Report on the Technical Inquiry into the Causes of Breaches in River Bunds in Sind and Steps to Minimize the Danger of Recurrence

(1943)

C. C. Inglis

A REPORT

ON THE

TECHNICAL INQUIRY INTO THE CAUSES OF BREACHES IN RIVER BUNDS IN SIND AND STEPS REQUIRED TO MINIMISE THE DANGER OF A RECURRENCE.

By

C. C. Inglis, C. I. E., B. A. I., M. Inst. C. E., M. Am. Soc., C. E., Director, Central Irrigation and Hydrodynamic Research Station, Poona.

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CENTRAL IRRIGATION AND HYDRODYNAMIC RESEARCH STATION, POONA.

Technical Enquiry into the causes of breaches in River Bunds in Sind and steps required to minimise the danger of a recurrence

By

C. C. Inglis, C.I.E., B.A., B.A.I., M. Inst. C.E., M. Am. Soc. C.E., Director, Central Irrigation and Hydrodynamic Research Station, Poona.

PART I.

Synopsis.

This Report, after describing the area inundated during the floods of 1942 as a result of breaches in embankments deals historically with the steps taken by Government since 1861—when the Indus Conservancy and Registration Department was first organized—to control the Indus in its passage through Sind.

This is followed by a technical analysis of all available data regarding the rate of rise of flood levels in the past and the probable rate of rise hereafter—as affected by changes resulting from :—

(*a*) natural causes,

(*b*) construction of the Sukkur Barrage,

(*c*) future construction in the Punjab, and

(*d*) the proposed new Barrage in Upper Sind.

The very real danger which lies ahead in Upper Sind is then summarised and recommendations made to minimise the risk of future breaches which, if allowed to recur, will lead to an avulsion.

PART II.

Area flooded as a result of breaches in embankments in Sind during the 1942 flood season.

Figure 1 is an Index plan of Sind showing canals, railways, embankments and river guages. It gives a good idea of general conditions. Fi

Figure 2 shows the area flooded on the right bank in 1942, with dates showing progress of the flood. Fi

During the night of 20th July 1942, water rose steadily in the compartment between the Sukkur-Begari Bund and the Mahomedabagh Loop. The free-board at that time was 1.5′ to 2.0′. The outer bund of the wetting trench was overtopped on the evening of 21st July 1942. Leaks then developed in the main Loop bund causing a breach at taki 22 at 9-30 p.m. Two more breaches occurred immediately after, at takis 28 and 33.

The discharge passing through the gaps could not be measured; but was of the order of 90,000 cusecs, and a length of about 1½ miles of the loop bund was washed away. The breach water crossed the Shikarpur-Sukkur Road at about mile 14 on 23rd July 1942 and breached the railway line between Jamra and Ruk in several places. Thence it spread south and west. It entered the North Western Canal at 3 p.m. on 23rd July 1942, at R. D. 72,000, where the bank had already been cut to allow the flood water to flow away. It entered the Rice Canal at 7 a.m. on 24th July 1942 and breached the banks of the Rice Canal and the Dadu Canal on the same day.

About half the water found its way back to the River between miles 12 and 17 downstream of the Barrage; some 30,000 cusecs flowed down the Canals, and a good deal of this breached into the country, and the rest flowed on south to the Manchar Lake 160 miles from the breach.

Eventually, an area of some 2,000 sq. miles of country was flooded. Figure 2 and Photos 2, 3 and 4 give a good idea of the conditions in the flooded tract. These photos were taken by Mr. Hawes when we flew from Karachi to Jacobabad to inspect the flooded areas, the breaches and the river, on 6th October 1942. Fig. 2. Photos 2, 3 and 4.

Breaches also occurred on the left bank of the river just upstream of Rohri at miles 0/4, 0/6 and 10/6 of the Kasimpur-Nabishah Bund, and at 7 places between miles 1/6 and 4/0 of the Sukkur-Larkana Bund.

The former led to a breach in the Main Line of the North-Western Railway, as a result of which through traffic between Karachi and Lahore was stopped for 10 days.

The breaches in the Sukkur-Larkana bund caused little additional damage.

PART III.

Historical review of steps taken by the Sind Government to collect data in connection with the Indus and to control it in its passage through Sind.

(1) Administration by the Indus River Commission.

(2) Observation of Guage readings.

(3) Measurement of silt passing down the river.

(4) Measurement of discharges.

(5) Indus Bulletin.

(6) Bund Manual and proposed revision.

(7) Construction of river embankments (Bunds).

(1) *Administration by the Indus River Commission* (1861-1942).—

The Indus River Commission, as it exists to-day, has developed from the Indus Conservancy and Registration Department, which was organized in 1861. In 1888 it was converted into a separate Indus River District under the control of the Irrigation Department.

In April 1898, Mr. Dawson of the Public Works Department was deputed to visit America to examine and enquire into the methods followed by the American Engineers in the scientific investigation and conservation of the river Mississippi and to advise Government as to what portions of the American practice could be adopted with advantage in dealing with the river Indus in its passage through Sind.

(1) "Notes on the Mississippi River including brief descriptions of the methods adopted by the Mississippi Engineers." by E. F. Dawson, Assoc., M. Inst., C. E., Executive Engineer, Bombay Presidency.

The Indus River Commission was formed in 1901 on Mr. Dawson's recommendation. The original constitution was :—

1.	Commissioner in Sind.	.. President.
2.	The Chief Engineer in Sind.	.. Member, Engineer and Secretary to the Commission.
3.	The Superintending Engineer, Indus Right Bank Circle. and	Members.
4.	The Superintending Engineer, Indus Left Bank Circle.	

In Government Resolution (Public Works Department), No. 4083/27, dated the 1st April 1931 the number of Members was increased from 3 to 7 by the addition of the Chief Engineer, Lloyd Barrage and Canals Construction, 2 Superintending Engineers and the State Engineer, Khairpur State. The post of Secretary, which had previously been held by the Chief Engineer in Sind was filled by the Executive Engineer, Development and Research Division, who was not a member.

From the 1st of April 1936, when Sind became a separate Province, His Excellency the Governor became Chairman. In 1937, when the first Ministry was formed, the Miniter-in-charge of the Public Works Department became Chairman.

The powers and functions of the Commission are detailed in Government Resolution (Public Works Department), No. 90-I, dated 12th May 1936. The functions of the Commission may be summarised as :—

(*i*) To deal with all questions of policy in connection with the river Indus.

(*ii*) To make and record scientific observations of the river regarding guage readings, velocities, discharges, matter carried in suspension, etc., and to carry out investigations regarding comparative guage readings and varying discharges.

(*iii*) To arrange for surveys of the river, whether topographical or hydrographical, and to maintain up-to-date maps of the river, showing thereon the river course from year to year, and its changes.

(*iv*) To sanction plans and estimates (within the powers delegated to them) and order the execution of all necessary works connected with the construction and maintenance of river embankments and subsidiary channels of the river which are required as feeders to canals.

(*v*) To prepare the budget for all works and establishment under their administrative control.

(*vi*) To approve administratively, and finance from the discretionary grant—or by re-appropriation within the limits of the powers delegated to them—works of immediate urgency not provided for specifically in the budget.

After the administrative approval of new works, the Chief Engineer and Superintending Engineers may exercise their ordinary powers of technical sanction.

The Commission can sanction from this grant unforeseen urgent new works estimated to cost up to Rs. 5,000."

(2) *Observation of Gauge Readings.*—

Guauge readings have been observed at Bukkur since 26th January 1848 and at Kotri since 20th April 1863.

(3) *Surveys.*—

Surveys of portions of the River were started in 1900. Annual surveys of the River have been carried out since 1911 but they were only published for alternate years in the Indus River Commission Records until 1930-31; since when annual surveys have been printed.

From time to time additional guages have been added as under :—

1.	Outfall	instituted in	1896	Records are available from		6th February 1903.
2.	Sadhbello	Do.	1896	Do.	do.	1st March 1896.
3.	Goaghat	Do.	1898	Do.	do.	9th May 1901.
4.	Jherruck	Do.	1900	Do.	do.	6th May 1900...
5.	Mehrani	Do.	1904	Do.	do.	1905.
6.	Naro	Do.	1904	Do.	do.	1905.
7.	Chowgazo	Do.	1906	Do.	do.	1st July 1906.

8.	Gharo	instituted in		1906	Records are	available from	16th July 1906.	
9.	Bhago Toro	Do.	May	1908	Do.	do.	19th May 1908.	
10.	Machka	Do.	Do.	1909	Do.	do.	1930-31.	
11.	Bachalshah	Do.	June	1917	Do.	do.	1st June 1917.	
12.	Sarhad	Do.	June	1930	Do.	do.	5th August 1930.	
13.	Aghimani	Do.	8th May	1932	Do.	do.	8th May 1932.	

From 1st September 1887 guage readings observed in the Punjab have been reported to Sind by wire or letter and since 1931 discharges at Sarhad have been computed.

Since 1931, registers have been maintained showing water levels at one mile intervals along all bunds from which maximum recorded water levels are shown—*See* Figs. 7 and 8. Figs. 7 and 8.

(4) *Silt passing down the river.*—

The charge of suspended silt passing down the river has been observed regularly at Sukkur and Kotri since 1902.

(5) *Measurement of discharges.*—

Current-meter discharges began to be observed at intervals from 1899 at Kotri and 1901 at Sukkur. From 1st June 1921 they have been observed regularly at Kotri and Sukkur.

Prior to 1918 the meters were rated in natural ponds from a boat which was moved with constant velocity. From 1918 to 1921 they were sent to Madras for rating, and from 1922 a meter rating station was started at Kotri.

Up to 1923, current-meters were suspended from a cable and due to curvature of the cable induced by the water flowing past it, the depth at which the current-meter was suspended was higher than the length of cable; but no correction was made for this—probably under the impression that it would make little difference. Experiments carried out subsequently have however shown that with high discharges, cable suspension introduces a considerable error. These errors are greater than can be explained by difference in depth resulting from cable sag; and so must be partly due to other causes—such as non-axial orientation. In this Report, the figures quoted and plotted up to 1923 are after allowing for cable suspension. From 1924, the current-meters have been fixed on rods projecting vertically into the river from platforms projecting from launches.

(6) *The Indus Bulletin.*—

The Indus Bulletin (fig. 3) has been published in its present form since 1st July 1930. Copies are sent to all concerned. Fig. 3.

(7) *Bund Manual and proposed revision.*—

From the early days of bund construction, orders were issued from time to time regarding methods of constructing and maintaining bunds; but, to a large extent, knowledge was passed on by experienced staff from one generation to another.

After the Adurtakio Breach of the Sukkur-Begari Bund in 1930, the Indus River Commission recommended the preparation of a comprehensive outline of bund construction and maintenance known as the Bund Manual. This comprises orders and circulars in force at that time, combined with a selection of recommendations made by officers experienced in Bund work.

No such valuable Manual has been prepared in any other Province in India; nor so far as I am aware anywhere else; and it was not due to any shortcomings of this Manual that the breaches occurred in 1942. In fact, had the instructions in the Manual been carefully observed, there would have been no breaches. That does not mean, however, that under the increasing menace resulting from rising water levels, those orders are adequate. Actually they are not, and at a meeting of Public Works Department Officers, convened by the Chief Engineer in Sind after the 1942 breaches, further instructions were drawn up and additional safeguards proposed. These are quoted in full in Appendices I and II of this Report. Appendices I and II.

(8) *Construction of river embankments (Bunds).*—

So far as is known, the only bunds in existence prior to 1861 were Zamindari bunds. These were improved and new bunds built as shown below:—

Kashmore Bund	(Miles 19 to 38)	probably completed in ..	.. 1875	Fig 5/1.
	(Miles 38 to 50)	" "	.. 1887	Fig 5/2.
Kasimpur-Nabishah Bund		" " ..	.. 1875	
Sukkur-Begari Bund		" " ..	.. 1878	

Figs. 5/1-7. Other river bunds were subsequently constructed as shown in figures 5/1-7.

Many bunds were constructed in the nineties of last centruy, and the remaining gaps were mostly closed during the construction of the Sukkur Barrage Canals.

Both banks are now completely embanked from the northern border of Sind to the sea except where high land renders this unnecessary.

PART IV.

The causes of floods in Sind.

Figs. 6. The basic reason for floods in Sind, is that the Indus is an alluvial river which is gradually building up its bed on a flood plain of its own making; so that the country slopes away from the river on both banks—see Figure 6—showing contours of Sind.

Consequently, prior to construction of the bunds, spill used to occur annually, flooding large areas. The flood of 1861, prior to construction of the Kashmore and Sukkur-Begari Bunds, was a good example. In that year—to quote Capt. Frederick Phillips' Report (1).—

"two flood streams burst over the country from the Indus. The first from above Kashmore, which after flooding vast tracts in the Jacobabad district, passed on to the south into the Shikarpur taluka, meeting the second flood stream from a place called 'Moromarce' close to the mouth, and north of the Sind Canal. Water five miles in breadth and varying from 5 to 3 ft. then swept across the country in a S. S. E. direction."

Figs. 5/1-7. It was in order to prevent such floods that embankments were built. Figures 5/1-7 show, in addition to the bunds, the maximum swing of the deep channel of the Indus between 19[illegible]1942.

From these it will be seen that during the last 30 years the main channel of the river has swung backwards and forwards over a wide belt, the period between successive swings to the same bank being of the order of 35 years. The swing is about 4 miles where the Indus enters Sind, and increases to 6 miles some 8 miles upstream of Sharhad; but just upstream of the Barrage the maximum swing is much greater—nearly 12 miles. This is natural above a gorge, because where a river is controlled by a fixed exit the full meander belt occurs on both sides of the axis of the river; and hence tends to be twice that where the exit is not fixed.

For 20 miles downstream of the Barrage, the swing of the Indus has varied in width between 4 and 6 miles; but then gradually narrows down till at Kotri it is about half a mile wide; and downstream of that it remains much narrower than above Kotri.

The sack-like, wide, portions of the river shown on the plans near Saidabad and upstream of Katiar—where it is proposed to build the Lower Sind Barrage—are due to the river having followed alternative courses near the right and left banks respectively. There are many projecting salients all down the river which have not been attacked in this 30 year period; but these will disappear in the course of time. There is, however, little reason to anticipate any considerable extension of the maximum swing of the river except for some miles above Sukkur.

At the time the bunds were built few, if any, doubted that they would be highly beneficial, but where bunds are built, spill is prevented, and so silting occurs on the river side of the bunds but not outside the bunds. Consequently, where river levels and river berm levels rise, and ground levels outside the bunds remain steady, the head against the bunds increases; so that when breaches occur, the resultant flooding and damage are locally much greater; so it is much more difficult to prevent breaches and to close them when they occur.

As a result, there is a wide spread belief in India that bunds are the cause of the rise of water levels in the river. This theory reached its zenith in Bengal about 1930; and still flourishes there. Partial embanking, especially embanking on one bank—as in the case of the Damodar in Bengal—is undoubtedly harmful; but river control by continuous embankments causes the river to be contained in a single channel; and so, after an initial rise, double embanking tends to reduce the rate of deterioration—See Part V—but there is no way of preventing further rise at a reasonable cost, and so we must face the fact that the basic reason for floods is the gradual rise of water level; which, in turn, leads to breaches so the next point to examine is the causes of breaches and how they can be prevented or controlled.

App. III. Appendix III gives information about the more breaches which occurred

a) between 1930 and 1941 and

(b) prior to 1930.

From these it will be seen that the main causes of breaches in the middle period were :—

(i) erosion of main and loop bunds,

(ii) failure of bund sluices resulting from undercutting of sluice foundations, and

(iii) development of leaks into breaches.

Before dealing with this period, the breaches of 1942—which have been written up in greater detail—will be described.

Photo. No. 1. In 1942, the main breach in the Mahomedabagh Loop Bund occurred on 21st July 1942. This loop was constructed in 1939-40 and partially sand-cored in 1941-42. A wetting trench was provided, and the loop was artificially wetted by pumping.

"In 1942 the river actually eroded part of the front slope of the main bund at mile 17/4 and the front bund was therefore cut, to allow river water to enter the compartment and prevent the rapid rise of water against the loop which might occur if the front bund was eroded rapidly and the river suddenly entered the compartment."

(1) Quoted by N. M. Billimoria in the *Sind Gazette*.

"River levels recorded in the section of the Loop Bund were up to 2.6 feet higher than the maximum taken for the design (*see* Fig. 7) and the Loop failed by the overtopping of the outer bank of the wetting trench, followed by the development of leaks in the top of the Loop Bund." **Fig. 7.**

"After the loop bund breached, the gaps in the Main Bund, the ends of which had only been lightly protected, widened to 600 ft., 1000 ft., and 750. ft. respectively."

A breach at Mile 13/4 of the left bank Bund near Moro resulted from cracks developing where the bund crossed the dry bed of a 'dhoro.' Here, a whirlpool developed on the river side some distance from the bund and water flowed from the bed downstream of the bund, which quickly collapsed.

The other breaches, which should not have been allowed to occur, were due to the omission to lead water to the bund by cuts through the high lip of the river's edge. This was the more necessary in the case of the Kasimpur-Nabishah Bund because water had not been against it for several years.

The main causes of breaches are thus found to be :—

(*i*) erosion of bunds by the river,
(*ii*) failure of bund sluices,
(*iii*) leaks, which develop into breaches due to:—
  (*a*) inadequate free board,
  (*b*) inadequate provision of sand cores,
  (*c*) lack of wetting trenches or failure to lead water from the river through cuts in the lip of the river banks to wet the bunds before the river rises,
  (*d*) inadequate supervision and materials on site.

I do not propose to go into detail here about the remedies to be applied. These are set forth in great detail in the Bund Manual and in Appendix I of this Report, so I will merely outline the main points :

(*i*) *River erosion.*—

Figure 5/2 shows that little now remains of the original Sukkur-Begari Bund, one loop after another having been consructed and destroyed. **Fig. 5/2.**

Similarly, though miles 4 to 20 of the Kasimpur-Nabishah Bund still stand; retirements had to be made between mile 4 and Rohri in 1907, 1922-23 and 1934-35 and in 1941, the river carved out a deep embayment (Photo 4). **Photo 4.**

This embayment was almost identical with an embayment which occurred at the same place in 1907. No breach occurred in 1907; but the North-Western Railway, in consultation with Mr. Hawes and myself, decided in 1941-42 to lay a falling apron on the river side of the toe of their embankment for a length of 4,000 ft. at a cost of Rs. 3 lakhs. This was designed so that should the embayment extend and undercut the apron, it would launch, forming a pitched face, and so protect the Railway line from being breached.

In general, however, the only remedy so far devised in Sind to meet erosion has been to build retired loop bunds.

(*ii*) *Failure of bund sluices* has been almost eliminated in Sind by new designs which prevent down-stream scour and creep along the walls.

(*iii*) *Leaks which develop into breaches.*

Here, prevention is better than cure. the causes of leaks are explained below :—

(*a*) *Inadequate freeboard.*—

This has been due in some cases to settlement of banks and in other cases to a rise of river water levels combined with 'direct attack' where the bund had not been previously attacked.

It is clear that far more strict rules must be enforced *re*: bunds being levelled periodically in future —*vide* Appendix I.

'Direct attack' is accompanied by sharp curvature of flow which increases water levels by about 2 ft. due to centrifugal action. Consequently 2 ft. of the 4 feet freeboard enjoined under Bund Manual rules above previous highest recorded flood levels are neutralised by this "set" of the river.

Prior to 1931, previous maximum flood levels were not properly recorded; but since then, registers have been maintained, in which water levels at one mile intervals along the bunds are recorded.

Figures 7 and 8 show the highest flood levels recorded along the Sukkur-Begari and Kasimpur-Nabishah Bunds in this period, but the record is not long enough to insure that maximum levels have been recorded in all cases. Though 4 ft. freeboard is adequate downstream of the Barrage it should be increased to 5 ft. upstream of Sukkur—*vide* Appendix I. **Fig. 7/8.**

(*b*) *Omission of Sand cores.*

Sand cores have generally been provided where this could be done economically; but it, should now be done wherever the cost is not prohibitive.

(*c*) *Wetting the bunds.*—

Where there are sand cores, wetting trenches are not so essential; but this year's experience—when breaches occurred where there was 7 ft. freeboard—shows the great importance of wetting, and that increased freeboard is not an alternative. Much greater care must, therefore, be taken, in future, to lead water along bunds by cuts in the river lip and by wetting trenches.

(*d*) Though every step possible should be taken to prevent leaks, they cannot be entirely eliminated, and the last line of defence will always be *unremitting inspection by adequate, trained staff.*

PART V.

Technical analysis of available data regarding the rise of water levels in the past and to be anticipated in future.

The order in which I will deal with the water level data in order to analyse it, is—

(*i*) Natural rate of rise of water levels;

(*ii*) Gauge readings at Bukkur since 1849;

(*iii*) Gauge readings for specific discharges at Bachalshah (just downstream of the Barrage) from 1919-42; and

(*iv*) Specific discharge guage curves at seven Stations between Bachalshah and Machka.

(*i*) *Natural rate of rise of water levels.*

Before dealing with the more recent Guage Readings, I will consider evidence regarding the rate of rise of water levels since the days of Mohan jo Daro—some 5,000 years ago. I am informed that the rise of water level has been some 30 ft. in that period, during which the river has swung backwards towards the east, and forwards towards the west on many occasions; so that the rise has been an average rise over a wide stretch of country. If this rise were translated into terms of riverside rise between embankments it would be much more—in my opinion at least double—but at any rate we can say that the rise was of the order of one foot per 100 years. This figure has been accepted as a fair figure by the Chief Engineer and Secretary to Government, Public Works Department, Sind—Mr. Hawes—and Prof. Pithawala, D. Sc., who has made a deep study of the Indus from the Geographer's viewpoint (1) and (2).

(*ii*) *Gauge Readings at Bukkur.*

Bukkur Gauge, which has been observed since 1849, is situated on Bukkur Island at the entrance to the larger, left-bank, channel of the Gorge, opposite Rohri town. (*See* photo 6).

Photo 6

It will be seen from Figure 9 that in 1849 the maximum gauge reading at Bukkur was 12 ft. and that it was only 12.25 in 1861, when a very high flood occurred, details of which have been given by Mr. N. M. Billimoria in an interesting article published early this year in the *Daily Gazette*. The reason why the Bukkur Gauge was not higher in 1861 than in previous years was because excess flood water spilled over the country. After 1861, the maximum annual Guage at Bukkur showed a rising trend, but was still only 13 ft. in 1872; but what is important to embhasise here is that the only clear-cut rise in water levels which took place at Bukkur between 1848 and 1924 was some 3 ft. between 1861 and 1882, most of which occurred in 10 years between 1872 and 1882. This rise synchronised with the period during which old river embankments were improved and new embankments constructed on both banks of the river above Sukkur. This, by stopping spill, caused a marked rise in water level, and increased deposition on sand banks and berms—which, in turn, led to a further rise of water levels—but this rise was followed by a long period of slight improvement, during which new condition of flow between embankments became established.

It is important to note—for reasons that will be apparent later—that prior to the construction of the embankments, the year to year fluctuations in maximum flood levels were small; whereas after the embankments had been built, the year to year fluctuations increased and have continued to increase as a result of deposition of silt and sand on islands, sand-banks, and berms. This indicates that the river is now contained within its banks with larger discharges than hitherto and, as a consequence, the rise of water level has increased, especially for medium floods. Despite this—indeed on account of it—the bed of the main river channel scoured from the time the bunds were built till the construction of the Barrage, and minimum water level at Bukkur did not rise; but had showed a slight, but quite definite, fall.

(*iii*) *Trends in the relation between specific discharges and corresponding' guage readings at Bachalshah* (1919-42).

Though Bachalshah guage is situated just downstream of Sukkur Barrage; yet it is the best Guage for indicating conditions just above the Barrage. Guage readings have been observed at this guage since 1919.

It is situated where the river is still narrow, and is flowing nearly axially; so that variations in guage due to curvature effect, are very small for dischrges in excess of 100,000 cusecs.

The great value of Bachalshah Guage is that it is not affected by ponding above the Barrage, as is the case at Outfall, Bukkur, and the head of Sukkur Canal.

It may be wondered why Bachalshah should indicate the effect of the Barrage on upstream conditions. The explanation is that during high floods (when there is little heading-up (afflux) at the Barrage, silt which has accumulated by deposition upstream during long periods of ponding, is scoured through the Barrage during the relatively short periods when the gates are fully open. Under these conditions, there is a supercharge of material in movement for the slope available downstream, so deposition takes place downstream of the Barrage. Consequently, though this is a measure of the rate of deterioration of the river just downstream of the Barrage; yet this deterioration affects, and hence indicates, conditions upstream of the Barrage, which cannot be obtained from upstream gauge readings except for discharges exceeding 4 lakhs—and floods of this magnitude have been a rare occurrence of recent years, and even when they have occurred, have been of short duration.

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(1) A geographical analysis of the Lower Indus Basin.

(2) Settlements in the Lower Indus Basin (Sind) and other papers.

When the Barrage gates were first closed in 1932, ponding was considerable, and large quantities of silt and sand deposited several miles upstream of the Barrage, even during the early part and end of the Abkalani (flood season). Only a part of this accretion was subsequently scoured away when the gates were fully opened during the high flood period; so that the charge of material in movement through the Barrage was considerably less than previously; with consequent retrogression of water levels at Bachalshah during 1933 and 1934 (*see* figure 10): but this relief was short-lived, and since 1935 the rise has been rapid. Fig. 10.

It will be seen that a somewhat similar drop in specific discharge guage readings occurred in 1925— which was followed by a steady rise from 1926-32. It has been suggested that this drop in 1925 might have been due to a 'good river' in 1924. This belief that a good river in one year is followed by lower specific discharge gauges the following year is widespread; but Figures 11/1 and 2 show no significant relationship and the same result was obtained when specific discharge gauges were compared with averages of 50 maximum dischairges of previous years at Sukkur. It was also thought that though a single good year might not have this effect yet a series of good years might bring out such a relationship; so Mr. Panchang tested this statistically; but no such inverse relation could be found. Hence, the temporary imrpovement in 1925 must have been due to some other disturbing factor. There seems to be little doubt that the improvement in gauge resulted from the banks between Bunder and the Barrage having been faced with stone pitching. The temporary effect of this would be to cause a deep channel to form along the left, concave, bank—which would persist downstream and cause a flattening of the gradient, and hence a lowering of specific discharge gauges. This is actually confirmed by river plans. Figs. 11/1 and 2

This improvment disappeared as soon as the stone facing got covered with silt, and during the period of construction of the Barrage, when large coffer-dams were constructed, so that foundation work could be done in the dry, these obstructed about 1/4th of the river width, so conditions deteriorated rapidly. This was followed by marked retrogression during 1933 and 1934—after completion of the Barrage—; since when the rise has been rapid. The 3 periods 1919-24, 1925-32 and 1934-42 have been dealt with statistically—*vide* Statement I and figure 10, which show that there was no trend between 1919 and 1924; but that the rises between 1925-32 and 1934-42 were highly significant, statistically. Fig. 10 and Statement I.

STATEMENT I.

Trend studies of specific discharge gauges at Bachalshah.

Equation type: Specific Discharge Gauge= A+ B $(t-\bar{t})$ where t stands for any individual year in the Christian era.

Period under considera-tion.	Specific Dis-charge (lacs cusecs) R=rising F=falling.	$\bar{t}$	A Mean gauge over the period.	B Annual trend +for rise, − for fall.	"Standard Deviation" or measure of deviation from trend value.	Significance of B value.
1919 to 1924	1 R	1921·5	188·02	·0200	·42	Non-significant.
	2 R	,,	190·62	—·0029	·80	,,
	3 R	,,	192·28	·2657	·85	,,
	4 R	,,	193·63	·2457	·71	,,
	1 F	,,	187·68	—·0143	·70	,,
	2 F	,,	190·33	·2114	·45	,,
	3 F	,,	192·42	·2086	·16	††
	4 F	,,	193·88	·2029	·61	Non-significant.
1925 to 1932	1 R	1928·5	186·99	·3417	·43	††
	2 R	,,	189·94	·2869	·18	†††
	3 R	,,	191·60	·3214	·35	†††
	4 R	,,	193·91	·3607	·52	††
	1 F	,,	187·51	·3107	·64	†
	2 F	,,	190·04	·4536	·25	†††
	3 F	,,	191·60	·4476	·51	††
	4 F	,,	193·08	·4452	·66	††
1935 to. 1942	1 R	1938·5	187·525	·5333	·45	†††
	2 R	,,	190·750	·4071	·26	†††
	3 R	,,	192·56	·3750	·37	†††
	4 R	,,	193·96	·3202	·39	††
1934 to 1942	1 F	1938·0	188·40	·5433	·546	†††
	2 F	,,	191·30	·3683	·404	†††
	3 F	,,	193·04	·3567	·436	†††
	4 F	,,	194·23	·2800	·523	††

1919 - 1921

† denotes significance at 5 per cent. level.
†† denote significance at 1 per cent. level.
††† denote significance at ·1 per cent. level.

The fall in 1925 and the subsequent rise between 1925 and 1932 is of no importance in this enquiry—except to show that it had a physical significance—; but the rise after completion of the Barrage is of great importance, and if water levels were to continue to rise at the same rate, the future would be very serious indeed. Fortunately, however, it is not so bad as may seem at first sight—for ~~two~~ several reasons two of which are—

(1) As already explained : when the Barrage gates were first closed, much of the silt deposited in low portions of the area covered by the ponded water ; and much of this deposit became permanent. This was followed by deposition of material at points from which it could be scoured when the gates were opened ; but as the process continued the material already laid down above the Barrage consolidated and we may anticipate that as the pond gradually extends further and further upstream, material subsequently deposited in reaches further from the Barrage will be less and less affected by draw-down, and hence will be less subject to scour during periods when the Barrage gates are open during high floods ; Consequently, the rate of rise of water level at Bachalshah will gradually decrease ;

and (2) As more and more material is deposited downstream of the Barrage—*i.e.* as the Guage Readings at Bachalshah rise for specific discharges—the shorter will be the period during which water has to be headed up at the Barrage ; and hence the less ponding will there be ; and consequently the less deposition of silt will there be, and the longer the period during which the gates will be open to move the material downstream of Bachalshah. Consequently, for this reason also, the rate of rise of the bed at Bachalshah will gradually decrease.

As a result of these two factors, a condition must eventually be reached when the rate of rise of water levels at Bachalshah will be identical with the pre-Barrage rate of rise.

Note.—Rao Bahadur Joglekar has workd out figures in this connection and has found that had the pond level at the Barrage not been raised above R. L. 194·5 in 1942—*i.e.*, had the designed level contemplated in the Project been adhered to—the Barrage gates could have been kept fully open when the river discharge at Outfall was 3,00,000 cusecs. He has also found that when the water level downstream of the Barrage rises a further 2 ft., the gates can be kept fully open with a discharge of 200,000 cusecs" and when the water level rises still further, to 4 ft. above 1942 level, the gates can be kept fully open when Outfall discharge becomes 1,40,000 cusecs. When this stage is reached, deposition due to ponding will be very small.

2. *New factors which will affect the rate of rise of water levels at Sukkur.*

(*i*) constructing Bhakra and other dams in the Punjab,

and (*ii*) constructing an Upper Sind Barrage.

It is often argued that, in accordance with Lacey formulas, a permanent reduction of river discharge requires a steeper slope ; and that, as a consequence, the river must shorten, and straighten, its course. This would undoubtedly be true if the only factor affected by constructing a dam were discharge ; but actually several changes take place, and the problem is highly complex ; so it must be dealt with by considering each factor, one at a time. Before doing this, I had better explain that the major cause of trouble in Sind results from meandering, which is dependent on sand-charge.

We have found at Poona that meandering occurs wherever the charge exceeds what can be carried by the discharge with the slope available. Where this is due to an excess of material having been washed into a river, it is called 'primary meandering'; but where it is due to local scour—resulting, for instance, from a cut off, which increases the charge locally, ~~so that~~ the slope downstream is flatter than that required to carry the increased charge and 'secondary meandering' occurs. Thus, primary meandering is the direct result of an excess charge entering the river ; and secondary meandering is the *indirect* effect of local excess slope.

Other factors remaining the same, we know that—

(*a*) an increase in grade, charge remaining the same, requires a corresponding increase in slope ;

(*b*) an increase of charge, grade remaining the same, also requires a corresponding increase of slope ; but this is complicated during the period of change (and possibly afterwards) by the fact that an increase of charge leads to primary meandering and may lead to the river splitting up into two or more channels ;

(*c*) an increase of discharge—charge and grade remaining the same—or alternatively a decrease of charge or grade—discharge remaining the same—will lead to retrogression and straightening in the length where the retrogression is taking place. Downstream of this, there will be increased meandering in a limited length ; and further downstream, conditions will differ little from previous conditions assuming the discharge remains the same.

Assuming this, and that the altered conditions persist, retrogression will progress gradually downstream.

All this is assuming homogeneous material in the bed ; but, as material exposed by scour generally increases in coarseness with increasing depth, the slope required immediately downstream of a dam may actually exceed the original slope, as is the case downstream of Boulder dam on the Colorado River in U. S. A. (1).—Further downstream, the slope must, however, be flatter than before. In this length, retrogression will be less and the material more homogeneous, making this possible.

To sum up : A new dam causes ponding, which throws down bed material at the upper end of the lake and caused much of the material in suspension to deposit where the velocity in the storage drops below that necessary to keep the material in suspension. Consequently, less material in suspension and no bed material passes through the dam. As a result, the energy, hitherto utilised to carry the charge, is set free, leading to increased turbulence. Retrogression therefore extends rapidly downstream—about 14 miles a year in the case of Boulder Dam—. Subsequently, retrogression extends more gradually, until eventually the effect must, in the case of an alluvial river, reach the sea. Each tributary stream is also affected ; because the lowering of water levels in the main stream at their junctions causes 'draw down' and hence increased scour and retrogression, which will work upstream the tributary unless prevented by a barrage, weir or rockbarrier. This type of retrogression, the late Mr. H. W. Nicholson of the Punjab called 'sympathetic retrogression'.

(1) Seventh Annual Report on "Retrogression observations...... Colorado" of U. S. Depot, of the Interior Bureau of Reclamation River Basin by J. W. Stanley, July 1st, 1942.

Retrogression occurs in a river in spite of the fact that with a storage added, peak discharges are flattened out by flood absorption, so that the 'dominant discharge' is reduced. A dam, therefore, acts in two different ways:—

(a) it reduces the 'dominant discharge.

and (b) it reduces the charge,

(a) tends to reduce meander length and breadth; and, other things being equal, to increase the slope;

(b) tends to straighten the channel and flatten the slope down to the point where retrogression ceases to be appreciable.

The total effect is a straightening, and shortening ~~and flattening of the slope~~ of the channel, and a reduction of meander length and breadth. ~~down to the point where retrogression fades out~~.

(ii) *the effect of constructing an Upper Sind Barrage on water levels lower down.*

It is the present intention to keep the Upper Sind Barrage open except in the kharif season from 1st April to 30th October. In that case, the changes brought about will be much less and will take much longer than at Sukkur.

The first effect will be to cause retrogression downstream, which will be followed, within a year or two, by accretion—due to the amount of material washed through the Barrage during periods when the gates are open exceeding what the downstream slope and discharge can carry away during periods when the water is clear. We thus have the apparent anomaly that though the total quantity of material which passes through a Barrage is less than what passed down the river before its construction, yet accretion occurs.

The explanation is that during periods when the gates are open, the charge is excessive—due to upstream scour—and subsequent low discharges are insufficient to remove this ever-consolidating deposit.

The Upper Sind Barrage will cause some rise in water levels both upstream and downstream; and this rise will progress slowly downstream. This slight rise will be unfavourable along the Kashmore Bund; but as deposition at this point will reduce the quantity of bed material passing down the river—which will tend to make the river straighter and reduce the rate of rise of water above Sukkur, where the danger is greatest, constructing the Upper Sind Barrage will, on the whole be favourable—especially if built near the left bank, as I recommend, to move the river axis away from the Kashmore and Sukkur- Begari Bunds.

The great difficulty in estimating probable rate of rise of water levels between the Upper Sind Barrage and Sukkur is the lack of data as to the rate at which such changes have taken place under similar conditions.

I can find no data for the rate of accretion downstream of a Barrage except at Sukkur and Bachalshah guage—about 1 mile downstream of Sukkur Barrage—is the only gauge for several miles downstream of Sukkur. A new Gauge is now being fixed about 10 miles downtream of the Barrage, which should in time, give valuable data.

Upstream of Sukkur Barrage, there are Guages at Outfall, Bukkur and Old Sukkur Canal Head (all close above the Barrage) and also at

Rijib Canal Head	..	23	miles upstream of Barrage.		
Satabani Loop	..	32	,,	,,	,,
Begari Head	..	53	,,	,,	,,
Unharwah	..	61	,,	,,	,,
Sarhad	..	70	,,	,,	,,
Machka	..	98	,,	,,	,,

Specific discharge: gauge relations for these Guages have been plotted one above the other according to their R. L.s. and are shown on Figures 12/1 to 3. Figs. 12/1 to 3.

Satabani Loop Gauge has given such divergent results from year to year that it cannot be looked on as at all reliable or helpful. Begari Head readings show that the rise at Sukkur has not begun to affect it. Rajib Head showed a rise with low discharges up to 1936 but no further change after 1936; and for 400,000 cusecs the change is small up to 1941—the last year for which I have received data.

This data, taken as a whole, does not, therefore, give any significant information and though I have tried to get data from other parts of India to throw light on this subject; I have so far failed.

In this predicament, I asked Mr. Panchang—Statistical Officer of the Development and Research Division, Sind, to investigate the quantity of silt in suspension at Sukkur and Kotri since 1913.

Figure 13 and Statement II (relation expressing dependence of silt charge on discharge) show a high correlation both for the period up to 1930 and after 1930 and it is also clear that the silt charge was markedly less after the construction of the Barrage. This data was also considered from another angle, as shown in Figure 14 in which the discharge and average charge per cubic ft. have both been plotted against years. It will be seen that the relation between discharge and time was not significant either for Sukkur or for Kotri; and that the average charge per cubic ft. was not significant prior to 1930 at Sukkur; but was significant to 1 per cent. level after 1930 and showed a marked drop with time. In the case of Kotri, on the other hand, there was a slight significance between charge and time prior to 1930; but no significance after 1930. The slope after 1930 was similar to that before 1930. This is in accordance with what was to be anticipated; because though the water was clearer downstream of Sukkur than before the Barrage, the river picked up its natural charge again before reaching Kotri—indeed it actually slightly increased its relative charge due to the river being contained for a longer period of the year inside its banks. Fig. 13 and Statement II. Fig. 14.

STATEMENT II.

(*a*) Relations expressing dependence of Qs. on Q.

Site.	Period.	Expression for Qs.	Stand. Devn. σ	Percentage co-efficient of variation.	Remarks.
Sukkur	1913-30	·002202 Q.—114·65	51	8·70	†††
	1930-42	·002182 Q.—187·42	64	14·72	††
Kotri	1913-30	·003065 Q.—275·48	49	8·85	†††
	1930-42	·001858 Q.— 23·00	48	12·00	†††

(*b*) Trend studies of Daily effective Discharge (Q) based on 183 days of the Abkalani (April—September) season; and silt quantity (qs.) in grains per cft. discharge at Sukkur and Kotri.

Equation type: Item (studied) = A plus B t. where t stands for the serial number of years with the initial year counting as 1.

Item (studied).	Period.	A	B annual rate of falling trend.	Standard deviation or measure of deviation from trend values.	Percentage co-efficient of variation.	Remarks.
			Sukkur.			
Discharge (in cusecs) ..	1913-30 ..	345856	—2917·5	38283	12·03	
	1930-42 ..	300434	—2364·4	36520	12·86	
Silt quantity (grains /Cft.) ..	1913-30 ..	1286	—6·87	105	8·61	
	1930-42 ..	1215	—29·91	99	9·84	††
			Kotri.			
Discharge (in cusecs) ..	1913-30 ..	288663	—1936·3	38685	14·31	
	1930-42 ..	257929	—4325·0	34881	15·32	
Silt quantity ..	1913-30 ..	1503	—16·64	127	9·48	†
	1930-42	1266	—14·14	118	10·15	

†denotes significance at 5 per cent. level.
††denote significance at 1 per cent. level.
††† denote significance at ·1 per cent. level.

This leads on to the question " has this reduction of volume of silt at Outfall (Sukkur) been wholly due to the Barrage or has it been partly due to less silt coming down from the Punjab ?"

The only Punjab data available regarding silt charge is from Kalabagh, just downstream of Attock Gorge on the Indus. The bed at that point consists of boulders and pebbles; so that it is not comparable and the data is also only available for one year.

There is reason to believe that there may be a small progressive reduction of silt entering Sind but even if this were the case, the first tendency under such conditions would be for the river to take up more silt by straightening its course; and though a reduction of silt upsteam must gradually affect the river downstream, this is a slow process and I am satisfied that the marked reduction of silt at Sukkur since the construction of the Barrage has been mainly due to afflux at the Barrage.

Conclusions to Part V.

I have put all my cards on the table, stating clearly where we can predict with accuracy and where we have little information to help us, so must rely on experience and judgment, what the Sind Government require, however, is a clear-cut statment of what is likely to happen and the time within which the chagnes may be expected to take place; so I give below my considered opinions:

(*i*) Specific discharge guages for floods up to 600,000 cusecs above Sukkur are likely to rise a further 2 ft. within the next 15 years and a total of 4 ft. within the next 50 years. This is likely to be the limit of rise due to the Sukkur Barrage.

(*ii*) The progressive rise at Sukkur will extend upstream at a rate which may be 2 miles a year at first and gradually slow down to a mile a year later.

(*iii*) The rate of rise after the pond effect first reaches a point will be affected both by the width of the river at the point and the distance it is uptsream of Sukkur Barrage. These two factors will act in opposite directions; so, for simplicity, I will assume that they cancel out; and, to err on the side of safety I will assume that the rate of rise after the pond effect reaches a point will be the same as the future rate of rise of specific discharge guages at Sukkur.

(*iv*) The rate of rise downstream of the proposed new Upper Sind Barrage will be considerably less than at Sukkur, due to the Barrage being kept open from November to the end of March or longer. This rise at the New Barrage will progress slowly downstream. There will be as light retardation in the rate of rise above Sukkur as a result of this Barrage.

(*v*) Dams constructed in the Punjab will reduce the peak discharge downstream, and will also reduce the 'dominant discharge' and hence will tend to reduce the rise of meanders. The reduction of bed material passing through the dam will also, eventually, have a beneficial effect in Sind.

(i) Assuming Barrage regulation and river conditions are similar to these up to the end of 1946, specific discharge gauges at Sukkur for a flood of 5,00,000 cusecs are likely to rise a further 2ft. within the next 15 years and a total of 4ft. within the next 50 years.

(*vi*) Additional Barrages in the Punjab will have two effects:

(*a*) They will throw down a limited amount of sand both upstream and downstream; but this accretion will be much less than in Sind—where slopes are flatter and material finer;

and (*b*) exlcuding and ejecting coarse material from the canals into the rivers, will throw down bed sand and cause primary meandering in the Punjab; with resultant further deposition upstream and downstream. I do not anticipate that this can affect Sind for many years; though eventually it must tend to set off the advantages resulting from dams.

Taking all these effects together, we may anticipate that, *without additional dams or Barrages* or special measures to retard the rise.

(*a*) a 2 ft. rise in specific discharge gauges at Sukkur is likely to occur in 15 years and 4 ft. in 50 years;

(*b*) 25 miles upstream, we may expect a 2½ ft. rise in 25 years and a 4 ft. rise in 60 years;

(*c*) 50 miles upstream we may expect at 2½ ft rise in 40 years and a 4 ft. rise in 80 years;

(*d*) 75 miles upstream we may expect a 2½ ft. rise in 60 years and a 4 ft. rise in 100 years.

If the proposed Upper Sind Barrage is constructed—

(*e*) the rise just upstream and downstream may be 2 ft. in 25 years and 3 ft. in 50 years. This may work downstream at ½ a mile per year to meet the rise due to the Barrage. The effects will not be super imposed.

(*f*) the further rate of rise upstream of Sukkur will be slightly reduced; and if the Barrage is completed 15 years hence—

(*i*) the rise at Sukkur thereafter might be reduced 1 ft. in 35 years—*i.e.*, a rise of 3 ft. in 50 years from now—and a total rise of 4 ft. in about 100 years, compared with 50 years without it,

and (*ii*) 50 miles upstream of Sukkur we might expect a 1 ft. rise 25 years after the Barrage is constructed, or 50 years from now.

If dams are constructed in the Punjab, the main effects will be—

(*g*) (*i*) The peak floods, and hence the peak guage readings at Sukkur will be reduced by flood absorption in the dams and rivers.

(*ii*) The dominant discharge will become less and so the river will tend to straighten and meandering will decrease.

(h) "If the retention level upstream of Barrage can be kept 1 ft. lower than hitherto during the period when silt is depositing, these figures may be reduced by 1 ft. and if for part of the time by a lesser amount."

PART VI

Conclusions and recommendations

When I agreed to write this Report, it was on the distinct understanding that it would be resricted to technical points and that I would not have to apportion blame, but a few points require emphasis:

(*i*) A long series of low flood seasons had prevented staff from getting experience of breaches and had lulled people into a false sense of security.

(*ii*) In days gone by, when officers had much more time to devote to bund inspection than they have to-day, and low-paid staff were adequate and contented, marvels of bund protection were achieved. Thus in 1929, bunds which were overtopped by as much as a foot were 'held' by sandbags and small 'banas' built on top of the bunds; but now-a-days, officers have to spend much more time on canal work and interviews, and a generation of officers is growing up, many of whom do not like touring or tramping for miles about the countryside to see things for themselves. What is perhaps even worse has resulted from the cheese-paring policy adopted of late years by the Sind Government regarding establishment. Economy in Bund and Canal maintenance has led to a gradual reduction and deterioration of staff nucleus; so that trained personnel are not now available in adequate numbers for work in the flood season. Truly, this has been a penny-wise, pound-foolish policy, which must be reversed.

(*iii*) It is inevitable that river flood-levels will rise; and as they rise, the danger of breaches, and the damage resulting from breaches, must increase. Consequently, the margin of safety considered adequate before the Barrage was built, is not sufficient now.

2. We have got to face the fact that there is the threat, indeed the certainty, that an avulsion will occur in Sind at no far distant date unless adequate steps are taken to prevent it.

Figure 6 which is a contour map of the whole of Sind (except Khairpur State) shows where the danger will be greatest in years to come. Serious breaches can only occur where there is a natural drainage line through which flood waters can develop a deep channel. These are:—

(*i*) near Kashmor on the Right Bank whence a depression runs along the toe of the Bakti Hills north of the Railway from Kashmor to Jacobabad;

(*ii*) along the Sukkur-Begari Bund, where the 1942 breach occurred;

(*iii*) along the left bank opposite Kashmor down to south of Ghotki;

(*iv*) along the Kasimpur-Nabishah Bund north of Rohri;

(*v*) near Larkana;

and (*vi*) near Hajipur, the proposed site of the South Sind Barrage, some 16 miles south of Hyderabad.

The first two are the most dangerous points; because the slope away from the river is greatest and also because they are situated upstream of Sukkur Barrage where the rate of rise of water levels is greatest.

3. The probable rate of rise of water levels is dealt with in detail in Part V. The prospect is far from re-assuring; but the rate of rise shown there probably gives an impression that conditions will deteriorate more rapidly than will actually be the case—for two reasons—

(*i*) flood discharges have been decreasing and will continue to decrease gradually as additional Barrages and dams are built,

(*ii*) the rate of rise of water levels can be, and must be, slowed down.

Regarding (*ii*): The pond level above the Barrage should henceforth be maintained as low as possible, taking into account irrigation requirements. The importance of this was pointed out more than a year ago, and it is now being acted on; but the success of this depends largely on lowering Full Supply levels at the heads of canals. The Rohri and Eastern Nara Canals, on the left bank, are scouring; so present no difficulty, but very heavy silting began to occur in the Right Bank Canals in 1938. The problem was referred to the Poona Station and, after model experiments, an entirely new method of sand exclusion, by means of a curved approach channel, was recommended. This was completed before the 1941 flood season. (1) The outstanding feature of this design is that it works with no additional head above that required at the Barrage.

After the approach channel was completed, the North-Western and Dadu Canals at once improved the accumulated sand banks in these canals being washed away; but, though the bed of the Rice Canal also scoured by some feet in the head portion, yet sand remained on its bed below mile 54. When the Rice Canal was breached by flood waters in July 1942, a very large discharge—probably more than 16,000 cs. compared with a designed Full Supply discharge of 10,278 cusecs—flowed down this Canal, and the Fall at R. D. 191,000 disappeared—probably breaking up, and sinking into the scouring bed. As a result, water levels downstream of the Railway Bridge near Ruk, at R. D. 75,000, will hereafter be some 2 ft. lower than before, and we may confidently anticipate that sand-waves in the canal downsstream of Mile 54 will now be washed away to below designed bed level. This lowering of the water level in the Rice Canal though beneficial in this way, has led to a scour-hole forming at a point 170 ft. downstream of the Railway Bridge. This scour-hole was 37 ft. deep—*i.e.*, 17 ft. below pier foundation—but the danger to this bridge has now been eliminated, in accordance with proposals made by the Poona Station, confirmed by model experiments. This being the case, we may anticipate that all the large Sukkur Canals will hereafter be run at, or below, designed Full Supply Levels; and by lowering supply levels in the Khairpur Canals, pond levels at the Barrage can hereafter be kept down to, or below, designed levels until the river rises on account of increasing flood discharges.

4. As already explained, attack along the Sukkur-Begari Bund can be somewhat reduced by building the proposed Upper Sind Barrage near the left bank of the river; but what is far more important is to 'centre' the river just upstream of the Barrage. There are several possible methods of doing this and I recommend that experiments be taken in hand at once at Poona in this connection.

5. The design and maintenance of bunds has been dealt with in great detail in the Bund Manual and Appendices I and II of this Report, so I need say no more here, except that I am in full agreement with the proposals in Appendices I and II, most of which were discussed with me before the Appendices were written. I suggest, however, that a double line of defence should be provided wherever practicable.

6. I suggest that the time has come when a Monograph should be written on predicting water levels along the river and at Canal heads based on data supplied by Punjab and Sind Stations. Many Officers have made a deep study of this question, but none has put his knowledge and experience on paper.

7. Additional carefully-placed Guages are required on both banks upstream and downstream of the Barrage—to trace the rate of rise of water levels.

8. The preparation of an apparatus for measuring the quantity of bed material in movement—a matter of vital importance—is long overdue. A suction type apparatus, which is the only type likely to give useful results, has been proposed by me year after year. Obviously such an apparatus presents considerable practical difficulties, yet the measurement of bed movement is of such great importance that these must be overcome.

9. The time seems to have come when at least one set of 'bulldozers' and 'scrappers' (*i.e.*, mechanical means for moving material quickly) should be maintained for rush jobs.

10. I am definitely of opinion that dams at the heads of rivers will be advantageous to Sind, in that they will reduce bed material in motion and will also reduce the 'dominant discharge' and hence the size of meanders. There seems to be an idea that though dams will reduce normal floods, they will not reduce peak discharges. I do not share this view. In the case of large dams, outflow is considerably less than inflow, and by delaying run-off, they also increase the river's flood-absorptive capacity. I may add that *the cause of both meandering and high river-levels is too much sand, not too much water.* Indeed if we only had to deal with water, the problem would be simple. Consequently, dams, levelling, terracing, and even barrages are all advantageous to Sind—provided, of course, they do not interfere with water supplies and supply levels.

11. I have already emphasised in Part III, how much has already been done in Sind in connection with control of the Indus; but much more must be done in future if a major catastrophe is to be averted.

12. On my first visit to inspect the breaches, I suggested that all river work should be centralised under one officer. For this work, I consider a Chief Engineer is essential; and his work should be mainly confined to Canal Headworks, Barrages and River Control in all its forms.

(1) See Central Irrigation and Hydrodynamic Research Station Annual Reports (Technical) 1938-39, 1939-40, 1940-41 and 1941-42.

Central control will effect some economies, in that staff and materials can be moved from places where no immediate danger threatens to places where an attack is likely to develop. This Officer should make a much deeper study of river movements than has been attempted in the past.

13. Finally, I am of opinion that river guaging should be made a Central subject, one of the questions which should be dealt with by an Inspector-General of Waterways. This is especially necessary in the case of the Indus; because its gauging and control is of vital interest to 3 Provinces and several Indian States.

I would like to convey my thanks to Mr. Hawes, Chief Engineer and Secretary to Government Public Works Department Sind, for providing me with everything I required, and also to Mr. K. K. Framji, who had to produce the data. Mr. Panchang's help on the statistical side was most useful.

I regret the considerable delay which has occurred in submitting this Report, but a great deal of study of maps and analysis of data—much of it not even mentioned in this Report—was necessary, and the Report had to be written in addition to all my other duties.

I realise that much of the Report—especially Part V— will be almost unintelligible to those who have not studied meandering and the complexities of flow of sand and water in open channels; but I hope that the conclusions arrived at are clear-cut.

C. C. INGLIS,
Director, Central Irrigation and
Hydrodynamic Research, Station.

APPENDIX I.

Suggestions for additions to and alterations in the Bund Manual.

1. *Saturation gradient*:

Saturation gradient of 1 in 6 may be continued to be adopted.

It is not practicable to specify different saturation gradients for different soils, but where the saturation gradient can actually be measured from H. F. L. in front and percolation level of the downstream face, this should be done, and the bund re-designed for the flatter saturation gradient, by the provision of a rear berm.

2. *Cover*:

Minimum cover of 4 feet should be provided everywhere over the assumed saturation gradient line of 1 in 6 by the provision of rear berms or flatter rear slopes; a rear berm being generally preferable.

3. *Design of low bunds*:—

For low bunds (up to 8 ft.) the rear slope should be designed to give cover of 4 feet with the saturation gradient of 1 in 6 and the front slope may be flattened to 1 in 3 where wave-wash is feared.

4. *H. F. L. to be adopted for designs.*—

The designed H. F. L. should be 2 feet higher than the recorded maximum in Upper Sind (Right Bank) 1 foot higher than the recorded maximum in Upper Sind (Left Bank) and for the reach Sukkur to Kotri, and the recorded maximum H.F.L. below Kotri. The 4 ft. free-board and the designed saturation gradient should be provided from this designed H. F. L. Diaphragm walls and sand cores should have their tops 1ft. above the designed H. F. L. In the case of a sand core the lower edge of the sand core should be 1 ft. above the designed H. F. L.

5. *Top width.*—

The standard top width of bund is 8 ft. widened to 12 ft. In case where composite side slope is not desirable the top width maybe kept 12 ft. and the section drawn in accordance with the cover and saturation gradient specified above.

6. *Rear Berm for Trench Bunds*:—

Rear berms are necessary even where wetting trenches are provided. In such cases saturation gradient should be taken from the point where the designed H. F. L. cuts the main, and not the wetting trench Bund.

7. *Cross and Ring Bunds.*—

Cross Bunds should not be allowed as they are a source of great danger in emergencies.

Where villages need to be protected, ring bunds of full bund section should be provided but the top width may necessarily be 8 ft.

8. *Sand Core.*—

A sand core is generally preferable to a diaphragm wall.

The following method of making the sand core may be adopted as it will render the sand less likly to be mixed with earth during construction. The land side portion of the bund is first raised 1 ft. above H. F. L. the back slope being according to specifications and the front undressed to about 1½' to 1'. A layer of sand should then be dumped at the foot of the front slope to a height of 1½' with a top width of 4½ ft. As the front slope of the sand will be about 3 to 1, the width of sand layer will be about 6½ft. In front of the sand, earth is now spread to make up the bottom width of the bund to a height of 1 ft. thus leaving the sand 6" higher than the earth. Another layer of sand 1 ft. deep is now piled on the sand core and the earth in front is also raised by a foot. The work thus proceeds in one foot steps, the sand core being always at least 6" ahead of the earth filling. The sketch attached. shows the method of sand core and the finished bund. Sand core will be taken up to 1 ft. above the designed H.F.L. and thereafter the bund is completed in the usual way. The minimum width of sand core will be 5 ft. and maximum 6½'.

In cracked soil and dhoro crossings the key trench should be excavated to at least 5 ft. below ground level and filled *with pure sand*.

In existing bunds where sandcoring is proposed, the steepest slopes at which the sides of the excavated trench will stand should be determined and sand core provided accordingly. But if, in spite of this, sides slip during excavation, all the debris should be carefully removed, and the full width of the trench filled with pure sand. In no case should a trench be allowed to be excavated unless arrangements exist for filling it in time with sand. In contracts for sand coring it should be made clear that the contractor will be required to fill in any excess excavation with pure sand at his own cost.

The lowest edge of the sand core should be, everywhere, at least 1 ft. above the assumed H. F. L.: figure 5 on Plate I of Bund Manual should be corrected accordingly.

9. *Allowance for settlement.—*

A shrinkage allowance of 1½" per foot height of bund in ordinary soils and 2" per foot in kalar soils must be made during construction. If the bulkage from the borrow pits is believed to be insufficient to permit of the extra quantity required for this shrinkage allowance, the extra provision should be made in the estimate.

10. *Fencing on bunds.—*

Public traffic should orinarily *not* be allowed on bunds.

In specified places it may be allowed on the rear berm where the country along side is flooded

11. *Alignment of bunds.—*

The procedure laid down in the Bund Manual is satisfactory. Bunds must never be taken into lower lands to avoid any village or piece of cultivation.

12. *Flooding compartments.—*

It is the responsibility of the local Excutive Engineer to flood the compartments whenever required. The Superintending Engineer is responsible for approving of proposals for flooding compartments.

13. *Loop Bunds.—*

It is desirable to obtain a formula to assess the likely penetration of erosion. This will automatically fix the necessity of loops and enable erosion to be forecasted.

14. *Retired Loops.—*

Plans and estimates for retired loops must be prepared when the minimum distance of the river edge from the bund is 3,000 feet. This would ensure that there is no delay in commencing work when the river comes within 1,500 feet of the front bund.

No gaps should be left for masonry works at crossing of channels in retired loops to save the cost of a sluice. Either the gap should be filled in or a sluice should be constructed.

15. *Best way of wetting Bunds.—*

In case of important bunds, wetting trench bunds must be provided and the Bund wetted by pumping in advance of the rise of river levels. This is essential in case of loop bunds. But this is also necessary in case of front bunds (such as the Sukkur-Begari Bund) where the stakes are so high, *unless* a front berm has been provided and arrangements for early wetting direct from the river exist.

But whether a wetting trench and pumps exist or not, special steps must be taken in all cases for leading in water to the front bund by cutting the river lip wherever it is higher than the land at the site of the bund or by constructing low-level wetting channels.

16. *Wetting loops and filling compartments.—*

It is essential to have sufficient discharging capacity in sluices for filling compartments. The wetting should be done gradually, so as not to strain the loop bunds unnecessarily. The necessity for early wetting in order to be prepared for the maximum level should also be borne in mind.

Where low level wetting trenches exist, these should be re-sectioned to enable pumping up to the H. F. L. to be done. Small longitudinal trenches may be dug for wetting by buckets or earthen jars or Persian Wheels, in cases where wetting trenches do not exist.

17. *Instructions regarding cuts.—*

Cuts should not be made in the front bund for wetting loops.

Even when a front bund is threatened by erosion it should *not* be cut unless a breach, by erosion of the front bund, is inevitable; and then only one cut should be made at the downstream end of the loop. The cut should be as far away from the river edge as possible and should have its ends strongly protected. The downstream cut must be some distance from the junction of the loop—to prevent cutting back; but it should not be so far upstream that it does not effectively relieve pocketing. Any obstacle in the way of draining out compartment water through the downstream cut should be removed.

Before a cut is made, sufficient earth, wood and other materials should be kept ready at points of safety on both sides to close a cut of double the ultimate anticipated size. The ends of all cuts should be well secured in advance by retired protection and cross groynes filled with sand bags.

18. *Establishment.—*

The establishment must have better time-scales and opportunities for promotion so as to attract men to stay on the bunds.

The present scales are *not* enough.

The I. R. C. should recommend details of the number of various kinds of establishment required per mile, pay scales etc., and the Government should accept these recommendations.

The Superintending Engineers should be responsible for seeing that adequate staff is provided for all requirements. The following strength of establishment is suggested in normal cases.

I. Annual establishment.

(*a*) *Darogas* :—1 daroga for 8 miles of active bund line. He should not have in his charge other work which would require supervision at the time when the river is high.

Darogas for bunds should be specially selected for their experience on bunds and, preferably, should be promoted mucadams of long experience.

(*b*) *Mucadams.*—1 muccadam for every two miles of active bund or 4 miles of total bund. Preferably, they should be selected from chosen beldars from bunds and *retained* in the same beat.

II. Abkalani establishment.

(*a*) *Sub-darogas.*—There should be at least 2 sub-darogas under each daroga. That is one sub-daroga for four miles of active bund line.

(*b*) *Beldars.*—At the beginning of the abkalani there should be 1 beldar per mile of active bund lines. When water touches the bund there should be at least 2 beldars for one mile in order to patrol in shifts. Depending on the rise of water and other circumstances the number should be increased to 4, 8, 16 or *more* beldars per mile where necessary.

(*c*) *Telephone operators.*—One telephone operator for night duty as well as one for day should be employed.

All abkalani establishment should be provided for four months and actually engaged from the time the river rises till the final drop.

(*d*) *Emergency gangs.*—Emergency gangs consisting of 20 experienced beldars and two muccadams should be maintained from the time the river rises above a prescribed guage till it finally drops below this gauge. This gang should be shifted to portions where leaks, wavewash or slipping are occurring as necessary.

It is useful to maintain a batch of Ode donkeys doing strengthening of bund, who could be shifted as required.

19 *Wavewash —*

Lai seed should be broadcast in September in front of the bund and 'doop' grass should be encouraged 5 ft. beyond the river tow of bund. Where lai will not grow "sur-grass' should be encouraged.

In the case of stone pitching, a 6" layer of graded gravel or quarry screenings, should be laid under the stone pitching

20. *Pocketing.—*

Recommendation No. I of I. R. C., approved under Government Resolution No. 830/27, dated 6th July 1931, provides that loop bunds and cross bunds should be designed with respect to the H.F.L. at the upstream end of the compartment. That is, the H. F. L. at the downstream end of the compartment may be taken as the designed H. F. L. at the upsteam of the compartment reduced at 1 in 10,000 for the length in the front bund. The front bund should be raised, if necessary to the level of the loop for half a mile upsteam of the downstream junction (*i.e.*, up to the point when the cut in the Front Bund is to be given) to allow for pocketing.

21. *Closing a breach.—*

In Appendix II one method of closing a breach in a River Bund is described.

22. *Miscellaneous.—*

The following points require special mention in the Bund Manual.

(*a*) No Katcha pipes should be allowed through a river bund, even though the bund at the time may have only a small depth of water against it, as an abrupt change of 'set' may cause a disaster in such cases.

(*b*) The S. D. O. and the E. E. must certify that they have satisfied themselves as to the correctness of level of the top of the bund and the side slopes by actual check levelling (25 per cent. by the S. D. O. and 10 per cent. by E. E.) in case of all new constructions.

The levelling should also be done every year. The S. E. will be responsible for seeing this is done.

(*c*) Vigilance should be enjoined on all the staff particularly after a series of low rivers.

(*d*) Whenever possible, either the S. D. O. or the Overseer must have bad Bund experience and arrangements should be made to give the necessary bund experience before they are placed in charge of important bunds.

(*e*) A copy of the Bund Manual should be given to every Overseer, S. D. O. and E. E. and each copy should be a personal copy. All should certify having read the same.

(*f*) All abandoned bunds and inundation canal heads likely to cause pocketing should be given large and effective cuts.

(*g*) Temporary headquarters of the S. D. O. and E. E. should, as far as possible, be in the centre of the active bund line in their charge. The E. E. and S. D. O. should, whenever necessary and as for as possible, patrol every night. Patrollig by foot in portions of active bund line and particularly in dangerous portions is necessary.

(*h*) Eroding bends upstream of the bund should be watched and reported, as much higher river evels may be expected downstream of a cut-off. Similar action is necessary in cases of marked changes of river 'set'.

(*i*) Appendix III gives a method of closing a leak where the upstream end of the leak cannot be detected. The treatment for an underground leak should be similar.

(*j*) A leak register should invariably be maintined showing the exact location of each leak; the method of treatment that it has received, that is whether it has been fully opened out or just plugged.

In addition to the leak register, deep nicks should be left on site along the slope and sides of the bund acilitating the exact location on site of leaks mentioned in the register.

A peg showing the number corresponding to the number assisgned in the leak register should also be fixed on the site.

(*k*) The most satisfactory method known of dealing with a 'slip' is to add earth to the rear slope giving the required cover over the saturation line, if necessary even by lowering the top of the bund.

In addition, at any point where there is clearly seeping water or other indication the E. E. must at once propose rear berms to ensure adequate cover.

APPENDIX II.

One method of closing a river breach.

1. Success in closing a river breach depends on preliminary, (brushwood fence) arrangements, the proper selection of the site of the 'juckwork muhari' and of the closing gap.

2. The first step is, therefore, a proper survey of the site. A grid of soundings should be taken both on the river and land side. The soundings should be at most 50 ft. apart and more detailed soundings are required near the projected line of muhari. The grid will extend beyond the scour-hole and until reasonable soundings are encountered, (not more than 15 to 18 ft.). At the same time, soil samples should be obtained, particularly from the proposed line of 'juckwork' to avoid fixing the line in a sandy bed.

3. It is, generally, preferable to consruct the 'juckwork muhari' on the river side as depths will be less and the 'muhari' line will be shorter, because the scour hole generally extends to a considerable distance downstream of the breach. But where a 'ghara' has cut back by retrogression from the scour-hole to the river edge, it may be unwise to align the brech 'muhari' there. In that case it should be constructed on the downstream side beyond the limits of the scour-hole.

The site of the 'juckwork' cannot be too carefully selected. A long line in shallow water or in good hard clay soil is far easier to construct, and far more likely to be successful than a short line in deep water or in sand.

4. Having decided the alignment of the 'muhari,' the time schedule should be made out so as to close the breach under the most favourable conditions possible ; thus, the closing of the final gap should coincide with the maximum fall in the river.

5. Materials and labour required can then be carefully estimated and arranged for. The estimate should be liberal, allowing at least 25 per cent. extra for contingencies, as it is fatal to run short of materials during the work. Arrangements should be made in advance to see that materials and labour are sufficient to continue even if the first attempt fails.

6. The first necessity is to protect the ends from widening. For this purpose it is *not* sufficient merely to pretect the ends with 'juckwork' and 'lai' brushwood or even whole 'babul' trees anchored to the bund. It is necessary to provide cross, double, groynes both upstream and downstream of the breached ends, and to step back the breached ends and to have retired, protected, positions sufficiently far from the ends for stacking materials.

7. When everything is ready, an earth 'manguli' should be constructed across the breached ends. For this purpose, it is necessary to provide a double 'muhari' filled with 'lai' complete with struts, both upstream and downstream of the earth 'manguli'.

The double 'muhari' may be from 4 ft. to 6 ft. wide, each main vertical ('muna') at least 4 ft. below ground and with 4 ft. freeboard. Cross struts ('patties') and verticals should be not more than 5 ft. apart. Longitudinal (waras) 12 ft. long connect three verticals 5 ft. apart with 1 ft. overlap at either end and transverse distance pieces '4 to 6' side ('patties') (depending on width of the double 'muhari') are provided at every main vertical. Inclined, diagonal, stays ('thunies' or 'mals') are provided on both sides at every alternate vertical, unless the height of earthwork is large, when it should be provided at every vertical. It is better to have natural V-shaped forks for this purpose; but where these are not available in sufficient number and of proper size, they may be prepared with a suitable joint. It is better to fix the V of the inclined struts about two-thirds the way up the vertical. The inclined stay should be carried at least four feet below ground. The vertical and inclined struts are supported by sand bags in the whole length of outer or downstream groyne, and in low 'ghara' portions and 'dhoros.' In addition to the inclined struts, there should be transverse pieces 12 ft. wide ('makris') temporarily while the earthwork proceeds, to connect the two double lines of 'muharis' together; these transverse pieces will be not more than 10 ft. apart and will be removed when the earthwork reaches them if it is found that they hamper the free passage of donkeys. They can be put in again, later if desired. Intermediate verticals ('panjars') should be fixed 1 ft. apart (*i. e.* 4 between every 2 'munas') driven at least 3 ft. into the ground and with 4 ft. freeboard.

8. It is necessary to decide from the start where the gap should be finally closed. It should be carefully selected at a site when the depth is shallow, the velocity of the current small, and the soil hard, consisting of inerodible clay. It is also advantageous to have a highridge or bar of hard, inerodible soil immediately downstream. Even if a suitable site for closing the final gap entails a longer lead and other difficulties; yet it will pay in the long run to select a site suitable in the above respects rather than risk failure by selecting a less stuitable site. This, in fact, is a point of crucial importance. The most difficult, that is the portions where the depths are large and the current swiftest, should be tackled, if not first of all, early in the course of the work and not left as the final gap.

9. Having decided where the final closing of the two ends is going to be, the flow through the breaches can be regulated, if necessary, by 'chabbing' the 'juckwork muharis.'

Subject to this, however, it is desirable only to do the 'juckwork' a day or two in advance of the earthwork, in order to avoid, scouring away the framework. Particularly in the deep 'ghara' portions, the earth work should immediately follow the 'juckwork.' The ends, after a day's work, should be well protected by providing a row of vertical stakes across the juckwork and lining these with mats.

10. The two rows of double 'juckwork' with horizontals, longitudinals, stays and connecting pieces having been completed, they are filled with 'lai' brushwood and well packed by divers trampling with their feet.

In 'ghara' portions, one or both sides of the double 'muhari' may need to be filled with sand bags if the current is so swift that 'lai' packing will not prevent undue wastage of earth filling. In case sand bags are used it is necessary to see that the rows are laid consecutively in headers and stretchers to minimise leakage through the points. A little initial care in laying the bags saves a lot of trouble later.

11. Earthwork done by means of donekys carrying earth from the two ends may with advantage be supplemented by earth from tip-waggons, motor lorries and/or barges, towed by tugs or launches. Work has to be organized to see that the main work done by donkeys is not interfered with, but helped by other arrangements. Space being limited, the out-turn and progress of works will depend on proper organization.

In the deep 'ghara' portions, earth should be deposited gradually otherwise there is undue wastage. To prevent wastage, small compartments should be made by cross groynes of mats supported by vertical stakes.

All clods should be broken and earthwork should be well rammed and watered in layers not exceeding 9."

The front slope should be gradual, particularly in the 'ghara' portions, to avoid leaks.

12. A critical stage is reached when the earthwork ends have to be joined and the gap closed. When owing to the contracted waterway and high velocity, earth is liable to be carried away as fast as it is dumped; so in order to provide a stilling chamber and minimise wastage in the reach covering the gap a third line of double 'juck muhari' may be constructed, either on the upstream of the front line or downstream of the rear line, depending on the soundings, soil, and convenience of earthwork arrangements.

A line of men should also stand in the water holding the ends of the newly formed earth until the junction is completed. Before attempting the final closing, twice the required amount of earth should be collected at the two ends and, if possible, arrangements should be made for supplementing the earthwork from a barge placed along side the gap.

13. The accompanying two sketches indicate the arrangments which proved successful in the case of the large breaches in the Sukkur-Begari Bund in 1942; but the method of closing a breach and the details must, be adapted to the circumstances of each case.

14. In the case of a breach 'manguli' on the upstream side, if the soil is sandy, retrogression may set in, a deep channel moving more and more upstream from the scour-hole upwards and preventing the closing of the gap by a 'manguli' across it. In such cases, a judicious use of diversion groynes of 'juckwork' filled with 'lai' or gunny bags or tree groynes, will help to deflect the current away from the main line of the 'muhari' and make it possible to proceed with work.

APPENDIX III (a).

Statement of Breaches from 1930 onwards.

Serial No.	Name of Bund.	Year of breaches.	Mile of Bund.	No. of Topo sheet (as shown in plan sent.)	Remarks.
1	2	3	4	5	6
1	D. E. Bund between 1896 Loop Mile 1 and Begari New Cut ..	1930	6/4	78	Development of under-ground leak.
2	Tori Bund	1930	8/6	78	Development of leaks. Also breach at mile 3/0 of Right Bank Begari and cuts made at miles 1 and 2 of Tori Bund to relieve pressure.
3	Do.	1930	6/4	78	
4	Do.	1930	10/0	78	Development of leak.
5	Do.	1932	2/0	78	Failure of sluice.
6	Do.	1942	2/6	78	Development of leak.
7	Do.	1942	3/2	78	Development of leak.
8	Goroghat Bund	1935	0/1	78	Failure of sluice.
9	L. B. Begari Bund	1941	4/5	78	Development of leak.
10	Do. do.	1942	7/1	78	Development of leak.
11	R. B. Begari Bund	1930	3/0	78	Development of leak.
12	Sukkur Begari Bund	1932	13/6	59	Cut to divert floods.
13	Do. do.	1932	15	59	Breached and cut to divert floods.
14	Do. do.	1932	15/1-15/2	59	Breached and cut to divert floods.
15	Do. do.	1932	17/3	59	Cut to divert floods.
16	Do. do.	1932	18/0-18/4	59	Eroded in 1932.
17	Do. do.	1932	20/4-20/6	59	Eroded in 1932.
18	Do. do.	1932	29/2	78	Failure of sluice.
19	Surfu Loop	1932	1/5-1/6	59	Breached 1/5 and 1/6 and cut also at mile 1/7.
20	Do.	1932	2/0-3/3	59	Breached at 2 or 3 places due to several leaks.
21	Mohemadabagh Loop ..	1942	Taki No. 22	59	Originally three breaches which developed into practically one breach 1½ miles long due to development of leaks into breaches.
22	Do. do.	1942	Do.	59	
23	Do. do.	1942	Do.	59	
24	Kasimpur Nabishah Bund ..	1935	8/0	79	Failure of sluice.
25	Do. do. ..	1942	0/4	60	Leaks developing into breaches.
26	Kasimpur Nabishah Bund ..	1942	0/6	60	Leaks developing into breaches.
27	Do. do. ..	1942	10/6	79	Leaks developing into breaches.
28	Loop of 1913 (New name S. B. B. Mile 17/3)	1932	1/0	80	Cut for passing floods.
29	Loop of 1913 (New name S. B. B. Mile 18/4)	1932	2/0	80	Eroded, miles 18/0 to 18/4 of S. B. B.
30	Sukkur Larkana Bund ..	1942	1/6	60	Development of leaks. Breaches at mile 1/6, 2/6 and 3/2 appear to have been at sites of old bund sluices dismantled and gaps filled up.
31	Do. do. ..	1942	1/6	60	
32	Do. do. ..	1942	2/4	60	
33	Do. do. ..	1942	2/5	60	
34	Do. do. ..	1942	2/6	60	
35	Do. do. ..	1942	3/2	60	
36	Do. do. ..	1942	4/0	60	
37	Flank Bund	1935	—	60	Eroded in 1935. This is opposite mile 46 of S. L. Bund.
38	Larkana Sehwan Bund ..	1930	54/6	23	
39	Do. do. ..	1942	28/2	42	Development of leaks.
40	Do. do. ..	1942	30/0	42	
41	Do. do. ..	1942	32/6	42	
42	Do. do. ..	1942	32/7	42	
43	Do. do. ..	1942	33/1	42	
44	Do. do. ..	1942	33/2	42	
45	Do. do. ..	1942	34/1	42	

Serial No.	Name of Bund.	Year of breaches.	Mile of Bund.	No. of Topo sheet (as shown in plan sent.)	Remarks.
1	2	3	4	5	6
46	Larkana Sehwan Bund. ..	1939	2/6-3/2	40	Eroded in 1939.
47	Do. do. ..	1940	1/3-2/1	40	Eroded in 1940.
48	Do. do. ..	1941	3/6-4/1	40	Eroded in 1941.
49	Do. do. ..	1941	4/5-4/7	40	Do. do.
50	Garkino Lundi	1933	1/7	42	Reasons not known.
51	Agani Abad Loop	1942		40	Eroded in 1942 and river water held against Maharwada Loop.
52	New Left Bank River Embankment.	1933	22/3	43	Reasons not known.
53	Sarda Taraki Loop	1933	2	51	Eroded in 1933.
54	Do. do.	1933	3	51	Do. do.
55	Sarda Hillaya		4	51	Do. do.
56	Do.		8	51	Eroded in 1940.
57	Sonda Kurari Loop		1	51	Eroded in 1934.
58	Do. do.		2	51	Do. do.
59	Alibahar Loop	1935	1/7	51	
60	Do. do.	1936	1/7	51	
61	Baghar Ochito Bund (Emergency Loop of 1930)	1931		33 and 34	Eroded in 1931.
62	Baghar (Front Bund) ..	1931		33 and 34	Do. do.
63	Baghar (Emergency Loop Oderolal)	1933		34	Eroded in 1933.
64	Mulchand Shahbunder Bund ..	1931	17/3	51	Eroded in 1931.
65	Mulchand (Gugo Loop of 1930-31).	1933		51	Eroded in 1933.
66	Mulchand	1933	42/5	52	Do. do.
67	Mulchand (Gugo Loop) ..	1935	16/1	51	Eroded in 1935.
68	Mulchand (Gugo Loop of 1933-34).	1936		51	Eroded in 1936.
69	Mulchand (Middle compartment).	1938		33	Eroded in 1938.
70	Mulchand (Sujawal)	1938	16/1 Sujawal	33	Do. do.
71	Mulchand	1942	18/5	51	Eroded in 1942.

APPENDIX III (b).

Statement of Breaches prior to 1930.

Serial No.	Name of Bund.	Year of breaches.	Mile of Bund.	No. of Topo sheet (as shown in plan sent).	Remarks.
1	2	3	4	5	6
1	1896 loop	1903	8/0	78	Flowed for 3 days up to Johu Kumb (2000 cs.)
2	Do.	1903	29/0	78	Flowed for 2 days and water reached Sind Dhoro, discharge about 2000 cusecs in both.
3	Do.	1903	29/0	78	
4	Do.	1904	6/0	78	About 50,000 cusecs flowing for one week, breaching Tori Loop in two furlongs. Water reached Jacobabad.
5	Do.	1912	Mileage not known.	78	Development of leak (mileage not on rocord).
6	Do.	1912	Do.	78	Do. do. do.
7	D. E. Bund between 1896 Loop, Mile 1 Begari New Cut ..	1929	6	78	Do. do. do.
8	Tori Bund	1904	Loop Bund Mile not known.	78	Due to breach in Mile 6 of 1896 loop (See above) This Bund breached in 2 furlongs.

Serail No.	Name of Bund.	Year of breaches.	Mile of Bund.	No. of Topo sheet (as shown in plan sent.)	Remarks.
1	2	3	4	5	6
9	Tori Bund	1912	6/2	78	Leaks developed into breaches Sudden rise of water of 4 ft. between 2 days gave rise to several leaks.
10	Tori (loop bund)	1912	5/4	78	
11	Tori (Cross bund)	1912	6/3	78	
12	Do. do.	1921	Mileage not known.	78	Mileage and cause not on record.
13	Do. do.	1924	Do.	78	Leak developed into breach (mileage not known) Cuts made near mile 1/7 to relieve pressure.
14	Do. do.	1925	Do.	78	Do. Flood flowed for 1½ months
15	Do. do.	1926	Do.	78	Do. Flood flowed for 2 months.
16	Do. do.	1927	Do.	78	Do. Flood flowed for 1½ months.
17	Do. do.	1928	Do.	78	Do. Flood flowed for 13 days.
18	Do. do.	1929	9/4	78	Due to development of leak. Cuts made at mile 1/7 Tori to relieve pressure.
19	Do. do.	1929	7/1	78	Development of leaks. Heavy rainfall and gale during day and night. Trench Bund eaten away by wavewash.
20	Goraghat Bund	1929	2/0-3/0	78	
21	Do. do.	1929	5/0	78	Development of leak. Cutsmade across Unherwah at Mile 1/4 and Tori Bund opposite.
22	Kashmore Bund	1904	20/0	78	Development of leak. Flood water reached Jacobabad.
23	Do. do.	1904	28/2-30/2	77	Leaks developed into breaches Flood water reached Jacobabad..
24	Do. do.	1904	Do.	77	
25	Do. do. ..	1904	Do.	77	
26	Larkana Sehwan Bund ..	1929	95/1-95/3	25	Reasons not givens.
27	New Left Bank River Embankment	1929	0 to 1/6	24	Eroded in 1929.
28	Jamshoro Front Bund ..	1894	1/5-2/2	49	Reasans not given.
29	Gidu Malh Bund	1914	2/0	49	Do. do.
30	Sonda Hillaya Bund	1924	Not known.	51	Erosion of 1924.
31	Do. do.	1926	0/1	51	Erosion of 1926.
32	Baghar Ochito Bund (New Loop of 1911-12) ..	1912	5/0	52	Washed away 1912
33	Do. do.	1920	5/5	52	Erosion of 1920.
34	Baghar (Madho Emergency loop)..	1921		33	Erosion of 1921.
35	Baghar (Thahimani Gulel Loop of 1921)	1922	9/4	33	Development of leak.
36	Baghar (Thahimani Abad Loop)..	1923	0/3	33	Do. do.
37	Do. do. do. ..	1923	1/3	33	Do. do.
38	Do. do. do. ..	1923	1/7	33	Do. do.
39	Do. do. do. ..	1923	2/7	33	Do. do.
40	Baghar (Thahimani Gulel Loop)..		6/4	33	Erosion of 1925.
41	Do. do. do. ..			33	Erosion of 1926.
42	Mulchand Shah Bunder ..	1912	30/2	52	Not known.
43	Do. do.	1916	Infront of Aplanki loop of 1912.	52 and 53	Failure of sluice.
44	Do. do.		33/5	51 and 52	Erosion of 1918.
45	Do. do.		33/7	51 and 52	Do. do.
46	Mulchand (Belo loop) ..	1919		52	Not known.
47	Mulchand (Emergency Loop of 1915)	1920		51 and 52	Eroded.
48	Do. do.. do. ..	1924	3/3	51	Not known.
49	Do. do. do. ..	1925	24/7	51	Leak through sluice developed into breach.
50	Kuka Bund		9/6	35	Eroded in 1910.
51	Do.		9/7	35	Eroded in 1916.
52	Do.		12/0	35	Eroded in 1926.

KARACHI: PRINTED AT THE GOVERNMENT PRESS.