbestos cement piping is being used for the new distribution system.