Central Board of Irrigation.
Publication No. 11.

ANNUAL REPORT

(TECHNICAL)

OF THE WORK OF THE

CENTRAL BOARD OF IRRIGATION, INDIA

1934-35.

PUBLISHED BY ORDER OF THE BOARD.

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SIMLA,
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FOREWORD.

CENTRAL BOARD OF IRRIGATION,
SIMLA, INDIA.

This Report, which records the technical portion of the work done by the Central Board of Irrigation in the year 1934-35, is the first of its kind issued by the Board.

The Board consists of the Chief Engineers (Irrigation) of all the Provinces in India, and the functions of the Board are to provide liaison between the various Provinces in regard to irrigation, and to co-ordinate irrigation research work which is carried out in India. The Board also provides Committees, when called upon, to investigate problems connected with irrigation, with which the Government of India, or any Provincial Government may be confronted. In addition, the Board issues Technical Publications. In order to deal with the research side of the work there is a Research Committee which comprises the Executive Committee (President, Vice-President and one Member), and the Research Officers of the Provinces. This Committee meets annually, generally in July, and discusses amongst other things, the annual reports of the Research Officers, which contain an account of the research carried out by them during the previous year. Special subjects such as Waterlogging and Land Reclamation are also taken up for discussion, and the findings of the Committee are recorded in the form of resolutions.

The Board itself also meets annually, generally in November, and the technical side of the business transacted covers discussions on many problems which are engaging the minds of irrigation engineers in India, and the findings of the Research Committee at their annual meeting are also discussed.

A record of the proceedings of the Board are contained in the minutes of the meeting, and the conclusions of the Board are embodied in resolutions.

Hitherto it has been the practice to issue separately the minutes of the Research Committee and Board meetings, and the agenda for the Board meeting contained summaries of the Research Officers' annual reports.

At the meeting of the Central Board of Irrigation, held at Delhi on the 23rd and 24th November 1934, it was resolved that the Research Officers be requested to prepare their reports in future on the lines of the summary hitherto prepared by the Secretary, and that those reports together with the minutes of the Research Committee meeting, be printed and issued annually as a Board Publication.

In amplification of that resolution, the Executive Committee of the Board decided, on the 20th July, 1935, that the Publication should issue after the annual meeting of the Board, in order that the findings of the Board on the resolutions of the Research Committee, might be incorporated in the Publication.

The Publication contains, therefore, the summarized annual reports for 1934-35, of the Irrigation Research Officers in India, the minutes of the Research Committee meeting held on the 18th and 19th July, 1935, and the technical portion of the agenda and minutes of the annual meeting of the Central Board of Irrigation, held at Delhi on the 4th and 5th November, 1935.

Further details on the subjects dealt with in the Research Officers' Reports are obtainable through the Board's Secretary, who will also welcome, on behalf of the Board, any information relating to those subjects, or any other branch of irrigation engineering.

M. T. GIBLING,
Secretary,
Central Board of Irrigation.

Dated 15th February, 1936.

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PART IV.

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PART I

RESEARCH OFFICERS' REPORTS.

(Summaries.)

PROVINCIAL REPORTS (SUMMARIES) ON RESEARCH WORK IN CONNECTION WITH IRRIGATION, DRAINAGE, RECLAMATION, ETC., IN INDIA, FOR THE YEAR 1934-1935.

PUNJAB.

In considering the work done during the past year, the summary relates to the work done by sections, except in the case of silt investigations where practically every section of the Research Institute was involved.

2. *Chemical Section.*—In the Chemical Section, investigation on the nature of soils has been continued. It has proved undesirable to work only with the pH value of soils, as this has proved an insufficiently sensitive test. Much work has been done on the degree of alkalization and dispersion co-efficient.

3. The study of soil deterioration led to a series of observations on the movement of salts in the soils, and also to the conclusion that a water was fit for irrigation which contained more than the conventionally accepted 60 parts per hundred thousand, provided that there was a certain quantity of calcium in the water. Studies were also continued on the reclamation of the highly alkaline soils found at Chakanwali.

4. *Physics Section.*—In the Physics Section, a series of studies were made on seepage losses from canals by dividing a distributary into sections, thus forming tanks and observing the rate at which the water emptied itself out of these tanks. Allied with this investigation, the transmission constant of water through different silts was determined, and also the effect of variations in temperature on the sub-soil pressures under works. At the same time as the transmission constant was under investigation, the relation of the floatation gradient to the stability of works on sand was also investigated.

5. A comparison was also made between the observations made in the pressure tanks in the Hydraulic Laboratory and the potential gradients obtained by an electric method for similar models. This method is giving satisfaction when due precautions are taken, and endeavours are being made to speed up the observations.

6. *Statistical Section.*—The Statistical Section has to carry out calculations for all the other sections in the Institute and has no time for any actual research work on statistics. Among the main investigations carried out were those on the rise in the water-table in the Shahpur branch area and in the fork between the Jhang and Rakh branches. The calculations relating to the desiccation of the Bist Doab were also carried out. The arithmetical analysis of the errors involved in various experiments in the laboratory formed a considerable proportion of the work of this section, while the numerous calculations for the silt curves also formed a very large proportion of their work. Various other tables required for investigations in the different sections were prepared, and this section prepared a layout for experimental plots on a randomized basis.

7. *Hydraulic Section.*—Owing to the lack of room in the Hydraulic Laboratory, the experiments are at present confined to investigations of pressures under models of works or on such investigations of wave position and form as can be done in a flume. A large number of investigations of similar type have been done. The uplift pressure investigations under standard forms of floor with sheet piles as well as under Khanki, Merala and Balloki Weirs have been carried out. The question of decreasing scour has been investigated for two Bays of Khanki Weir and for Merala Weir. The problem of fixing the standing wave in a desired spot and generally decreasing scour downstream, was carried out for the Jaba level-crossing and for the rapids on the Upper Bari Doab Canal. The importance of this latter investigation may be gauged from the fact that it has been customary to spend about Rs. 30,000 a year on these works, while the results at present show that the scour holes beneath the rapids are filling up. Several outdoor experiments have been carried out in continuation of those which led to the construction of the silt ejector at Madhopur which was put in last year.

8. In addition to these activities in the laboratory, a certain number of observers are taking daily observations on various channels including the sampling of bed-silt. These results have been used in the laboratory for studying certain variations in silt size, and are the basis on which the Physical,

Chemical and Mathematical Sections are carrying out investigations on silt behaviour.

9. *Reclamation Section.*—In the Land Reclamation Section, works on the reclamation of *Thur* and *Rakkar* are proceeding. At the same time it has been found possible to reclaim certain types of land on Kharif water only. Studies have also been made of the yield and general behaviour of rice plants in salty and alkaline lands. In a few places land reclamation is being carried out at the request of local zamindars, and the results of these experiments are being carefully watched. For the purpose of investigating soil deterioration, a few small soil surveys have been made.

10. *General Section.*—The work of the General Section has been mainly confined to analysis of soil samples, and to the determination of the salt content of certain drainage waters.

11. *Mathematical Section.*—In the Mathematical Section certain investigations on the best design for a glacis of falls and the derivation of five-thirds Discharge Formula were carried out at the request of the Central Board of Irrigation. For the most of the time, investigations have been carried out based on the observations on pressures made in the Hydraulic Laboratory, and on certain preliminary investigations connecting various hydraulic data of channels with the bed-silt that they carry.

BOMBAY (DECCAN).

12. *Canal Falls.*—Experiments were carried out, in accordance with resolution No. 27, passed by the Central Board of Irrigation at the 4th Annual meeting of November 1933, to compare the dissipation of energy below standing wave flume falls and parallel sided weir falls.

The experiments showed that :—

(1) the standing wave flume fall with baffle cistern and deflectors and 1 in 3 apron slope gave very satisfactory results. On the other hand, the weir fall gave unsatisfactory results, the dissipation of energy being incomplete, the flow downstream unbalanced, and the isotachs distorted, while the wave wash was considerable,

(2) the weir fall design can be improved provided the fall is greater than D/3 by making the apron down-stream of the curtain wall slope at 1 in 3, and adopting the standard design of baffle, cistern and deflectors,

(3) if discharges are to be measured or proportionately maintained and H > D/3, the standing wave flume fall with baffle is the most satisfactory solution,

(4) in the case of weirs where the flow is not axial, and also where the drop in water levels is less than D/3, a design consisting of arrows and discontinuous walls as recently used in the Punjab with arrows $d_3/5$ in height and apron to 1 in 3 slope is suitable.

NOTE :—

D = upstream depth over crest,

H = difference in W. L. upstream and downstream,

d_3 = Downstream depth in channel.

13. It is frequently desired during the course of model experiments, particularly experiments with falls, to compare the distribution of velocities obtained with that in a normal channel. Isotachs were therefore observed for this purpose in a 10 cusec model of a canal, the depth to bed-with ratio being 1/20, the banks being of concrete and at 1 to 1 slope. The isotachs were plotted to form a basis of comparison in future experiments. When compared with mean results obtained from observations in the Jamrao system, Sind, they showed that in the model the falling off of velocity near the banks was less marked than in the prototype.

14. Further investigation of the data of fall experiments with baffles showed that the best results are obtained when the height of a baffle below a fall is equal to the critical depth less the free flow depth downstream of the fall—*i.e.*

$$h_b = D_c - d_2$$

$$= \sqrt[3]{\frac{q^2_o}{g}} - d_2$$

Where .. .. D_c = critical depth

d_2 = depth of water at toe of fall assuming that no standing wave has formed

h_b = height of baffle

q_o = discharge per foot width at the throat

and distance of baffle from toe of fall = 5 × height of baffle.

15. At the Fall on the Hardoi branch, U. P., there has been a retrogression of 2.45 ft. in water levels followed by a general bed scour of about the same amount. Due mainly to this heavy retrogression, scour occurred below the fall to a maximum depth of 25 ft. below the pavement which was badly undermined. Experiments were carried out with a model of this fall to see how best to prevent scour. The standard baffle design with a cistern downstream, bed- and side-slope deflectors and 1 in 3 apron slope downstream gave the best results.

16. The case of the 10 ft. tail fall on Sarda Deoha Feeder (United Provinces) was very similar. This Feeder, which was designed for 1,250 cusecs, but sometimes carries 1,600 cusecs, discharges into the Perwain Nadi and thus feeds the Deoha river. The Nadi had been retrogressing since the construction of the feeder, causing the bed and banks of the latter to scour heavily below the fall. The standard baffle design was recommended in this case, because *the baffle not only effectively dissipates energy but also holds the standing wave near the toe of the fall irrespective of any subsequent retrogression in water levels downstream* of the fall. The advantage of the baffle design increases with the height of the fall.

17. Experiments in connection with falls, with (*i*) the standard baffle having a semi-circular concave upstream face and (*ii*) a rising floor, sloping up at 1 in 5 to the same level as a standard baffle, showed that the standard baffle was more effective than the rising floor in throwing the high velocity jet upwards and so dissipating energy. Similarly, a standard deflector, having a vertical or concave upstream face, produced less scour than a pavement sloping up at either 1 in 5 or 1 in 10. The better results with a deflector were due to the horizontal bed roller which formed downstream. This was smaller in cross section and extended over a shorter length, than with the tilted pavement.

18. *Skimming Baffle in Standing Wave Flume.*—Last year's experiments with the skimming baffle in the throat of a standing wave flume were continued. The object of this skimming baffle is to cause maximum possible afflux when excess water is passed down a channel. The primary object of the experiments was in connection with causing rapid afflux to cause overflow from escapes of the siphon spillway or free overflow type ; but it can also be used to prevent excess water being passed down a channel. The best design of baffle was found to be a vertical slab without any curvature and its optimum position was at the downstream end of the throat, with its bottom edge just clear of the water at F. S. L. Under these conditions, when the water level increased, due to excess discharge, the baffle caused maximum afflux.

19. *Bed silt exclusion from Canals.*—Experiments were carried out to see the effect on bed silt exclusion from canals taking off from alluvial rivers of :—

(*i*) curvature of flow induced by the regulation of barrage gates, and

(*ii*) discharge per foot width of the canal, total discharge remaining the same.

In connection with (*i*), experiments were done with the part model of the Sukkur Barrage, including the four canals taking off from the left bank.

(1) Favourable curvature of flow was obtained with the barrage gates furthest from the canals opened, when less bed water and more top water was drawn by the canals. The curvature of flow was reversed when the barrage gates near the canals were opened; when the canals drew excess bed silt.

(2) The canals drew maximum silt when the discharge of the river was a maximum.

(3) The two upstream canals took more than their share of silt.

The above experiments were done with a bed consisting of silt and with silt in suspension.

As regards (*ii*), the effect on silt exclusion when the discharge per foot width of the canal was reduced, the total discharge remaining the same, was that less bed silt was drawn by the canal.

20. *Improvements to increase Discharge through Regulator.*—Experiments were carried out with a model of the Head Regulator of the Nira Left Bank Canal to ascertain whether by constructing a bellmouth upstream, with 1 in 10 diverging side and roof downstream of the gates, the discharge could be increased from 455 to 720 cusecs without additional loss of head. The result was even better than expected, as it was found that with this arrangement 720 cusecs could be passed with only a 2″ loss of head; or alternatively, for the same head, more than double the discharge could be passed. It was found important to bring the bellmouth rim above water so as to prevent the inflow of water through the gate slot and to have gates which, when open, were flush with the roof of the sluice, otherwise the co-efficient of discharge was considerably reduced.

21. *Silt sample from Turbulence below Fall or Regulator.*—Experiments were carried out to ascertain whether a silt sample taken from the turbulence below an undershot regulator or glacis fall gave a true indication of the silt moving down the channel. It was found that in the turbulence downstream of a fall or an undershot regulator, a true representative sample of silt was not obtained from the turbulence unless the difference of head was greater than D/3 (where D = depth of water upstream over the sill or crest) and there was a baffle.

22. *Range of Gibb type Module.*—Experiments were carried out on the range of a spiral Gibb module in which the water rose centrally, and then flowed round a spiral eddy chamber of increasing radius of length equal to 3 semi-circles. The results were compared with a standard module with a semi-circular eddy chamber. The main difference between the spiral and the standard module lay in the manner in which vortex flow was created before water entered the eddy chamber. In the spiral modules, there was a semi-circular vortex chamber with guides to create the vortex flow, whereas in the standard module, the vortex flow is created in a curved rising pipe of varying section. The range of up-stream water levels within which the discharge of the 3 semi-circular spiral module varied within less than ± 3 per cent. was found to be 1.32 ft., *i.e.*, 1.43 times the range of the standard single semi-circle module. When two outer semi-circles were removed the range was reduced almost to that of the standard module. That is to say, central entry did not increase range, and it was found that with central entry the design had to be much more exact.

23. *Silt Abrasion.*—Last year's experiment with the silt abrader, to ascertain whether silt becomes finer under continuous movement and mutual abrasion, was continued. It was found that the abrasion of the coarse particles was taking place more rapidly than the abrasion of fine particles: in other words that silt is chiefly abraded when it is lying on the bed and not when it is in motion. Last year's argument that silt would reach the sea long before it was appreciably abraded is therefore beside the point.

After 3775 hours of working, the percentage fraction of coarse sand to total sand (1.0 to 0.2 mm.) was reduced from 90 per cent. to 71 per cent., and the percentage fraction of fine sand (0.2 to 0.02 mm.) was increased from 9 per cent. to 25 per cent. when compared with the original sand.

A glass sided model to 1/8th scale was constructed for observation. This showed that most of the abrasion was due to the movement of sand over the stationary sand of the bed.

24. *Soil and Subsoil Research.*—The work done in the Baramati Soil Laboratory during the year concerned the removal of alkalinity and reclamation of damaged land.

(1) Treatment with CO_2 water.

The result of the previous year that carbonated water improves the soil was fully confirmed.

(2) Treatment with Farmyard Manure and Rice Crop.

This combination gave the best results as in the previous year. F. Y. M. facilitates the growth of the rice and is thus indirectly as well as directly responsible for improving the soil.

(3) Application of alum under conditions of continuous and intermittent (rotational) irrigation.

There was similar and considerable improvement under both conditions. Alum removed a very much greater quantity of bicarbonate of soda than did irrigation alone.

(4) Flooding compared with rotational (intermittent) irrigation in the presence of F. Y. M.

The results were in favour of intermittent irrigation as it removed a larger quantity of salts, particularly the bicarbonates of sodium.

(5) Treatment with gypsum and calcium carbonate in presence of F. Y. M.

Results were decidedly in favour of gypsum, 3 tons per acre being an adequate dose. F. Y. M. was found to have little additional effect on the physical condition of the soil. Calcium carbonate, though inferior to gypsum, is more easily obtainable in many districts, and does effect appreciable soil improvement.

(6) The effect of varying doses of gypsum on stiff soil, judged by trial sugarcane crops.

Both soil tests and size of crops indicated 3 tons of gypsum per acre to be the optimum dose for the particular soil treated.

25. *Effluent Farm Research.*—The following problems were investigated during the year.

(1) Transpiration ratios for cane.

This year the ratio was determined for the variety P. O. J. 2878. The ratio obtained was lower than the ratios previously obtained for Pundia cane, and the cane was a heavier crop, thus supporting the general conclusion from the previous results that good cane crops transpire less water.

(2) Observations on the growth and maturity of sugarcane under effluent manurial treatment.

At the present time the dose of nitrogen is far in excess of what was anticipated and the area of land suitable for effluent irrigation is insufficient. Our object is to increase the dose so long as this does not reduce profits or damage the land. It has already been shown that the land is not damaged even by 500 lbs. of N per acre per year. This year we have been examining the effect of heavier doses on the crops.

(*i*) Varying doses of effluent.

Both the pot and field experiments showed a better growth of cane with increasing doses of effluent, but higher doses than the normal dose giving 300 lbs. N per acre, lowered the brix and purity of the juice.

(*ii*) Period of effluent treatment.

Effluent applied to cane was in one case discontinued after 10 months and in the other was continued for 13 months, *i.e.*, up to harvesting.

In the latter case the total dose of effluent was correspondingly greater. The former gave juice of better brix and purity, but the latter produced a heavier crop.

UNITED PROVINCES.

26. During the year the Irrigation Research Section of the United Provinces has confined its enquiries, in the main, to the following heads :—

1. The Lining of Channels and Guls.*
2. Losses from Small Channels and Guls.
3. Losses from Large Channels.
4. Silt Theory Observations.
5. Silt Selective Heads.

The year's work is described in full detail in Technical Memoranda Nos. 1, 2 and 3. (Issued by P. W. D., I. B., U. P.)

Operations were generally restricted to the Sarda Canal System.

27. *The Lining of Channels and Guls.*—A bibliography (Appendix I) on this subject has been prepared, and includes the results obtained during the year by the Research Section.

In addition to the type of lining mentioned in the bibliography, experiments were made with the following materials.

Bitumuls XRM.

Bitumatti.

Various mixtures of Kankar Lime, Molasses and Sugar factory by-products.

28. Regarding Bitumuls XRM and Bitumatti, high hopes were entertained, but the trial sections are already softening and disintegrating under the action of water.

The linings constructed with kankar lime, molasses and sugar factory by-products are under observation.

29. *Losses from Small Channels and Guls.*—The number of observations made during the year brings the total up to 523.

In conjunction with loss observations, samples of the soil involved are now analysed mechanically in the Research Laboratory at Lucknow and the percentage of clay in each case determined. This, it is felt, is an advance on the old method of describing soils as loam, sandy loam, dumat, etc., terms capable of wide interpretation.

30. Appended are the results of the few experiments based on the new soil analysis :—

Percentage of Clay in Gul Soil.	Gul Loss Observed per million square feet (Cusecs).
8·15	29·2
32·20	22·4
46·40	14·8
52·00	4·9
53·40	11·6
69·50	1·84
72·50	9·80
86·00	8·65
89·50	8·5

*Gul : Cultivator's irrigation channel discharging up to approximately 2 cusecs.

These are the sum total of results based on the mechanical soil analysis to date, but it is the intention to collect all results in future on this basis.

31. The problem of lining guls, and the rate of loss from them are obviously interconnected. Investigations are showing that gul losses are of a higher order than channel losses, and that if lining is to be profitable anywhere, it should be profitable on guls.

32. The financial aspect has been investigated to some extent. Each system presents its own peculiar case. It has been shown that on the Upper Ganges Canal, if the loss in a main gul is 8 cusecs per million sq. ft., lining shows no loss (lining at 2.26 annas per sq. ft. with anticipated life of 30 years). 8 cusecs per million square feet is below the average of losses investigated to-date.

The decision is, that further investigations of this rather involved actuarial problem should be deferred until more data on losses has been accumulated.

33. *Losses from Large Channels.*—The results so far obtained, have been based on the discharges of calibrated falls.

It has been decided that the ideal would be calibrated falls fitted with automatic gauge recorders. On the Sarda Main Canal, observations are based almost entirely on falls so equipped, and in this reach, therefore, the calculated losses are probably the relatively most accurate of loss calculations on large channels. (The designed full supply of the Sarda Canal is 9,500 cusecs).

34. Hereunder are given the losses so determined by months on the Sarda Main Canal.

Year.	Month.	Losses per Million square Feet of Wetted Perimeter. (Cusecs).
1933	December	2·54
1934	January	1·88
"	February	5·35
"	March	3·44
"	April	4·57
"	May	4·62
"	June	8·47
"	October	10·54
"	November	4·42
"	December	3·73
1935	January	4·42
"	February	5·47

In calculating the losses, due allowance was made for evaporation and rain effects. The observation of evaporation losses from canals, it may be added, is a regular routine of the Research Section.

35. The limits of accuracy of the large calibrated falls is an unknown factor, and it is for this reason that efforts have been made to arrive at the losses by other means.

Attempts were made on a smaller canal (Designed Head Discharge 158 cusecs) to arrive at losses :—

(*a*) by observing the rate of rise and ultimate slope of the ground water, (*b*) by chemical means.

The experiments could not be brought to a successful conclusion. The actual loss in the observed reach as determined by the compartment method (reaches of the channel formed into reservoirs by dykes, and filled with water), showed losses at full supply level of 7.84 cusecs per M. S. ft. of wetted perimeter. (Clay content of subsoil 97.5 per cent. and voids 44.58 per cent.).

The experiments affirmed that losses vary roughly as the square root of the water depth. In the particular case above, the formula arrived at was :—

$$L = 4.1\ D^{0.418}$$

36. A new method of determining losses was initiated on the Main Sarda Canal. The phenomenon is well known to Irrigation Engineers that after a canal is closed, a stage is soon reached when the residual water forms a series of isolated pools. During the March 1935 closure of the Sarda Main Canal, gauges were fixed in such pools at well distributed points in the 27 mile reach, and the rates of loss observed. The intention was to obtain the mean depths of the pools, and determine the losses at full supply level by applying a formula of the form shown above. Owing to lack of time the observations could not be completed, but they furnished some interesting data on the location of those reaches where the losses were greatest.

37. What might be termed a by-product of observations for channel losses, is the following collection of a set of empirical formulæ for discharges over weirs, which obviously have considerable value.

The drawing on the opposite page gives the necessary dimensions of the falls.

Site.	Formula.
3·0′ Fall at M. 6-0-0 Sarda Deoha Feeder	$Q = 3{\cdot}03\ LD^{5/3}$.
4·0′ Fall at M. 14-7-165′ Nigohi Branch	$Q = 2{\cdot}83\ LD^{1{\cdot}5} + 3 \times n$.
3·0′ Fall at M. 1-2-0 Nigohi Branch	$Q = 3{\cdot}04\ LD^{1{\cdot}76} + 2{\cdot}5 \times n$.
3·0′ Fall at M. 1-0-1½ Hardoi Branch	$Q = 3{\cdot}17\ LD^{3/2}$.
5·0′ Fall at M. 16-4-0 Hardoi Branch	$Q = 3{\cdot}16\ LD^{1{\cdot}76} + 10 \times n$.
3·13′ Fall at M. 1-0-337′ Kheri Branch	$Q = 3{\cdot}26\ LD^{5/3}$.

Note.—In the above formulæ Q represents discharge passing over the fall, L the length of crest (as shown in drawing), D the depth of water over the crest, and n the number of draining pipes.

38. *Silt Theory Observations.*—Work has been concentrated during the year on the determination of the silt factor by the mechanical analysis of silt, and correlating this factor with hydraulic conditions on channels held to be in regime.

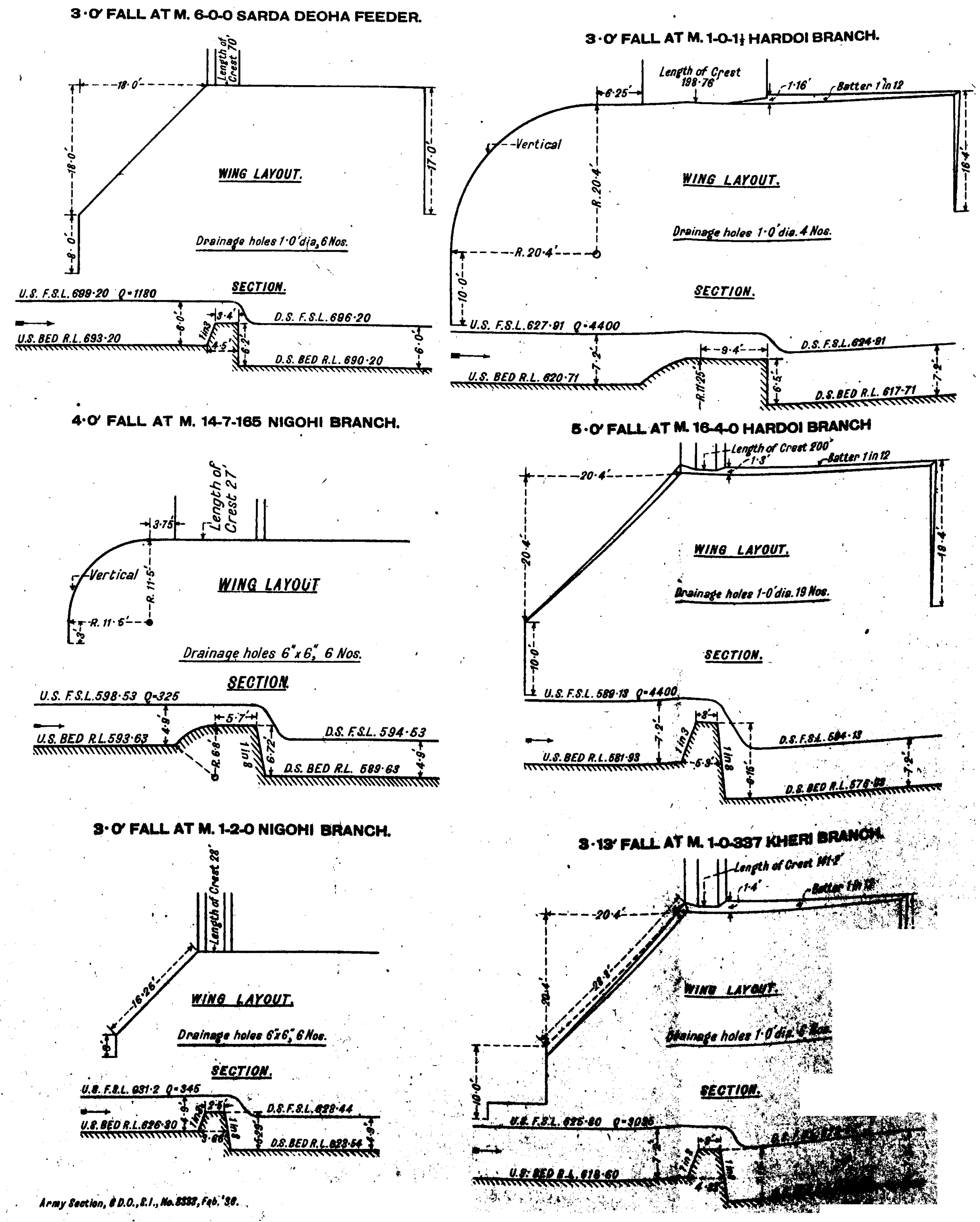
Observations have been carried out at three selected sites on the Main Sarda Canal.* At these sites the bed of the canal when viewed in March 1935 appeared to indicate regime conditions. The tabular statement hereunder shows the silt factors obtained by observation of slope and hydraulic mean depth

*Sarda Main Canal : Designed bed width 350 ft. Water depth 8.1 ft. Discharge 9,500 cusecs.

UNITED PROVINCES P. W. D. IRRIGATION BRANCH. RESEARCH SECTION.

CALIBRATED FALLS ON SARDA CANAL SYSTEM.

LUCKNOW, MAY 1935.



and the corresponding silt factors obtained by mechanical analysis of the bed silt.

Date of Observation.	Site.	Slope per mile (feet).	Slope expressed as a fraction.	Mean value of R.	Value of 'f'.	Value of 'f' obtained by Puri Siltometer.	Remarks.
8-4-35	M. 6-0	·573	$\frac{1}{9209}$	6·626	0·811	0·945	Samples for Siltometer taken 6th, 7th, and 8th June 1935, when canal water carried considerable silt.
8-4-35	M. 14-0	·573	$\frac{1}{9209}$	6·297	0·797	0·878	
8-4-35	M. 20-5	·613	$\frac{1}{8609}$	5·512	0·797	0·758	Samples taken by scooping silt from centre of bed with bucket; canal running.

The water surface slopes and wetted perimeters were observed with great accuracy, the hydraulic mean depth in each case being based on five cross sections (taken during canal closure) in the observation reach of one furlong.

39. In response to enquiries from Divisions on other Canal Systems within the United Provinces, many silt samples have been mechanically analysed with the Puri Siltometer, and the silt factors determined from the median size of the constituent particles.

These samples were all taken from non-stable channels with a view to their remodelling, and it is interesting to note that in all cases the distribution curves exhibit the peculiar peak which Dr. McKenzie Taylor asserts, is the sign of a channel in unstable equilibrium.

40. One further important point. The silt factors are of channels constructed in one case (Hathras Branch) 22 years ago, and in the other (Mat Branch) 80 years ago. The silt factors diminish as the distance from the head increases, with one exception, *i.e.*, M. 35 of the Mat Branch.

The silt tested was, of course, bed silt. Observations on suspended silt tend to substantiate Mr. C. G. Hawes' assertion that the composition of suspended, as opposed to bed silt, is nearly constant throughout a canal system.*

41. *Silt Selective Heads.*—Various forms of silt selective heads, all depending for their action on reversed curvature, have been kept under observation by the Research Section during the year. No conclusive evidence of their having functioned satisfactorily has yet been obtained.

BOMBAY (SIND).

42. During the year the work of the Research Division in Sind has been carried on under the following heads :—

1. Model Experiments.
2. Hydraulic Data.
3. Silt Survey of Channels.
4. Results of Silt Analysis.
5. Velocity distribution below Falls and Regulators.
6. River Surveys and Discharge observations.
7. Soil Physics, Waterlogging and Drainage.
8. Laboratory Work.

43. *Model Experiments.*—The important experiments carried out at Karachi during the year are given below.

(i) *Experiments on models of R. C. C. Bund Sluices* ex-*Sarfoo and Arain loops.*

*Bombay Technical Paper No. 53.

Experiments to obtain suitable forms of downstream expansion, baffle wall, cistern, deflector, etc., for seven R.C.C. sluices through the river bunds, to supply water to irrigation karias, were successfully carried out.

(ii) *Experiments to suggest modifications to pass high flood discharge through the bridges over the Durani and Habib Nallas near Quetta in Baluchistan.*

These experiments were taken in hand on the recommendations of a Committee of the Central Board of Irrigation on behalf of the Baluchistan P. W. D.

As a result of numerous experiments, the modifications proposed are of the following nature to suit each case as necessary :—

(*a*) Providing winding approaches and pier noses at 1 in 5 to avoid sudden shock at entry.

(*b*) Shifting the position of maximum afflux by providing longer piers and abutments on the upstream of the bridge.

(*c*) Increasing waterway by removing piers or adding new spans.

(*d*) Raising of the road-way.

(iii) *Model experiments to obtain experimental evidence of the value of sand coring in river bunds.*

The sand coring in river bunds in treacherous soils, like bad kalar, is considered to be of doubtful utility. Model experiments were therefore started to obtain experimental evidence whether sand coring in treacherous soils is useful for the prevention of leaks and consequent breaches or whether sand can be replaced by a mixture of sand and clay or sand and kalar soil as could be cheaply obtained at the sites where bunds are to be constructed.

Some experiments have been carried out and a preliminary note on the same is under preparation.

44. *Hydraulic Data.*—A report on the non-silting channel observations for 25 sites on the Jamrao Canal system for the period 1930-33 has been sent to the Government of Bombay.

As a result of those investigations it was found that silting channels could not be separated out from the stable ones by any of the relationships between various hydraulic factors including the relationships established by Kennedy and Lacey. Further investigation for the solution of the silting problem is therefore necessary.

45. The following formulæ which it is considered will help to design nearly stable channels in Sind, have been recommended.

$$A = a\,Q^{\cdot 825}$$

$$V = c\sqrt{R}$$

$$\frac{1}{\sqrt{S}} = \frac{1\cdot 4}{c.N}\,R^{\cdot 21}$$

where A, V, R, Q, S & N are the area, velocity, hydraulic mean depth, discharge, hydraulic gradient and Kutter's co-efficient of rugosity respectively, and a and c are constants. The values of a, c & N for different discharges are :—

Q			a	c	N
Below 50	..	..	1·28	1·1	·02
50—200	..	..	1·38	1·0	·0225
above 200	..	..	1·50	0·9	·02

Observations at the 73 sites on the Barrage Canals and 25 sites on the Jamrao Canal were continued during the year.

46. *Silt Survey of Channels.*—Important modifications based on the results of model experiments at Poona were carried out to the approach channels of the Mithrao and the Khipro Canals with a view to reducing the silting trouble in the Mithrao Canal. As a result of these modifications, it was found that whereas the silting trouble had decreased in the Mithrao, it had considerably increased in the Khipro Canal. To investigate the possibilities of reducing the silting trouble in the Khipro Canal, therefore, a silt survey to determine the grade and quantity of silt entering in each channel, taking off above the Makhi Regulator across the Eastern Nara, was carried out.

As a result of this survey it was found that the quantity of harmful silt (larger than 0.075 mm. dia.) entering the Khipro was larger than that entering the Mithrao. This excessive entry of harmful silt appears to be the main cause of silting in the Khipro.

47. *Results of Silt Analysis.*—A comparison of the results of silt analysis for samples collected from the berms of the Jamrao Canal system and 73 sites on the Barrage Canals show that both the silts are very similar in character.

48. The silt samples obtained from turbulence below the Regulators on the Jamrao system and the River water at Kotri during the abkalani season (hot weather) are very similar to those obtained from the bed at Sukkur above the Barrage in the cold weather.

49. *Velocity distribution below Falls and Regulators.*—Considerable scour was noticed below the Pirsher Regulator at R. D. 2,50,000 of the Dadu Canal after it had run without any trouble for two years. The bed material at this place is 1 ft. of clay with sand underneath.

The wearing away of the clay layer and consequent exposure of sand appears to be the cause of this deep scour.

50. *River Surveys and Discharge observations.*—The usual survey, gauge and discharge observations on the river Indus have been made and will be published in the Indus River Commission Records.

Specific discharge gauge graphs for eight sites above Sukkur in order to ascertain whether there is any indication of accretion of levels in the river bed caused by the working of the Barrage, have been maintained.

51. Alberta meters specially obtained for measurements of low velocities have not given satisfactory results so far, as the ball races get very easily clogged even with a very small quantity of silt in the water.

52. Graphs for the 5 day average discharges to study the effect of the Bakhra Dam on the inundation canals in Sind have been maintained.

53. *Soil Physics, Waterlogging and Drainage.*—Detailed investigation of about 1,025 sq. miles of kalar lands in Sind was carried out during the year.

The subsoil water table in the Begari Canal area during 1934-35 shows a fall over the levels obtained during 1933-34, probably due to the early failure of the Begari Canal.

54. *Shikarpur Canal Division.*—The chief causes of the relatively high water table appears to be the floods of 1930-32, heavy rain-fall of 1929 and 1933, and large areas of rice cultivation with very low duty.

Investigations carried out with a view to determining the effect of the Barrage Canals on the flow of the sub-soil water showed that the irrigation channels do not obstruct the flow of the sub-soil water in any way. During these investigations it was further observed that, owing to the Sind soil being more or less pervious, the sub-soil water appeared to flow both towards and along the valley lines.

55. *Khairpur Waterlogging.*—The water table in this tract shows a tendency to rise. It has, however, been kept under check by means of pumps installed on the Rohri Canal. The total discharging capacity of these pumps is about 50 cusecs.

56. The recording of water levels in about 2,000 observation pipes and about 625 wells in the Barrage command and preparation of plans to study the behaviour of the water table in different areas is continued.

57. *Laboratory work.*—The usual physical, chemical and analytical work for water, soil and silt samples has been continued.

58. The full report is accompanied by two photographs, five statements, 28 plates and the following appendices.

Appendix I.—A Note by the Executive Engineer, Right Bank Drainage Division, dealing mainly with experiments carried out to find a cheap and effective water-proofing material for lining of canals.

Appendix II.—A note on recuperation tests on unlined bores and pits.

From the preliminary observations carried out on the unlined bores and pits it was found that the formula

$$K/A = \frac{1}{T} \log \frac{H}{h} \times 2{\cdot}303$$

given in Bombay P. W. D. Hand Book, Volume II, page 673, was suitable for lined bores or wells but not for unlined ones.

PART II

MINUTES OF THE RESEARCH COMMITTEE MEETING.

MINUTES OF THE FIFTH MEETING OF THE RESEARCH COMMITTEE OF THE CENTRAL BOARD OF IRRIGATION, HELD IN SIMLA ON THE 18TH AND 19TH JULY, 1935.

The fifth meeting of the Research Committee was held at the Cecil Hotel, Simla, on the 18th and 19th July, 1935, commencing at 10 A.M. on the 18th.

The following officers were present on the first day :—

Mr. W. L. C. Trench, *President.*

Mr. C. C. Inglis, Superintending Engineer, Bombay (Deccan).

Mr. V. Ayyadurai Ayyar, Deputy Chief Engineer for Irrigation, Madras.

Mr. J. P. Gunn, Director, Punjab Research Institute.

Mr. G. Lacey, Superintending Engineer, United Provinces.

Mr. A. R. B. Edgecombe, Executive Engineer and Research Officer, United Provinces.

Mr. H. S. Kahai, Research Officer, Bombay (Sind).

Mr. M. T. Gibling, Secretary, Central Board of Irrigation.

2. Mr. Trench occupied the chair, and in his opening remarks, stated that it had been decided to change slightly the procedure of the Research Committee meetings. In the past it had been the practice for the Research Officers only to meet informally on the first day to discuss their reports for the year, and on the second day the full Committee, comprising the Executive Committee and the Research Officers, met and dealt with the agenda for the meeting. As that meant going over some of the ground covered on the first day, it had been decided that the Committee as a whole should meet on both days and that the agenda, which always included discussion of the Research Officers' reports, should be gone through item by item.

3. This procedure was then adopted.

4. *Item I.*—The minutes of the proceedings of the fourth meeting of the Research Committee held in Simla on the 19th and 20th July 1934, were confirmed.

5. *Item II.—Discussion of Research Officers' Annual Reports.*—Mr. Gunn in introducing the Report of the research activities in the Punjab during the preceding year, stated that owing to pressure of work he had been unable to study the Report closely before its circulation, and there were several portions which would have to be amended before the Report was circulated in its final form. Proof copies of the Report had been circulated but they did not contain the diagrams, etc.

6. The following subjects were under investigation during the year :—

(1) Soil deterioration ..	.. Methods of measurement and prevention. Salt movements in soil.
(2) Soil reclamation ..	.. On Kharif water on y. Rice yields. Reclamation by zemindars. Soil surveys.
(3) Analysis of water for irrigation	.. Method of test and formula for suitability.
(4) Silt testing and grading ..	.. Instruments. "Goldstein" diameters. Distribution curves.
(5) Silt movement and regime of channels.	"Schocklitsch's" numbers. Tabulation and analysis of data.
(6) Weirs on sand foundations	.. Floatation Gradients. Temperature variations. Electrical Analogy method of measuring pressures. Seasonal fluctuations. Model experiments.
(7) Design of falls	.. Shape of glacis. Protection.
(8) Silting of canals ..	.. Design of silt ejector.
(9) Seepage losses from canals	.. Model and field experiments. Transmission constants.
(10) Sub-soil water table ..	.. Rises and falls. Diurnal variations.

7. Mr. Gunn passed round copies of the diagrams and photographs, and proceeded to explain them.

8. In response to Mr. Inglis, Mr. Gunn stated that the angle between the two arms of the arrows constructed on the downstream floor of some of the Punjab weirs was 60°. Mr. Inglis stated that in his experiments he had started with an angle of 45° but had now decreased it.

9. During the discussion on the Silt Ejector on the Salampur Feeder, Mr. Inglis asked if the discharge in the Upper Bari Doab Canal had been increased in order to work the ejector. Mr. Gunn stated that the discharge had been increased by 500 cusecs. Mr. Inglis said this would result in a heavier silt charge and the fact that the ejector was passing off a certain quantity of silt of various grades did not necessarily prove that conditions had been improved.

10. Mr. Gunn explained how they had introduced the Schocklitsch Number (K) as a characteristic of bed silt samples in their investigations, and although he had not investigated the dimensions of this Number, they had been able to establish relationship indicating that K was a useful characteristic of silt. They had established one relationship between "Water surface slope of the channel" and the ratio of the "average depth" to the "water surface width" by the use of K, and Mr. Gunn preferred that ratio to one involving "hydraulic mean radius" and "wetted perimeter", as it was simpler for observations.

11. On enquiry, Mr. Gunn explained the Punjab method of taking silt samples, and as it was evident that a full discussion on the question of standardizing methods was necessary, it was decided to add it as an extra item to the agenda.

12. Mr. Inglis then introduced the Bombay (Deccan) Report, and stated that certain portions of it would have to be revised, as, unfortunately, he had been unable to study the Report before it was issued.

The following subjects had been under investigation during the year :—

(1) Canal falls	.. Experiments with models to ascertain dissipation of energy below flumed and parallel sided falls. Design of baffles.
(2) Silting of canals ..	.. Exclusion by regulation of barrage gates. Decrease when discharge per foot run decreased by increasing width of canal head regulator.
(3) Discharge	.. Increase with bellmouth upstream and gradual expansion downstream.
(4) Silt sampling	.. From turbulence below regulator or fall.
(5) Modules	.. Range of Gibb type.
(6) Silt abrasion	.. Measurement. Observations with glass sided model.
(7) Soil reclamation ..	.. Treatment with CO_2 water. Farm Yard Manure and Rice. Alum. Flooding compared with rotational irrigation. Gypsum and Calcium Carbonate.
(8) Sugar-cane	.. Transpiration ratios. Effluent manurial treatment.

13. Mr. Inglis explained the diagram and photographs and replied to several queries.

14. He had found that the friction blocks evolved by Mr. A. M. R. Montagu (described in Central Board of Irrigation Publication No. 10), for dissipating energy below a fall were not so satisfactory as the arrangement of arrows recently used in the Punjab.

15. In reply to a question, Mr. Inglis stated that when deflectors were used they should be extended up the side slopes of the channel and their height on the slopes should be double the height of the bed deflector.

Mr. Gunn mentioned that slightly decreasing the discharge through the side notches of a fall had the effect in some cases of reducing wave lap below a fall.

In Mr. Inglis' opinion the best test for canal fall designs is the disposition of the isotachs at the downstream end of the structure.

16. During a discussion of the best method of measuring discharges in canals, Mr. Gunn stated that in the Punjab where they used current meters, their errors were generally within ½ per cent. in canals and 2 per cent. in rivers. Mr. Lacey stated that in the United Provinces telescopic rods were in general use and were found satisfactory. Current meters were employed for the calibration of metered falls. Both Messrs. Inglis and Lacey pointed out that "errors were generally within ½ per cent. in canals" merely meant that the variation was only ½ per cent., but that the divergence from the true discharge due to .6 depth being adopted might be far in excess of ½ per cent., and they held that where the section was good and the depth 6 ft. or less, rods gave more correct results. Mr. Gunn stated that he considered it necessary in measuring absorption to adopt one method only, either by meters or by rods.

17. Mr. Inglis stated that Gibb modules had already been constructed on all outlets of most of the distributions of the Nira Left Bank Canal and that they had proved highly successful.

18. After an interval for lunch, Mr. Edgecombe, in presenting the United Provinces Report, stated that they had no whole time Research Officer in the United Provinces, but that he performed the duties of Research Officer in addition to his ordinary duties as an Executive Engineer. During the year the Irrigation Research Section of the United Provinces had confined its enquiries in the main to :—

(1) The lining of channels and guls.	Experiments with cement plaster reinforced with wire netting.
	Experiments with earth stabilized with bituminous products, and with sugar factory by-products.
	Actuarial investigations of the problem.
(2) Seepage losses from Canals ..	Losses from small channels and "guls". Soil analysis. Losses from large channels. Methods of measuring losses.
	The calibration of falls, and the determination of empirical discharge formulae for the same.
(3) Silt Theory Observations ..	Determination of the silt factor by the mechanical analysis of silt.
	Correlation of this silt factor with the hydraulic conditions on channels held to be in regime.
	The shape of silt distribution curves derived from silting, stable and scouring channels.
(4) Silt Selective Heads ..	Observation of various forms of silt selective heads depending on reversed curvature for their action.

20. Mr. Edgecombe stated that Bitumals and Bitumatti had not proved satisfactory for canal linings. Bitumatti was the same as Bitumals except that it contained chopped hemp. For lining small channels up to 1½ cusecs capacity, fed from tube wells, they were using a brick in cement lining, 3 in. thick, at a cost of Rs. 1,500 per mile.

21. Mr. Kahai then presented the Bombay (Sind) Report containing an account of their investigations of the following subjects :—

22.	(1) Design of R. C. C. Bund Sluices ..	Experiments with models.
	(2) Bridge redesign	Experiments with models, to pass flood discharges.
	(3) Sand coring in river bunds ..	Model experiments.
	(4) Silt movement and regime of channels.	Evolution of formulæ.
	(5) Silting of canals	Modifications based on model experiments. Silt survey.
	(6) Silt analysis	Samples from the Indus, and Sind canals.
	(7) Scour below a fall-regulator ..	Treatment.
	(8) Indus survey and discharge observations.	....
	(9) Soil reclamation and drainage ..	Investigation of "kalar" land. Rise in sub-soil water levels. Obstruction to flow by new canals. Recuperation tests.
	(10) Laboratory work	Tests of water, soil and silt samples.
	(11) Seepage from canals	Experiments with materials for lining.

23. During the discussion on data relating to silt movement and regime of channels Mr. Kahai tabled a copy of the report* on the subject which had been submitted to the Bombay Government. After examination of the accompanying graphs Mr. Lacey pointed out that there was much closer correlation between the points for regime channels than there was for the regime and non-regime channels when taken together, and he thought they should be considered separately. The P_w relationship, however, appeared to apply to both regime and non-regime channels alike.

Mr. Lacey considered that the miscellaneous data for the inundation canals on Plate XVII of the report should be dealt with separately as there appeared to be a different curve for them. Mr. Inglis pointed out that the curves on Plate XIII of the report took into account "f" whereas the others did not, and that it was very important to take silt into account. Mr. Kahai explained at length the waterlogging problems in Shikarpur, and Khairpur State, and stated that in the former case the rise of sub-soil water level was attributed to rice cultivation, heavy rain and other causes, and not to the new canals constructed in the vicinity, as had been alleged.

The meeting was then adjourned.

24. The Committee met the next day, the 19th July, and in the absence of Mr. Trench who was indisposed, Mr. Waller took the chair.

25. Item III of the Agenda was taken up.

26. (1) *Means of conserving irrigation water.*—Under instructions from the Chairman, the Secretary read the resolutions on this subject passed at the Research Committee Meeting of July 1934, and the Board Meeting of November 1934, and stated that he had been in communication with Brigadier Haswell regarding experiments in Baluchistan, but had not received any report of such experiments and as Brigadier Haswell had since retired he did not think the reports would now be forthcoming.

27. Mr. Edgecombe stated that experiments had been carried out in the United Provinces with Bitumals, and had not proved successful. They were still experimenting with linings for channels, and the most suitable form so far obtained, having regard to cost, was cement plaster re-inforced with wire netting, which could be constructed on an experimental scale at prices varying from Rs. 11-10-0 to Rs. 16 per 100 sq. ft. Thicknesses of ¾ in. and 1 in. were used.

*Copy on record in the Central Board of Irrigation Office.

28. Mr. Lacey said that on small watercourses up to 1½ cusecs capacity, for tube wells, they had adopted a brick in cement lining 3 in. thick at Rs. 1,500 per mile. They had considered kankar lime concrete with kankar aggregate, and experiments would be made.

29. The Chairman stated that a suggestion had been made in the Punjab to line the Jhang Branch with a lining of two layers of 2 in. brick tiles with a cement "sandwich" in between. He thought the suggestion was a good one, but they had not been able to carry it out owing to financial reasons.

30. Mr. Inglis stated that No-Frango had been tried but was not satisfactory in the form of a slab. It was useful, however, for buildings where it could be used on frames, but it was essential to use an open mesh hessian so that there was intermingling of the concrete on both sides of it.

31. *Resolved.*—This Committee are of the opinion that although some of the types of lining already experimented with have proved satisfactory in particular cases, there is still need for further research in an endeavour to evolve an efficient and cheap lining for small channels, and it is hoped that the investigations will continue.

32. (2) *Testing and grading of silt.*—The Secretary read the resolution passed at the previous Research Committee meeting.

33. Mr. Gunn stated that the memoir on the Puri Siltometer had been published by the Punjab Research Institute and was under circulation.

34. Mr. Inglis considered that it was essential to standardize methods of silt sampling for general adoption and thought that the matter could best be dealt with by a sub-committee.

35. Mr. Gunn stated that he had recently prepared a set of instructions for the guidance of his staff in the field and he thought they might be printed up as a memoir of the Institute and circulated.

36. Mr. Lacey agreed that standard methods of taking silt samples and grading them were necessary, and suggested that each Province should forward to Mr. Gunn a note explaining the local methods at present in use, with a view to subsequent standardizing by the Research Committee.

37. Mr. Inglis stated that the method he used for taking silt samples in model experiments, which had proved very satisfactory, was to draw off water through a tube facing upstream, into which water was sucked at the same velocity as the flowing water ; so that a true sample was obtained. The correct velocity was obtained by regulating the outfall level. This was easy to arrange where there was some fall, or into the bottom of a boat. This method had yet to be tried out in the field. Mr. Kahai promised to test the method in Sind on a large scale.

38. On enquiry from the chair, it was learned that the Puri Siltometer was being used in the United Provinces and Sind, and recently in the Deccan, and was proving satisfactory.

39. *Resolution.*—This Committee consider it necessary to establish standard methods of taking samples of both bed silt and suspended silt, and recommend that Provinces making such investigations should be asked to forward to Mr. J. P. Gunn, Director, Punjab Research Institute, Lahore, a note describing the method and apparatus at present used for taking samples.

The Committee consider the Puri Siltometer to be the most suitable "field" instrument for grading silt samples and recommend its adoption as a standard.

40. (3) *Lacey Silt and flow theories.*—The Secretary read the Resolution passed at the Fourth Meeting of the Research Committee in July 1934.

41. Mr. Gunn explained that the Schocklitsch number (K) which he had adopted was obtained by dividing the area on the left hand side of the silt sample summation curve into the area on the right hand side of the curve, and he had found it a very useful number to deal with and it gave very good results. It was a characteristic number and although he had not investigated its dimensions, he felt certain that its use would prove to be of considerable practical value. He proposed to deal with it more fully in the memoir he was preparing.

42. Mr. Inglis stated that temperature variations in canal water were responsible for greater changes in viscosity than were varying changes in silt content, and it was agreed that when silt samples were being taken, the temperature of the water should invariably be recorded.

43. Mr. Kahai stated that from the Jamrao Canal data for 1933, the following formulæ had been evolved which were very close to Lacey's formulæ :—

From Jamrao data.	Lacey's formula.
$P = 2\cdot63\ Q^{0\cdot5}$	$P = 2\cdot67\ Q^{0\cdot5}$
$V = \cdot893\ R^{0\cdot48}$	$V = \cdot92\ R^{0\cdot5}$
$V = 9\cdot49\ (R^2\ S)^{0\cdot267}$	$V = 16\cdot11\ (R^2S)^{\frac{1}{3}}$
$\frac{1}{\sqrt{S}} = 82\cdot4\ R^{0\cdot12}$	$\frac{1}{\sqrt{S}} = 73\cdot18\ R^{\cdot25}$
$\frac{V}{\sqrt{S}} = 73\cdot35\ R^{0\cdot6}$	$\frac{V}{\sqrt{S}} = 64\ R^{\cdot75}$ $N = \cdot021$

44. Mr. Lacey stated that if manifestly discordant data such as for the Jamrao head were eliminated, he thought the Jamrao data would give results closer to his own formulæ, than those evolved in Sind, and recommended that the data should be re-examined.

45. *Resolution.*—This Committee consider it essential for the temperature of the water to be recorded at the time silt samples are taken, as temperature changes affect the viscosity more than changes in silt content. They find that the data relating to the Jamrao Canal stable channels appear to confirm the Lacey relationships.

46. (4) *Land reclamation and prevention of soil deterioration.*—The Secretary read the Resolutions passed at the Research Committee meeting of July 1934, and the Board meeting held in November 1934.

47. Mr. Gunn drew attention to the work done in the Chemical Section of the Punjab Research Institute, which is described in the annual report. It had been found that the presence of calcium salts in the water prevented the base-exchange action taking place between the sodium and calcium in the clay complex, and it would therefore not be harmful to apply irrigation water having a salt content of more than 60 parts per 100,000 of water, provided there was sufficient calcium in the water.

48. Mr. Gunn referred to the new formula quoted in his report which would indicate whether a water was suitable for irrigation or not.

49. The Chairman then asked Mr. Gunn to state what had been done on the practical side, whether any tests had been carried out in the field. Mr. Gunn stated that they had commenced investigations with applications of gypsum on deteriorated land, but he was unable to give any results. They were using it in a powdered form which cost five or six rupees per ton at the quarry. In reply to a question by Mr. Lacey as to how often gypsum need be applied, Mr. Gunn stated that normally it should be applied once in five years.

50. Mr. Inglis stated that gypsum had been used in the Deccan and was found suitable. He considered it to be a local problem as some soils responded better than others, and it was impossible to make a general ruling.

51. *Resolution.*—This Committee find that irrigation water with a salt content of more than 60 parts per 100,000 of water, may be used without detriment to the soil, provided there is sufficient calcium present in the water, or in the soil, or in both.

52. (5) *Model experiments in hydraulic laboratories.*—The Secretary read the Resolution passed by the Research Committee at their meeting in July 1934.

53. Mr. Gunn stated that his experiments on the Khanki weir protection had been printed up and the report was now under circulation.

54. Mr. Inglis reported that his model experiments on falls were still incomplete as he had been awaiting Mr. Gunn's report. He said, however, that it was clear that for canals with falls of more than 1/3rd the depth, flumed falls gave the best results, and if the falls were to be used as meters, bridges or regulators, the advantage was very marked ; but for low falls and weirs the arrow and block design appeared to be suitable. He stated that he was using models for other experiments, and described briefly the model of the Ganges at the Hardinge Bridge site, with which he was carrying out certain experiments for the Railway Department. In the case of the large model (up to 12 cusecs) he had followed Lacey's rules ; but with the small model (about 1 cusec) he had

encountered several difficulties as regards vertical exaggeration and time factors. He would like Mr. Lacey to visit Poona to see the model and discuss the various problems.

55. Mr. Kahai mentioned the use of models for framing proposals for improvements to bridges in Baluchistan to enable them to take flood discharges. These experiments were carried out at the request of the Central Board of Irrigation.

56. *Resolution.*—The Committee consider the use of models to be of immense value, and in the interests of the study of irrigation problems by means of models in general, and the Hardinge Bridge model in particular, Mr. Lacey should, if possible, pay a visit to Poona to see the model and discuss the difficulties with Mr. Inglis.

57. Item IV of the Agenda was then taken up.

Protection down-stream of falls.—Mr. Inglis said that he hoped to continue his experiments with falls as soon as he received Mr. Gunn's report, copies of which were about to be distributed. Mr. Gunn stated that he had found that arrows were very useful in shallow swift jets, but not in deep jets where the top layers of water over-rode the jets thrown up by the arrows and thus rendered them ineffective.

58. Mr. V. Ayyadurai Ayyar stated that in Madras their vertical falls had given satisfaction, and they were cheaper than Mr. Montagu's design. In response to an enquiry Mr. V. Ayyadurai Ayyar said that the banks were composed of stiff clay and there was no scour. The canals were flowing continuously.

59. *Resolution.*—This Committee consider that the reports of Messrs. Gunn and Inglis must be awaited before the subject of fall design can be discussed further.

60. Item V of the Agenda was then considered.

Mr. V. Ayyadurai Ayyar had previously intimated that he desired to raise the question of eradication of weeds from canals, and the Chairman consented.

61. Mr. V. Ayyadurai Ayyar referred to the summary of the previous year's Research reports wherein the matter was mentioned. They had tried the copper plate method in an attempt to destroy weeds in the Ellore Canal but without success. They had tried dragging them out with rakes, but that method was found to be expensive. They had tried stirring up the silt in the water to exclude the sun's rays, but the silt re-deposited itself almost immediately.

62. Mr. Inglis stated that they had been able to kill weeds in the Deccan—even where there was very little silt in suspension—by closures of three days in ten, to which Mr. V. Ayyadurai Ayyar replied that as the canal in question was used for irrigation-*cum*-navigation they could not have closures.

Mr. Inglis then said that weeds do not grow if the velocity of the water is more than 2 feet per second, and he suggested that the canal be narrowed down by adopting a Lacey section in order to increase the velocity.

63. Further enquiry from Mr. V. Ayyadurai Ayyar elicited the fact that they only experienced the difficulty in 12 miles of the canal, and in the remaining length there were no weeds.

It was then suggested that observations should be taken in the length of canal where they had no weed trouble, with a view to establishing the same conditons in the length of 12 miles where the weeds were now giving trouble.

64. Mr. Inglis proposed that the Research Officers' Reports should be submitted one month earlier, *i.e.*, by the 1st June, as there was not sufficient time to study them before the meeting.

This was accepted.

65. Mr. Edgecombe suggested that the Research meeting be held at headquarters where experiments were in progress, but after some discussion it was decided that it was necessary to hold the Research Committee meeting in Simla.

66. Mr. Lacey proposed that the present arrangement be adhered to, but Research Officers should foregather at one of the research centres during the cold weather at the time of the local Engineering Congress meeting.

67. *Resolution.*—This Committee are of the opinion that officers engaged on research work should meet at one of the research centres at some time during the cold weather, if possible at the time of the local Engineering Congress meeting. If local Governments permit this the first meeting should be at Poona.

68. Mr. V. Ayyadurai Ayyar, then asked Members of the Committee what formulæ were generally used in channel design. In Madras they used Kutter's formula and found it cumbersome.

Mr. Lacey stated that in the United Provinces they used Garrett's Tables. In Egypt they used Manning's formula. The Punjab used Kutter's which was practically the same for regime channels. Mr. Inglis said that he used Lacey's formula, which was the only formula which specified shape and slope—the most important factors in design.

A vote of thanks to the Chair terminated the meeting.

W. L. C. TRENCH.
F. J. WALLER. } *Chairmen.*

PART III.

TECHNICAL PORTION OF THE AGENDA FOR THE ANNUAL BOARD MEETING, NOVEMBER 1935.

TECHNICAL PORTION OF THE AGENDA OF THE ANNUAL MEETING OF THE CENTRAL BOARD OF IRRIGATION, NOVEMBER, 1935.

PROFESSIONAL AND TECHNICAL.

Item I.—

COPY OF PRESIDENT'S LETTER No. 2552-A. 4, DATED THE 13TH MAY, 1935, TO THE SECRETARY, INDUSTRIES AND LABOUR DEPARTMENT, GOVERNMENT OF INDIA.

"I am requested by the Central Board of Irrigation to approach you once more in connection with the question of water rights in India.

Your attention is invited to the discussion on this subject which took place at the Board meeting of November 1934. Copies of the Proceedings were forwarded to you with Secretary's letter No. 841-F.41, dated the 16th February 1935.

2. The Board desire me to enquire—

Firstly : if the Government of India are yet in a position to inform the Board as to the method of dealing with the general question of water rights under the new constitution.

The members of the Board have studied the relevant sections of the Government of India Act 1934 and understand that it will be possible to set up some central authority to deal with disputes of this nature. My Board will be grateful if the Government of India could inform them if any action is proposed on these lines.

3. Secondly : the Board understands that legislative action is proposed in the United Provinces with a view to regulate the position of the cultivator in respect to his rights to water and to safe-guard him from undue interference in the enjoyments of those rights. A reference to the discussion on this point at page 8 of the Proceedings referred to above will assist you in understanding the uneasiness with which my Board views the present indeterminate position. The Members of my Board represent various Provinces in India and would be most grateful for an expression of the views of the Government of India as to what action in this connection can be taken within the present Government of India Act.

4. My Board fully realize the importance and complexity of the two matters referred to above, but I am desired to emphasize once more the views they hold, which have been placed before the Government of India on previous occasions. In other countries of the world the haphazard growth of legislation on the subject of water rights has led to the greatest administrative difficulties. My Board is definitely of the opinion that with this abject lesson before them they would be failing in their duty if they refrained from drawing the attention of the Government of India to the situation which is likely to develop. They feel most strongly that the whole question is of a magnitude and importance which justifies the most serious attention of the Central Government at an early date."

COPY OF LETTER No. IR53, DATED THE 27TH JUNE, 1935, FROM THE OFFG., JOINT SECRETARY TO THE GOVERNMENT OF INDIA, DEPARTMENT OF INDUSTRIES AND LABOUR, SIMLA, IN REPLY TO THE ABOVE.

SUBJECT :—*Water rights.*

"I am directed to refer to your letter No. 2552-A.4, dated the 13th of May 1935, on the subject noted above. As regards the general question of water rights under the new constitution, I am to observe that provision has been made in the revised clauses 130 to 134 of the Government of India Bill (a copy of which is enclosed) for the settlement of inter-unit disputes by a special procedure. The final form of these clauses will not be known until the Bill is passed into law, but their general effect is to maintain for Governors' and Chief Commissioners' Provinces and for Federated States the Rulers of which have made no declaration under Clause 134, the procedure which has been in force for many years. Disputes in which a State which has not acceded to the Federation, or the ruler of which has made a declaration under Clause 134, is concerned would form part of the relations between the Crown and Indian States and would be dealt with by the Crown Representative.

2. Turning to the suggestion that immediate legislation should be undertaken to safeguard the individual cultivator from undue interference, I am to say that provincial legislation is possible under the existing constitution in respect of water supplies, irrigation and canals within a province. Under the new Constitution these subjects remain provincial, and the only change will be that they will be in the charge of a Minister responsible to the provincial legislature. The Government of India do not know the precise scope of the legislation which the Board have in mind, but I am to suggest that in this, as in other similar matters, it will be necessary to rely upon the discretion of the provincial Legislature and of those responsible for administering the law in the provinces. No very useful purpose would be served by the introduction of special legislation which could at any moment be repealed, and the best safeguard for the cultivator is probably the existence of sound irrigation practice at the present time."

ENCLOSURE.

Revised clauses 130—134 of the Government of India Bill.

Interference with water supplies.

130. *Complaints as to interference with water supplies.*—If it appears to the Government of any Governor's Province or to the Ruler of any Federated State that the interests of that Province or State, or of any of the inhabitants thereof, in the water from any natural source of supply in any Governor's or Chief Commissioner's Province or Federated State, have been, or are likely to be, affected prejudicially by—

(*a*) any executive action or legislation taken or passed, or proposed to be taken or passed ; or

(*b*) the failure of any authority to exercise any of their powers,

with respect to the use, distribution or control of water from that source, the Government or Ruler may complain to the Governor-General.

131. *Decision of complaints.*—(1) If the Governor-General receives such a complaint as aforesaid, he shall, unless he is of opinion that the issues involved are not of sufficient importance to warrant such action, appoint a Commission consisting of such persons having special knowledge and experience in irrigation, engineering administration, finance or law as he thinks fit, and request that Commission to investigate, in accordance with such instructions as he may give to them, and to report to him on, the matters to which the complaint relates, or such of those matters as he may refer to them.

(2) A Commission so appointed shall investigate the matters referred to them and present to the Governor-General a report setting out the facts as found by them and making such recommendations as they think proper.

(3) If it appears to the Governor-General upon consideration of the Commission's report that anything therein contained requires explanation, or that he needs guidance upon any point not originally referred by him to the Commission, he may again refer the matter to the Commission for further investigation and a further report.

(4) For the purpose of assisting a Commission appointed under this section in investigating any matters referred to them, the Federal Court, if requested by the Commission so to do, shall make such orders and issue such letters of request for the purposes of the proceedings of the Commission as they may make or issue in the exercise of the jurisdiction of the court.

(5) After considering any report made to him by the Commission, the Governor-General shall give such decision and make such order, if any, in the matter of the complaint as he may deem proper :

Provided that if, before the Governor-General has given any decision, the Government of any Province or the Ruler of any State affected request him so to do, he shall refer the matter to His Majesty in Council and His Majesty in Council may give such decision and make such order, if any, in the matter as he deems proper.

(6) Effect shall be given in any Province or State affected to any order made under this section by His Majesty in Council or the Governor-General, and any Act of a Provincial Legislature or of a State which is repugnant to the order shall, to the extent of the repugnancy, be void.

(7) Subject as hereinafter provided the Governor-General, on application made to him by the Government of any Province, or the Ruler of any State affected, may at any time, if after a reference to, and report from, a Commission appointed as aforesaid he considers it proper so to do, vary any decision or order given or made under this section :

Provided that, where the application relates to a decision or order of His Majesty in Council and in any other case if the Government of any Province or the Ruler of any State affected request him so to do, the Governor-General shall refer the matter to His Majesty in Council, and His Majesty in Council may, if he considers proper so to do, vary the decision or order.

(8) An order made by His Majesty in Council or the Governor-General under this section may contain directions as to the Government or persons by whom the expenses of the Commission and any costs incurred by any Province, State or persons in appearing before the Commission are to be paid, and may fix the amount of any expenses or costs to be so paid, and so far as it relates to expenses or costs, may be enforced as if it were an order made by the Federal Court.

(9) The functions of the Governor-General under this section shall be exercised by him in his discretion.

132. *Interference with water supplies of Chief Commissioner's Province.*—If it appears to the Governor-General that the interests of any Chief Commissioner's Province, or of any of the inhabitants of such a Province, in the water from any natural source of supply in any Governor's Province or Federated State have been or are likely to be affected detrimentally by—

(*a*) any executive action or legislation taken or passed, or proposed to be taken or passed ; or

(*b*) the failure of any authority to exercise any of their powers,

with respect to the use, distribution or control of water from that source, he may, if he in his discretion thinks fit, refer the matter to a Commission appointed in accordance with the provisions of the last preceding section and thereupon those provisions shall apply as if the Chief Commissioner's Province were a Governor's Province and as if a complaint with respect to the matter had been made by the Government of that Province to the Governor-General.

133. *Jurisdiction of Courts excluded.*—Notwithstanding anything in this Act neither the Federal Court nor any other court shall have jurisdiction to entertain any action or suit in respect of any matter if action in respect of that matter might have been taken under any of the three last preceding sections by the Government of a Province, the Ruler of a State, or the Governor-General.

134. *Ruler of State may exclude application of provisions as to water supply.*—The provisions contained in Part VI of this Act with respect to interference with water supplies shall not apply in relation to any Federated State the Ruler whereof has declared in his Instrument of Accession that those provisions are not to apply in relation to his State.

ITEM IV.

"Tortuosity of rivers and their training by means of embankments".

Board Meeting November 1934.—Secretary was instructed to enquire from the Railway Board as to what information was available with them, particularly in regard to the deepest recorded river embayments behind guide banks. He should address all Members requesting contribution of information from records, and of papers by selected officers on the subject.

In accordance with the above instructions the Secretary addressed the Railway Board on the subject who referred him to the Chief Engineer of the Eastern Bengal Railway. That officer supplied a graph showing the change in length of the Ganges between Sarda and Pabna, and some yearly surveys of Bengal rivers crossed by the Railway. Composite plans of the Ganges surveys between Sarda and Pabna have been promised and are awaited.

Foreign correspondents were addressed and a copy of the enquiry, together with abstracts from some of the replies, is attached herewith. Many correspondents supplied bibliographies, and a complete bibliography has been supplied to Mr. Inglis (Bombay) who is experimenting with a model of the Ganges above and below the Hardinge Bridge. A copy of that bibliography is also attached. (Appendix VI.)

Members of the Board have been asked to supply information and to invite selected officers to read papers on the subject.

The following Note on the subject has been prepared by Mr. W. L. C. Trench, President and will be presented at the Board meeting.

NOTE ON "TORTUOSITY OF RIVERS" TO BE READ BY MR. W. L. C. TRENCH, (PRESIDENT).

The question of the tortuosity of alluvial rivers is one in regard to which a considerable amount of data exist, but which has not so far been systematically treated. It is moreover one of the hydraulic problems in which the irrigation engineer and the railway engineer are both vitally interested. The reason which leads to increased curvature, and the minimum radius of curvature which any river can assume before a cut-off occurs are matters of importance in connection with the width and location of railway bridges. The interest of the irrigation engineer in the matter is due to his pre-occupation with the safety of bund lines in his charge and the safety of weirs and regulators. A certain amount of data of a generalised type in regard to the tortuosity, existing and in the past, of the Indus and distributaries can be found in appendix 7(*c*) of the Bakhra Dam Report. In this appendix the actual length of the river is shown as a percentage of the direct length between various points.

It will be seen by an examination of these figures that although they are in many cases conflicting and not reduceable to any general theorem, there is, in general, a progressive increase of tortuosity from the head reaches of the tributaries and the Indus itself down to the sea. For instance, it will be seen on page 137 that whereas the tortuosity between Bakhra and Patial is only 9.4 per cent., it rises to 40 per cent. between Usufpur and Hareki in the case of the most recent surveys. Similarly the river Sutlej rises from 40.5 per cent. between Hareki and Ferozepur to 56 per cent. between Adamwahan and Panjnad. The Beas river does not indicate any increase in tortuosity throughout its length. The Ravi river shows an increase of from 11.1 per cent. between Muktesar and Madhopur, to 61.7 per cent. between Sidhnai and Chenab junction. This river, however, includes the curious reach of the Sidhnai which has no tortuosity. I understand, however, that there is an ancient tradition that the Sidhnai is, in origin, artificial. Similarly the Jhelum river rises from tortuosity 2.8 in its upper reaches to 7.9 above Haveli. In the Chenab river the tortuosity is very irregular in different reaches, but the same general trend, *i.e.*, from no tortuosity to tortuosity of 10 to 20 per cent. in the lower reaches, is indicated. On the Indus itself the tortuosity is 3.7 per cent. between Kalabagh and Bilot and from 44 to 54 per cent. between Kotri and the sea. The factors which control the tortuosity may be as follows :—

(*a*) the general slope of the country to which the river must conform. This slope diminishes from the foot hills to the sea in the same way that the tortuosity increases,

(*b*) the erodability of the strata through which the river passes. It is probable that as the sea is approached, apart from any local variations, the strata is more easily eroded than it is in the upper reaches,

(*c*) the actual discharge and silt charge carried by the river.

It is common knowledge that even a very small stream flowing through flat land meanders about. There are also cases of large rivers in similar conditions developing a high degree of tortuosity, so that the influence of discharge is obscure. In regard to the silt charge carried by the water, it would appear reasonable to assume that a lesser silt charge would increase the capacity for erosion of any stream and increase its capacity for developing curves. The following questions would appear to require detailed investigation :—

(*a*) Under what conditions does a river tend to increase its tortuosity ?

(*b*) Under what conditions will tortuosity diminish ?

(*c*) If erosive action occurs at any place tending to form a curve, and assuming that the soil is uniformly erodable, is there any method of ascertaining what degree of curvature will eventually be obtained and how far the erosion will proceed ?

With regard to the question of the conditions under which the tortuosity of the river will increase, it would appear to be a matter of practical observation as well as theoretical soundness that when the energy of a river is, for any reason increased, the river will endeavour to absorb that energy by increasing its length and an instance of this has occurred in recent years in Lower Sind. In the delta area the river Indus used to flow to the sea through two main branches below the bifurcation. These were known as the Ochito and the Hydari. In years gone by, the Ochito took the main discharge but it was a river of extreme tortuosity. The discharge passing through the Hydari was an insignificant amount. Gradually discharge of the Hydari increased and that of the Ochito diminished. A year or two ago the Ochito ceased to flow as a perennial mouth of the Indus and continues to flow in the kharif season only by reason of the fact that a new or two new heads have recently been excavated for it. The Hydari now takes the whole of the cold weather flow and the vast bulk of the hot weather flow, and is, compared to the Ochito, substantially straight. The river therefore has greatly increased energy per unit of length. In addition, within recent years 3 large bends have disappeared at and above the former bifurcation. The result has been a retrogression of levels and a reduction of specific discharge levels between Jherruck and the sea, and intensive erosion in certain places where the river is forming fresh bends necessitating the construction of loop bunds. It would therefore appear reasonable to state that when the velocity of the river is increased for any reason, a lengthening process will take place. It is, however, not so easy to obtain data in regard to the reverse process, *i.e.*, does a river tend to lengthen itself when, for any reason, the velocity is artificially diminished ? In fact it has been observed in many cases that when a weir or obstruction is placed in a river so as to flatten the slope and diminish the velocity, not only does the river not tend to straighten itself above that point, but it tends on the contrary to wander. The reason, however, is different and is probably due to the fact that any checking or diminution of the velocity of a soluble river tends to create silt or sand banks consisting of the heavier grades of material carried by the river, the silt or sand banks form obstructions in the river and increase the liability of the river to erode its banks in greater curves. One would imagine therefore that in such conditions a river was in an unstable equilibrium. The greater the initial check of velocity, the greater the tendency to form such banks, and the greater the curvature becomes, resulting in a further checking of velocity, owing to the flatter slope so obtained, and therefore the formation of additional curves should proceed indefinitely. No doubt there is a limit to this tendency, but what the limit is and what would lead to a river resuming a straighter course would appear to be a matter deserving of investigation. In this connection an interesting article has recently appeared in the Engineering News Record of August 22nd, 1935, in which is described the conditions of the Missouri river between Sioux City and Portsmouth 100 years ago and at the present time. The distance by river in year 1804 between these two points was 250 miles, today it is about 150 miles. The extraordinarily great tortuosity in this river 100 years ago is described as being due to the fact that the river channel was bordered by heavy timber so that the river was almost completely filled with tree-snags to such an extent that one observer described the appearance of the river as being like a field of dead trees. This heavy timber has in the course of the last century been cut down and in great flood of 1881 the river straightened itself out to its present alignment with the result that the level of destructive floods has been reduced by some 8 or 9 feet. This would therefore appear to be a case in which an increase of energy and, in addition, a decrease in the powers of resistance due to the destruction of the forest on the banks has led down to a decreased tortuosity and not to an increase. The river during the flood mentioned found, in fact, that its line of least resistance was in a more or less direct route. This is therefore a case in which the opposite effect to that discussed above in the case of the Indus occurred. The conditions under which such a reversal of what appears to be at first sight the reasonable behaviour of a river would seem to require detailed study. A further very important point is in regard to the question of the minimum radius which an alluvial river can take out without causing an avulsion. Sir Francis Spring has stated in his study of the behaviour of the rivers that the minimum radius of curvature is equal to the width of the river. It may, however, be that the relationship between the width of the river and the radius of curvature is indirect. If we agree with Lacey that for any given discharge and silt charge the dimensions of a stable channel are fixed, then the width of the river, assuming that it is on the average stable throughout its width, would be a function of the discharge and therefore the radius to which the river will adjust itself will be a function of the discharge and the silt charge in it. This would appear to be a more logical conception and basing the minimum curvature merely on the widths of the river. There is a further subject in connection with the tortuosity of the river about which very little, if any, literature is available. Both to the irrigation engineer and the railway engineer the length and position of the guide banks constructed up and downstream for the protection of permanent works on the bed of the river is a matter of first class importance. When a river assumes a tortuous channel immediately above such guide banks the main current of the river is inclined to strike across the channel and to hit the guide banks at a more or less acute angle. Whether the current thereafter flows smoothly along the guide banks or whether it tends to form dangerous whirls and eddies must, one would imagine, depend on the acuteness of the angle between the direction of current and the axis of the guide banks. What then is the maximum obliquity of the angle between the current and the guide banks which can safely be permitted? In canal structures it has been found that where fluming has been adopted the maximum obliquity of the entrance wing walls to the current should not be more than 1 in 5, with an exit expanding obliquity of 1 in 10. It would appear desirable therefore to know whether these ratios have any utility in regard to the location of the guide banks of permanent structures in rivers.

There appears, in short, to be a very great field for research in these matters, and the method of research by means of models is likely to prove of utility. As a first step a precise definition of what each separate problem is would appear to be required so that not more than one problem is investigated at a time and secondly a decision in regard to agency and method by which such investigation should be conducted.

No. 165-J. 136.
CENTRAL BOARD OF IRRIGATION.
"KENNEDY COTTAGE".
Simla, S. W., the 11th January 1935.

FROM

A. M. R. MONTAGU, ESQ., I.S.E., M.I.C.E.,
Secretary,
Central Board of Irrigation.

To

32 foreign correspondents.

SIR,

I am directed to inform you that the subject "Tortuosity of Rivers" has been listed by the Central Board of Irrigation for detailed examination.

The necessity for this examination has arisen from the fact that during the last flood season, certain large river works, *e.g.*, railways bridges, have been damaged by the record discharges attained. Moreover, some difficulty is being experienced in restoring the training works owing to a tendency on the part of the rivers to assume a fresh course.

2. The information required by my Board is best described as under :—

What causes tortuosity or sinuosity of rivers?

What is the effect of regulating the discharge by retardation reservoirs or escapes, on the length of channel below?

What is the effect of "cut-off"?

What is the effect of weirs and bridges or other control points, erected in the bed of the river?

What is the effect of varying the silt burden of the stream on the tortuosity of rivers?

Does a river, whose mean discharge is reduced by draw-off for irrigation purposes, shorten its length by reducing its tortuosity?

3. The above are the questions which the Board is circulating in India and I am to say that my Board would be greatly obliged if you can furnish any information or reference to published views on those and any other points regarding the "Tortuosity of Rivers.".

I have the honour to be,
SIR,
Your most obedient servant,
(Sd.) A. M. R. MONTAGU,
11-1-35.
Secretary,
Central Board of Irrigation.

INSTITUT
DE
Geographie Alpine,
2, rue Tres-cloitre.

UNIVERSITE DE GRENOBLE.
Grenoble, le 4th February 1935.

(Translation.)

DEAR SIR,

I received this morning your very excellent technical articles; they have interested me very much, and, in view of their special and novel character, I propose passing them on to an engineer friend who is particularly interested in the experimental hydraulic study of irrigation and who has organised here, on behalf of an important hydro-electric construction company, a hydraulic laboratory with small scale models of dams, water catchments, irrigation canals, etc.

You ask my opinion regarding the sinuosity of water courses and certain of its effects. I must confess to a certain measure of embarrassment as regards this important question. The origin of sinuosity appears to me to be perfectly natural. In every water course, the current tends to strike alternatively first against one bank and then against the other. Gradually, the current cuts into each point attacked and at these points moves the bed laterally by forming concavities which increase ceaselessly. Hence the bends in a stream. The older the stream, the more accentuated these bends become; by older I mean the case where the evolution of the profile lengthwise has reduced the slope to a small factor. The more slowly the stream flows, the more tortuous is its course. The Mississippi and the Danube in Hungary afford examples of this, as did also the Tisza prior to the construction of certain works, about which I will have something to say further on. When a water course, which, from the story of its course, is obviously very old, finds itself raised by a positive movement of the ground or when its basic water level, at confluence or estuary, is lowered, it very quickly resumes its erosive activities; in this case, it digs itself in, where it is, between the raised banks or even in a veritable canon and remains tortuous. This is so in the case of the Meuse and the Moselle when crossing the Ardennes plateau or the Schistose Rhine Massif. One of our rivers, the Lot, is extraordinarily tortuous in its lower reaches in spite of quite a considerable slope—0.60 metres or a little more per kilometre. There is no doubt this was formerly a very old river with a small declivity whose erosive activity was resumed as the result of a lowering of its basic water level.

In the case of windings between high steep banks, there is no danger to solidly fixed bridges or for banks, generally speaking, of a good height. The situation is quite different in the case of non-sunken bends which flow through broad, floodable, alluvial valleys; here, in the case of flood, the current very often cuts straight across the cord of bends by the most direct route. It can attain quite a considerable speed over the flooded area, tear up the culturable earth, cut new beds outside its old normal bed, and break down bridges. Thus for example, in June 1875, the Garonne, during exceptional floods, forsook a bridge which had been constructed for it a little downstream of Toulouse, and great efforts were necessary to force it back to its course under the bridge. When the currents which cut across the bends in this fashion meet villages or towns on their route, they occasion damage which is sometimes " murderous ". This fact was proved in a cruel fashion along the Garonne and the Tarn during the terrible floods of March 1930.

I find it difficult to say what should be the effects of abundant transport and deposits of mud and sand on these phenomena. It seems to me that, in places where the deposits are such that the bed fills up, it is more difficult to contain the water within its bed, and that the breaches in flood-time are more serious and more numerous. This, apparently, is what is happening on a large scale in the too flat and too wide valley of the Hoang Ho.

As regards remedies, I see nothing for it but continuous embankment, but with one condition, and that is that, by an artificial grouping of the bends, a new bed be previously decided upon which is shorter and where, as a result, the slope is more marked and where the increased current will be strong enough to clear the bed of obstacles which block it. A magnificient example of this type of work is to be found on the Tisza, a river which is extremely tortuous and used to be very dangerous, as the disaster of Szegedin in 1879 showed. The Hungarian engineers shortened the course by 453 kilometres or by 32 per cent. The slope changed from one of 3.7 centimetres per kilometre to one of approximately 6.* The accelerated current dug down at certain places to a depth of 2 metres, so that floods, which became more sudden and higher because they no longer overflowed the banks but followed a shorter and steeper path, have not for a long time over-flowed the embankments. These are however cases to be met where these remedies are impracticable, for the nature of water courses is very complex and varied. Certain courses, even when shortened and embanked appear to carry and deposit sufficient matter to continue raising their beds. In such a case, the embankments are impotent.

I must apologize, Sir, for confining myself thus to the domain of generalities and for not quoting more concrete examples. Any fresh information which may reach me I will send on to you.

Yours, etc.,

(Sd.) M. PARDE.

P. S.—You ask me whether a reduction of the average discharge increases the tendency to sinuosity ? I do not think so. A reduced discharge carries less mud, but at the same time the erosion carried on against the concave banks becomes more feeble.

M. PARDE.

War Department,
United States Engineer Office
615 Commerce Building,
St. Paul. Minn.
February 15, 1935.

File No. 54.2.

Mr. A. M. R. Montagu, I.S.E., M.I.C.E., etc.,
Secretary, Central Board of Irrigation, Simla, S. W., India.

Dear Sir,

In reply to your letter dated January 11, 1935, in which you request information concerning the sinuosity of rivers, I regret to say that we have very little first-hand data available which would supply direct answers to your questions. However, the following suggestions are offered in regard to some of your questions.

*From Tisza auflak, 206 kilometres from the source, to the confluence with the Danube.

1. What causes tortuosity and sinuosity of rivers ?

It is believed that the tendency of a stream to deviate from straight line flow is essentially the result of a combination of non-uniformity of the bed as regards its resistance to erosion and the presence of complex systems of cross currents induced by changes in stage and irregularities which may exist in the bed.

2. What is the effect of " cut-off " ?

Experience with cut-offs on the Mississippi River in this district has indicated no injurious results when the cut-off is properly placed with respect to curvature above and below the cut-off. However, cut-offs which are not properly placed or which cause large increases in river slope are quite liable to result in excessive erosion and further changes in the course of the stream. It is believed that the effect of proposed cut-offs may be studied to advantage by means of model tests.

Enclosed is a number of references which you may find of value in your study of sinuosity of rivers. It is suggested that you correspond directly with the Director, U. S. Waterways Experiment Station, Vicksburg, Mississippi, for further information applying to the application of model tests to problems of sinuous streams.

Very truly yours,

(Sd.) DWIGHT F. JOHNS,
Major,
District Engineer,
Corps of Engineers.

Stevens and Koon,
Consulting Engineers.

Spalding Building,
Portland, Oregon.
February 25, 1935.

F. 500.

A. M. R. Mongagu, Esq., I.S.E., M.I.C.E., etc.,
Secretary, Central Board of Irrigation, Kennedy Cottage, Simla, S. W., India.

Dear Sir,

I have your favor of January 11, regarding " Tortuosity of Rivers.". This subject is being specially studied by the U. S. Engineers staff at the experiment station in Vicksburg, Mississippi. I submitted your questions to Herbert D. Vogel, former director of that institution. He has submitted a brief note on each of the six questions under your paragraph 2, which I am transmitting to you as follows :—

" 1. Tortuosity of rivers appears to be the result of an effort by the river to establish an adjustment of slope necessary to produce a velocity not too great for the material through which the river flows. I am enclosing a self explanatory photo of tests now in progress at Vicksburg.

2. Little data is available on this point, but in my opinion the main effect will be to produce a length that will remain fairly constant over an extended period of time.

3. Tests at Vicksburg, and cut-off recently made on the Mississippi River tend to dispel the belief that cataclysmic changes will follow the occurrence of a cut-off. In Paper I of the U. S. Waterways Experiment Station, a full discussion is given, and a fairly complete Bibliography presented.

4. This is difficult to answer in general terms but I believe there will be very little, if any, practical effect unless the system is greatly extended.

5. I know of no experiments dealing with this, but believe a large burden of silt would have considerable effect on the regime of the stream. I might ask, however, ' How is one to vary the silt burden of the

stream by any considerable amount ? ' This would be a fine subject for experimentation, and we might suggest it to the lab. at Vicksburg when we meet there in April.

6. Again I have to answer that I don't know. The tests now in progress at Vicksburg are designed to obtain the answer ".

An adequate answer to either one of these questions is a thesis in itself but I think Mr. Vogel has answered your questions as tersely as could be done.

In addition to what he has said, the following comments occur to me :

1. The sinuosity of a river is largely dependent on whether or not it carries and deposits sediment. A sediment-carrying stream builds up its banks higher than the surrounding ground, which flattens the slope until a break occurs which causes the river to seek a new channel. These things are well-known to the engineers in India and it were common-place to mention it.

2. If by regulation the discharge could be made absolutely constant and the stream still carried sediment, it would be tortuous.

5. The silt burden of a stream can be reduced by the construction of storage reservoirs. If, however, the channel below the reservoir is alluvial, the stream becomes a silt-bearing stream again before many miles. If silt could be entirely removed from a stream and its channel be made stable, its tortuosity would not be subject to change.

I am including the photograph mentioned by Mr. Vogel.

Very truly yours,

(Sd.) J. C. STEVENS.

Municipalite d'Alexandrie. *Alexandrie le 19th April 1935.*

Service Technical.

FROM

J. D. ATKINSON, ESQ., B.A., M.I.C.E.,

Chief Engineer, Alexandria Municipality, Egypt.

To

A. M. R. MONTAGU, ESQ., I.S.E., M.I.C.E., etc.,

Secretary, Central Board of Irrigation, India, Simla, S. W.

DEAR SIR,

With reference to your letter No. 165-J. 136 of the 11th January, 1935, I enclose a few notes which, I hope, may be of some little interest.

I must apologize for the delay in answering your letter and for the brief nature of these notes ; the subject is one which interests me greatly and I should have liked to have discussed the matter at considerably greater length but I really have not the time to do so.

The reason for this is that I have just recently been nominated to the post of Chief Engineer of the City of Alexandria and have left the Irrigation Service and find my time very full occupied in my new post.

I have been replaced in the Hydraulic and Researches Section at the Ministry of Public Works by Mr. J. E. O.'B. Echlin and I trust that you will be good enough to continue to send to him the very interesting papers that you, from time to time, have in the past sent me, and he, for his part, will, I am sure, be only too glad to correspond with you on matters of mutual interest and to forward you copies of publications of the Section.

I have the honour to be,

SIR,

Your most obedient servant,

(Sd.) J. D. ATKINSON,

Chief Engineer.

Copy of Note received from Mr. J. D. Atkinson, Chief Engineer, Alexandria Municipality, with his letter dated the 19th April, 1935.

The Nile in Egypt has followed a remarkably stable course during the 24 years in which I have had knowledge of it and the necessity for study of the points raised in your letter has never arisen to the extent that it would appear to have done in the rivers of India.

It is true that very considerable sums are spent annually in protective works in the Nile but practically all of this has gone into repairs of the banks, which are almost continuous throughout the course of the river in Egypt proper, in the construction of safety banks, in dry stone pitching and in spurs almost universally constructed of stone which is plentiful and easily obtained from the hills bordering the valley.

I hesitate to dogmatise regarding the points mentioned in paragraph 2 of your letter and give the following remarks from my own observation of the Nile and its branches for what they are worth. Unfortunately I have not all my notes with me to refer to.

(a) *What causes tortuosity or sinuosity of rivers ?*

The principle cause would appear to be the natural tendency of any channel towards a stable regime ; that is to say a velocity producing neither scour nor accretion. The windings of the stream, where, of course, the nature of the terrain through which it passes enables it to do so, are no more nor less than nature's adjustments.

The range of discharge of the Nile from low summer to high flood is of the order of 1 to 25 and the range of level is 7 to 8 metres and during the flood it carries a silt charge of the order of 2000 parts per million by weight.

During the height and early fall of the flood the river appears to level its bed to a very considerable extent ; it is unquestionable that a very rapid fall, whether naturally caused or resulting from reservoir filling operations, makes navigation difficult where it had, during the previous low season, been comparatively easy.

A stage is reached when the river commences to cut its low stage or summer channel. The summer channel varies very considerably from year to year and has been observed to determine the points of attack on, or retreat from, the main bank during the next flood and to this extent exerts an influence upon the course of the river.

(b) *What is the effect of regulating the discharge by retardation reservoirs or escapes, on the length of channel below ?*

Generally such effects appear to be quite local and only observable in the immediate vicinity of the regulation unless this has been done so rapidly as to cause slipping of the water-logged banks of the river.

(c) *What is the effect of " cut-off " ?*

We have no recent practical experience of this in Egypt. I recommend to your notice the very interesting series of experiments and reports on this subject issued by the U. S. Waterways Experiment Station, Vicksburg, Mississippi. I attach a list* of those which I have personally seen. You will find observations on a number of your questions contained in these papers.

(d) *What is the effect of weirs and bridges or other control points erected in the bed of the river ?*

My observations regarding this are that such effects are again purely localised in the immediate vicinity of control points.

(e) *What is the effect of varying the silt burden of the stream on the tortuosity of river ?*

This is rather a difficult question to answer. If the question concerns the effect of the silt burden towards tortuosity in a straight channel, I do not think it has any effect. But certain experiments made in Egypt on the distribution of silt on bends seem to show that there should be a tendency to accentuate an existing bend but this would naturally be within the limits of the stable regime.

(f) *Does a river, whose mean discharge is reduced by draw-off for irrigation purposes, shorten its length by reducing its tortuosity ?*

I have not observed, so far the Nile is concerned, that such is the case.

*Not printed.

Extracts from letter dated 29th April, 1935, from Mr. R. F. Walter, Chief Engineer, United States, Department of the Interior, Bureau of Reclamation, Denver, Colorado, to Mr. A. M. R. Montagu, Secretary, Central Board of Irrigation, Simla.

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The more widely accepted view to-day is in general and briefly, that the length and slope of a debris-carrying river, *i.e.*, its " tortuosite " is a still obscure function of the discharge and the solids load. Below a reservoir which removes the entire solids load, there will be a tendency to flatten the slope by degradation or meandering or by both. If the channel is limited laterally by bluffs, a vertical lowering of the bed (degradation) will result. A river in a wide alluvial plain might decrease its slope between ground sills by lateral migration or meandering.

Likewise, if for some reason the material of the bed load coarsens, a shortening of the river length and a concomitant increase in slope should result.

N.B.—Bibliography on the subject " Tortuosity of Rivers " is given as Appendix VI.

ITEM V (1).

Résumé of " Design of Weirs on Permeable Foundations ".

Board Meeting November 1930.—It was generally agreed that the theory in use on this subject was far from perfect and required further investigation and research. It was decided to invite all Chief Engineers to collect information on the subject and to have experiments made, pipes being inserted in suitable weirs for the purpose.

Board Meeting November 1931.—Mr. Burkitt tabled his note on a reinforced concrete design and after discussion the Board requested Mr. Burkitt to elaborate his note and to send copies thereof to the Secretary who would furnish them to all Provinces for opinions.

Further discussion took place as to the existing knowledge of sub-soil flow below such works and the following conclusions were reached :—

(*i*) Design of works on sand foundations must be materially affected by consideration of the sub-soil water-table. Whereas in rivers the presence of sub-soil water-table was evident and must be taken into consideration when designing works, its presence below new canals was not so obvious, and the stability of such works was liable to be affected by considerable rises in the sub-soil water-table after the canal had been opened.

(*ii*) Observations on existing works founded on sand indicate that the nature of the sub-soil is so variable that it is not possible definitely to foretell the actual pressure which will obtain at any specific point under a flat floor.

Further observations are required to confirm this. When making these observations, pressure pipes should be driven to the under-side (but not lower) of the floor in each case.

(*iii*) Experience goes to show that it is not possible to estimate accurately the length of the horizontal floor required to check the removal of sand from below it.

(*iv*) For the above reason a vertical impervious cut-off at the down-steam edge of the impermeable floor, is an absolute necessity and should be sufficiently deep to prevent the withdrawal of sand.

It was further decided that the Provinces should be invited to express opinions in regard to the essential principles of weir design with special reference to the necessity of other lines of piles.

Board Meeting November 1932.—Mr. Hadow tabled results of observations made on the Panjnad Weir by means of pressure pipes, and they were compared with similar observations on the Deoha Barrage, United Provinces. After some discussion the Board decided not to record any conclusions in amplification of those recorded the previous year. The pressure observations discussed and the tentative conclusions already recorded, required considerably more data for their substantiation. It was decided to call for more observations from wherever facilities existed, and also to await the mathematical analysis promised from the Punjab. Mr. Burkitt's reinforced concrete design for a barrage was discussed and Mr. Burkitt replied to the various criticisms.

Board Meeting November 1933.—After some discussion on the matter of procedure adopted in examining subjects discussed by the Board the following resolution was recorded :—

(*a*) that further intensive study of sub-soil flow beneath actual works was essential,

(*b*) that in view of the active part already taken by Mr. Khosla, and his published papers on the subject, the compilation of a comprehensive note on the subject should be entrusted to him,

(*c*) that Mr. Khosla should be supplied with all available observations on the subject from India,

(*d*) that in order to secure uniformity of observations he should prepare a note on the nature of observations required and the form in which they should be tabulated : this note to be communicated to all interested, through the office of the Board.

Mr. Khosla read a paper on the following :—

(*a*) the observations he was conducting at Panjnad,

(*b*) the instruments he was using,

(*c*) the method of recording observations,

(*d*) the interim results achieved,

and after a discussion on the paper the Board passed the following resolution :—

(*a*) that Secretary should communicate with all Members of the Board drawing attention to the importance of the work now being carried out in the laboratory of the Research Institute at Lahore on model experiments, on the flow of sub-soil water beneath works on sand foundations : and also to the importance of the observations and work therein being carried out by Mr. Khosla on full scale works,

(*b*) that Secretary should suggest the advisability of placing pressure pipe points and making observations in accordance with the methods developed by Mr. Khosla in all new works and in old works under repair and in other situations where possible,

(*c*) that in co-operating in respect to (*b*) above, Members might well ask Mr. Khosla to suggest the number and position of observation points, to facilitate uniformity of observations.

Board Meeting November 1934.—The Chairman referred to Mr. Khosla's note on the subject which was about to be published by the Board, and to Dr. McKenzie-Taylor's memoirs on his laboratory investigations. He drew the attention of the Board to one phenomenon noticed by Mr. Khosla, *viz.*, the effect of temperature on the pressure gradient below a work on permeable foundations.

The Secretary tabled a short bibliography on the subject.

Subsequent developments.—Reference is invited to Board Publication No. 8. Owing to further demands for copies of the Publication, the question of its revision is under disposal. Reference is also invited to the Punjab Research Publications Volume I, No. 5, Volume II, Nos. 9 and 10, already supplied to Members.

In reply to a request for suggestions for improving the methods described in Technical Paper No. 8, the Chief Engineer, Bahawalpur State (Sir Bernard Darley) proposed that an attempt be made to frame some rules for the design of these works. An extract from his letter is given below.

Extract from letter No. 9453, dated 29th July 1935, from Sir Bernard Darley, Kt., C.I.E., Chief Engineer, Bahawalpur Government, to the Secretary, Central Board of Irrigation, Simla.

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I do think however that the information now before the Board received from various sources should be sufficient to enable tentative rules to be framed for the guidance of officers when designing works to be built on homogenous sand foundations. Possibly the Executive Committee might think it advisable to ask Mr. Khosla to frame a tentative set of rules for discussion at the next meeting of the Board.

Now that it is known that the Bligh theory does not hold good, it is very necessary that officers should have rules to guide them in fixing the following data before attempting the design of a work to be founded on sand :—

(*i*) Length of flexible protection upstream to prevent scour which might reduce the effective value of the vertical cut off.

(*ii*) Depth of vertical cut offs below the floor and position of same.

(*iii*) Length of pucca floor up and downstream of the work and method for calculating the thickness at each point.

(*iv*) Length and best type of flexible protection downstream of a work.

These probably could be fixed in terms of the maximum head on and the velocity through the works, separate figures being given for fine, average and course sand.

Such rules would be of the utmost value to engineers throughout India.

ITEM V (2).

Résumé of " Design of Falls ".

Board Meeting November 1930.—Colonel Pollard Lowsley referred to experiments carried out in the Central Provinces to prevent erosion below falls and suggested that information on the subject should be collected from all provinces with a view to a type design being evolved which, while economical in cost, would obviate scour and wave action downstream. Various solutions, such as the employment of baffle walls or floating booms, were discussed. The importance of the question was acknowledged by the Board and all Chief Engineers were asked to examine it and forward the results to the Bureau, for discussion at the next meeting.

Board Meeting November 1931.—The Board first examined the type plans and the completion plans which had been provided by the members in response to this enquiry.

After discussion the Board recorded the following conclusions :—

(*i*) In general the Board recommends that the " vertical drop " type of fall (referred to in the Digests as " free overfall ") is preferable to the rapid type.

(*ii*) A raised crest is preferable to the notch type.

(*iii*) The length of the crest should be as great as possible having regard to the channel bed width, in order to reduce the discharge per foot run of crest to the lowest possible. The Board were not prepared to lay down any maximum discharge per foot run of crest as this was bound up with so many other considerations.

(*iv*) The Board declined to make any definite recommendation as to the maximum height of any individual fall, but recorded the opinion that the United Provinces practice of breaking a large fall into a number of steps appeared to be highly satisfactory.

(*v*) On the subject of cisterns the Board invited the attention of its members to the practice and formula in vogue on the Sarda Project wherein the depth of cistern depended upon the discharge per foot run of crest, the drop in water surface and the depth of water in the channel. Sir Bernard Darley pointed out that provided the depth on crest is not greater than 4 feet, no cistern is required unless the drop in water surface is more than 7 feet.

(*vi*) As regards protection downstream the Board considered it impossible to record any recommendation in view of the diversity of opinion and practice. This item required further enquiry.

The Board expressed the opinion that protection against lapping action was not susceptible of theoretical treatment and could best be met by a layer of gravel or broken brick at a little above and below full supply level.

Board Meeting November 1932.—After discussion of types of falls in Madras, the following *addendum* was made to conclusion (*ii*) of the previous year :—

" In the case of free falls, a number of notches distributed across the width of the channel had proved satisfactory in practice, owing to the interaction of the individual jets one upon another ".

Mr. Haigh's paper on the subject was discussed and the following conclusions were recorded :—

(1) The Board is of opinion that Mr. Haigh's note on the Dissipation of Energy below Canal Falls, has broken fresh ground in the treatment of this subject. Its value justifies the Board in ordering its printing and distribution as a Board publication.

(2) The sharp-crested weir is preferable to a broad crested weir from the point of view of energy dissipation but other considerations, *e.g.*, modularity and metering, may make the provision of a broad crested weir necessary.

(3) Any contraction of the total crest width must involve additional expense in the cistern. Where unavoidable, arrangements should be made to spread the jet uniformly over the cistern entry. Experience shews that radial diaphragms on the glacis are effective for this purpose.

(4) Attention is also invited to a deflecting wall or baffle, described in Bombay Technical Paper No. 44 by Mr. C. C. Inglis (Superintending Engineer, Irrigation Research and Development Circle). This device is to ensure a reverse roller which scours the bed well below the end of the masonry work and piles up the silt against the downstream end of the work.

Board Meeting November 1933.—After discussing the method of examining the subjects discussed by the Board the following resolution was adopted :—

(*a*) that Mr. C. C. Inglis be approached with a view to his undertaking the preparation of a comprehensive note on the subject of " Falls ",

(*b*) that all information that Secretary could obtain should be placed at Mr. Inglis' disposal for this purpose,

(*c*) that Mr. Lane, (Chief Engineer, Bombay Deccan) be requested to afford reasonable facilities to Mr. Inglis for this purpose.

The decision to publish Mr. Haigh's paper on " Dissipation of Energy below Canal Falls " was reconsidered, and after discussion of the various criticisms of the paper the following resolutions were recorded :—

(*a*) that the Board endorses Sir Bernard Darley's action in postponing publication of Mr. Haigh's paper on the " Dissipation of Energy below Canal Falls ",

(*b*) that before any further action is taken in this regard, the result arising from action on the resolution on falls (above) should be awaited,

(*c*) that Mr. Lane, (Member, Bombay) be requested to permit an experiment to be carried out by Mr. C. C. Inglis on the following lines :—

(*i*) For purposes of comparison with the model experiments already completed on the Tando Masti Khan Fall, construct a model for the same total discharge and the same surface drop, of a free overfall, the full width of the channel.

(*ii*) Experiments should be conducted as far as possible for the same variations of discharge as were utilized in the former experiments, and to include one at a discharge of about 25 cusecs per foot run of cill in the prototype.

(*iii*) The experiments also to include enquiry into the effects of varying cistern depth if time permitted.

Board Meeting November, 1934.—Chairman stated that various reports were awaited and until they were received there was nothing specific for discussion. Mr. Burkitt mentioned the possibility of utilization, instead of destruction, of energy below falls, and the economical construction of flank walls at a fall.

Mr. Murphy outlined the model tests on the destruction of energy below Khanki Weir.

Subsequent developments.—Reference is invited to the minutes of proceedings of the Research Committee meeting of July 1935, paragraphs 53 to 59, pages 22 and 23 of this compilation, and to the Punjab Research Publication Volume II, No. 8, already supplied to Members.

Item V (3).

Résumé of " Waterlogging and Land Reclamation ".

Board Meeting November 1930.—Mr. Harrison explained methods being adopted to watch the rise of the sub-soil watertable in Sind. Mr. Hadow explained the work being done by the Waterlogging Board in the Punjab. Mr. Hadow proposed to prepare a history of waterlogging in the Punjab since 1880, and it was decided that similar papers should be invited from Bombay, Bengal, and the United Provinces, for discussion at the next meeting.

Board Meeting November 1931.—The discussion opened by reference to notes submitted from the Punjab, and the following conclusions were reached :—

(*a*) that a high spring level caused salinity of the surface where salts were present in the soil, but salinity at the surface did not necessarily denote a high water-table,

(*b*) the effect of rise in the water-table depended on the nature of the soil,

(*c*) where land was only waterlogged, drainage was an efficient remedy.

The Board requested the Punjab to concentrate on Dr. McKenzie-Taylor's enquiry on rotations on damaged lands and to favour the Board with a detailed report of progress.

The Board requested Mr. Harrison to furnish a report on the progress of the sub-soil survey in Sind.

In conclusion, the Board recorded its provisional opinion that reclamation of waterlogged and alkaline soils was definitely possible by lowering the sub-soil water-table except where a hard and impermeable crust had formed. Even in this latter case it appeared that reclamation was possible—and perhaps economically possible—and requested the individual Members to provide the Board with all the possible information on the subject.

Board Meeting November 1932.—The following conclusions were recorded :—

(1) Prior to the undertaking of any scheme for the reclamation of salt affected lands, it is essential to conduct an examination of the sub-soil by experts in this subject.

(2) An efficient surface drainage system for the rapid removal of storm water. in areas subject to appreciable rainfall, plays a most important part in checking the rise of the sub-soil water table.

The converse holds good. Where the water table shews signs of falling due to natural causes. the retention of rainfall by obstruction of drainages and the construction of tanks, tends to check the fall.

(3) Among others, Dr. McKenzie-Taylor's notes and reports clearly indicate that under certain circumstances reclamation of salt affected lands definitely is possible, but Sir Bernard Darley's remarks go to shew that reclamation has failed in certain areas in the United Provinces. The Board cannot, therefore, record final conclusions on this head. Investigation should continue and it is hoped that Members will continue to communicate all information on this important subject.

Board Meeting November 1933.—The Secretary reported receipt of reports from Research Officers, and information from foreign sources on the subject.

Mr. Hawes gave an account of the conditions in Sind which led to the institution of sub-soil investigations. Mr. Murphy stated that prior to any attempt on reclamation of lands damaged by waterlogging or salts, a thoroughly efficient system of surface drainage had to be constructed as an essential preliminary. Unless this was done, the various processes involved in the restoration of damaged areas, were so much wasted labour.

Board Meeting November 1934.—After reference to the findings of the Research Committee on the subject it was resolved that Members should invite the attention of their Local Governments to the harmful effect on agricultural lands of the application of irrigation water having a salt content exceeding 60 parts per 100,000 of water.

Subsequent developments.—Reference is invited to the minutes of the Research Committee meeting of July 1935 at page 22 of this compilation.

Item V (4).

Résumé of " Staunching of Canals ".

Board Meeting November 1932.—Mr. Hadow referred to a note on the subject from the Punjab, which included a full description of the lining of the Bikaner Main Line. Mr. Burkitt instanced his experiences with a self-staunched channel—the Dipalpur Canal—and after some discussion on the question of the bed silting, the following conclusions were reached :—

(1) The staunching of canals was advisable in the interests of conservation of water and the prevention of waterlogging.

(2) The self staunching of canals by the deposit of fine clay silt was clearly only possible in those channels carrying a full charge of suitable silt and flowing under conditions which made such deposit possible. Whereas the staunching of banks by this means was fairly effective, staunching of the bed was decidedly problematical.

(3) The staunching of canals by masonry or concrete was purely a question of economics. Where the losses were so high as to render lining imperative, masonry or concrete linings were effective. There were other considerations which might justify such linings but, in general, these were not economical at the rates ruling in India.

Board Meeting November 1933.—Mr. Burkitt stated that while the lining of a new canal in concrete was possible, it was not feasible in the case of an old canal which had already been excavated in earth and opened for irrigation. Not only was the design very different but the time during which the canal must be closed to allow of the lining being done, rendered it impossible. Mr. Hawes gave an account of the experimental work being done in Sind in connection with sealing the Rohri Canal.

Board Meeting November 1934.—Brigadier Haswell promised to supply the Board with a note on the work of lining a reservoir with " gunite ". He also said he would see if some experiments could be carried out in Baluchistan on the use of stabilized earth for canal linings.

The following resolution was recorded :—

That this meeting of the Central Board of Irrigation records its unanimous opinion that the lining of existing large channels or main canals, is impracticable on administrative grounds alone.

It is also of the opinion that the lining of smaller channels, branches, distributaries, etc., is possible.

Where the soil is permeable, lining may be economically possible, but that no material exists at present, suitable for general use. The search for such material, should continue as the subject was of prime importance to the irrigation departments in India.

Subsequent developments.—Attention is invited to the minutes of the Research Committee meeting of July 1935, paragraphs 26 to 31, pages 20 and 21 of this publication.

ITEM VI.

Copy of Resolution No. 11, passed by the 12th Conference of Medical Research Workers in November 1934, and adopted by the Scientific Advisory Board and the Governing Body of the Indian Research Fund Association.

This Conference notes the rise of malaria that has occurred as the result of the Sind Irrigation Project and regrets that the definite early warnings of the Malaria Survey in this respect had apparently gone unheeded.

In future, in all provinces in India, before any irrigation or major engineering projects are undertaken there should be, where it does not already exist, compulsory co-operation between the Irrigation or other Department concerned and the Public Health Department.

PART IV.

TECHNICAL PORTION OF THE PROCEEDINGS OF THE ANNUAL BOARD MEETING, NOVEMBER 1935.

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TECHNICAL PORTION OF THE PROCEEDINGS OF THE ANNUAL BOARD MEETING, NOVEMBER, 1935.

PART II.—*Professional and Technical.*

Item III.—To consider the recommendation of the Executive Committee regarding the necessity for an Irrigation Adviser with the Government of India.

In introducing the subject the President recalled Sir Frank Noyce's reference to it in his address to the Board when opening the proceedings, and explained that it arose out of the discussions of the Indus Waters Distribution Committee*. The matter was brought to the notice of the Executive Committee and was discussed by them at their meeting in July 1935. The Executive Committee considered it to be a matter for discussion by the Board and therefore resolved that it should be included in the agenda for the next Board meeting, and that any findings of the Indus Waters Distribution Committee should be put before the Board.

The President then read the opinion expressed by the Independent Members of the Indus Waters Distribution Committee to the effect that the presence of an Irrigation Adviser with the Government of India would have greatly expedited the disposal of that case, and that the creation of such a post would facilitate early settlement of similar controversies which must undoubtedly arise in the future.

The President then said it was for the consideration of the Board whether such a functionary was desirable, what his duties would be, and whether there would be sufficient work for him.

Mr. Bedford was of the opinion that the Irrigation Adviser should be associated with the Board, which position would create sufficient work for him. The President stated that he was not in favour of a permanent President for the Board, and an Irrigation Adviser with the Government of India would be too senior an officer to undertake the duties of Secretary. Although the Irrigation Adviser could be a member of the Board he did not think his association with it would occupy his time to any extent.

Sir William Stampe stated that in his opinion there would be no great scope for such a post under the new constitution, and the Board would be undermining its own importance by supporting the proposal.

The discussion then turned to the procedure for examining projects submitted to the Government of India, and whether an Inspector General was necessary for that work. The President stated that he presumed the Government of India would continue to convene sub-committees of the Board to deal with such cases, as had been done in the past. In his opinion it was better for a Committee of two or three Members to examine a project, rather than one officer. This opinion was also shared by the other Members of the Board. Mr. Waller stated that if there was a big case to deal with the Members would not be able to spare the time to examine it thoroughly. Mr. Bedford was of the opinion that most of the heavy work would fall on the Secretary. It was then suggested that when a big case is required to be dealt with by a Sub-Committee of the Board a special technical secretary with staff should be appointed for the purpose, as the Board's Secretary was unable to continue with his normal work, when work of that nature was on hand, as had been the case with the Indus Waters Distribution Committee. This proposal was unanimously supported and the following resolution was framed and passed.

Resolution.—The Board have considered the question referred to by Sir Frank Noyce in his opening address of advising the Government of India to re-appoint an Inspector-General of Irrigation or a Consulting Engineer, and are of the opinion that the present system under which important projects, controversies, or other special matters are submitted to the Board for disposal by Sub-Committees of the Board, is more suitable.

The Board are of the opinion, however, that when such heavy cases have to be examined, a special technical secretary and staff should be appointed to the Sub-Committees, by the Board, and the cost should be included in the cost of the enquiry.

Item VI was then taken up.

*Vide Volume I of the Report, paragraph 7, page 28.

Item VI.—To consider a resolution passed by the Medical Research Workers regarding rise of malaria in Sind and co-operation between the Irrigation and Public Health Departments.

The President stated that this matter came up at the last meeting of the Executive Committee as the Secretary had received a copy of the resolution from the Industries and Labour Department and he desired instructions as to whether the matter should be considered by the Board. The President then read out the resolution as follows :—

" This Conference notes the rise of malaria that has occurred as the result of the Sind Irrigation Project and regrets that the definite early warnings of the Malaria Survey in this respect had apparently gone unheeded.

In future, in all provinces in India, before any irrigation or major engineering projects are undertaken there should be, where it does not already exist, compulsory co-operation between the Irrigation or other Department concerned and the Public Health Department."

The President stated that with regard to the first portion of the resolution, he had made enquiries and found that it originated in a report from a firm who had put up a ginning factory in Potoro and who complained that their work was handicapped owing to their staff and labour being down with malaria. The area was malaria-ridden even before the project came into existence, and although there was the possibility of malaria having increased since the Barrage was opened, there was no data to support that view.

With regard to the second part of the resolution, Mr. Richardson stated that he was in favour of working in co-operation with the Medical Department. This was agreed to by all the Members of the Board and the following resolution was passed, and the Secretary was instructed to communicate a copy of it to the Government of India, Industries and Labour Department.

> *Resolution.*—The Central Board of Irrigation have noted that the Conference of Medical Research Workers find that there has been an increase in the incidence of malaria in Sind, but do not consider there is sufficient evidence to decide the cause. The Board agree with the Conference of Medical Research Workers that close co-operation between the Irrigation and Medical authorities to prevent the increase of disease is desirable.

Item I of Part II was then taken up for discussion.

Item I.—To consider the President's letter to the Government of India regarding water rights and the reply thereto.

The President stated that copies of the letters had been included in the Agenda (pages 27 to 29 of this Report), and since the issue of the Agenda, Mr. Richardson had written a note on the subject, copies of which had been circulated to the Members. He asked Mr. Richardson to open the discussion.

Mr. Richardson stated that in his opinion it was necessary to have the terms of water rights definitely laid down as conditions were changing, and under the reforms irrigation was not a reserved subject. He feared that water might be used as a political weapon, and the cultivator would be rendered helpless. The Northern India Canal and Drainage Act did not give specific rights to those persons who were entitled to water and unless they had a definite claim under the Act he foresaw considerable difficulties in the future. If that were not possible then he advocated the introduction of a Water Board which would deal with complaints of water shortage.

The President referred to clause 21 of the Bombay Irrigation Act which stated that the owner of a Watercourse was entitled to have a supply of water subject to the rules in force. This would appear to mean, and it has been so held, that the Watercourse could not be closed, but it would also appear to imply that the amount of water to be given could be varied. Clause 27 of the Act however stipulated that every person desiring to have a supply of water had to submit a written application to that effect thus inferring that unless an application was made and approved, water need not be given. He referred to a legal case decided in 1902 which ruled that the Executive Engineer could not close an outlet.

Sir William Stampe was of the opinion that it was desirable to make cultivators secure against interference under the new constitution, but he did not think a Water Board would serve the purpose as speedy disposal was necessary in such cases, and there was bound to be delay if they had to be dealt with by a central agency. Mr. Lane agreed with that view.

The President then read the findings of the Indus Waters Distribution Committee, to the effect that they were unable to frame any rules for the allocation of water, but had endeavoured to act according to the general direction of the Secretary of State, namely, that in allocating water, the greatest good to the greatest number must be sought. They were of the opinion that, generally speaking, the acquiring of rights in water in perpetuity should not be allowed.

After some discussion Mr. Lane proposed that a resolution be framed recording the opinion of the Board that in the irrigation acts of the various provinces the right of application of water rights required to be defined more precisely. Mr. Bedford did not agree as he thought the resolution would cut across the findings of the Indus Waters Distribution Committee.

Diwan Bahadur R. Narasimha Ayyangar said that in his opinion the main factor to be considered was the question of claims for compensation, and he thought it would be dangerous to define the rights. After further discussion the Board decided to take no further action in the matter.

At this stage the Research Officers and other visitors were invited to join the meeting, and Item II, Part II of the Agenda, was taken up for discussion.

Item II.—To consider the question of means to secure the equitable distribution of irrigation water in the future.

The President explained that this question had arisen out of the discussion on Water Rights at the last meeting of the Board, when it was decided that Members should consider means suitable to their own provinces, with a view to discussion at the next meeting, and he would like to know whether Members had considered it.

Sir William Stampe stated that in his opinion the only means of securing the equitable distribution of water was through the co-operative or volumetric system which has been successful in the United Provinces on tube-well irrigation. Mr. Inglis said that where the whole supply of a large channel or distributary was sold to a single consumer—like a sugar company in the Deccan—sale of water by measurement was suitable but it was impracticable in the case of small cultivators. Mr. Waller referred to the Contract System which existed in the Punjab under which the water of an outlet was sold to a cultivator or cultivators at a fixed price. No guarantee was given that the outlet would get full discharge throughout the year or any season, and the cultivators took their chance. The supply factor was generally in the neighbourhood of .8 for kharif and .7 for rabi. Mr. Lacey said that there were two aspects of the case, that is, a fair basis of sale, and the equitable distribution of supplies, and pointed out that whether the sales were volumetric or based on the acreage matured, difficulties would always arise when the demand was in excess of the supply. The President stated that the two aspects were administrative and technical. The Board had just dealt with the administrative side of the question, and it was now for them to consider the other side, but as there was nothing before the Board to go upon, further information would have to be obtained. He was of the opinion that the question should be taken up first by the Research Committee, and later by the Board. This was agreed to and the following resolution was passed.

> *Resolution.*—The Board are of the opinion that means to promote the equitable distribution of irrigation water should be considered by the Research Committee, and that in this connection the aspects of the method of charging for such water on its equitable distribution should be considered.

Item V was then taken up.

Item V.—To discuss the subjects brought forward from the previous meeting, the Research Officers' Reports, and the resolutions of the Research Committee.

ITEM V (1).—*Design of Weirs on permeable foundations.*

Under instructions from the Chair the Secretary stated that he had prepared a résumé on the subject which would be found in the Agenda (pages 38 to 39 of this Report). The present position was that the question of Rai Bahadur Khosla's paper being re-written had been considered by the Executive Committee, and the Punjab Government had been addresed in the matter. It had since been decided that Rai Bahadur Khosla and/or the Director of the Research Institute should re-write the publication incorporating therein the results recently obtained in the field and the laboratory. Sir Bernard Darley had also suggested that Rai Bahadur Khosla should be asked to frame tentative rules on certain points for the guidance of engineers designing such works.

At the invitation of the President, Rai Bahadur Khosla stated that since he spoke on the subject before the Board in November 1933, a considerable amount of work had been done in the field—notably at Panjnad and Khanki and in the Irrigation Research Institute at Lahore (Punjab). It had been established that the field results could be exactly reproduced on the hydraulic or the electric model, both for homogeneous subsoils and for stratified ones. It had also been established that the seasonal variations in field due to silt and temperature changes could be reproduced equally well on the two types of models. This was an advance of a fundamental nature, as it laid the foundation for rational design. From a study of the field data and of the results obtained from models and from mathematical analysis he had evolved a very simple formula which gave uplift pressures under any given base profile within 2 or 3 per cent. From this formula it was possible to work out the maximum head which any given structure could stand. Given the maximum head, and the discharge and nature of subsoil the most economical and safe design could be worked out.

The controlling factor in all designs was the exit gradient or the hydraulic gradient, at emergence at the tail end of a work. The limiting exit gradient was 1 : 1. Above this value the subsoil at the tail end would lift up, resulting in failure of the work. For security a factor of safety was essential. Four was considered a suitable value for this.

The other controlling factors were the depth and location of the standing wave. This latter must occur well up on the " pacca " floor. These factors determined the length of the downstream floor and, in conjunction with uplift pressures from subsoil water, the thickness of this floor.

Rai Bahadur Khosla then stated that he had written a note (Appendix II) giving a general outline of the scope of the work to be covered in the revised edition of Publication No. 8, which he hoped would be ready early in 1936, but a certain amount of investigation at the Research Institute had still to be completed. He said he would like the Board to decide the factor of safety which should be adopted for the purpose of the calculations. The President said that the Board would like to have his views on the point, and suggested that it be brought up at the time the revised publication was presented to the Board. The President stressed the necessity for the revised publication being complete in itself and not in any way supplementary to the first edition.

Item V (2).—*Design of Falls.*

Under instructions from the Chair the Secretary stated that a résumé on the subject would be found in the Agenda (pages 40 to 42 of this Report), and called attention to the minutes of the last Research Committee meeting (page 23) wherein it was resolved that the reports of Messrs. Gunn and Inglis should be awaited before the matter was further discussed. Since then a copy of Mr. Gunn's report had been supplied to Mr. Inglis.

Mr. Inglis was invited by the President to state what the position was. Mr. Inglis said that from his investigations he had concluded that the Khanki design of downstream treatment with arrows was very satisfactory for weirs. With regard to canal falls, he found that for low heads the non-flumed design was suitable, but for ordinary canal falls the flume design had given the best results. From the hydraulic point of view the flume fall was satisfactory, as also for distributaries taking off upstream. He was not sure of the question of cost, and suggested that the two types should be dealt with on the same lines and the costs compared.

The Secretary stated that on a suggestion from Sir Bernard Darley he had written to Members asking them to submit to him copies of the designs of falls which had worked satisfactorily in their Provinces, with a view to preparing type designs, as suggested by Sir Bernard Darley. The question of cost would be considered at the time of deciding upon the type to be adopted for particular conditions. Mr. Lane said that he had been asked to supply designs for an 8' fall, but no such fall existed in the Deccan. Sir Benard Darley stated that he had proposed that after plans had been received from provinces, of falls which

had proved successful, they should be studied by an officer placed on special duty for the purpose, who should then prepare some typical designs for comparison of cost, after which standard designs could be prepared for those types which were found to be the best under particular conditions, for discharges of say 100, 500, 1,000, 2,000, 5,000 and 10,000 cusecs.

The President proposed that the results of experiments on falls should be considered at the next meeting of the Research Committee, and if certain types were found suitable for particular conditions, they could be compared with the designs which had proved successful in practice. The question of cost would also have to be considered. Meanwhile, the ranges over which the type designs were to be prepared should be decided. This was agreed to and the following resolution was passed.

Resolution.—The Board approve of the proposal that type designs for Canal Falls should be prepared, and are of the opinion that the question should be considered at the next meeting of the Research Committee. Meanwhile, the Secretary should obtain plans of those falls which have proved successful, and the ranges over which the type designs are to be prepared should be decided.

Item V (3) *Waterlogging and Land Reclamation.*

Under instructions from the President the Secretary invited attention to the résumé on the subject in the Agenda (pages 42 to 43 of this Report), and the minutes of the Research Committee (page 22). He read out the Committee's resolution to the effect that irrigation water with a salt content of more than 60 parts per 100,000 of water may be used without detriment to the soil, provided there is sufficient calcium present in the water, or in the soil, or in both.

The President then asked Dr. McKenzie-Taylor if he could inform the Board the limit of salt content up to which the water would not be detrimental if calcium were present in the water or soil, or in both. Dr. McKenzie-Taylor replied that up to 117 parts per 100,000 the water could be used, but above that proportion there was no possibility of preventing damage. He referred to experiments carried out in America in support of his contention, and also to work done in the Lower Bari Doab Canal area and in the Sargodha District. He stated that a formula* had been evolved at the Punjab Irrigation Research Institute which would indicate whether a water was suitable for irrigation or not. It could be said that if the salt content was not above 60 parts per 100,000 parts water, then the water was safe ; if it was between 60 and 117 then it could be used provided there was calcium present ; above 117 it could not be used without causing damage. The President then proposed the following resolution, which was accepted.

Resolution.—The Board call attention to the fact that from results so far achieved water may be used for irrigation without detriment to the soil if its soluble salt contents do not exceed 60 parts per 100,000 parts of water. Above that proportion and up to a salt content of about 120 the water may safely be used provided there is calcium present in either the soil or water, or in both. Above a salt content of 120 there is no possibility of preventing damage.

The President stated that the waterlogging question was bound to arise again, and the resolution indicated the extent to which the Board could go at present. When further results were available from the work being done in the Punjab and in Sind, the results could be considered by the Research Committee and then later by the Board.

Mr. Bedford suggested that the results from the Punjab and Sind be pooled and circulated, to which the President agreed.

Item V (4).—*Staunching of Canals.*

Under instructions from the President the Secretary invited reference to the résumé on the subject in the Agenda (page 43 of this Report), and to the minutes of the last Research Committee meeting (page 21), and the resolution

*Salt Index = (Total Na — 24.5) — [(Total Ca — Ca in $CaCO_3$) × 4.85].
All quantities refer to parts per 100,000.
Index is negative for good water, and positive for unsuitable water.

of the Committee to the effect that although some of the types of lining already experimented with had proved satisfactory in particular cases, there was still need for further research in an endeavour to evolve an efficient and cheap lining for small channels. The President then asked if Members were able to report any further progress on investigations.

Sir William Stampe and Mr. Anderson stated that experiments were still in progress in the United Provinces, but so far they had not been able to improve on the brick in cement lining used in connection with the tube well irrigation schemes, which had been discussed at the last Research Committee. Thereafter, the following resolution was passed.

Resolution.—The Board confirm the resolution of the Research Committee that although some of the types of lining already experimented with have proved satisfactory in particular cases, there is still need for further research in an endeavour to evolve an efficient and cheap lining for small channels.

Item V (*b*). To consider the summarized reports on irrigation research during the year, and the conclusions arrived at by the Research Committee at their meeting in July, 1935.

The President asked if any Member wished to raise any points regarding the reports, as some of the Research Officers were present and would no doubt be able to reply. Mr. Inglis asked if Mr. Lacey would explain the methods by which the losses in channels recorded on page 31 of the Agenda (pages 8 and 9 of this Report) were obtained. Mr. Lacey gave the necessary explanation. The President asked whether the case of a long reach of canal in which there was an off-take had been considered, because in such a case it had been found that there was a variation of discharge at the lower end. He thought that this could probably be connected with the fact that during the day the evaporation losses were greater. It was apparent that no such case had been considered.

The President then read the Resolution of the Research Committee on page 49 of the Agenda (page 21 of this Report), to the effect that the Committee considered it necessary to establish standard methods of taking silt samples, and that Provinces making such investigations should submit a note to the Director of the Punjab Research Institute describing the methods used in their Provinces. The President asked Dr. McKenzie-Taylor whether he had received any notes on the subject. Dr. McKenzie-Taylor replied that he had written a Memoir on the subject and it had been sent to the press for printing, but he had not received any notes from the Provinces. Mr. Inglis and Mr. Lacey stated that the Punjab methods were in use in the Deccan and the United Provinces. The President then proposed that the resolution of the Research Committee be accepted, and the following resolution was passed by the Board.

Resolution.—The Board confirm the resolution of the Research Committee that it is necessary to establish standard methods of taking bed and suspended silt samples, and consider that on receipt of notes on the methods in use in other Provinces, the Director, Punjab Research Institute, should be asked to make proposals for the methods to be standardized, and present them for consideration at the next meeting of the Research Committee.

The President then read out for the consideration of the Board the resolution of the Research Committee on page 51 of the Agenda (page 22 of this Report) to the effect that it was essential for the temperature of the water to be taken at the time silt samples were taken, as temperature changes affected the viscosity more than changes in silt content, and that the Committee found that the data relating to the Jamrao Canal stable channels appeared to confirm the Lacey relationships.

The President stated that Sind would present a note on the latter part of the resolution at the next meeting of the Research Committee, and for the time being he proposed that the Board should accept the first part of the resolution. This was agreed to and the following resolution was passed.

Resolution.—The Board accept the recommendation of the Research Committee that the temperature of the water should be recorded at the time silt samples are taken.

The President then read out for the consideration of the Board the finding of the Research Committee on page 53 of the Agenda (page 23 of this Report) to the effect that the use of models was of immense value in the study of

irrigation problems, and asked Mr. Inglis to give the Board an account of the work he had done at Poona on the model of the River Ganges in connection with the Hardinge Bridge Enquiry Committee. Mr. Inglis replied that he thought it would be better if the President explained what had been done, as he had dealt with the case on the Committee. The President then said that although he had not seen the model he had seen the report containing the photographs of the work, and the results achieved. He then proceeded to explain by means of a rough diagram, that the River Ganges above the Hardinge Bridge had a fairly straight approach for about three miles, but in recent years the river had changed its course several miles upstream of the bridge and in doing so had affected the direction of flow of water in the approach to the bridge. There had been scour on the left bank of the river above Sara, and to protect that a protective bank had been built, but the water appeared to be thrown across to the right bank and had caused embayments between the Damukdia protective bank and the Right Guide Bank, which were threatening the safety of the bridge. It had been proposed to connect the Right Guide Bank with the Damukdia protective bank, and to cut off the protuberance that existed on the left bank above Sara. Before that was decided upon however, the Railway Department had constructed several spurs in an attempt to divert the water across towards the left bank in approaching the bridge. These had not proved successful, and it was then decided to ask the Bombay Government to allow Mr. Inglis to construct a model of the river for 16 miles above the bridge. The experiments had shown that cutting off the protuberance on the left bank would definitely give the water a straight line of approach to the bridge, but the cost of that work which entailed about 30 crores cubic feet of earthwork, mostly hard clay, was prohibitive.

Mr. Inglis had also eliminated the Damukdia protective bank in his model, but it was found that the embayments were deeper. From the results of the experiments they had concluded that the Damukdia protective bank and the protective bank above Sara were definite dangers to the safety of the bridge. It had been recommended that the latter bank be removed to allow the river to attack the protuberance, and thereby make its own straight approach to the bridge. The colony at Paksey would have to be protected. It was also considered necessary to extend the Right Guide Bank. The President stated that they had found that Spring was right in his contention that any protections to a bridge should be continuous, and that the length of the protection should be the same length as the bridge. In conclusion, the President asked Mr. Inglis whether he proposed to put the results of the experiments before the Research Committee, in reply to which Mr. Inglis stated that such results as had been published by that time would be put before the Committee. He said that there was still a considerable amount of work to be done if the experiment was to be completed, and this would be of very great value to Irrigation and Railway Departments. He explained the use of the "pilot" model with which one year's flow in the Ganges was reproduced in six hours. The large model however was much slower in action and took almost as many weeks as the "pilot" model took hours. Although the "pilot" model was very useful for its purpose, that is, to give a general indication of what was going to happen, so that the large model could be regulated accordingly, it was not sufficiently accurate to allow detailed conclusions to be reached in the present state of our knowledge. As he had already said earlier in the meeting, he considered the work was of very great value and should be continued, but as it was of interest to nearly all the Provinces and Railways, some arrangement should be made for meeting the cost from the centre.

The meeting was then adjourned until 9-30 A.M. the next day.

The Board assembled at 9.30 on the 5th November and proceeded to discuss the items on the Agenda.

Item VII of Part II of the Agenda was taken up.

The President stated that Mr. Lacey had kindly promised to read a paper on "Regime Flow", and asked Mr. Lacey to deliver it.

Mr. Lacey stated that it would be seen on page 11 of the Agenda compilation that he had been asked to prepare a publication on the design of regime channels. Actually he had written a paper on the subject in 1931, Technical Paper No. 1, United Provinces, Public Works Department, Irrigation Branch, but the proposed publication would bring the subject up to date by summarizing his most recent work. He now proposed to explain simply his hydraulic theories, as not everyone had seen his 1931 paper, or read his contributions to the Institution of Civil Engineers, and it would serve as an introduction to the publication he had been asked to prepare. Mr. Lacey then read a brief note on the subject (Appendix III), at the conclusion of which the President thanked him for explaining the subject so clearly and concisely.

Item IV of Part II of the Agenda was then taken up.

Item IV.—To discuss the subject " Tortuosity of rivers and their training by means of embankments ".

The President opened the discussion by stating that as he was responsible for the subject being added to the Agenda, he felt that he ought introduce it. He had prepared a note (see pages 30 to 32) with that object in view, but as it had been printed up with the Agenda there was no need for him to read it. It was merely an attempt to indicate the extent of the problem, and the possible lines of investigation, and the last paragraph of the note really summed it up.

The President then asked Mr. Lacey if he had prepared any note on the subject, to which he replied in the negative, but he had seen Mr. Inglis' note with which he was in agreement. The President then asked Mr. Inglis to read his note.

Mr. Inglis stated that it was very short and merely dealt with first principles, and then proceeded to read it (Appendix IV). The President then invited the Members to discuss the subject.

Mr. Bedford asked if Mr. Lacey had been able to form an idea as to the relative effect on tortuosity of the variations in silt and discharge. Mr. Lacey replied that his experiments and investigations were very largely associated with fine materials. Surplus energy would appear to be absorbed in different ways according to the materials transported. In the middle and upper reaches of the Indus River where the material was coarser and the slope in excess of what the discharge demanded, the energy was destroyed by the river shoaling, forming islands and increasing its width and not its length. Meandering in fine material was occasioned by the slope being in excess of the requirements of the discharge, and always occurred in the lower reaches of a river.

The President stated that there was more tendency for meandering where the river flowed at a very flat slope than at a steep slope, and cited the case of the Indus at its mouth where it bifurcates into the Ochito and Hydari rivers. At one time the Ochito, which is a meandering river, took the bulk of the discharge but in recent years the flow in the Hydari, which is a shorter and steeper river, has increased, and that branch now takes practically the whole of the discharge. Mr. Inglis referred to one length of the Missouri river which at one time was 250 miles long and was now only about 150 miles. The shortening had taken place as a result of removing dead trees and snags. He was of opinion that the degree of tortuosity increased as the difference between silting and scouring velocities increased. This would explain the Missouri and the excessive meandering of rivers in clay reaches.

Mr. Inglis then stated that he had been authorized by the Railway Board to get his report printed, and as extra copies could be supplied to Members of the Central Board of Irrigation for their Provinces, at practically the cost of the paper, he would like to know how many copies were likely to be required so that he could make his indent accordingly.

The President then passed round Mr. Inglis' report on the Hardinge Bridge experiment and asked for the number of copies required.

After enquiry from the Members the Secretary informed Mr. Inglis that, tentatively, 400 copies could be considered as the Board's requirements.

The President then said that the question as to who was going to continue the research on this subject should be discussed by the Board. Mr. Lane had informed them that the Bombay Government would not be able to carry on their Research Station at Poona, and it was for the consideration of the Board whether research with such large models should be continued, and what arrangements could be made for the work to be done, and whether it should be made a responsibility of the Board. Mr. Lane said that the question of continuing the Research Station at Poona was under consideration, and until it was finally decided he thought the work would continue. The President, continuing, stated that he saw the necessity for an experimental station where large models of

lengths of river could be installed, and at one time he thought it would be a good thing to have one near the Barrage at Sukkur.

Mr. Inglis stated that in his opinion no single Province could or should take on experimental work of that nature, and it should be the work of a special research station financed from the centre. He was of the opinion that the work was not of a nature to be done by scientific Pundits. Mr. Lacey supported this view very strongly.

Mr. Bedford stated that he was in favour of having a central research station as well as provincial stations.

Mr. Inglis, continuing, gave his opinion that Poona was admirably suited for such a research station, as it provided the necessary facilities, and the climate was good. The existing Research Station had an ample supply of water from Lake Fife with a good command, so that no pumping was required ; the discharge was free from fluctuation and the water was clear for ten months of the year. That was an important factor, as different grades of silt had to be used in the experiments, and if the water already contained silt it was difficult to get the desired silt content. There was also an advantage in being close to the Meteorological Station at Poona, which was dealing with the closely allied sister science of aerodynamics, and had rendered them valuable assistance. India was so vast that no station would be easily accessible for all Provinces. Poona could be reached in four hours from Bombay ; and so was handy for those proceeding on or returning from leave. Sir Bernard Darley stated that the Agricultural Commission favoured a central research station, but at that time, before the extensive use of models came into practice, the provinces were in favour of provincial stations. He thought it would be a question of going to the provinces to subscribe to the central station. The President then read out paragraph 49 of the Report of the Royal Commission on Agriculture in India which deals with the procedure proposed in connection with agricultural research, and stated that the procedure described therein could be applied to irrigation research merely by substituting " the Central Board of Irrigation " for " the Council of Agricultural Research ". In reply to Mr. Lacey the President said he visualized certain problems, for example, the Hardinge Bridge case, for which a central station was required, but he agreed that the provinces should be encouraged to solve their own local problems. The Board then passed the following resolution.

Resolution.—This Board having considered the present state of hydraulic research in India, especially by means of models, find that the work so far done indicates that the time has come to expand the work beyond the capacity of any one Province to finance, and that a central research station is necessary. The conduct of such a station would be a special responsibility of the Central Board of Irrigation with a view to keeping the work in touch with practical considerations.

The special suitability of the present Poona station for such work and the fact that it is likely to be closed down almost immediately was brought to the attention of the Board indicating that immediate action is required. It is not intended that the work of this central research station shall be a substitution of such research work as must necessarily be done by individual Provinces for the solution of their local problems.

The system described in paragraph 49 of the Report of the Royal Commission on Agriculture in India, dealing with agricultural research, would appear to be eminently suitable for hydraulic research work and is such as is contemplated by the Central Board of Irrigation.

Mr. Sen Gupta who had prepared a paper (Appendix V) on the tortuosity of rivers in Bengal was then asked by the President to describe briefly the observations contained in his note.

Mr. D. N. Sen Gupta opened his remarks by saying that he had not had much time to prepare the note which he now submitted, and still less time to study the intricate problem very thoroughly, and for that reason his note would not be very conclusive. It was an attempt to place before the Board observations from some of the Bengal rivers, which might assist them in their deliberations. His observations showed that the rivers were more tortuous in the upper reaches than in the lower ones, and that the tortuosity was affected by the discharges, with particular reference to branches taking off the main stream. The Ganges started with a tortuosity of 10 per cent., then fell to 5 per cent., increased to 30 per cent., dropping again lower down to 15 per cent. From his observations it appeared that the tortuosity of the rivers increased as the discharge was reduced. The introduction of artificial obstructions was also responsible for changes in tortuosity, for instance the construction of the Hardinge Bridge across the Ganges. He had seen the plans on which the course of the river had been plotted for the years 1868, 1915 and 1933, and it was interesting to note that whereas in the year 1868 the river was very tortuous above the site of the bridge, in 1915 it was fairly straight, but in 1933 it had assumed once more a tortuous course. The flow in the river was considerably obstructed by the bridge, and tortuosity followed. In reply to a question from the Chair, Mr. D. N. Sen Gupta stated that the discharge in the river at that place had not changed appreciably since the bridge was constructed.

Mr. D. N. Sen Gupta stated that there were so many rivers in Bengal to be studied and so much data to collect, that it was not possible to investigate the subject properly unless special facilities were provided.

The President thanked Mr. D. N. Sen Gupta for his remarks and said that it would be better to put the matter before the Research Committee at their next meeting. This proposal was agreed to and the following resolution was passed.

Resolution.—The Board consider that the subject "Tortuosity of rivers and their training by means of embankments" should be included in the agenda for the next meeting of the Research Committee, at which they should consider the lines on which further investigation and research were necessary, and the steps to get the necessary investigations undertaken.

APPENDICES.

APPENDIX I.

Bibliography on Lining of Channels and Guls.

1904—1910.

1. *Punjab Irrigation Technical Papers.*—Tests of linings of crude oil, hydraulic lime slurry, cement slurry clay puddle and coal-tar were made in the Punjab. With linings 4 to 5 years old the efficiency ratios compared with unlined channels were: crude oil 1|16 in. thick 4.0, cement slurry 1|16 in. to ⅛ in. 5.7, clay puddle 6 in. thick 5.7. The cost of crude oil lining was Rs. 2-8-0 per 100 sq. ft., cement slurry Rs. 2-4-0 to Rs. 3 per 100 sq.ft., clay puddle Rs. 3 per 100 sq.ft. Concrete linings are the most efficient, but the materials used and the workmanship must be the best and close supervision is very necessary.

1913.

Newell, F. H.

2. *Principles of Irrigation Engineering, N. Y., McGraw-Hill, 1913.*—On pages 55-6 discusses lined canals. Where concrete lining is used it is economical to make the side slopes as steep as possible. In placing concrete in canals with slopes as great as ½ : 1, it is ordinarily necessary to use forms. With slopes of 1 horizontal to 1 vertical or flatter, forms are not required. Canal linings are usually constructed in slabs, of 10 ft. or more, 3 to 6 in. thick. In cold climate the customary thickness is 6 in. Weep holes are used to prevent excessive hydrostatic pressure behind linings and frost damage.

1915.

Etcheverry, B. A.

3. *Irrigation Practice and Engineering, N. Y., McGraw-Hill.*—States that minimum thickness for concrete lining with favourable soil conditions may be taken as 1 in. and preferably 1½ in.

Gives tabular statement showing variation of thickness of lining necessary for various side slopes taking into account the slope of the repose of the earth.

Describes methods of laying concrete.

Gives table of costs of various linings which have been constructed on different schemes.

Gives a general formula for determining the justifiable expenditure on lining, and the rate of seepage for which linings of different costs can be used economically.

$$C = \frac{SQvd}{26 \cdot 4ip} \qquad S = \frac{26 \cdot 4ipc}{Qvd}$$

C=Cost of lining per square foot in cents, which will vary with the thickness.

S=rate of loss by seepage in per cent. of flow mile.

Q=flow in canal in cubic feet per second.

v=value of 1 acre-foot of water, in dollars.

d=number of 24 hours days during which canal is operated.

p=length of perimeter to be lined in feet.

i=rate of interest, repairs, depreciation.

1917.

Harding, S. T.

4. *Operation and Maintenance of Irrigation Systems, N. Y., McGraw-Hill, 1917.*—Discusses maintenance of concrete-lined canals on p. 71-2. Lining reduces maintenance costs by preventing aquatic growths, erosion, silting and canals breaks. In Southern California a moss-like growth attaches itself to the concrete, making 3 to 4 cleanings per season necessary.

1919.

Davis, A. P. and Wilson, H. M.

5. *Irrigation Engineering, N. Y., Wiley, 1919.*—Discusses canal lining on pages 236—45. Canal lining prevents loss of water, prevents sloughing of banks, avoids water-logging of land, prevents erosion of the canal bed under high velocities, reduces friction. Canal lining is usually cement-mortar or concrete. Concrete linings are usually 2 to 4 in. thick—they should be placed in cool weather to prevent cracking. In cold climates reinforcing is required. Side slopes of 45° or flatter may be concreted without forms. The concrete mix should be about 1 : 2 : 4. The diameter of the largest gravel used should not exceed one-half the thickness of the lining. Where the lining is less than $1\frac{1}{2}$ in. it is best to omit gravel. On the Orland Project the maintenance cost for unlined canals is 123 dollars per mile (Rs. 338 per mile) for lined canal. Gives cost data for concrete lining on several projects.

1920.

6. *Advantages of Lining Irrigation Canals, 1920.* (*In Engineering News Record, v. 85, p. 892*).—Advantages of concrete lining for irrigation canals are: they permit use of higher velocities and smaller cross-sections, thus decreasing excavation costs; can be built in locations where larger canals would be impossible; reduces seepage losses; reduces maintenance costs; maintains and permits use of efficient canal cross sections; prevents bank erosion and perforation.

7. *Columbia Basin Survey Commission, Washington.*—Columbia Basin Irrigation project. Published by the Commission, 1920.

On pp. 94-5 discusses concrete lined canal; lining permits use of higher velocities and thus smaller cross sections, reduces seepage losses, requires less maintenance; the volume of water in the canal is small and is therefore easier to dispose of when shutting down; lining also permits use of a section with desirable cross section, prevents erosion and burrowing of the banks and the growth of weeds in the canal. Average lining thickness in rock and earth with a 1 : 2 : 4 : mix is from 8 in. under a depth of water of 29 ft. to 3 in. under a depth of 4 to 5 ft.

8. *Concrete Lined Irrigation Canal, 1920.* (*In Concrete, v. 16, pp. 244-6*).—U. S. Reclamation Service, Orland Project for longer stretches a 4 cu.ft. mixer was used. The proportions of mix were 1 : 3 : 5. The mixer is set up at the centre of a 500 ft. section to make the maximum wheel 250 ft.

Total cost per sq. yd. for lining was 34.30 cents (cost per 100 sq. ft. = Rs. 10-6-0) for $1\frac{1}{2}$ in. lining. Gives an illustrated description of the bank trimmer and its operation.

9. *Costs of Concrete Canal Lining Compared, 1920.* (*In Engineering News Record, v. 84, p. 975*).—Itemized costs for lining in 1918, 1918-19 and 1919-1920, on the Orland Project in California. Total cost per sq. yd. was 35.47 (Rs. 11-2-0 for 100 sq. ft.) to 42.48 cents. (cost per 100 sq.ft.=Rs. 13-3-0).

Cuttle, F.

10. *Lining Irrigation Canals with Concrete without Forms, 1920.* (*In Engineering News Record, v. 85, pp. 17-18*).—States that lining of irrigation canals is too expensive where form-work is required. A plaster concrete mortar has been placed without forms at Riverside, California. The first canal lined in this region was 12 ft. wide at the bottom and 4 ft. deep. The cement mortar lining $\frac{3}{4}$ in. thick. The canal has weathered long dry summers and high flood flows during the rainy season for 26 years and is still in good condition. Eight miles of canal were built in 1914 with 2 in. thick cement mortar linings plastered directly on to the prepared bank, without the use of forms. The concrete used is 1 part cement, 3 parts sand, and 5 parts of stone passing a $1\frac{1}{4}$ in. screen. Describes method of preparing the banks. The 2 in. lining can be placed at the rate of 100 ft. per hour. Describes the method of mixing and placing the lining.

Sanborn, K.

11. *Lining Canals with Concrete without Forms, 1920.* (*In Concrete, v. 17, pp. 167—9*).—Riverside, California canals were lined with cement in the 1890's. At first a $\frac{1}{2}$ to 1 in. lining was used. The slope on which green concrete will stand without forms is $8\frac{3}{4}$: 12. The average mix used was 1 part cement to 3 parts sand and 3 parts $1\frac{1}{4}$ in. rock. The canal banks were prepared by plowing and use of a slope knife. The cement was supplied from a portable mixer. The sides were poured and then finished with a float, after which the bottom was poured and a 6 in. shoulder was

built at the top of each side. The cost of this work in 1913-14 was $1.096 per linear foot of a canal 8 ft. 11 in. across the top, 3 ft. wide at the bottom, and 4 ft. 3 in. deep.

1921.

12. *Special Joints for Concrete Canal Lining, 1921.* (*In Engineering News Record, v. 86, p. 902*).—U. S. Reclamation Service, Flathead Project in Montana, specifies lining of either 3 in. reinforced concrete or 2 in. gunite with woven wire reinforcement. Joints are to be placed at 10 ft. intervals extending from the base of the lining to the reinforcement.

1922.

Weber, R. C. E.

13. *Thin Concrete Lining Successful in Irrigation Canals, 1922.* (*In Engineering News Record, v. 88, pp. 436-7*).—Canal lining $1\frac{1}{2}$ in. thick, placed on 64 miles of the Orland Project of the U. S. Reclamation Service has effected a saving of 60 per cent. in maintenance costs over earth sections and has reduced seepage losses to less than 1|3 of those in clay. The first concrete lining was placed in 1911, in loamy soil. Estimated increased cost for lining 70 miles of canals and laterals was $ 220,000 (Rs. 6,03,300). Table shows seepage and evaporation from lined and unlined canals. Average annual maintenance cost was $ 19.50 (Rs. 53) per mile for concrete lined sections, as compared with $ 53.70 (Rs. 147) for earth sections. Lining must be done from October to April, not in the irrigation season. About 75 per cent. of the concrete placed was machine mixed, using mixers of 3-4 yd. capacity. Line and grade stakes were spaced at 15 ft. intervals. A force of 15—25 men was required to prepare the surface for concreting. A fairly dry concrete mix must be used. Expansion joints were provided, on the side slopes only, at intervals of 6 ft. 622,000 sq. yd. of $1\frac{1}{2}$ in. lining has been placed at an average cost of 39.1 cents per yd. (cost for 100 ft=Rs. 11-12-0) Table gives cost details.

1923.

14. *Lining Canals, 1923.* (*In Public Works, v. 54, p. 349.*). *Orland Irrigation District, California.*—A 1.5 in. concrete lining reduced seepage loss by 50 to 90 per cent., increased carrying capacity, and reduced maintenance cost by 60 per cent. The unit costs per sq.ft. of lining were: preparing section 7.6 cents, cement 13.0 cents, gravel 5 cents, mixing 2.5 cents, placing 4.2 cents, finishing 0.5 cents, sprinkling and protecting 0.2 cent, water 0.4 cent, repairs and supplies 0.3 cent, equipment charge 0.5 cent. Total cost 34.2 cents (Rs. 10-5-0 per 100 sq.ft.).

Weber, R. C. E.

15. *Concrete Lining of Irrigation Canals and Laterals, 1923.* (*In Engineering and Contracting v. 60, pp. 539—41*).—Orland Project, U. S. Reclamation Service. Maintenance cost for earth canals was $ 55.70 (Rs. 153) per mile as compared with $ 19.50 (Rs. 53-8-0) for concrete lined canals. Current meter measurements show that seepage loss from concrete lined canals is much less than from any other type. Cost of lining on this project averaged 38.9 cents per sq. yd. (cost for 100 sq. ft. = Rs. 11-13-0). Gives itemized cost data. Lining placed in 1911 was in excellent condition in 1923. The lining is $1\frac{1}{2}$ in. thick; no reinforcement has been necessary.

1924.

Code, W. E.

16. *Construction of Concrete Lined Irrigation Canals, 1924.* (*In Engineering and Contracting, v. 61, pp. 1314—16*).—The 2 in. lining of the Southwest Cotton Co., canal in Arizona, was applied by a crew of 20 men. The concrete was dumped from wheelbarrows, onto a 2 ft. float and spread. Section 16 ft. long was made and the bottom was poured after the sides had set 6 hours. The bottom was poured by means of chutes. The mix was 5 to 7 parts sand and gravel to 1 of cement. The cost of concrete lining was 10.98 cents per sq.ft. (cost for 100 sq.ft.=Rs. 29-11-0). On the Pima Farms Co. Project 2 in. lining was placed in about 2|3 mile of canal. Stakes were used to mark the upper edge of the concrete. The cost of lining on this job was 10.44 cents per sq.ft. (cost for 100 sq.ft. Rs. 28-2-0).

Code, W. E.

17. *Design and Construction of Small Concrete Lined Canals, 1924.* (*In Engineering News Record v. 93, p. 59.*).—The economy of concrete lining is said to have

been proved. The chief advantages are : Prevention of seepage, reliability, and reduced maintenance costs. Lining 1 to 2 in. thick have been used successfully in regions where frost action is not severe. In present practice, 1½ in. is minimum thickness, but for large canals a greater thickness should be used to eliminate inside forms, which increase the cost. The canal slope partially determines the thickness of concrete to be used. Tree roots, stock, gopher* holes, settling, fills, and entrance of water from the sides are the greatest disruptive forces to lined canals. The material used should be first class. In Arizona the cost of 2 in. lining was found to be 10½ to 11 cents per sq.ft. (cost of 100 sq.ft. Rs. 28-2-0 to Rs. 29-11-0) including preparation of the earth slopes.

Katnhack, F. E.

18. *Principles of Irrigation Engineering, London, Longmans, 1924.*—Discusses canal lining on pp. 145—7. Advantages of lining. Tests of linings consisting of crude oil, hydraulic lime slurry, cement slurry, clay puddle and coal-tar were made in India in 1903 and 1908—10. With linings 4 to 5 years old the efficiency ratios compared with unlined channels were : crude oil 1|16 in. thick 4.0, clay puddle 6 in. thick 4.0, cement 1|24 to ½ in. thick 4.9. While concrete linings are the most efficient, it is essential that the materials used and the workmanship be of the best, and close attention must be paid to construction details.

1926.

19. *Large Ditch-Lining Job done at Low Cost and High Speed, 1926. (In Engineering News Record, v. 97, pp. 52-3).*—Salt River Project, Arizona ; 32 miles of main canal requiring 8,000,000 sq.ft. of lining. The canals were first cleaned up and smoothed by grading. Stock piles of cement, sand, and gravel were made along the bank of the canal and a portable mixer was used for each two guns, the mixed material being brought to the guns by wheelbarrows. Delivery to the guns was by gravity discharge. A 1 : 4½ mix was used. Sand was obtained from borrow pits. Most of the canal lined was 45 ft. wide at the bottom with a 1 to 1 slope. The reinforcing used was Clinton welded 4 × 4 in Nos. 14 galvanized wire fabric in 100 in. widths. It was attempted to place a gunite lining of 1 to 1½ in. in thickness. Two men were needed for each gun. With 6 guns working two nine-hour shifts, daily progress of 65,000 sq.ft. was frequently made. Average progress throughout the work 4,700 ft. per gun 9 hour shift. Average cost including plant, was 9½ cents per sq.ft. (cost per 100 sq.ft.=Rs. 25).

1927.

20. *Cement Linings in Irrigation Canals Economic Success, 1927. (In Engineering News Record, v. 99, pp. 144-5).*—In the Imperial Valley system lined sections were required where velocities exceeded 10 ft. per second. In the case of Birch Canal, maintenance costs were reduced from about $ 500 (Rs. 1,371) per mile per year, to $ 15 (Rs. 41) per mile per year, by lining that cost $ 8,000 (Rs. 22,000) per mile. No expansion joints were used, and chicken fence wire mesh was used as reinforcing. The job would have been more substantial if a coping had been added and if expansion joints were placed 20 ft. apart. Examination after 4 years showed general buckling. A plastered lining 2 in. thick, without expansion joints, was found to be in perfect condition after 3 years. Several other types of lining were tried—including gunite lining with coping and expansion joints. Separate costs kept on plastered and gunite linings showed them to be about the same.

1929.

21. *Concrete Lined Canals, 1929. (In Concrete, v. 35, pp. 19-20. Oct.).*—Maximum size of coarse aggregate for canal lining is 1 in. on the Kittitas County, Washington project of the U. S. Reclamation Service. Brief general discussion of preparation and placing of the concrete, on p. 20.

22. *Lining Canals with Concrete on the Yakima Project, 1929. (In Engineering News Record, v. 103, pp. 722—5).*—Lined canals of a specified section are smaller than earth canals. Diversion of surface water was effected by means of cut-off walls and drains, but in several places ground-water pressure cracked the lining. The sides of the canal were trimmed to 1¼ to 1 slope and then were kept sprinkled until the concrete was poured. ⅜ in. round-deformed bars were used in the reinforcement for the 3 in. concrete lining. Concrete was chuted directly from the mixer. The weight of the form was enough to permit vigorous tamping of the concrete.

*Small burrowing rodent.

1930.

23. *Little Greek Flood Channel, Santa Anna River Basin, California, U. S. A., (Personal Enquiry of Research Officer).*—Lined throughout with gunite 2 in. thick. 2,816,600 sq.ft. at $ 0.16 per sq.ft.=$ 450,555, (cost of 100 sq.ft.=Rs. 42-14-0).

1931.

Huff, C. L.

24. *Concrete Lining for Irrigation Canals, 1931. (In Engineering News Record, v. 107, p. 270).*—On the Mercedes District, Texas the lined canals were almost all circular in section. The lining was placed by guniting and finished by troweling. The trowel finish reduced the coefficient of friction, but fouling of the walls by moss and silt increased the coefficient to some extent. The gunite was mixed in the proportion of 1 sack of cement to 4½ cu.ft. dry sand. Electric welded wire mesh, with 4 in. transverse spacing and 8 in. longitudinal spacing of No. 12 wire was used for reinforcements, but newer specifications call for 6 × 6 in. No. 14 wire. A marked fall in ground-water level followed the construction of these lined canals and a considerable acreage of waterlogged land was reclaimed.

25. *Rohilkhand Canals Division, U. P., P. W. D., I. B.*—Reinforced brick lining was tried on Dhakia Minor, and after three years it has been found that it has stood very well. the cost per sq. ft. is Ans. 2.56 or Rs. 16 per 100 sq.ft. as follows :—

300 Nos. IInd Class Bricks @ Rs. 13-4-0‰ ..	= 4·0
300 Nos. IInd Class Bricks carriage 8 miles @ Rs. 6-2-0‰ ..	= 1·8
1·75 c. ft. Cement at site @ Rs. 2-8-0 c. ft. ..	= 4·4
5·25 c. ft. sand at site @ Rs. 6 per % c. ft. ..	= 0·3
¼ in. Rods (160-¼ cwt.) @ Rs. 12 cwt. ..	= 3·0
Labour including cleaning of surface 25 c. ft. @ Rs. 10 % c. ft. ..	= 2·5
Total Rs. ..	16·0 %S. ft.

Moore, A. J.

26. *Concrete Lining for Irrigation Canals in Texas, 1931. (In Engineering News Record, v. 107, pp. 60-1).*—Some 250 miles of canals and ditches were lined in Texas between 1928 and 1931. The canals lined were parabolic, circular and trapezoidal in section. Hand lining was used in the trapezoidal sections, the parabolic sections were lined either by hand or by cement guns, and the circular sections were usually lined by cement guns. Linings have been placed with and without expansion joints. The gunite lining is 1 in. thick, the mix used is 1 : 4 or 1 : 4½. Steel wire mesh reinforcement was used on the larger canals and in most of the smaller ditches. Maintenance has been limited to tarring the wider contraction cracks and cleaning. Lining cost on an average of 15 to 16 cents per sq. ft. (cost of 100 sq. ft.=Rs. 43-12-0) including preparation and reconditioning old canals. The cost per mile was approximately $ 6,500 (Rs. 17,825) for a ditch of average size ; *i.e.*, 15 to 20 sec.ft. capacity.

Ruettgers, A. and Whitmore, A. A.

27. *Construction of Main Canal Lining on Kittitas Division, Yakima Reclamation Project, 1931. (In American Concrete Institute, Journal, v. 2, pp. 117—50, 669—74).*—52 per cent. of the lining was 3 in. thick. Trimming was effected by means of a template. Underdrains were provided. Lists difficulties encountered in concreting. The side slopes were lined by a steel plate lining machine. Stationary and portable concrete mixers were used. It was necessary to sprinkle the subgrade from the time it was trimmed until the concrete was placed. The concrete was water-cured, difficulty was experienced in obtaining satisfactory panel joints, describes the joint adopted.

Surface cracks developed in both water-cured and asphalt-cured linings, but were more common in the latter. Describes the concrete control methods. Results of tests of concrete samples from the canal linings. The concrete used was a 1 : 2.4 : 3.6 dry rodded mix. Cost of reinforcement was about 10 per cent. of the cost of the lining. Discussion.

1932.

28. *Turlock Irrigation District, California, U. S. A.* (*Personal enquiry by Research Officer*).—2 in. layer of unreinforced concrete laid by hand without expansion joints. In preparing a channel for concreting they stand water in the channel by blocking it up in sections for 36 hours. The water is then run out after which the channel is graded and the concrete laid.

A 20 cusec channel cost $5,000 per mile to line. This is equivalent to Rs. 13,400 per mile.

29. *Yuma Irrigation Project, Arizona, U. S. Bureau of Reclamation* (*Personal enquiry of Research Officer*).—Small channels lined with $1\frac{1}{2}$ in. concrete reinforced with chicken wire. Sides poured first and then bottom. All plastered by hand. Aggregate dumped in piles along bank. Lorry with mixer mounted on it.

30. *Prosser Scheme near Yakima, Washington.* (*Personal enquiry of Research Officer*).—Intake canal lined with 3 in. reinforced concrete (cured by Hunt process) canal discharge 1,100 cusecs.

A gravel blanket having an average thickness of 6 in. placed under the lining. Construction joints at intervals of not less than 8 feet nor more than 20 feet. Tile drains laid in the gravel blanket (see specification No. 547-D. U. S. Department of the Bureau of Reclamation).

Lining had burst in one place due to excessive pressure at back of lining when canal was closed.

Velocity in lined section 5 feet per second.

Cost including trimming of canal section in earth but exclusive of steel and cement Ans. 3.36 per sq.ft. (cost of 100 sq.ft. Rs. 21).

31. *Minnedoka Project, Idaho, U. S. A.* (*Personal Investigation of Research Officer*).—The New York Canal, Boise ; 2,800 cusecs ; lined with 4 in. unreinforced concrete. In one section the lining consisted of 3 in. gunite. Gunite said not to last under the action of the silt. Now placing 4 in. reinforced concrete over the old work.

32. *Report dated January 7, 1932 by U. S. Bureau of Reclamation on Proposed Columbia Basin Project.*—All canals to be lined with reinforced concrete 4 in. to 8 in. thick.

Israelsen, O. W.

33. *Irrigation Principles and Practice, N. Y., Wiley, 1932.*—On p. 32 discusses concrete lined canals. Many irrigation canals are being lined to decrease water loss, prevent weed growth, decrease erosion, reduce maintenance costs, and to increase the capacity of the canal.

Neville, F. A.

34. *Charts for the Design of Irrigation Channels, 1932.* (*In Commonwealth Engineer, v. 19, pp. 239–42*).—On p. 242 gives a cross section view of a 2 ft. by 2 ft. concrete lined channel.

Columbia Basin Project.

35. *Extract from Report of U. S. Bureau of Reclamation, dated January 7, 1932.*—Total cost of proposed Columbia Basin Project $ 376,631,000.

Total cost per acre of Irrigation Project $ 17,355.

All canals to be lined with reinforced concrete 4 in. to 12 in. thick.

1933.

36. *U. P. Agricultural Canals in Tube Well Area, Moradabad District.*—Brick lining has been done on Agricultural canals in Tube Well area. Two types have been used.

1. Lining with 3 in. flat bricks and 1 : 4 cement mortar. Cost = Rs. 12-8-0 100 sq. ft.
2. Lining with 12 in. × 6 in. × 2 in. bricks and 1 : 4 cement mortar. Cost = Rs. 9-4-0 per 100 sq.ft.

Lining of Agricultural Canal.

Analysis for 100 sq.ft. of lining with 3 in. Flat Bricks and 1 : 4 cement mortar. (Leads—Bricks 12 miles, sand 10 miles.)

375 Bricks @ Rs. 9 ‰	= 3·37
Carriage 12 miles @ Rs. 10 ‰	= 3·74
0·9 Cement bags @ Rs. 3 each (including carriage) ..	= 2·7
4·5 c. ft. of sand including carriage of 10 miles @ Rs. 6 %	= 0·27
Plastering of the inside of canal for fixing of bricks in proper position	= 2·50
Total ..	12·50
Say Rs. ..	12-8-0% s. ft.
	As. 2 per s. ft.

Alternative Estimate for lining with 12 in. × 6 in. × 2 in. Flat Bricks 100 s. ft. of channel (1 : 4 Cement mortar)—

200 Tile Bricks @ Rs. 16‰	= 2·2
Carriage 12 miles @ Rs. 10‰	= 2·0
0·45 bags of cement @ Rs. 3 each (including carriage)	= 1·35
2·5 c. ft. sand @ Rs. 6 % (including carriage of 10 miles)	= 0·15
Labour including mud plastering of the inside of canal for fixing the tiles in proper position ..	= 2·5
Total ..	9·2
	Say Rs. 9-4-0 % s. ft.
	Rs. 1·48 per s. ft.

Discharges in the region of 1 to 2 cusecs. Nofrango lining tried and pronounced a failure. The hessian was not properly encased in the cement plaster.

37. *Research Section, I. B., P. W. D., U. P.*—Tests were carried out with Nofrango lining, *i.e.* 1 : 2 cement mortar lining reinforced with Hessian cloth of $\frac{1}{4}$ in. mesh. These linings were 5|16 in. thick $\frac{3}{8}$ in. thick, $\frac{1}{2}$ in. thick $\frac{3}{4}$ in. thick. All these linings except the first one could take up the load of a walking buffalo without showing any signs of damage or cracks. The test reaches are under observation. The cost per sq. ft. of $\frac{1}{2}$ in. thick lining is Re. 0-1-3 per sq. ft. (cost of 100 sq. ft. = Rs. 8-0-0).

38. *Proceedings of 4th Meeting of Central Board of Irrigation, India.*—Development and Research Division, Karachi experimented in injection into bed sand of fine colloidal clay, chemicals, cement, etc., with the object of building up impermeable layer. Experiments in the actual lining of the canal itself by cement concrete $4\frac{1}{2}$ in. thick, Nofrango 1 in. thick, puddled clay 1 in. thick and various types of bitumen linings.

Injections of clay not successful.

Injections of cement into the bed sand not successful. Costs will appear in Minutes of Proceedings for 1934. No satisfactory account given of performance of bitumen lining.

39. *Flexible Lining of Tile Used for Drainage Ditch, 1933.* (*In Engineering News Record, v. 110, p. 585.*)—Cedar Fork drainage canal has been paved, at Galesburg, Ill., for some $3\frac{1}{2}$ miles with a flexible lining of vitrified blocks. The blocks were 12 in. × 12 in. × 3 in. and were made with tongue and groove edges.

Mason, M.

40. *Construction Work on a Federal Reclamation Project, 1933.* (*In American Society of Civil Engineers, Transactions, v. 98, pp. 362—417*).—The canals in the Kittitas Division of the Yakima Project in Washington were lined with 3 to 4 in. reinforced concrete, with a 5 in. berm at the top. In the 3 in. lining $\frac{3}{8}$ in. round bars were

spaced 24 in. transversely and 12 in. longitudinal; the spacing was the same in 4 in. linings but ½ in. bars were used. All lined canals were supplied with sub-drainage. A special machine was used to place the concrete on the slopes. On p. 401 gives canal lining costs: for trimming 18 to 25 cents per sq. yd. (cost of 100 sq. ft. = Rs. 5-9-0 and Rs. 8-5-0) for concrete $ 8.00 (Rs. 22) to $ 15.00 (Rs. 41) per cu. yd.; for reinforcing, .014 to .04 cents per lb.

41. *U. S. Bureau of Reclamation.*—Specification No. 546, 1933, Washington, D. C. Government Printing Office, $ 2.00 (Rs. 5-8-0).

Specifications for concrete canal lining on pages 38-39 and in drawing No. 10.

42. *U. S. Bureau of Reclamation.*—Specification No. 550, 1933, Washington, D. C. Government Printing Office, $2.00.

Specifications for concrete lining on page 24 and in drawing No. 5.

1934.

43. *Research Section, I. B., P. W. D., U. P.*—Test carried out with cement concrete lining with different mixtures. The thickness was 1½ in. and the ratios tried were 1 : 5 : 10, 1 : 4 : 8 and 1 : 3 : 6. The side slopes were 1¼ : 1 and no forms were used. 1 : 3 : 6 mixture was the best as it gave very good finish and was easy to work with. No expansion joints have been provided. The cost of 1½ in. lining including the earthwork and preparation of surface for laying concrete is Ans. 2.26 per sq.ft. (cost of 100 sq.ft. = Rs. 14-2-0).

44. *Research Section, I. B., P. W. D., U. P.*—Experiments conducted of providing Spun Concrete Hume Pipe lines in place of surface Cultivator's channels.

Cost Rs. 9,000 per mile.

1935.

45. *Research Section, I. B., P. W. D., U. P.*—Tests carried out with 1 : 3 Cement plaster lining with wire netting reinforcement. The thickness was ¾ in. and ½ in. mesh wire netting was used. The cost of ¾ in. lining including preparation of surface for laying plaster is Rs. 16 per cent. sq.ft. and for ½ in. is Rs. 14 per cent. sq.ft. When silt was used the cost for 1 in. thick lining came to Rs. 13-5-0 per cent. sq.ft. and for ¾ in. Rs. 11-10-0 per cent. sq.ft.

APPENDIX II.

Design of Weirs on Permeable Foundations by Rai Bahadur A. N. Khosla, I.S.E., Executive Engineer, Punjab.

C. B. I. Publication No. 8 (15th December 1934) on "The Location and Erection of Pressure Pipes and standard methods of observation and Record of pressures under works on Permeable Foundations" was the outcome of the resolution No. 7, of the Central Board of Irrigation at the fourth annual meeting held at Lahore in November 1933. The object was to standardise practice to enable reliable data of pressures under various works on permeable soils to be secured and presented in readily comparable form for analysis and thus establish a rational approach to the problem of design of such works.

200 copies of this publication were printed, which were all distributed early in the year and there was demand for more. It was at first proposed to issue a reprint but there had been a considerable advance in the knowledge of the subject in the meantime and it was resolved by the Executive Committee (20th July 1935) to publish a revised edition or an entirely rewritten paper embodying all up-to-date information on the subject in addition to the essential matter contained in the original text. Since then Sir Bernard Darley in his letter No. 9453, dated the 29th July 1935 has made specific suggestions regarding the scope and the ultimate aim of this new publication. In view of the fresh information received from various sources and the fact that the Bligh theory as commonly understood did not hold good, he wanted tentative rules to be framed for design of works, founded on sand.

Resolution No. 7 of the Central Board of Irrigation at its 4th Annual Meeting (November 1933) reads as below :—

(*a*) that further intensive study of subsoil flow beneath actual works was essential.

(*b*) that in view of the active part already taken by Mr. Khosla and his published papers on the subject, the completion of a comprehensive note on the subject should be entrusted to him.

(*c*) that Mr. Khosla should be supplied with all available observations on the subject, from India,

(*d*) that in order to secure uniformity of observations he should prepare a note on the nature of observations required and the form in which they should be tabulated : this note to be communicated to all interested, through the office of the Board.

Publication No. 8 fulfils the requirement of item (*d*). In respect of item (*c*) however, there has been little response from the other provinces. This has been a serious handicap and were it not for the intensive work already done and now in progress on this subject in the Punjab, the compilation of a comprehensive note as contemplated in item (*b*) would still have remained a remote possibility.

With regard to item (*a*) further intensive study has been made of the subject in field—notably at the Panjnad and Khanki Weirs—and in the Research Institute at Lahore. By close collaboration between the field and laboratory work, it has been possible to make an immense advance on existing knowledge. It is now possible without much mental effort to determine uplift pressures and exist gradients under complicated Weir profiles within two to three per cent. We can now predict not only the distribution of pressures under a work but also whether such distribution is safe. The study of the subject is being vigorously pursued on models in the Lahore Research Institute under the direction of Dr. McKenzie Taylor and is being simultaneously checked against field results. It is hoped that in a couple of months or so it would be possible to predict uplift pressures and exist gradients under the most complicated base profiles, with almost mathematical accuracy, and that without the application of any involved mathematics whatsoever.

The advance in knowledge has therefore been so great and of such fundamental character that a mere revised edition will be inadequate. It is proposed, therefore, to embark on the compilation of a comprehensive note dealing with all aspects of the problem, as contemplated in item (*b*) of the above resolution. This comprehensive work will be called "The Design of Works on Permeable Foundation".

I was requested to have the text of this new compilation ready for the present meeting of the Central Board. This has, however, not been possible in view of the immense labour involved and the fact that the essential experiments for the purpose kindly undertaken at my request by the Director of Research (Lahore) might yet take another two months or so to complete. The final draft will, therefore, have to wait for sometime, though every effort will be made to get it ready as early as possible. A general outline indicating the scope of the proposed work is, however, presented for discussion, with a view to eliciting opinion and further suggestions.

Before starting with the discussion of the proposed text, it will be desirable to review the knowledge on the subject leading to the present advance and to discuss the simple methods of design which it has now been possible to evolve.

The law of flow of water through permeable soils was enunciated for the first time in 1856 by H. Darcy after a series of experiments. It states that the velocity of seepage flow is proportional to the hydraulic gradient or

if V = velocity

H = total head, and

L = length of path of flow.

then $V \propto \frac{H}{L}$

A considerable amount of research on those lines was done in 1898 by Slichter and King of the U. S. Geological Survey. Their object, however, was to determine the amount of water passing through various classes of soils. They were not concerned with the details of pressure distribution along the path of flow.

In 1898 Col. Clibborn, as a result of a series of laboratory experiments, proposed that the hydraulic gradients along the path of flow should form the basis of the design of weirs resting on permeable subsoils. This was the first rational approach to the solution of the problem.

The 1907 edition of Bligh's book on "Practical Design of Irrigation Works" discloses that he believed that the stability of a weir on permeable foundations depended on the weight of the structure and not on the ratio of head to creep distance. In the 1910 edition, he admitted the fallacy of his original contention and accepted the hydraulic gradient theory of Col. Clibborn. This he codified according to his interpretation of Col. Clibborn's work. This is the commonly understood "Creep Theory" of today. This creep theory connotes two things (*a*) that the hydraulic gradient under the work is linear and (*b*) that the line of major flow is in contact with the base profile of the work. The theory was based on extremely meagre data but because of its simplicity it was blindly followed by the profession. Doubts arose off and on. Some works failed although they were quite sound according to this theory and others stood inspite of it. This theory was therefore, faulty. It lacked a proper appreciation of vertical cut offs and other fundamental factors.

The first set of scale model experiments on simple hydraulic structures were carried out by Colman (U. S. A.) in 1916. These brought out the importance of vertical cut-offs but as the technique was crude, no material advance was made.

In 1920 Pavlovsky (U. S. S. R.) attacked the problem of flow of water through subsoils by the electric method. This method is based on the well known Ohm's law for the flow of electricity in conductors, *viz.*, Current = $\frac{\text{potential difference}}{\text{resistance}}$

$$C = \frac{E}{R} = \frac{E}{a.l} \quad \text{where } l = \text{length of conductor.}$$

This is identical with the Darcy's equation for seepage flow. He achieved success in solving many complicated cases in the laboratory. But the work did not create confidence and was not accepted by the profession as it could not be shown that results obtained by the electrical analogy compared even remotely with those obtaining under field conditions. This method, though the most potent one in our hand today, did not go beyond the class room lecture stage.

In 1928-29 the trouble at the syphons on the Upper Chenab Canal drew pointed attention to the potential danger, involved in a blind adherence to the Bligh theory. Papers No. 138 and 142 read by the writer at the 1930 session of the Punjab Engineering Congress deal with these cases. These researches led to some important conclusions, notable among which were :—

(*a*) The outer faces of the end sheet piles were much more effective than the inner ones and the horizontal length of floor.

(*b*) The intermediate piles if smaller in length than the outer ones were ineffective except for local redistribution of pressures.

(*c*) Undermining of floors started from the tail end. If the hydraulic gradient at exit was more than the critical gradient for the particular subsoil, the soil particles would move with the flow of water thus causing progressive degradation of the subsoil, resulting in cavities and ultimate failure.

(*d*) It was absolutely essential to have a reasonably deep vertical cut-off at the downstream end to prevent undermining.

(*e*) There was urgent necessity for research work with regard to pressures under existing and new structures and in the laboratory. The former could be done by inserting suitably located pressure pipes in these structures and by maintaining a continuous and comprehensive record of the observations of pressures from those pipes.

In 1929, a notable contribution to knowledge came from Karl Terzaghi (U. S. A. and Vienna) who stated that failures occurred by undermining if the hydraulic gradient at exit was in excess of what he called the "flotation gradient". This was the same as the critical gradient enunciated by the writer but it was more precise as it showed that if the exit gradient exceeded unity, the soil mass would be bodily lifted up by flotation due to the upward force of flowing water being in excess of the weight of the overlain soil. This upward force is directly proportional to the hydraulic gradient and acts in the direction of flow. He also did some work on the effect of stratification and minor geological details on the uplift pressures.

Forchheimer had developed a method of plotting stream lines and pressure lines by a geometrical process as far back as 1911.

In 1931, Dr. Rehbock produced his photographs of stream lines under a weir model.

In 1929, it was decided to extend the Panjnad Weir. This afforded the opportunity of putting in a comprehensive set of pressure pipes and of conducting full scale experiments as suggested in papers No. 138 and 142. This was the first large scale experiment of its kind in the world and the results obtained from it, mark the first important advance in that line. The results of observations confirmed the conclusions of 1928-29 and made it possible to state the following further facts.

(*a*) The flow of water through the subsoil is in stream lines and can therefore be theoretically investigated.

(*b*) The ratio (ϕ) of uplift pressure (P) at any point of a structure founded on sand to the total head (H), is constant and independent of—

(1) Head (H),

(2) Class of subsoil so long as it is homogeneous,

(3) Upstream and downstream water levels,

(4) Temperature, provided it is uniform through the subsoil,

but it varies along the work with :—

(1) Silt deposits or scour upstream or downstream of the impervious floor,

(2) Temperature which generally varies from point to point in the body of the subsoil.

So far so good, but Mr. Hadow raised the question whether the deductions made from the Panjnad experiments would hold good on other works with different arrangement of sheet piles and horizontal floor and, if they were enough and suitable to form a basis of future design. He suggested that the field work should be tested on a model of the Panjnad weir in the Research Institute at Lahore. This has been the happiest suggestion ever made, for, the work on the Panjnad model has paved the way to the final solution of the problem.

While work was going on, on the Panjnad and other models at Lahore, Lane and Hebert were busy in the United States testing the Panjnad and other results by the electric analogy method. Lane tested Colman's results of 1916 by the electric method and found that there was no comparison. Hebert tested the Panjnad results by the electric method and was equally unsuccessful in finding a comparison. Consequently the electrical analogy method of approach, though considered as a possible line of attack, was discarded by them as being full of uncertain factors and therefore not suitable for a study of actual works.

However, the results obtained from the hydraulic scale model by Harbans Lal agreed fairly closely with those obtained from the electrical model by Hebert.

Hebert's electrical model had certain drawbacks. These drawbacks have been removed and the technique perfected in the Research Institute, Lahore by Drs. McKenzie Taylor and Vaidhianathan. They have succeeded in getting identical results on the hydraulic and electrical models. Again it has been possible on the Panjnad hydraulic model to reproduce the field results almost exactly by superimposition of more or less silt on the upstream flexible floor and by varying the temperature of inflowing water or by a combination of the two.

Thus for the first time in the history of research on this subject it has been possible in the Punjab to demonstrate that :—

(a) the distribution of pressures under works on sand foundations can be exactly reproduced on hydraulic or electrical models.

(b) All seasonal and other variations from the normal conditions can be reproduced equally well on the hydraulic model, by the superimposition of silt, temperature or both, and by simulating the stratification.

(c) The problem is susceptible of mathematical treatment. But only the simplest cases have so far been solved. For complicated cases the mathematics becomes too involved.

This advance may be considered as a definite land-mark in the history of development of this branch of Engineering and one that may be taken as the foundation for a final solution of the problem.

Subsequent to this, work was done at the Irrigation Research Institute, (Lahore) on a model of the Khanki Weir (Bay 4) where the foundation is complicated by the presence of a clay substratum some depth below the floor. The model reproduced the field results within a few per cent. This was a further demonstration of the fact, that complicated stratification in the sobsoil could be successfully simulated in the models and reliable results could be obtained.

Mr. Haigh's important contribution (Paper 182 of the 1934, Punjab Engineering Congress) introduces us once more to the fundamentals of design. In this he lays stress on the fact that it is not enough to know distribution of pressures under a floor but it is essential also to know what distribution would be safe. He rightly states that it is the exit gradient that controls the margin of safety in design.

A similar line of approach has been made by Harza in his Paper to the American Society (September 1934).

Some very useful work has been done in this direction by Drs. Bose and Vaidhianathan under the direction of Dr. McKenzie Taylor. They find that the safe exit gradients are governed by the ratio of the depth of sheet piles to the length of horizontal floor. This marks a further advance.

Having laid the foundation for a rational approach to the final solution of the problem, it was decided to proceed on with the work leading to that solution. A series of standard forms have been drawn up by the writer for investigation. The work on some of these has already been completed in the Research Institute. When the work on the rest of them is also completed, it will be possible to lay down simple rules which will give results with almost mathematical accuracy. The exceedingly useful nature of work done in the Research Institute cannot be too highly stressed. But for that, there would have been wide gaps in our knowledge which gaps may have taken decades to fill. There has no doubt been considerable activity on the subject, in recent years, in other parts of the world but so far it had not resulted in any substantial advance. The Punjab had the advantage of full size structures fitted for research and had simultaneously developed a high class of technique and experimental skill, which has enabled this Province to give the final lead in the subject.

The results outlined above deal with the flow of water through homogeneous porous subsoils. No rules that can be formulated on these will apply completely to stratified subsoils. In such cases it will always be best to have recourse to models where the stratification can be simulated.

The bulk of the research work, dealt with above, relates to only one aspect of the problem ; namely the flow of water through the subsoil under works as affecting their design and stability. But there is the other and equally important aspect. That is the flow of water over such works in relation to their design and stability. At present there is very scanty data on which to formulate rules to determine the shape, length and thickness of floor. For a proper study of this part of the problem research work must be pursued as vigorously and intensively in this case as has been done in the case of subsoil flow.

The following is an outline of the proposed comprehensive note on the subject as indicated by Resolution 7 (b) of the November 1933 meeting of the Central Board.

Design of Works on Permeable Foundations by Rai Bahadur A. N. Khosla, I.S.E., Executive Engineer, Punjab.

Outline of Headings.

I. *Introductory.*—Including a review of the development of the science of flow of water through sub-soil in relation to the design of works resting on permeable soils.

II. *Theory of seepage flow.*

(a) Darcey's law.

Slichter and King.

Col. Clibborn.

(b) Forch-Heimer's deductions.

(c) Direct deduction of the Potential law.

(d) Flow of electricity through a conductor anologous to flow of water through sub-soil.

(e) Haigh—convergent and divergent flow.

(The entire treatment will be free from involved mathematics.)

III. *Verification of laws of seepage flow.*

(a) Simple cases of floor and sheet pile.

Combinations.

1. Mathematical,
2. Electric model,
3. Hydraulic model.

IV. *Location and erection of pressure pipes and standard methods of observation and record.*

(This will be reprinted from Publication No. 8.)

V. (a) *Panjnad observations.*

1. Prototype
2. Hydraulic model.
3. Electric model.

(b) *Khanki observations.*

1. Prototype.
2. Hydraulic model.
3. Electric model.

(c) *Other Weirs.*

(d) *Important deductions.*

VI. *Seasonal Variations in uplift pressures.*

Reasons for the same

1. (a) Silt or Scour on pervious aprons.

(b) Temperature difference between river and sub-soil water.

2. Factor of safety provided by nature due to (a) and (b).

3. Interpretation of abnormalities, *i.e.*, whether seasonal or due to underming or other reasons.

Here a short review of the experimental work done in this connection in the Research Institute will be added. It will be partly a reprint from Publication No. 8 and partly new matter since available.

VII. *Safe distribution of pressures.*

1. Flotation gradient.

2. Factor of safety depending on—
   - (*a*) Nature of sub-soil.
   - (*b*) Importance of structure.
   - (*c*) Minor Geological Abnormalities.
   - (*d*) General stratification.
3. Inverted filters.

VIII. *Stratification.*
   - (*a*) General types.
   - (*b*) Favourable or unfavourable
   - (*c*) Influence on design.

IX. *Standard forms.*
1. (*a*) Single pile line.
   - (*b*) Simple floor flush and depressed.
   - (*c*) Simple floor and one pile line.
   - (*d*) Simple floor and two pile lines.
   - (*e*) (*c*) and intermediate pile lines.
   - (*f*) (*d*) and floor upstream and|or downstream of end pile lines.
   - (*g*) Falls.
   - (*h*) Syphons.
   - (*k*) Aqueducts.
2. Safe and unsafe forms.
3. Abutments and wings.

X. *Working Rules for Design.*

The Author's new method.

Order of accuracy.

Limitation.

Curves and their application for design

XI. *Modifications in above designs by the flow of surface water over the crest.*
   - (*a*) Flood, scour, parallel flow, swirls and design of aprons and inverted filters.
   - (*b*) Standing wave.
   - (*c*) Slope of glacis, length and thickness of floor determined by standing wave.
   - (*d*) Dissipation of energy of surface flow. Arrows, baffles, blocks, depressed compartments, etc.

APPENDIX III.

Note on Regime Flow by Mr. G. Lacey, B.Sc., M.I.C.E., I.S.E., Superintending Engineer, (United Provinces).

Introductory.—The writer has very frequently been asked to explain the practical significance of his theory or regime flow and in what way it differed from that of Kennedy. He has also been asked to give some physical explanation of his silt factor. In this very brief note the writer attempts to explain the manner in which his formulas were derived and to give them a simple physical significance that may appeal to practical engineers.

2. *Critical velocity.*—Kennedy's well-known formula for the critical velocity may be written $V \propto D^n$. One inconvenience of this formula is that it cannot be equated with any flow formula of the type $V \propto R^b S^c$. The writer some years ago evolved from Kennedy's data the formula $V \propto R^a$. The advantage of this formula is that the critical velocity may be be equated with the velocity obtained from any flow formula of the exponential type involving R and S. When channels are in bad regime with ragged berms and irregular beds the slope is exaggerated by these extra resistances which may be summed up in the word "shock". When on the contrary a channel is in regime with a wetted surface consisting throughout of silt the regime slope is a function of the grade of silt transported and it is possible to derive a formula for regime slope instead of a formula for regime velocity.

3. *Critical slope.*—If the flow formula is correct, and the critical velocity formula is known, one can proceed direct to calculate the regime slope, thus :—

$$V \propto R^a \propto R^b S^c$$

and hence

$$S \propto R^{\frac{a-b}{c}}$$

In the writer's first paper presented to the Institution of Civil Engineers he derived from the Kennedy and Madras data the critical velocity formula :—

$V = 1\cdot17\sqrt{fR}$; f = silt factor = $\cdot73\ V^2/R$ that is to say for constant silt grade the ratio V^2/R was a constant.

The Lindley data was unique since there were no observations of the velocity, the slope being measured instead. From the Lindley data the writer, in the reply to the discussion on his paper, derived the expression.

$$S \propto R^{-\frac{1}{2}}$$

that is to say for constant silt grade the product $R^{\frac{1}{2}}S$ was also a constant.

It will be observed that the two relationships derived are very simple. The inference from these two relationships is that for a constant silt grade the velocity, hydraulic mean depth, and slope are uniquely determined. That is to say if we know the silt grade, and *one* of the fundamental dimensions V, R, and S the other two dimensions may be at once determined.

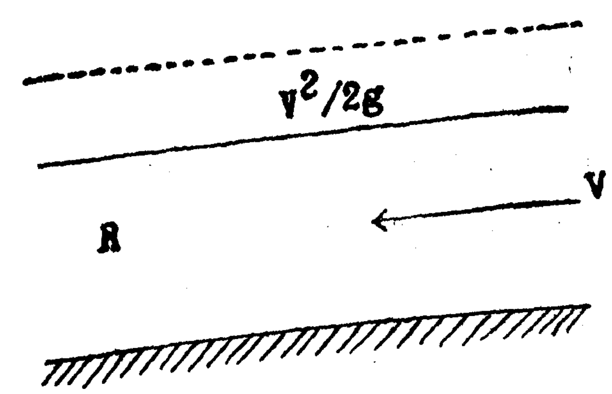


Figure 1.

Energy of Flow Diagram.

4. *The Ratio V^2/R.*—Figure 1 represents the *hydraulic longitudinal* section of a regime channel. The wetted surface is developed horizontally, and the hydraulic mean depth erected upon it. Such a channel has also an hydraulic mean width which is the wetted

perimeter. It will be observed that the longitudinal section is also an energy of flow diagram and the total energy line has been elevated above the water surface by the vertical height $V^2/2g$. This diagram, as Tchikoff has pointed out, has an interesting geometrical significance.

5. It has already been shown that when the silt grade is constant the ratio V^2/R is constant. This is equivalent to stating that the ratio $V^2/2gR$ is constant if we divide through by the constant $2g$. A glance at the figure shows that for constant silt grade $V^2/2gR$ being a constant, the velocity head as plotted vertically bears a constant ratio to the hydraulic depth of flow. We thus see that for constant silt grade regime channels have geometrically similar energy of flow diagrams, in respect of vertical dimensions.

6. *Froude number.*—It has been shown that when the silt grade is constant, or the silt factor constant, the expression $V^2/2gR$ is also a constant. This expression is a dimensionless quantity the dimensions of the numerator being L^2/T^2 and of the denominator $L \times L/T^2$. It is also equal to one half of the Froude number V^2/gR. It is sufficient to say here that if all channels large and small work to the same Froude number, homologous forces will always bear the ratio of the channel scales, such scales being vertical. The silt factor bears a constant ratio to the Froude number, and had the Froude number been adopted in the first instance by the writer instead of the silt factor, his equations would have made a greater appeal to the physicist. The silt factor was however adopted in order that unit silt factor would correspond with Kennedy's standard sand silt with a critical velocity ratio of unity.

7. *Discharge.*—It will be observed that the only dimensions dealt with so far have been V, R, and S for constant silt grade f. No mention has been made of the wetted perimeter. Once this is introduced the discharge is involved.

Referring now to paragraph 3 above we can see the difficulty in which the canal engineer has been placed. It is quite true that knowing the silt grade and one of the three dimensions V, R, and S a channel can be designed. The trouble is that the *one* dimension must be selected empirically. In other words we do not know the correct ratio of P the wetted perimeter to R the hydraulic mean depth, and until we do the channel as designed may have a tendency either to widen by silting its bed and scouring its banks, or to narrow by scouring its bed and by berming.

8. In the writer's first paper he concluded, after plotting the wetted perimeters against discharges, that the wetted perimeters of channels with constant silt grade varied as the square root of the discharge. The relationship is difficult to obtain owing to the stiffness of the sides of some channels restricting the width. Of all the regime relationships however that connecting the wetted perimeter and the discharge would appear to have received the widest confirmation. The question arises whether it is possible on theoretical grounds to derive the wetted perimeter relationship from values of V, R, and S *without recourse to measurements of the discharge.* The relationship was so derived by the writer in the reply to the discussion on his paper, and is reproduced in this note.

9. Referring now to Figure 1 it will be seen that the slope is somewhat exaggerated. Every practical engineer notices the same exaggeration in the slope when he studies longitudinal sections as ordinarily plotted. The vertical scale may be one inch equals ten feet, the horizontal scale sixteen inches equals one mile. Whatever the precise scales adopted every practical engineer will agree that the exaggeration in the slope is none other than the exaggeration in the vertical scale as compared with the horizontal scale. This vertical scale is an hydraulic vertical scale in the figure, the hydraulic mean depth being involved and not the mean vertical depth, or the depth on the bed.

10. The horizontal scale applies not merely to the length of the channel but also to its hydraulic width, that is to say to its wetted perimeter. In Nature we know from observation that other things being equal small channels have a larger ratio of R to P than large channels. Further, other things being equal, the slope in the smaller channel will be *greater* than in the large channel. Applying the principle that the exaggeration in the hydraulic vertical scale is none other than the exaggeration in the slope.

$R/P \propto S$

but $S \propto R^{-\frac{1}{2}}$ (*vide* para. 3)

hence $P/R \propto R^{\frac{1}{2}} \propto V$

and $P. \propto R^{3/2} \propto V^3$ (since $R^{\frac{1}{2}} \propto V$)

multiplying through by RV which varies as V^3

$PRV = Q \propto V^6 \propto P^2$

and $P \propto Q^{\frac{1}{2}}$

for constant silt grade. The wetted perimeter-discharger relationship has therefore been deduced without recourse to any data involving the discharge. The significance of such a

simple designing rule will be immediately appreciated. The shape, for constant silt grade, P|R varies as the mean velocity. The shape it will be noticed is yet another dimensionless number.

11. The geometrical similarity in the energy of flow diagrams and the incorporation of the Froude number give the writer's critical velocity formula a significance denied to alternative relationships, many of which have been put forward of late. The simplicity of the wetted perimeter discharge relationship and the degree of confirmation it has received during the last few years from many independent workers indicate that this expression must hold the field until replaced by another expression supported by overwhelming evidence.

12. *Effect of silt grade on the P, Q relationship.*—One problem remains for solution, and that is the question, frequently raised in the past, whether the silt factor, or for that matter the Froude number, enters the wetted perimeter-discharge relationship. In other words if for Kennedy standard silt the expression is

$$P = 2{\cdot}67\, Q^{\frac{1}{2}}$$

would it be necessary to change the constant 2.67 if the silt were fine or coarse. As matters stand there is so much scatter in the data and so many variables at work that it has not been possible on a statistical analysis to state definitely whether the constant 2.67 varies with the silt grade or not. The writer has shown how it is possible *without* recourse to wetted perimeter data to derive the fundamental formula which subsequent collections of data serve to confirm. The question arises whether any geometrical or physical significance can be ascribed to the relationship, and whether, if, as the writer assumes to be correct, the constant 2.67 is a true constant, the significance is enhanced thereby.

13. A little reflection shows that if two channels are taken with different silt grades the geometrical similarity in the two respective energy of flow diagrams immediately breaks down. Is there any similarity left, and in what respect can one channel resemble, *or be considered as a model of, the other?* The only thing left is to *model the discharge*

We have seen in paragraph 10 that when the silt grade is constant the shape P|R varies as the mean velocity. This expression can be re-written P|RV equals a constant number. But RV clearly is the mean discharge per foot run, or more fundamentally, the discharge intensity.

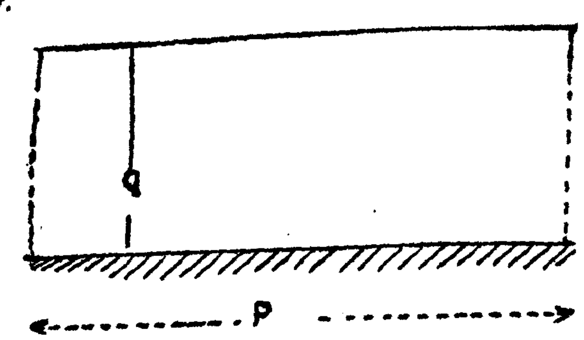


Figure 2.

Discharge Diagram.

Referring now to Figure 2, the wetted perimeter has been plotted horizontally and the mean discharge per foot run, q, vertically. If we integrate this diagram we obtain the discharge. For channels of the same silt grade therefore we observe that not only is there a geometrical similarity in the energy of flow diagram, but there is also geometrical similarity in the discharge diagram, for channels large and small, the ratio of the wetted perimeter to the discharge intensity q being a constant.

14. When the silt grade is a variable the similarity in the energy of flow diagram breaks down, but, *if* the relationship between the wetted perimeter and the discharge is independent of the silt factor, the geometrical similarity in the discharge diagrams would still persist. That is to say that in all regime channels, irrespective of silt grade, the ratio of the discharge per foot run to the wetted perimeter would remain a constant, or in other words, *the discharge per foot run per foot run is a constant.*

15. There, for the present, the problem of regime flow rests. So long as the viscosity of the water and its density remain constant, as also the density and "distribution" of the silt particles, the silt factor will bear a constant ratio to the Froude number, and the average silt diameter remain a simple function of either the Froude number, or the silt factor. Silt grade, whether determined in terms of average diameter, or in terms of yet another number such as the Schoklitsch, will always remain the fundamental variable.

November 1935.
January 1936.

APPENDIX IV.

Sinuosity.

By Mr. C. C. Inglis, I.S.E., Superintending Engineer, Bombay (Deccan).

In this note I merely propose to deal with the simplest factors which seem to me to explain the sinuosity of rivers, starting from the simplest case.

2. The simplest case is that visualized by Mr. Lacey in his Paper on 'The flow of water in incoherent alluvium'. Under such conditions the slope, the hydraulic mean depth and the wetted perimeter (in other words, the shape), and the velocity, are all dependent on the discharge and the silt. Under such conditions, with constant flow and constant silt charge, the river will tend to build itself up or scour down until it is approximately straight, because this gives the condition of minimum energy of flow.

3. In nature the silt is not uniform and due to abrasion and other causes the silt is coarse near the hills and becomes finer and finer, due to attrition, until near the sea it is generally composed of fine clay ; consequently a longitudinal section is concave : this, however, being partly due to the discharge near the sea being greater than near the hills—because the larger the discharge and the finer the silt, the flatter the slope. Varying one factor at a time, let us consider the effect of a varying silt charge. We will assume that the discharge remains the same, while the silt charge varies throughout the year. This is approximately the condition on some canals. When there is coarse silt in the water, the river cannot carry it and so it is deposited at the head and the slope gradually increases. This may continue until regime is approximately attained. Let us then assume that the silt charge becomes finer or decreases, the discharge remaining the same. The channel will then have a slope which is in excess of that required to carry the silt charge. This will lead to erosion and the way the slope can be decreased with a minimum expenditure of energy is by sinuosity.

APPENDIX V.

Tortuosity of rivers and their training by means of Embankments.

By Mr. D. N. Sen Gupta, Executive Engineer, Bengal.

In the province of Bengal—a land of rivers—most of the rivers are active delta builders, spilling freely over the land and such spilling is beneficial in different ways to the area traversed by them. In a few rivers only which are of a torrential nature embankments were found necessary and have been in existence from times past. But the general mass of rivers are entirely devoid of them and this is considered desirable on account of their harmful effects. The relation between embankments and tortuosity has not, therefore, been a subject of serious attention or study. Moreover the principal rivers of Bengal, *viz.*, the Ganges and the Brahmaputra are known to oscillate like a pendulum, to build up the delta, and this oscillation according to some engineers should not ordinarily be checked as it would interfere with their delta building function.

2. Topographically the Bengal soil can be classified into the following separate zones :—

(*a*) Non-deltaic zone where the rivers do not ordinarily spill.

(*b*) Upper deltaic zone where the rivers are not appreciably affected by tides and unless obstructed artificially spill sweet water over the land during freshets.

(*c*) Lower deltaic zone where the rivers are subject to the influence of strong tides and the land receives spill of saline water unless protected by embankments.

3. In the first zone which covers only the Western and Northern most parts of the province of Bengal, the rivers are more or less steady. The soil generally is sufficiently hard to withstand fairly high velocity, and accretion and diluvian that help a river to become tortuous are comparatively weak. In the 2nd zone the soil is composed principally of Indo-gangetic alluvium which is more or less loose. The rivers can cut through this soil fairly rapidly. In this zone it is a common phenomenon for the river Ganges to open up a wide channel in one season for its main current which is again completely obliterated in course of 2 or 3 years. To combat against tortuosity of such mighty streams is, therefore, a problem of gigantic magnitude. The 3rd zone near the sea coast on the south is covered by tidal rivers and estuaries with reversing current which generally maintain more or less straight courses. The rivers of this zone have not, therefore, been dealt with at great length in this note.

4. Most of the live rivers of Bengal carry a strong current and erode their banks where they pass through the 2nd zone and frequently change their courses. The very existence of important places on their banks has thus from time to time been threatened. Except cases where very valuable properties are involved no protective measures are taken on the score of excessive cost. Therefore wherever such erosion takes place the local people are generally compelled to leave the place to the mercy of the river. It would be a matter of great public welfare, if protective measures of reasonable expense could be thought out to prevent these erosions. The subject of controlling the tortuosity of rivers, therefore, deserves consideration. Two cases of river erosion which threatened two important towns of Bengal in recent times are worth mentioning here. The town of Sirajgung situated on the bank of the Jamuna (Brahmaputra) was threatened with complete obliteration and a part of the city was actually carried away by the vagaries of the powerful stream when the town was saved by adoption of suitable bank protective works and erosion arrested altogether. But the town of Noakhali situated on the Meghna estuary, where no attempt was made for protection, when it was attacked, owing to the cost involved being prohibitive and not commensurate with the value of property to be protected, has practically disappeared.

5. An index map of the Province is enclosed* showing the important rivers of the country. The Ganges now flows in a southeasterly direction and is joined on its seaward course by the Brahmaputra at Goalundo and the Meghna at Chandpur. The previous course of the Ganges was along the Bhagirathi, the lower portion of which is called the Hooghly. The town of Calcutta is situated on this latter river. Various places of business have in recent years cropped up on the banks of this river. A substantial volume of seaborne trade of India is centred in Calcutta and its neighbourhood.

6. It is believed that the avulsion diverting the Ganges from its extreme westerly, *viz.*, the Bhagirathi—Hooghly course into its present southeasterly one took place about four hundred years ago. Since then the headwaters of the river Hooghly have been gradually dwindling. The ordinary flood discharge of the river Ganges is about 1,500,000 cusecs and that in dry weather 50,000 cusecs. The river Hooghly and its upper reach the Bhagirathi is practically cut off from its parent river during the dry weather and the very

*Not included in this Report.

maximum discharge that could now come down the Hooghly from its head including the discharges from the tributaries of the Bhagirathi as Ajoy, Mor and other small channels is about 450,000 cusecs. The channel of the Bhagirathi and upper reach of the Hooghly which originally carried a discharge nearly four times the probable maximum discharge of the present day has, therefore, considerably dwindled in size.

7. The Brahmaputra also left its old course towards the end of the 18th century and is now following the present course along the Jamuna. The old Brahmaputra has considerably dwindled in size. Towns like Mymensingh situated on the old river have been affected by this avulsion.

8. Such changes in the course of rivers affect not only the volume of the river-borne traffic but also the health of the localities along the old channel. Previous to the change in the course of the Ganges, rivers like the Bhairab, the Nabaganga and the Mathabhanga in Central Bengal were active rivers and the basins served by them were healthy and flourishing. Now these places have become extremely unhealthy and the soil has been considerably impoverished.

9. The above mentioned avulsions appear to have taken place when the old channel in the course of delta building became very tortuous and the new channel now followed was a much shorter route to the sea. If by any means the tortuosity of rivers could be reduced and a more direct flow into the sea established such avulsions could be avoided or made less frequent. It should, however, be borne in mind that the activity of the rivers in building up the delta should not be seriously interfered with in the course of the training work as such interference is likely to cause disastrous results in future.

10. The rivers of Bengal may be divided into the following main classes :—

(a) Large snow fed perennial rivers such as the Ganges and the Brahmaputra.

(b) Tributary channels of the rivers in class (a) also fed by the snow such as the Mahananda and the Teesta in North Bengal.

(c) Tributary channels of the rivers in class (a) fed from their catchment in the plains and the Chota-Nagpur hills—such as the Damodar, the Rupnarayan, the Cossye—Haldi and the rivers to the West of and falling into the Bhagirathi.

(d) Distributaries of the rivers in class (a), which are still active delta builders, such as the Gorai-Madhumati.

(e) Distributaries of the rivers in class (a), which are in a more or less moribund state, such as the Bhairab, the Jalangi, the Nabaganga and the Mathabhanga.

11. The rivers of the classes (a) and (b) are big and carry a strong current. Erosion and shelving of banks are noticeable in many places along the course of their channels. No attempt has been made to control these erosions with the exception of mattresses and other measures adopted to protect important towns on these rivers. In the monsoon the discharge in these rivers and also those of class (b) increases slowly and the flooding of the land near these rivers is gradual and suited to cultivation. Practically no embankments have, therefore, been constructed along these rivers. Rivers of class (c) are fed by the drainage from the Chota-Nagpur hills and have no perennial source of supply. Their catchment areas also are small. They are practically dry in the dry weather except in those reaches which are affected by tides and are subject to heavy sudden and shortlived floods during the monsoon. The Damodar which is an important river of this class has been known to carry a flood discharge which occasionally mounts to as high as 650,000 cusecs between banks barely 3,500 feet apart, whereas the dry weather discharge falls so low as 100 cusecs even. Although flood spilling is a valuable asset in fertilising the land, such sudden rush of water in these rivers is not always conducive of cultivation. Attempts have accordingly been made even from ancient times to control these rivers by means of embankments which have been constructed along their banks wherever the lands alongside are so low as to be subject to heavy flooding. These embankments, however, are situated at safe distances from the river channels and the space between embankments usually accommodate the movements of the river channels. Where the channel encroaches upon the embankment, it is the usual practice to retire the same unless the erosion involves encroachment upon valuable property. With the exception of the Bhagirathi-Hooghly, the rivers of class (e) have no embankments save along their lower tidal reaches where the water is saline. Along the Bhagirathi-Hooghly, there are protective and also road and railway embankments running almost along its entire length. The river Hooghly has a wide estuary and carries very strong tides. The banks are well protected against erosion up to about 16 miles below Diamond Harbour. Up to Calcutta the river water is more or less saline in most part of the year. Wherever the bank is low in this reach, there is an embankment to prevent spilling. These embankments are close to the river and as they are revetted on the river side, the channel does not get any opportunity to erode. For about 30 miles above Calcutta the condition is similar. Both the banks in this reach are

thickly populated and there are numerous masonry structures along the banks which prevent all erosions. Higher up, however, there are stretches of low banks and the places are not so thickly populated nor so well protected. A study of the two reaches of this river would be interesting.

12. A statement is enclosed showing the degree of present tortuosity of the more important rivers of the Province. The average widths of the rivers in the different reaches have also been noted in the statement. The information on these points is not, however, altogether accurate and the statement also is not exhaustive. It is intended to give only a general idea of the nature of the channels.

13. *The Ganges.*—In the length dealt with in the statement the river Ganges has a tortuosity varying from 5 per cent. to 30 per cent. It would be interesting to note that just above the Hardinge bridge the river is more tortuous (30 per cent.) than anywhere else. This excessive tortuosity may be due partially to several branch channels taking off in this reach. There is a tendency in a certain school of thought to believe that the construction of the Hardinge bridge and its approaches is also in a certain measure responsible for the acceleration in the tortuosity in the reaches immediately above it. It is conjectured that the waterway provided in the bridge although sufficient to carry the discharge of the river channel is not enough to accommodate the spill discharge of high floods. The river is a strong delta-builder and spills over the banks during the flood season. In dealing with such rivers the channels alone should not be considered. The spill areas carry a large portion of their flood discharges and are insuperably connected with them. Any blockage in the spill areas tells adversely on the rivers also. The average surface slope in the river is about 4 in. 1 mile. The surface slope may have been flattened to some extent locally for some distance above the Hardinge bridge. In the absence of sufficient gauge readings in the Bengal Irrigation Department, I am not in a position to thoroughly substantiate the flattening of the slope above the bridge. There is, however, an excellent superplotted map of the river prepared by the Railway Department showing on it the different courses in 1868, 1915 and 1933 in the neighbourhood of the Hardinge bridge. In 1868 the river was very tortuous—the index of tortuosity being about 50 per cent. In 1915, *i.e.*, when construction of the Hardinge bridge was just finished it was reduced to 15 per cent. which is believed to have been due to natural causes. Now it has increased to 30 per cent. Since I have written this note I have come across a note by Sir Robert Gales in which he gives the following information about the Hardinge bridge.

Length of the Ganges from Sarda to Pabna by the main cold weather course in 1782 was 72 miles, in 1855 was 59.5 miles, in 1868 was 66 miles, in 1910 was 57 miles and in 1933 was 54 miles.

He attributes it to the decrease in the amount of water drawn off by the Nadia rivers and the Baral. But this does not explain the increase in 1868. The cold weather discharge is generally very low and its percentage variation from year to year may be considerable without any permanent change in the river but due to the vagaries of the weather. Variations in this length therefore may not indicate any permanent change. In these figures the straightest courses of the river have been taken in the account and the more tortuous alternative courses neglected. The increased tortuosity at the present day is mainly confined above the Hardinge bridge. In 1868 the Nadia rivers—namely—the Bhagirathi, the Jalangi, the Bhairab and the Mathabhanga were in a better condition and no doubt took away a large discharge. Probably the parent river thus deprived of a substantial portion of its discharge could not retain its usual condition in the higher reach and adopted a more tortuous course. Gradually with the deterioration of the branch channels it was carrying more water and was able to improve its channel and assume a straighter course. The obstruction created by the Hardinge bridge and its approaches may have now adversely affected the channel again as suggested before. The river is probably taking the present tortuous course in its attempt to remove the obstruction created by the bridge. The view mentioned above appears to be supported theoretically also as will be evident from the explanation given at the end of this paper. If it is correct any obstruction such as a weir across a river should also produce tortuosity in its course. There are only three weirs in Bengal one of which is very short in length and another constructed only about 3 years back. It is hardly possible to arrive at a definite conclusion on this point from these cases. If the Nadia rivers were improved to take larger discharges and the strength of the parent river consequently reduced, it might be possible to make the latter more or less steady in its present tortuous course. This matter, however, requires a careful study over a fairly long length of the river both up and down stream of the bridge and its courses for a long period covering many years, both before and after construction of the bridge. The discharges of the main river and its branches have also to be ascertained for a long period. It would be a very interesting study and it is believed that it would show clearly the effect on rivers produced by bridges with insufficient waterways as also by roads and railway embankments which do not provide sufficient spill openings.

14. The river carries a very strong current. In the deepest part of the river the velocity runs as high as 10′/sec. It is significant that the river on the whole is fairly straight. It is more tortuous in the reach above the Hardinge bridge for reasons stated before. Near the off-take of the Gorai-Madhumati also it is more tortuous than usual. This is probably due to the fact that the river here is less vigorous owing to the draw into the distributary. Below its junction with the Brahmaputra, the river is very vigorous and shows very little tortuosity.

15. The figures of tortuosity of this river given in the statement is not an index of its activity in erosion. On account of its strong current there is a good deal of bank erosion on this river. But due to the friable nature of the soil it is able to cut a fairly straight channel which oscillates from one bank to another periodically. The amplitude of this oscillation is, however, limited within a certain maximum width. No reliable and definite data are available on this point and will have to be collected by local enquiry. This is likely to give an idea about the likelihood of the places situated on the river to be attacked by erosion. The oscillation, generally does not affect the tortuosity of the river.

16. *The Brahmaputra* (Jumna).—What has been stated about the Ganges holds good for this river as well. The Brahmaputra is more vigorous than the Ganges and carries a higher discharge. It is, therefore, a straighter stream. Only in the reach near its outfall into the Ganges it is more tortuous. The channel here is narrow and less vigorous due to the draw by the Dhaleswari.

17. *The Damodar.*—This river does not spill nor change its course to any appreciable degree in the upper reach where it passes through rocky and hard soil. It begins to spill about 20 miles above Burdwan. From this place the river is embanked along its left bank. But the right bank is exposed to flood except for a short length about 30 miles below Burdwan. For the last 20 miles near its outfall it is embanked on both sides. The river has a very steep fall, it being about 36 in. 1 mile in the upper reach. It is gradually reduced to about 18 in. per mile at Amta. Lower down it is considerably reduced and is about 6 in. per mile on the average. The river runs fairly straight probably owing to the strong current generated by the steep fall. It gradually widens up to about 30 miles below Burdwan. Below this reach a branch channel takes off a large portion of its discharge and the width of the river lower down is reduced to less than half of the original. It is on the whole more tortuous in the narrower reach than in the wider. In the upper reach although the channel is narrow, the tortuosity has not increased. This is probably due to the fact that the stronger current caused by the steeper fall has helped in keeping the channel straight. It does not appear to show much difference in its behaviour of tortuosity in the reaches where it has embankment on one side as compared with that where both the sides are embanked.

18. *The Rupnarayan.*—The lower reach of this river is embanked on both sides and has a flat slope of about 3 in. per mile as in the Hooghly into which it falls. In the upper reach there is no embankment along the left bank. The tortuosity in the upper reach is a little more than in the lower although the slope there is much steeper (8 in. 1 mile). This is probably due to the narrowness of the channel. Although there is no embankment on one side in the upper reach, the channel is more or less steady.

19. *The Ajoy.*—This river has embankments where the land along-side is very low and subject to heavy inundation during floods. The surface slope in the upper reach is rather steep being about 4 feet per mile. Near the outfall the slope must be flatter. But there are no gauge readings available to give any correct idea of the same. The tortuosity of the Ajoy is the same in the upper reaches referred to in the statement. But near the outfall the channel is much more tortuous. This is probably due to the flatter slope caused by the water being backed up by the volume in the Bhagirathi into which it falls.

20. *The Gorai-Madhumati.*—A 52 mile length of this river has been scrutinised. In this reach it has a tortuosity of 30 per cent. Sometime back this river was developing rather rapidly and it was apprehended that the Ganges might be diverted along this course. It will be seen that the Ganges joins the Brahmaputra about 50 miles below the offtake of this river. The Brahmaputra is a vigorous river when it is in flood at the same time as the Ganges, the discharge of the latter river is to some extent checked and this no doubt helped in the development of the Gorai-Madhumati. But it appears that a balancing limit has been reached for the time being. The Ganges has a straighter channel and it is not unlikely that this advantage predominated and the river kept itself to its present course.

21. *The Attrabanka*—is a river of a short length taking off from the Madhumati. It has a tortuosity of 61 per cent. The surface slope in the river is very flat being only 2 in. per mile. There is heavy steamer traffic in the rivers in this locality. The other rivers require very little attention to keep them navigable. But bars in the bed of the

Attrabanka have to be dredged annually to keep it navigable. This is probably due to its tortuous nature. It appears to indicate that when a river loses vigour it becomes more tortuous.

22. *The Bhagirathi-Hooghly.*—The estuary below Geoukhali has taken rather a crooked course due to the combined volume of water of the Damodar, Rupnarayan and Haldi flowing into the river at a sharp angle. Otherwise the river in the lower reach is fairly straight. Omitting the estuary, the average tortuosity in the lower reaches is only 20 per cent. The river here is well-trained and it gradually widens as it proceeds to the sea. In the upper reach above Nasarai the average tortuosity is 62 per cent. The figure for the Bhagirathi is as high as 98 per cent. The training works in the lower Hooghly along with occasional dredging of sand bars in the bed have helped in the maintenance of a good navigable channel even for sea going vessels up to the Port of Calcutta. Higher up the river, the channel is gradually poor in section and ordinarily navigable by country boats only. The upper portion of this river above Nabadwip is called Bhagirathi. In the upper reach of this section there is a little or no water in the channel during the dry season. The average fall in the Bhagirathi-Hooghly is approximately 3 in./mile against 4 in./mile in the parent river Ganges.

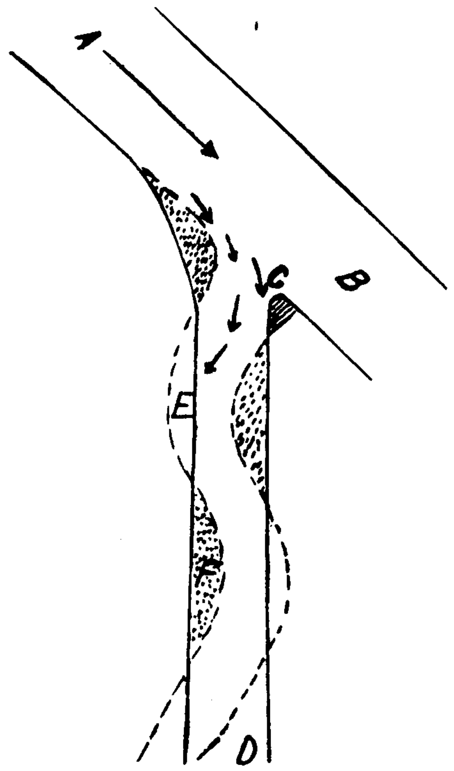
23. *The Jalangi and the Mathabhanga.*—These two rivers also are very tortuous as the Bhagirathi—the average figure of tortuosity being 128 per cent. and 92 per cent. respectively, and they are more or less in a moribund state.

24. The Bhagirathi, the Jalangi and the Mathabhanga, as already stated, are more or less in a moribund state. Similar is the condition of the other rivers lying between the Bhagirathi-Hooghly and the Gorai-Madhumati in Central Bengal. These rivers are very tortuous and it is likely that with straighter channels they would improve. But as the outlay involved is very heavy, practically nothing has been done in this direction up till now.

25. From what has been stated before, embankments do not appear to have any marked effect in reducing the tortuosity of a river although theoretically they should create, if properly aligned with gradual curves and provided with wide berms between the channel and the embankments, a tendency in rivers to follow a straighter course. The comparatively still water on the berm in front of embankments should flow more or less parallel to the bank and by its influence the current in the deeper channel should also take a straighter course. This view has been expressed by a senior officer of the Bengal Irrigation Department whom I consulted in the matter. There may be another explanation for it also. Rivers carrying more discharge are more vigorous and straighter in their course. Embankments by cutting off the spill retain more water for the river and should therefore reduce their tortuosity. But as the berms of the Bengal rivers which are embanked are overflooded on very few occasions and as in many places the embankment is very close to the channel, this effect is not marked.

26. The evils of embankments have been seriously felt in Bengal in almost all cases and it is very difficult to undo the mischief created by them and there is hardly anything but regret for the legacy of embankments left in this province. It may not, therefore, be desirable to go for them even if they are found to reduce tortuosity in rivers. The construction of embankments along a river to cut off or reduce its spill discharge affects the locality adversely in many ways. Spill water has been known in Bengal to fertilise the soil over which it passes. Flooded areas have been found to be more healthy also. Further the spill being cut off building up of the delta along the course of the river is stopped. The solid matter in suspension is thus carried forward in much larger quantities into the sea. Expansion of delta into the sea is, therefore, much more rapid. A record has been kept of the extension of the delta of the Mississippi before and after construction of the embankments along the river. Previously it was 96 feet a year and now it is 300 feet per annum. This reduces the surface fall in the river more quickly, raises the water level in the lower delta and causes breaches in the embankment. It was on this consideration that the right embankment of the river Damodar was abandoned in order to allow some spilling to the river. This policy of abandonment of embankments wherever it can be done without much damage to property is now steadily followed by the Bengal Department of Irrigation.

27. Tortuosity of a river may be arrested by providing hard skin protection to banks at places of erosion. Such works would not prevent spill and affect health and prosperity of the localities in any way. It may not be possible to afford such protection along the rivers like the Ganges and the Brahmaputra except in places of very great importance. As oscillation of these very active rivers is closely connected with building up of their delta, forcing them to follow the same channel throughout their course, may not, as already stated, be desirable. But the position is not exactly the same with their distributary channels which are fairly close to each other and if they follow the same channel always, building up of the delta is not likely to be interfered with appreciably.



28. It will not be out of place to note how the distributary channels mainly form their bends. Let A B be a parent river running in a straight course and C D a spill channel taking off the parent river. Ordinarily the spill waters of the parent river would try to flow along the line of least resistance and the shortest line to traverse would be a straight line. What really happens is, however, entirely different. The stream of water entering from the parent river cannot go at a sharp angle but tries to flow with a gentle sweep. They strike and attack the corner C and if the land is friable as is the case in most of the deltaic areas, the corner shown in hatch is carried away and the current being deflected from this corner strikes the opposite bank at an angle instead of flowing parallel to it. The next stage is shown in dotted lines and this oscillation is carried downwards. The following factor also begins to operate and accelerates the formation of oscillations. The earth and sand washed away from the point of attack say E are mostly deposited below the embayment say at F and form an accretion which in its turn functioning like a deflecting spur helps in throwing the current more towards the opposite bank and attacking that bank more vigorously. Minor local factors such as existence of pockets of hard soil and clay, local obstructions caused by roots of big trees, fallen trees, eroded buildings even sunken boats disturb the homogeneous nature of the oscillations.

29. The process of growth of tortuosity described above has its limits depending on the velocity and nature of soil. But it may be necessary to keep the channel straighter. From the statement it is evident that when a river becomes tortuous its condition is rendered worse. Rivers like the Bhagirathi, the Jalangi and the Mathabhanga are examples of this nature. Entrances to these rivers are always shifting, so also the main channel of the parent river near the offtakes. It may be possible to straighten these channels if the parent river could be trained to pass close to the entrances and offtakes kept steady at some suitable positions by protecting their noses against erosion. Erosion lower down may also have to be stopped by giving a skin protection to the bank. There has, however, been no such systematic works carried out in Bengal to give any definite opinion on their effect.

30. Behaviours of the Ganges near the Hardinge bridge appears to indicate that tortuosity of a river increases with slackened current. This seems to be supported by the moribund condition of the very tortuous rivers of Central Bengal like the Bhagirathi, the Jalangi and the Mathabhanga and the weak nature of the Attrabanka. The Ganges, the Brahmaputra and the Damodar also have more tortuous channels where they carry less discharges and therefore are less vigorous. Theoretically also this view appears to be supported. Erosion is due to the tortuous moment created by the difference in the strength of current of the adjoining particles of water. When due to an obstruction in the course of a river or otherwise the slope is flattened, its effect in reducing the strength of the current is felt more nearer the bank than midstream with the result that the change

in the strength of current from midstream to bank is more rapid and the tortuous moment is increased. Therefore with a reduced fall bank erosion is increased giving a more tortuous course to the channel.

31. The statement also seems to indicate that channels in more friable soil as in the Gangetic delta are straighter. Such soil is less capable of diverting the current which causes erosion. Further a narrow river is more tortuous. The current causing erosion in one bank turns back and strikes at the opposite bank within a short distance.

Statement.

Name of river.	Reach. From.	Reach. To.	Direct distance.	Tortuous distance.	Percentage of Tortuosity.	Average width.	Remarks.
			Miles	Miles	%	Miles	
Ganges ..	Nimtola ..	Panka ..	20	22	10	2	
	Panka ..	Godagari ..	20	22	10	1¼	
	Godagari ..	Nabipur ..	20	21	5	2½	
	Nabipur ..	Sultanpur ..	20	26	30	2	
	Sultanpur ..	Joyanpur ..	20	23	15	1¼	The Hardinge bridge is situated midway of this reach.
	Joyanpur ..	Harirampur ..	20	23	15	1¼	Gorai taking off about 3 miles above this reach.
	Harirampur ..	Alokdia ..	20	22½	12	1¼	
	Alokdia ..	Solepur ..	20	20½	2	3	Brahmaputra joins at the head of this reach.
	Solepur ..	Kalipara ..	20	21	5	2¾	
	Kalipara ..	Sureswar ..	20	20½	5	3¼	
Brahmaputra ..	Maganhat ..	Chardalika ..	17	17	*Nil*	3	
Jamuna ..	Chardalika ..	Sarishabari ..	20	22	10	2½	
	Sarishabari ..	Serajganj ..	20	22	10	3	
	Serajganj ..	Khasdhalai ..	20	20½	2	3½	
	Khasdhalai ..	Mouth ..	20	26	30	1½	This excessive tortousity is probably due to the Dhaleswari taking off just above this reach, and less width.
Damodar ..	Bhaladi ..	Ondal ..	20	22½	12	1/16	
	Ondal ..	Bharatpur ..	20	23½	17	1/16	
	Bharatpur ..	Patashpur ..	20	22	10	1/8	
	Patashpur ..	Sadipur ..	20	22½	12	1/8	
	Sadipur ..	Champadanga	20	24½	22	3/32	
	Champadanga	Amta ..	20	24	20	3/16	
	Amta ..	Junction with Hooghly.	20	27	35	3/16	
Rupnarayan ..	Pratappur ..	Bakshi ..	12	15	25	5/32	
	Bakshi ..	Gewnkhali ..	24½	29	18	3/4	
Ajoy	Kendra ..	Islambazar ..	20	26	30	1/16	
	Islambazar ..	Mamudpur ..	20	26	30	1/16	

Name of river.	Reach. From	Reach. To	Direct distance.	Tortuous distance.	Percentage of Tortuosity.	Average width.	Remarks.
			Miles	Miles	%	Miles	
Ajoy—*contd.*	Mamudpur ..	Katwa ..	20	34	70	1/16	
Gorai ..	Talbaria ..	Sarutia ..	20	26	30	5/16	
	Sarutia ..	Ramchandrapur	20	26	30	5/24	
Attrabanka ..	Chapail ..	Khulna ..	18	29	61	1/8	
Bhagirathi Hooghly.	Chohatpur ..	Kamnagar ..	16	27	69	1/8	
	Kamnagar ..	Darihat ..	20	35	75	1/8	
	Darihat ..	Nabadwip ..	20	48	140	1/8	
	Nabadwip ..	Kalna ..	12	19	58	1/4	
	Kalna ..	Nasari ..	20	33	65	1/4	
	Nasari ..	Kharda ..	20	24	20	1/2	
	Kharda ..	Nangi ..	20	24	20	1/2	
	Nangi ..	Gariapol ..	20	24½	22	3/4	
	Gariapol ..	Channel creek	20	29	45	2½	
Jalangi ..	Jalangi ..	Nabinganj ..	8	17	112	1/16	
	Nabinganj ..	Chanderghat ..	20	50	150	1/8	
	Chanderghat ..	Nabadwip ..	20	54	170	1/8	
Mathabhanga ..	Offtake ..	Pahoria ..	10	20	100	1/16	
	Pahoria ..	Bagadia ..	20	38	90	1/16	
	Bagadia ..	Raghunathpur	16½	31	88	1/8	

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