

CENTRAL BOARD OF IRRIGATION.

PUBLICATION No. 22.

ANNUAL REPORT (TECHNICAL)
OF THE
CENTRAL BOARD OF IRRIGATION,
INDIA

1938-39.



PUBLISHED BY ORDER OF THE BOARD.

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EDITED BY

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Secretary.

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1940.

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FOREWORD.

CENTRAL BOARD OF IRRIGATION
SIMLA, INDIA.

This "Annual Report", which is published to make known to Engineers in India and other countries the problems confronting Irrigation Engineers in India, and the research and investigations, undertaken to solve them, is the fifth issue of its kind, and records the technical work of the Central Board of Irrigation during the year 1938-39.

The technical discussions are the result of three meetings given hereunder in chronological order :—

- (i) The Third Winter Meeting of the Research Committee, March 1939.
- (ii) The Ninth Annual Meeting of the Research Committee, July 1939.
- (iii) The Tenth Annual Meeting of the Central Board of Irrigation, November 1939.

For the information of the two last named meetings, summaries were prepared of the work done during 1938-39 by the five Research Stations which operate under the aegis of the Central Board of Irrigation, and are included with discussions in this publication.

The technical contents of the volume have been divided into seventeen groups, and the relevant discussions of the three meetings appear under their respective groups. It is thought that this new arrangement will facilitate reference.

Efforts have been made to provide a fully comprehensive index.

The undersigned would like to repeat the request contained in previous reports, for the supply of information relating to any of the problems mentioned in this publication, or any other matters of interest to Irrigation Engineers. He will gladly furnish further details of any of the experiments, investigations, etc., or other information relating to the problems mentioned in this Report.

A. R. B. EDGECOMBE,
Secretary,
Central Board of Irrigation.

Dated the 8th January, 1940.

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MEETINGS OF THE BOARD AND COMMITTEES DURING 1939.

THE THIRD WINTER MEETING OF THE RESEARCH COMMITTEE, 1939.

The Third Winter Meeting of the Research Committee of the Central Board of Irrigation was held at Lahore, Punjab, from the 9th to the 11th March 1939, at the time of the Annual Meeting of the Punjab Engineering Congress.

At the invitation of the Punjab Engineering Congress Committee, the Research Committee attended the meetings of the Congress during the discussions on some of the papers.

The Committee paid several visits to the Punjab Irrigation Research Institute, when Dr. McKenzie-Taylor and his staff explained the various experiments in progress. An informal meeting of the Committee, presided over by Mr. S. H. Bigsby, was held at the Punjab Irrigation Secretariat on Saturday, the 11th March, and the following officers were present :—

1. S. H. Bigsby, C.I.E., I.S.E.	Vice-President.
2. T. M. Lyle, C.I.E., I.S.E.	Executive Committee Member.
3. G. A. M. Brown, O.B.E., I.S.E.	N.-W. F. P.
4. Capt. C. G. Caffin, R.E.	Do.
5. E. S. Crump, C.I.E., I.S.E.	Punjab.
6. M. T. Gibling, I.S.E.	Secretary, Central Board of Irrigation.
7. G. E. Hartley, I.S.E.	United Provinces.
8. J. P. Jain	Do.
9. H. S. Kahai	Sind.
10. Dr. E. McKenzie-Taylor, M.B.E.	Punjab.
11. J. N. Mitra	Assistant Secretary, Central Board of Irrigation.

The meeting discussed items connected with—

- (a) Canal Losses and Means of Conserving Irrigation Water (Staunching of Canals).
- (b) Water logging and Land Reclamation.
- (c) Field Results of Measures Adopted after Model Experiments.

Records of the discussions appear under the appropriate groups in the body of this Report with the exception of (a), under which heading Mr. H. S. Kahai gave the Committee the information given on page 22 of this Report.

The meeting was then adjourned with a vote of thanks to the Chair.

Several members of the Research Committee paid a visit to Trimmu (The Head-works of the Haveli Project), leaving Lahore on the 11th March, and returning the next day. Rai Bahadur Khosla and his staff kindly entertained the party, and conducted them round the works.

NINTH ANNUAL MEETING OF THE RESEARCH COMMITTEE, 1939.

This Meeting was held at Simla from the 11th to the 15th July, 1939.

The Chair was taken by Mr. S. H. Bigsby, C.I.E., I.S.E., Vice-President of the Board. The following is a list of members of the Committee :—

1. S. H. Bigsby, C.I.E., I.S.E.	Punjab.
2. T. Blench, I.S.E.	Punjab.
3. Dr. N. K. Bose, M.Sc., Ph.D.	Punjab.
4. E. O. Cox, M.B.E., I.S.E.	Punjab.
5. E. S. Crump, C.I.E., I.S.E.	Punjab.
6. G. H. Dundon, I.S.E.	Punjab.

7. A. R. B. Edgecombe, I.S.E.	Secretary.
8. N. B. Gadre, I.S.E.	Bombay.
9. F. F. Haigh, I.S.E.	Punjab.
10. G. E. Hartley, I.S.E.	United Provinces.
11. D. A. Howell	Punjab.
12. J. P. Jain	United Provinces.
13. H. S. Kahai	* Sind.
14. G. Lacey, I.S.E.	United Provinces.
15. T. M. Lyle, C.I.E., I.S.E.	United Provinces.
16. Dr. J. K. Malhotra	Punjab.
17. W. N. McLeod, I.S.E.	Punjab.
18. C. H. McKenna, I.S.E.	Punjab.
19. Dr. E. McKenzie-Taylor, M.B.E.	Punjab.
20. M. L. Mehta	Punjab.
21. A. R. Thomas, I.S.E.	C. I. & H. Res. Stn.
22. L. Venkatakrishnaiyer, I.S.E.	Madras.

The Committee considered the annual reports, 1938-39, of the five research stations ; revised programmes for 1939-40 ; and reports on the following subjects :—

1. Field Results of Measures Adopted after Model Experiments.
2. Design of Canal Falls.
3. Meandering of Rivers.
4. The Role of Reservoirs in River Flood Control, and Floods and Deforestation.
5. Canal Losses and Means of Conserving Irrigation Water (Staunching of Canals).
6. Waterlogging and Land Reclamation.
7. The Design of Drains in Irrigated Areas.
8. Silting of Reservoirs.
9. Silt Excluders and Ejectors.
10. The Collection of Hydraulic Data of Torrents in Boulder Rivers and Streams.

The discussions under each subject are recorded in the body of this Report under the appropriate group.

TENTH ANNUAL MEETING OF THE CENTRAL BOARD OF IRRIGATION, 1939.

The Tenth Annual Meeting of the Board commenced on Saturday the 4th November, 1939, at the Hotel Cecil, Delhi, the following officers being present :—

Members of the Board.

1. A. Gordon, C.I.E., I.S.E.	Sind (President).
2. S. H. Bigsby, C.I.E., I.S.E.	Punjab (Vice-President).
3. Khan Bahadur M. Abdul Aziz, C.I.E., I.S.E.	United Provinces.
4. C. E. Aitken, I.S.E.	Bombay.
5. E. O. Cox, M.B.E., I.S.E.	Punjab.
6. F. A. Farquharson, M.C., I.S.E.	Do.
7. T. M. Lyle, C.I.E., I.S.E.	United Provinces.
8. S. C. Majumdar, I.S.E.	Bengal.
9. A. Oram, I.S.E.	N.-W. F. P.
10. A. Vipan, C.I.E.	Orissa.

Attending Officers.

11. The Hon'ble Mr. M. S. A. Hydari, C.I.E., I.C.S., Secretary to the Government of India, Labour Department (attended on the 4th November).
12. W. G. Came, I.S.E. (Deputy Chief Engineer, P. W. D., Bihar).
13. A. R. B. Edgecombe, I.S.E., *Secretary.*

Mr. Gordon, President, took the Chair, and opened the proceedings at 10-30 A.M with the following Presidential Address :—

“ GENTLEMEN :

I have to thank you for the great honour you have done me in electing me as your President, particularly as you were aware that I could not do full justice to my responsibilities, and the Board, and particularly myself, are very much indebted to Mr. Bigsby who has had to do much more work than is normally expected of a Vice-President, and has ungrudgingly devoted himself to the work, which, I can assure you, involves not only sacrificing one's time, but also undertaking considerable responsibility.

I wish to welcome those who have been able to come here to-day. Considering the conditions, the provinces are very well represented. We all know that these meetings do produce valuable results, but I am afraid that modern conditions tend to increase the difficulty in getting away from one's Province—particularly where irrigation work is only a fraction of that which had to be done by the Chief Engineer—and that difficulty is increased to-day by the existing political situation. Apologies have been received from Mr. Dowley of Madras, Col. Pyne of Baluchistan and Mr. Mounq of Burma. Those of you who were present two years ago will particularly regret the fact that we are not to have the benefit of Mr. Dowley's assistance. We welcome those who are attending the meetings of this Board for the first time.

We are meeting to-day under conditions which could not exist if the rulers of the world had scientifically ordered minds. Whatever the outcome of the struggle in which we are engaged, all parties stand to lose. To India, it will be more important than ever that its irrigation systems should be maintained on as economical a basis as possible, *i.e.*, in a high state of efficiency and at the minimum cost possible.

The Irrigation Department is a large spending Department, and Finance Departments are apt to regard it as a convenient outlet from the exchequer to use as a balancing control. We know that any such action under present day circumstances would have serious effects on the development of the country, but it is to be hoped that the people, through their representatives in the Legislatures, will insist on the efficiency of irrigation systems being maintained.

We are now reaching a stage when the value of this body as a co-ordinating one for the results of research and experiment is becoming very apparent. Hydrodynamic experiments have been giving results which can be easily appreciated even by the layman. Diffusion of effort has been minimized by the existence of a Central Hydrodynamic and Research Station, and by the opportunities given to discuss results and programmes at the meetings of this Board, and the meetings of Research Officers held at Lahore and Simla. It is highly desirable that Research Officers should be in touch with field conditions, and for that reason, if no other, it is hoped that it will always be possible to draw a considerable proportion of the Research Officers from Irrigation Officers with an intimate knowledge of field conditions. When we come to consider the position regarding research, it will be appreciated that a very large and valuable programme is being carried out.

The affairs of this Board have always been run with a very modest expenditure. I feel convinced that any other country in the world would be astonished at what has been done considering the small outlay. While we still desire to avoid increasing expenditure, we have reached a stage where our activities will have to be curtailed or else increased funds placed at our disposal. The contingency has already arisen, and it will be most unfortunate should this state of affairs continue. Important papers which are out of print cannot be reprinted, and others have to be produced without illustrations which would greatly add to their value.

We are living in a period of transition, when the Officers who have built up India's irrigation systems are being replaced by Indians who have a different upbringing, and have not the same opportunity for being in touch with practical engineering from an early age. Their task will be a difficult one, particularly in the early stages, but with the help and guidance of the Officers at present in service it is to be hoped that a standard of efficiency will be maintained which will prevent any deterioration in our irrigation systems.

Were we in a position to put forward a clear statement of the financial benefits of irrigation, the necessity for the maintenance of a highly efficient service would be more appreciated. Naturally, most people look to the financial return on capital expended, and seldom beyond that, but there is a large accession to the wealth of the country which is indirectly due to irrigation, and would not exist but for irrigation.

Probably more than any of the other services we realize that the cultivator has little to come and go on, and that it takes very little to make the difference between having a full stomach and inadequate nutrition. There is, therefore, a very large number of human beings who suffer severely if the best possible result is not obtained from our canals, and such results can only be obtained if our establishment be highly efficient. I hope I am wrong, but my opinion is that the new services which are being introduced are not likely to attract the type of man who is required.

We are indebted to Khan Bahadur Abdul Aziz and Rao Bahadur B. Viswa Nath for placing facilities at our disposal to visit the tube well area, and the Imperial Institute of Agricultural Research. The former may shortly be taking over the post of Principal of the Thomason Civil Engineering College at Roorkee, and I am sure that those of us who have had the privilege of working with him on this Board consider the College lucky to have his services, and we all wish him every success in what was always an important post, and is particularly so now that the Irrigation Departments are to be staffed in a different way from in the past.

During our meetings we hoped to have the benefit of help from Dr. Burns of the Agricultural Department, but circumstances prevent his attending, but Dr. Gorrie of the Forest Department will lend us assistance, and we are grateful to him for sparing time to help us in our deliberations.

We had now better get down to business. Besides technical matters, we have to discuss the future constitution of the Board under the new political conditions, and it is hoped that we shall be able to reach unanimity on this difficult subject. Mr. Hydari, Secretary to the Department of Labour has shown a keen interest in the affairs of this Board, and we have had the benefit of discussion with him, and of very helpful guidance.

Developments in recent years would seem to indicate that very close examination will require to be made as to the responsibility of different Provinces in river control matters, and it might be advisable for the Government of India to look ahead, and consider how this problem is to be tackled.

We shall now proceed to consider the agenda before us. It is essential that we should stick to our time table, and your Secretary has given every assistance by carefully preparing a thorough resumé of each subject.

I think you will agree that he has prepared the material for this meeting very thoroughly, and given every indication that our selection of a Secretary has been fortunate."

During the Meeting the Board considered the annual reports, 1938-39, of the five research stations and the 9th Research Committee's discussions thereon; the research programmes for 1939-40 and the 9th Research Committee's discussion thereon; and the following technical subjects—

1. Field Results of Measures Adopted after Model Experiments.
2. The Design of Canal Falls.
3. The Meandering of Rivers.
4. The Role of Reservoirs in River Flood Control.
5. Canal Losses and Means of Conserving Irrigation Water (Staunching of Canals).
6. Waterlogging and Land Reclamation.
7. Drainage Systems in Irrigated Areas.
8. Soil Denudation as an Adverse Factor on River Supplies and Agriculture.
9. The Fair Incidence of the Cost of Irrigation Water on Different Classes of Crops.
10. The Design of Channels in Alluvium.
11. The Design of Distributary Heads.

It will be observed that subjects 1 to 7 are identical to those listed on page 2 as discussed by the 9th Research Committee, and in discussing them the Board considered the discussions of that Committee.

The Board also passed a resolution on subject 8 of the 9th Research Committee's list given on page 2.

The discussions of the Board appear in the body of the Report under the relevant groups.

During the "Professional and Technical" proceedings of the Board Meeting, the following Research Officers and other visitors attended the meeting in an advisory capacity in addition to the Board Members :—

1. W. G. Came, I.S.E. Bihar.
2. Dr. R. M. Gorrie, D.Sc., I.F.S. Punjab. (Attended on the 8th and 9th November).
3. F. F. Haigh, I.S.E. Punjab.
4. G. E. Hartley, I.S.E. United Provinces.
5. Rai Bahadur A. N. Khosla, I.S.E. Punjab.
6. Gerald Lacey, I.S.E. United Provinces.
7. Dr. E. McKenzie-Taylor, M.B.E. Director of the Punjab Irrigation Research Institute.
8. W. N. McLeod, I.S.E. Punjab.
9. J. Shaw, I.S.E. Orissa.

Several visits were arranged for the Board during the Meeting at Delhi.

Tuesday the 7th November, 1939, was occupied in a tour of tube well areas in the vicinity of Hapur and Meerut in the United Provinces. An account of the discussion which took place at Meerut will be found on pages 152 to 163.

The President opened the proceedings on the 8th November with the following remarks : " Before commencing the programme set for to-day, I will take this opportunity of thanking Khan Bahadur Abdul Aziz for the great trouble he took in arranging yesterday's most interest tour.

We returned with a great deal of most valuable information on tube wells, which will be incorporated in our annual technical report. The efforts of Messrs. Hutchinson, and Ram Chandra Sahai, have produced for us a mass of invaluable data "

The President proposed the following resolution, which was carried by acclamation.

Resolved—"*THAT THE THANKS OF THE MEETING BE GIVEN TO KHAN BAHADUR ABDUL AZIZ FOR ARRANGING A TOUR OF TUBE WELLS, AND PROVIDING THE MEMBERS WITH LUNCH.*

THE SECRETARY IS INSTRUCTED TO CONVEY THE THANKS OF THE BOARD TO KHAN BAHADUR ABDUL AZIZ AND HIS STAFF, WITH SPECIAL REFERENCE TO MESSRS. HUTCHINSON AND RAM CHANDRA SAHAI."

The President welcomed Dr. R. M. Gorrie, D.Sc., I.F.S., who attended the meeting on this and the following day.

The Board visited the Imperial Agricultural Research Institute, New Delhi, on the morning of the 9th November, and when they assembled later in the morning the President opened proceedings with the following remarks :—

" Before commencing the discussion set for to-day, I would like to propose a hearty vote of thanks to Rao Bahadur B. Viswa Nath, and the officers of the Imperial Agricultural Research Institute, for the trouble they have taken in arranging what has proved a most interesting and instructive visit. In my opinion our future discussions on a subject like " The Fair Incidence of the Cost of Irrigation Water on Different Classes of Crops " might be held with advantage at the Institute, where so much valuable data is ready to hand, and where the various agricultural experts could attend, to our mutual advantage. Such a meeting could be combined with the annual visit to the Institute, an tem of our Delhi visit which I consider to be a very important one."

Resolved—"*THAT THE THANKS OF THE BOARD BE GIVEN TO RAO BAHADUR B. VISWA NATH, F.I.C., AND THE OFFICERS OF THE IMPERIAL AGRICULTURAL RESEARCH INSTITUTE, FOR SO KINDLY ARRANGING A CONDUCTED TOUR OF THEIR VARIOUS DEPARTMENTS BY THE BOARD."*

An account of the visit will be found on pages 147 to 149.

On Friday, November 10th, by kind invitation of Lt.-Col. G. Covell, C.I.E., I.M.S., Director, Members of the Meeting visited the Malaria Institute of India, Delhi. An account of the visit will be found on pages 150 to 151.

When the Board met later on the same morning, the President proposed the following resolution which was duly carried.

Resolved—“*THAT THE THANKS OF THE MEETING BE GIVEN TO LT.-COL. G. COVELL, AND OFFICERS OF THE MALARIA INSTITUTE OF INDIA FOR THE VERY INFORMATIVE VISIT TO THE INSTITUTE, AND FOR THE DETAILED EXPOSITION OF THEIR ACTIVITIES IN COMBATING THE INCIDENCE OF MALARIA.*”

The President, in winding up the proceedings on Friday the 10th November, thanked the Members for the help they had given to the Meeting.

He said that the criticism, that the Board often failed to reach final conclusions, was frequently levelled at them. But this was due to the very complex nature of some of the subjects on their agenda.

Continuing, the President maintained that meetings, such as the one then terminating, were excellent for the dissemination of information.

After twelve years of existence, the Board was reaching a much more advanced stage. They were now able to lay down principles which could not have been laid down before the Board was constituted.

As regards their advisory functions to the Government of India, the President felt they had been well and usefully performed, and that in the near future the Board would be called upon to provide yet more committees.

On the motion of Mr. T. M. Lyle, it was resolved—“*THAT THE THANKS OF THE MEETING BE ACCORDED TO MR. A. GORDON, PRESIDENT OF THE BOARD, FOR HIS CONDUCT OF THE BUSINESS AS CHAIRMAN OF THE MEETING.*”

The President acknowledged the Resolution.

The proceedings then ended.

SUMMARIZED REPORT OF THE CENTRAL IRRIGATION AND HYDRO-DYNAMIC RESEARCH STATION, POONA (INDIA) FOR 1938-39.

GENERAL.

The report is divided into three parts. Part I deals with specific experiments; Part II with basic experiments; and Part III with advisory work which did not entail experiments.

There is an introduction giving particulars of the Staff, and saying that during the year "Silt Control at Heads of Canals and Distributaries" by C. C. Inglis and Rao Sahib Joglekar, was published as Bombay P. W. D. Technical Paper No. 59.

A map of India shows the various places connected with experiments and enquiries dealt with by the Central Irrigation and Hydrodynamic Research Station.

BASIC EXPERIMENTS.

(a) *Model of the Indus and the Lloyd Barrage at Sukkur.*—There is a slight curve on the Indus so that the left bank canals draw little silt while the right bank canals draw excessive bed silt.

The object of the experiments was to test various alternative designs to reduce silting.

Suitable scale ratios were decided by three tests.

The device experimented with was a single large radius vane in the river. With high discharges it appears that the vane would be effective but not so with low discharges—such as might occur, it is added, if the Bhakra Dam is constructed.

It appeared possible that the conditions might be improved by controlling the discharge passing through the right gorge between Bukkur and Sukkur. Experiments showed that conditions could be so improved.

The building up and scouring of the central sand bank which has formed upstream of the barrage was studied on the model.

The final design put forward takes the form of an approach channel embodying the principle of curvature of flow for silt exclusion, and formed by an embankment in the shape of an elongated S running from the barrage upstream and parallel to the right bank. This design is based on the same principle as the silt excluding approach channel to the Mithrao Canal from the Nara at Makhi.

(b) *Training of the River Sarda above the Barrage at Banbassa, United Provinces.*—

There are two spurs projecting from the left bank of the river above the barrage, the Burma and the Nepal Spurs, the latter being upstream of the former. It should also be explained that the river has three approach channels above the barrage, the Eastern channel on the left, the Western channel nearby and then, separated by the large Kala-Jala island, the Solani Got channel near the right bank.

While model experiments were being conducted with a view to forcing the river from its eastern channel, the prototype took to meandering and in the flood of 1937 switched into the Solani Got channel near the right bank and threatened the right upstream afflux bund of the barrage. Ever since this occurrence the river has been in a condition described as sensitive.

The latest model experiments concentrated on protecting the right afflux bund.

A series of experiments was first conducted in an endeavour to reproduce the prototype conditions, the criterion being that the model laid according to 1936 conditions should reproduce the development of 1937 conditions.

Then followed a series of experiments with the Nepal spur extended. The model was run for the equivalent of 5 years. The extension failed to produce the desired curvature of flow.

The next series of experiments was to discover whether two proposed bunds for the diversion of water into the Western Channel would be effective. This was in addition to the extension of the Nepal Spur. The device was not successful.

The protection of the right afflux bund was then the object of a series of experiments. A short spur projecting from the right afflux bund appeared to improve matters.

Modifications of the spur were the subject of experiments run for a period equivalent to three years. Further experiments are in progress.

(c) *The Training of the River Jumna at New Delhi.*—The Delhi Gate Pumping Station was constructed on the right bank of the Jumna in 1922 when the river's course was along that bank. The river subsequently showed a preference for the left bank.

The alteration of existing spurs and the construction of a new spur near the pumping station and on the same bank, was tested on the model with a view to bringing the river back to the pumping station.

Vertical exaggeration exaggerated the beneficial influence of the spurs. Therefore the model was reconstructed with a vertical exaggeration of one half the first model.

Further experiments with this latter model are in progress.

(d) *Training of the Watrack River to protect Kaira Town Gujarat (Bombay Presidency).*—Erosion has been taking place at a sharp bend of the river just upstream of Kaira Town. The N. W. corner of the town wall was undermined and collapsed into the river together with some houses, and there was every indication that the erosion would extend. Groynes constructed on the concave bank had been washed away.

The primary object was to protect the corner of the town, but it was also important to deflect attack away from the west wall of the town for its whole length, and, if practicable, to reduce further erosion of the river upstream.

Experiments were carried out with two models: A vertically exaggerated model to discover the effect on the river course of various spurs, and a geometrically similar model to show the flow and local scour around certain spurs.

The problem was complicated by a proposal to bridge the river.

Recommendations were made for the location of the bridge and suitable river protection.

(e) *Experiments with a Model of the Rajuri Nala and Aqueduct 14—Nira Right Bank Canal (Bombay).*—Aqueduct 14 crosses the Rajuri Nala. The right wing wall of the aqueduct collapsed in the floods of 1937 and the cause of the collapse was discovered by model experiments to be overtopping and not underscour as was at first thought.

Model experiments were conducted with a view to reducing the afflux by straightening the course of the rivers up stream, and to test the efficiency of various forms of right wing walls.

The ultimate recommendation was a warped wing wall for the aqueduct.

(f) *1/500 Model of the Ganges above the Hardinge Bridge (E. B. Railway), Experiments to Reproduce the Changes in the River Course in 1935-37.*—The experiments comprise the 15th series with a model of the Ganges (scale ratios 1/500 horizontal: 1/65 vertical) and have as their object the development of the technique of reproducing, in a model the changes in the course of a large alluvial river.

To overcome the difficulty of reproducing silt depositions the discharge was increased as an experiment, the slope being increased by 50 per cent. The time scale was also increased to allow more settlement.

The results of the 1935 flood on the model were almost identical with those of the prototype, and the course of the river above Raita in 1937 was almost identical with that of the prototype.

It is now considered possible to forecast tendencies to changes in the river course one year in advance, and that the accuracy with which this can be done will increase with further improvement in the technique of river model research.

Further experiments are in progress.

(g) *Experiments with a Model of the Proposed Railway Bridge (Eastern Bengal Railway) at Amingaon across the Brahmaputra River.*—River investigations in connection with this experiment showed that when the discharge exceeds about 1 million cusecs scour commences at the bridge site and reaches a maximum on a falling flood. During a very rapidly rising flood, the river does not scour and may actually silt and there is a very rapid increase in velocity; whereas during a steady flood, scour takes place and the velocity and gauge readings drop. For this reason, the discharge—gauge graph is not reliable, the scatter for different conditions being wide; and it may be said that if a gauge of 178 has ever been attained, it must have occurred on a rapidly rising flood with a rising bed. It is considered unlikely that the discharge has ever exceeded 2½ million cusecs.

Probable scour around the bridge piers could not be reproduced in a vertically exaggerated model, and was therefore estimated from the known scour which occurred around the Hardinge Bridge over the Ganges.

The position at which stone protection around the piers would stabilise was determined by choosing one of the Hardinge Bridge experiments to fit the conditions of the Brahmaputra Bridge. Stone pitching (1/8 inch to 1/4 inch grade 88 lbs. stone as against 120 lbs. stone, which would be more stable, proposed for the Brahmaputra Bridge) was

laid at a depth of 1.18 feet (3.74 feet) below water level, and it sank (due to scouring action under steady axial flow with $q=1.8$ cusecs/ft. = 900 cusecs/ft. if the linear scale ratio were 1/63) to 1.4 ft. (4.88 ft.) below water level. Under these conditions the stone protection at the Brahmaputra Bridge pier would stabilize at R. L. 171—88 = R. L. 83.0.

(h) *Experiments with models of the Proportional and Non-Proportional Standing Wave Flume Meter Fall at R. D.40280, Montgomery-Pakpattan Link (Punjab).*—As a result of experiments on a 1/5 scale model of a 700 cusec proportional S. W. F. Meter Fall, the standard design of bed and side slope deflectors with two rows of control blocks added was considered suitable and was finally adopted.

Maximum scour with 25 per cent. retrogression downstream, and wave wash near the banks, were taken into consideration.

(i) *Experiments with a Non-Proportional S. W. F. M. Fall.*—Flumed Falls designed to be “proportional”—i.e., no afflux or draw-down throughout the range of discharge—have a lower hump and narrower throat than would otherwise be necessary. This adds to the length of expansion and thus increases cost. Proportionality is frequently not required, for example, the general practice in the Punjab is to run canals only at full supply. An alternative design to that described under (h) above was therefore tested on a 1/5 scale ratio model, all tests being carried out with 25 per cent. retrogression of the D. S. water level.

A drawing is given of the design thus evolved. There are two rows of control blocks, and bed and side slope deflectors as in the design adopted in (h) above.

(j) *Experiments with Models of Submersible Bridges.*—Several submersible bridges in the Central Provinces had their deck slabs carried away during floods and model experiments were carried out to investigate the phenomenon, and at the same time to estimate the magnitude of the pressures on the slabs.

The steady uplift pressures were found to be small at all stages of flood, and the movement of the unanchored slabs was explained by vibration caused by turbulence or instability of flow.

Suggestions for the future construction of such bridge decks were advanced.

BASIC EXPERIMENTS.

(a) *Record of Turbulence by Hot Wire and Oscillograph.*—The hot wire consists of a short platinum wire (in this case 1 cm. long and 0.1 mm. dia.), through which an electric current is passed, sufficient to heat it. The wire when placed in flowing water is cooled to a degree which depends on the speed of flow. The cooling reduces the resistance and so induces a greater flow of current through the wire, thus the higher the speed the greater the current.

If the flow of water is laminar, the speed and therefore also the electric current are constant. In turbulent flow, however, the hot wire is subjected to a fluctuating velocity, the amplitude and pattern of the fluctuations depending on the degree and pattern of the turbulence.

Some results obtained on models of a S. W. F. Fall and a submersible bridge are shown.

(b) *Experiments with Falling Aprons. Effect of Disposition of Stone.*—The experiments are described and certain conclusions are arrived at. It is inferred that angular stone is more economical and offers better protection than rounded stone.

(c) *The Protection of Bridge Piers against Scour.*—At the request of the Railway Board, experiments are being carried out to determine the best means of protecting bridge piers against scour, with particular reference to the piers of the Hardinge Bridge (E. B. Railway) across the River Ganges.

Experiments so far carried out and the results are described.

Further experiments are in progress.

(d) *Divergence Experiments.*—Experiments were continued to find a practical method of causing flow to follow a divergence or expansion, in an open channel, without the development of return flow or one sided or unstable flow downstream.

Baffle type stabilizers and stabilizers designed to create turbulence have shown practical disadvantages. A third type was therefore investigated, viz., stabilizer blocks fixed to the bed, as often used in the expansion below canal falls.

Referring to all the types, experiments have shown that a baffle convex upstream was an improvement over the straight and concave designs. The best height for the straight stabilizer was found to be $d/4$ and the same applies to the blocks.

It was decided to continue experiments with the blocks placed so that their diagonals in plan were parallel to the axis of the stream.

The effect of a 1 in 5 divergence was experimented on, return flow being reduced to a minimum by an arrangement of blocks.

The experiments will be continued with other shapes of divergence.

(e) *Calibration of a Standing Wave Flume without Side Contractions in a 5 ft. Channel.*—The calibration of a standing wave flume suitable for measuring discharges with a small loss of head in a rectangular channel is fully described.

(f) *Experiments with Silt Channels to find their relative divergence from Lacey Regime Channels for Various Discharges.*—It was found that small channels of limited length flowing in silt or sand without side restraint, used for experimental purposes at this Station, tend to assume stable dimensions which depart from the Lacey formulæ for regime channels. In general the sections are broader and shallower.

An experiment was carried out with a model channel of 3·8 cusecs. A table shows the divergence from Lacey's formulæ. There was a very close agreement with the regime test formula $V=16 R^{\frac{1}{2}} S^{\frac{1}{3}}$.

(g) *Silt Channel Experiments without Injection.*—Experiments were carried out with channels in incoherent sand designed and laid according to Lacey's formula for discharges 1; 1·5; 2; 4; 6; 9; 12 and 18 cusecs.

As regards the various 'f' values f_{VQ} appears to agree with f_d better than other values do for discharges of 4 to 18 cusecs, the formula being $f=2\cdot014 V^3/Q^{\frac{1}{2}}$ or say $2 V^3 / Q^{\frac{1}{2}}$.

The ratio $P/R \div Pr/Rr$ is about 1·38, whereas $V/Vr=1\cdot0$; (the subscript 'r' refers to dimensions according to Lacey). The practical value of this is that in models with moveable bed and sides, the vertical exaggeration will be reduced in the ratio of 1·38, whereas the velocity will remain the same. Also, where there is no silt movement, the slope ratio should be only 1/2 the regime ratio.

(h) *Experiments with Silt Abrader.*—The experiment which was started in November 1932 to determine the rate of abrasion of sand was continued during the year. The rate of abrasion is very slow. The experiment is being continued.

(i) *Experiments in Connection with Seepage from Canals.*—These experiments were started over two years ago to correlate seepage with depth of water table.

They are laboratory experiments, and they have provided a striking confirmation of Mr. Crump's conclusions and of the field experiments reported in Paper No. 209 of the Punjab Engineering Congress, 1938.

The experiments are being continued.

ADVISORY WITHOUT EXPERIMENTS.

The advice given in the following cases with full details is given in the Annual Report.

- (a) Training the Jumna near Palla Village (Delhi Province).
- (b) Training of River Auranga to Protect Bhadeli Village, District Surat (Bombay).
- (c) Remodelling the Intake for the Raunahi Pumping Station of Fyzabad Pumping and Gogra Electric Supply Scheme (U. P.).
- (d) Durani Outfall Channel, Quetta (Baluchistan).
- (e) Silting of the Grand Anicut Canal at Grand Anicut on Cauvery River (Madras).
- (f) Approximate Formula for Venturi Flumes.
- (g) Measuring Device at the Head of the Mutha Right Bank Canal.
- (h) The Effect of Canal Closures on Weed Growth in the Mutha Right Bank Canal, Poona, during the Cold Weather Season.
- (i) Unsuitability of Proposal for Siphon Spillway over the Waste Weir of the Lake Arthur Hill at Bhandardara (Bombay).

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

DR. E. MCKENZIE-TAYLOR referred to the experiments with silt channels to find their relative divergence from the Lacey regime channel for various discharges, and said that in the Punjab they never came across sands of such sizes in small channels. Mr. Thomas explained that the experiments were not a check on the Lacey formula, but were being made to determine the divergence from these formulæ of channels used in model experiments.

MR. GERALD LACEY enquired whether Mr. Thomas had checked the V, R, and S relationship; whether the sand was absolutely incoherent. In nature the silt was seldom entirely incoherent at the sides, and he assumed that the experiment was largely a practical one for Mr. Thomas' own ends in developing his model experiments.

MR. THOMAS replied that considerable divergence was found from the V, R, and S relationship; mainly due to slope difference neither would the PQ and RQ relationships hold for model work. The sand was incoherent, and the experiment was a practical one for a particular application.

DR. N. K. BOSE enquired of Mr. Thomas as to the slopes which showed movement with 1 cusec discharge for the various silt sizes.

MR. THOMAS replied that the slope in the 1 cusec channel was 0·0018. The mean diameter of the particles was 1·4 mm.

MR. LACEY remarked that Dr. Bose appeared to refer to the drag theory of Du Buoy's. Effectively that theory meant that in regime channels large and small of the same silt grade, the drag, which was proportional to the product RS , was a constant. Regime theory clearly demonstrated that the drag, far from being constant, was a function of the velocity, and the Du Buoy's theory was therefore incorrect.

DR. BOSE said he noted that Mr. Thomas had tested the discharge scale ratios for his Indus model at Sukkur, and he would like to know how these scales were arrived at.

MR. THOMAS explained that this model was a special case because it is a combination of various conditions.

Upstream of the Sukkur Barrage was a rocky gorge followed by an alluvial stretch below which is the rigid barrage. As a result it was extremely difficult to choose scale ratios. Three scale ratios all based on Lacey formulae, were tested and the one chosen which agreed best when results were compared with bed levels in the prototype observed at fortnightly intervals at various sections upstreams of the Barrage.

DR. BOSE said they had a similar case at Khanki where they were investigating silt entry into the canal. They divided the problem into two parts, (1) River regulation, for which they used a distorted model, and (2) Silt movement, for which they used a geometrically similar model.

Suspended silt depends on velocity distributions which did not occur in a distorted model.

MR. THOMAS said that three models were in use for the Sukkur experiments (i) a distorted model of 1/300 scale, (ii) a distorted model of 1/150 scale and (iii) a model of part width of the prototype of 1/40 scale, and geometrically similar.

The first difficulty in a geometrically similar model is the space available, and 1/40 is the smallest scale to give a sufficient bed movement in the case of the Sukkur Barrage.

If the model is long, distortion is required for better reproduction of bed movement. Such a model with an erodable bed, if made geometrically similar, would not work, because the channel would try to formulate its own shape i.e., distorted compared with the prototype.

Distorted models may not be correct in all details, but if you have two or more such models you can extrapolate to obtain results applicable to the prototype.

DR. BOSE said that they had come to the conclusion from the Haveli and Khanki models that to simulate silt movement you must not distort.

MR. THOMAS said the distortion must not be excessive.

DR. BOSE asked if the time scale was in accordance with Lacey's.

MR. THOMAS replied that the time scales at Poona were based on the principles laid down in Lacey's "Uniform Flow in Alluvial Rivers and Canals" * viz., time scale = $\frac{\text{length scale}}{\text{velocity scale}}$. He (Mr. Thomas) found these scales correct for scour, but not for deposition. Correct deposition could not be reproduced with any reasonable time scale, and they could only get indications.

MR. THOMAS noted that in the Punjab they used time scales about five times as short as he used, and he was puzzled as to how they obtained correct scour.

MR. LACEY said his time scales were derived directly from the regime equations, and if the silt grade is maintained constant they are identical.

DR. BOSE mentioned the "one-man-stone" to which there is reference in Mr. Thomas' full report †. Had Mr. Thomas arrived at this size of stone for protection by model experiments or by other means?

MR. THOMAS replied that the size of stone was determined by practical considerations. It was "one-man stone", weighing about 100 lbs., and generally selected for such works as it could be easily handled.

DR. BOSE said that Butcher in Egypt experienced the same difficulty. Dr. Bose continued, that he found Mr. Thomas' divergence experiments very interesting. He (Dr. Bose) had found that with certain divergences in models they could make the stream lines hug the sides. Divergence depends on velocities, but as in a model the velocities are changed, the result cannot be applied to the prototype.

MR. THOMAS replied that boundary conditions enter to some extent, and that they were pursuing the investigation, but it was of interest to note that successful results in certain divergences had been obtained with rows of stabilizer blocks $D/4$ in height, where D = depth of water.

* Paper No. 4893, Minutes of Proceedings of the Institution of Civil Engineers, Vol. 237. Session 1933-34, Part I.

† Not included in this Report.

SUMMARIZED REPORT OF THE PUNJAB IRRIGATION RESEARCH INSTITUTE 1938-39.

In a previous Annual Report, it was stated that as the rising water-table approached a soil crust, the rate of rise decreased and no instance of a water-table entering the soil crust had been recorded. This statement is of great importance in connection with the forecast of areas likely to become water-logged and of lesser importance regarding the development of Thur. During the past year a considerable number of borings have been made and the conclusion has generally been upheld. The well level records which have been examined during the year also support the conclusion. In the report of the Chemical Section the records of a boring of particular interest are mentioned. This boring is exceptional in that on piercing the soil crust and tapping the underlying water, sand and water rushed into the bore, the final water level indicating that the water was under a pressure equivalent to 7, head of water. It has been held that the final level of the water in the bore represents the depth of the true water-table. This point of view is not at present accepted by the Irrigation Research Institute and further experimental work is in progress as a result of which it is hoped to reach a definite conclusion.

The distribution of salt in the soil crust has been further studied. The greatest variations in salt content in an un-irrigated area occur in the top five feet of the soil crust. The diagram attached to the Chemical Section report shows that soil profiles of high and low salt content can occur side by side and, therefore, that the lateral movement of salt is small while the vertical movement may be large.

In the Punjab, earth roads are the main means of communication between villages. The factors determining the condition of these earth-roads have been under investigation for some time. This year particular attention has been devoted to the effect of salts on the state of the roads. The disintegrating effect of sodium sulphate and the beneficial effect of sodium chloride have been explained. Calcium chloride has been used in other countries for improving earth roads, the improvement being due to the binding effect of the water absorbed by this hygroscopic salt. It has been shown that the same effect can be produced more cheaply by using sodium chloride. A method of treating roads affected by sodium sulphate has been suggested and is under investigation.

A subject of considerable practical importance is the production of a mud plaster which is non-erodable under rainfall or flowing water. This plaster has already been successfully used on katcha buildings in some areas and its use is considerably reducing maintenance charges. On two large farms minors and water-courses have been lined with the plaster. This has resulted in a considerable saving of water as indicated both by gauge readings and the area irrigated. In one area the smaller zemindars have adopted the process and the practice would spread quickly if Government would give an assurance that the water so saved would be available for use in the area served by the lined channels. The question is of considerable importance as it affords a solution of the problems connected with the increased intensity of irrigation which is a consequence of the fragmentation of holdings. The lining of water-courses will also be of value in connection with fodder production, a subject of considerable interest at the present moment.

An apparatus for measuring the capillary power of sands and soils is described. This is proving useful in connection with the introduction of sand layers under earth roads to prevent the rise of salts. By means of the apparatus, the mean diameter of sand particles can be approximately determined.

The design of tube-wells has been under further examination in the Physics Section. It has been shown that when the drawdown is small compared to the depth of water in the well, the yield of the tube-well is proportional to the drawdown. For other conditions which are of purely theoretical interest the linear relationship does not hold. An examination was made of the relationship between the diameter of the strainer and the yield of the tube-well. The sizes of the strainers used were the same as those usually employed in the field. The experiments did not support the general belief that the discharge of a tube-well is proportional to the diameter, and, therefore, to the surface area of the strainer. In a study of shrouding it has been shown that there is an optimum size of the shrouding material with reference to the grade of the water-bearing sand. For the average Punjab water-bearing sand, the most suitable particle size for the shrouding material is 3.5 mm. A large number of sands from borings were examined for their transmission constants to determine the most suitable positions for strainers.

Further work on the detection of cavities under weirs has been undertaken during the year. The apparatus used depends upon the vibrations set up by impacts on sound and unsound work. When the work is unsound, the amplitude of the vibration is greater than for sound work. Photographs illustrating the vibrations are attached to the report of this Section.

An investigation which is of considerable importance in connection with the interpretation of well records concerns the negative pressures developed in water films surrounding soil particles. It has been shown that wells are probably acting as manometers. In the field the greatest negative pressures are developed during the hot weather. The rainfall during the monsoon period flattens the concave menisci of the water films thus reducing the pressure deficiency. As a result the water in the well shows a considerable rise which is out of all proportion to the rainfall received. The rise in well levels during the monsoon period does not, therefore, represent additions of water to the water-table.

In the Mathematical Section considerable time was spent on the model of the River Chenab at Khanki. The model when completed was handed over to the Hydraulic Section for the investigation of the river and silt control.

With the development of the drainage system of the Province fears had been expressed that certain drains might be increasing the seepage from canals. An investigation of the effect of a drain constructed at a distance of 1,200 feet from the Upper Gugera Branch, Lower Chenab Canal, on the seepage from the Branch was undertaken. The method of investigation is given in the report of the Section and the results show that this particular drain in its present position is not materially increasing the seepage from the canal.

The factors influencing the silt entry into the Lower Jhelum Canal are being studied. The tentative conclusion reached is that an increase in discharge in the river, an increase in the river slope and an increase in depth of silt in the pocket, all lead to increased silt entry into the canal. A further examination of the problem is in progress.

A start has been made on the study of silt movement in a tilting flume. Experiments have been started to find the frictional drag exerted by a sand bed of different grades on the flow of water in a channel. From the experiments so far conducted it has been possible to show that the law governing the velocity distribution in a smooth channel is identical with that obtained by Prandtl for smooth pipes.

During the year a series of hydraulic observations on the Mississippi River were published by the U. S. Waterways Experimental Station, Vicksburg. These have been examined to determine whether the slope-discharge-silt formula of the Irrigation Research Institute applied. It has been shown that the calculation of slope from the formula $S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$ agrees well with the observed values. It seems probable, therefore, that the formula may be of more general application than was originally claimed.

The results obtained from the tube-well investigation in the Physics Section were examined in the Statistical Section. It has been shown that the discharge of a tube well increases more rapidly than the drawdown and less rapidly than the length of the strainer. At very small drawdowns the discharge is directly proportional to the drawdown.

The relation between the rainfall and the rise in water-table has been examined for the lower half of the Rechna Doab. In this area the water-table is fairly deep and the rainfall low. A high correlation was obtained which does not support a suggestion that a high correlation would only be obtained when the water-table was near the surface. It was also pointed out that the water-table in this area has been showing a steady rise of 9 inches per annum over the last eighteen years and that there are no signs of a reduction in the rate of rise.

During the year hydraulic data were obtained for channels in the Gujranwala Division. It was found that the P—Q and R—Q relationships derived from observations on regime sites on other canals systems held well for the channels in the Gujranwala Division.

Considerable attention has been paid to seepage losses from canals. The mean monthly losses and their probable errors were worked out for various channels of the Lower Chenab Canal system for the last twenty years. It was found that the probable error was high as compared with the mean. The analysis of variance of the data is being undertaken.

Small experiments have been in progress to determine the effect of plant cover on run-off and soil erosion. At the observation site it was found that bare soil was eroded ten times as quickly as soil with a grass and scrub cover. The greatest loss of soil occurred during the monsoon months.

Two important investigations on river models have been in progress during the year in the Hydraulic Section. The tray in the laboratory was occupied by a model of the river downstream of Panjnad Weir for the study of methods that might be adopted to control bank erosion. A large bela has been formed downstream of the weir with the result that two channels have developed, the left channel taking one-third of the supply and the right channel two-thirds. Considerable erosion of the left bank has taken place and as a consequence the civil station has been endangered. The erosion of the right bank has been even greater than that of the left but from the point of view of Government property it is not so important.

The model showed that the best form of protection was the construction of two T head spurs, the first situated 3,500 feet downstream of the weir line and the second 6,500 feet from the weir line. The investigation has shown that the spurs are most effective when the ratio—

$$\frac{\text{Distance between the spurs.}}{\text{Length of the spur.}}$$

is between 4 and 5.

The second river model was constructed at Malikpur and the problems concerned the development of methods for the control of the River Chenab at Khanki weir. Owing to alterations in the method of regulation the right channel upstream of the weir has developed considerably and as a consequence the left channel has tended to silt up. The head regulator of the Lower Chenab Canal being situated on the left channel, some difficulty might be experienced in feeding the canal during periods of low supplies if the present conditions continued. Further, the bays of the weir on the right side might be subjected to very severe conditions during floods. The problems set out by the Chief Engineer are detailed in the report of this Section. An account is given of the measures that have been investigated. Two solutions seem to be possible (a) to allow the right channel to develop and feed the canal by flow across the weir, and (b) to construct a spur at Palku so that the channel to Bay 4 is developed which will allow control to be obtained of the supplies in the left branch. The effects of these alternative measures are still under examination.

A large scale model of the river immediately upstream of Khanki Headworks has also been under examination to determine the conditions most favourable to minimise silt entry into the canal and to secure the maximum efficiency of the silt excluder.

A model of Dhanaura Regulator on the Western Jumna Canal has been under examination in one of the flumes. A silt excluder is now operating at the head of the Main Line Lower, Western Jumna Canal, and as a result considerable silt movement is to be expected on the bed. In order to stabilize the channel it was decided to flatten the slope by raising Dhanaura Regulator. The designs for the remodelling and the shape of the cistern to control the action downstream were examined. The design was especially considered with respect to the maximum co-efficient of discharge.

A model of the Jaba Level Crossing and the torrent in which it is situated was also constructed. From time to time the crossing has had to be extended in order to counteract the effects of retrogression. An attempt has been made to re-design the crossing to give maximum stability and the control of the retrogression is now being studied.

Silt surveys of the Upper Bari Doab Canal, the Lower Chenab Canal and the Western Jumna Canal have been in progress during the year. The silt work on the Upper Bari Doab Canal has been carried out with special reference to the proposed construction of a silt excluder at the head of the Main Line. With the river conditions and silt entry as at present there should be no difficulty in extracting the majority of the silt which is causing trouble on the branches.

The most important work of the Land Reclamation Section has been that connected with the appearance of Thur. Until recently it was thought that the formation of Thur was intimately connected with the rise of water-table and that when the water-table reached a certain distance (18 feet was stated) from the surface Thur began to make its appearance. A number of villages were selected so that a large range of depths of water-table could be studied with reference to the appearance of Thur in the future. Before selection no Thur had been reported in the selected villages. On surveying the villages it was found that Thur had appeared in each one although the range of depth of water-table was from 9 to 40 feet. It seemed, therefore, that the water-table was not an essential factor in the formation of Thur. A considerable number of profiles were examined and it was found that over a large area there is a zone of salt accumulation in the soil crust situated at different distances from the surface. The first conclusion reached was that the salt which gives rise to Thur is present originally in the soil crust and is not derived from the water-table. The experiments reported last year in connection with the formation of a zone of salt accumulation in the soil crust under irrigation indicated that the factors responsible for the formation of Thur

are probably associated with the water applied at the surface and the associated system of agriculture. As a result of further investigation, it seems probable that if the water applied to the soil surface is insufficient to balance that lost by evaporation and transpiration then the balance of salt movement is in an upward direction and there is a tendency for Thur formation. An essential feature in the formation of Thur land is the sudden deterioration which takes place. It seems, therefore, that a concentrated salt solution is approaching the surface from below and that Thur is not due to the gradual concentration of salt in the surface layer by the evaporation of a dilute solution. An examination has been made of the intensity of irrigation during the Kharif season for the branches of the Lower Chenab Canal. On each branch the intensity of irrigation has increased considerably. The leaching of the salts from the surface layers which formerly took place with the heavier irrigations has ceased. A further factor which may assist in the recent increase in the Thur area is the poor monsoons of the past five years. It is recommended that in Thur danger areas a rice crop should be grown so that the salt may be removed from the soil crust to the underlying sand. Examples of the results of this process have been given and it has been shown that there is no tendency for a return to the deteriorated conditions over a period of eight years.

Several areas have been taken up for reclamation of Thur during the past year. On the Renala Estate it has been shown that if reclamation is commenced as soon as Thur appears then the land can be reclaimed by one rice crop. It has also been demonstrated that field drains for reclamation are not necessary in the Punjab if the water-table is more than five feet below the natural surface.

An investigation of open well irrigation was made in order that data regarding water-requirements of crops and the cost of this form of irrigation might be available for the Officer on Special Duty, Tube-well Investigation. Valuable information regarding the discharge of open wells, the cost of irrigation and the factors determining the area irrigated by a well have been obtained.

Three small cantonment areas were placed under observation for run-off in connection with drainage requirements. It has been shown that in a cropped area very little of the rainfall runs off the surface of the land owing to the bunds around the cultivated fields. In uncropped areas with heavy rainfall the run-off amounted to as much as 20.5 cusecs per square mile in one case and in another to 22 cusecs per square mile.

During the run-off investigation, observations were made on the well levels in the areas. These observations afford interesting evidence of the magnitude of the negative pressures developed in soil and the release of the negative pressures by rainfall. The release of this negative pressure accounts for the apparent large rise in the water-table following a small rain-fall at the end of a dry period.

A large part of the time of the General Section has been taken up by the project work and reclamation schemes. The analyses of a large number of waters from exploratory borings in connection with tube-well projects have been made. An attempt has been made to classify the waters with reference to their liability to cause choking of the strainers on account of calcium carbonate deposition. A complete check has been kept on the movements of salt in the soil crust during the reclamation of areas on Renala Estate.

A survey of wheat soils with reference to yield and their chemical characteristics was undertaken in order to obtain some information regarding the initial stages of soil deterioration. It is of interest that a significant correlation has been obtained between the yield of wheat and the available phosphate, as determined by the CO₂ method. This would be expected in a country where the water supply is one of the main factors limiting wheat production. There is also a significant correlation between the manganese content of the soil and the yield of wheat. In general, soils giving a high yield of wheat have a low manganese content and a low yield appears to be associated with a high manganese content. No information is available to decide whether manganese is exerting a direct effect or whether the conditions suitable for the accumulation of manganese are at the same time harmful to wheat production.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

DR. MCKENZIE-TAYLOR replying to a question on lining with Sodium Carbonate said that it had been found that it was only necessary to go to pH value of 10.8 to obtain complete dispersion and maximum impermeability with all soils.

In the Chemical Section they were attempting to relate soil texture with dispersion. This was new work.

MESSRS. S. H. BIGSBY and F. F. HAIGH questioned Dr. McKenzie-Taylor on his non-erodable mud plaster. In reply Dr. McKenzie-Taylor said that the quantities of material required to cover 1,000 sq. feet with a plaster 1 inch thick were:

75 cubic feet of earth,
25 cubic feet of sand,
4 bags of cement,
5 to 8 maunds* of straw,
20 lbs. of sodium carbonate.

*1 maund = 80 lbs.

The Sodium carbonate should be dissolved in sufficient water to soak 5 to 8 maunds of straw, earth is then added and the mass worked up. This mixture is kept for a week being worked up every day and sufficient water added to make up evaporation losses. After a week the soil will have dispersed completely and the straw will have well rotted. Four bags of cement mixed with 25 cubic feet of sand are then added and the entire mass worked up to a suitable consistency. It should then be used as soon as possible.

Keeping the relative proportion of the various ingredients constant, the quantity of the mud plaster can be varied to suit individual requirements such as the area to be plastered and the thickness of the plaster. For ordinary plastering of kacha walls and roofs a layer of $\frac{1}{4}$ inch is quite sufficient. For plastering water courses or tanks for storing water a layer 1 inch thick is recommended.

The surface to which the plaster is to be applied should be thoroughly wetted immediately before applying the plaster. During summer when the plaster is likely to dry up quickly, a gentle spray of water given occasionally improves the quality of the plaster by preventing rapid drying. Plastering of the sides of old water courses that have developed silt berms requires careful examination of the type of silt and the side slopes.

DR. MCKENZIE-TAYLOR said figures of cost of this plaster were not available.

Dealing with the detection of cavities under weirs Dr. McKenzie-Taylor said the method he employed depends on the principle of the seismograph. The floor is given an artificial impact and the vibrations are recorded photographically.

DR. MCKENZIE-TAYLOR passed round vibrometer photographs taken at Rasul which illustrated that the apparatus in its present form is able to indicate a fairly large cavity under a floor.

MR. H. S. KAHAI referred to the examination of the Mississippi River data in the light of the slope-discharge-silt formula of the Punjab Research Institute, and enquired whether it was likely that Sind data would show the same agreement.

DR. MCKENZIE-TAYLOR expressed an opinion that as the Sind silt was very fine, cohesion would probably enter and upset the relationship.

MR. GERALD LACEY enquired from Dr. McKenzie-Taylor whether the lowest average diameter of the silt particle dealt with in the Punjab experiments was not of the order of 0.20 mm., and was informed that this was so, the diameter of the particles in the watercourses being of the order of 0.10 m.m. Mr. Lacey remarked that from his study of the subject the law changed when the average diameter of the silt particle was less than 0.20 m.m. and this was due to cohesion of the particles. Dr. Chatley had recently drawn attention to this feature of very fine silt.

In reply to a question on the model of the river above Khanki Headworks Dr. McKenzie-Taylor said that the model discharge was 70 cusecs.

DR. MCKENZIE-TAYLOR explained the method of measuring uplift pressures on capillary tank models of weirs. A micromanometer was used so that considerable accuracy was obtained in reading the pressures. The results by this method agreed within 1 per cent. with the electrical and hydraulic methods.

An item not mentioned in the summary was briefly referred to by Dr. McKenzie-Taylor; the experiments on the Pakpattan Link (Haveli Project) trial falls. These three falls were designed by Mr. Kanwar Sain of the Central Designs Office, Mr. Montagu and Mr. Inglis respectively. They each take a maximum discharge of 700 cusecs. The falls as constructed were reproduced in models and tested. From the point of view of bed scour, side erosion, and coefficient of discharge, the Inglis fall gave the best results. The models of the other two designs were then modified and results comparable to the Inglis results were obtained except that the coefficients of discharge were lower. There was no bed scour or side erosion with the Inglis fall.

Questioned on the work of the land reclamation section Dr. McKenzie-Taylor said that sodium sulphate was the main salt in the Punjab soils.

DR. MCKENZIE-TAYLOR stated that when sand existed below the soil crust, it was easy to wash out salts and thereafter there was little tendency for these salts to reappear as evidenced by tests on 8 feet soil crusts extending over 8 years. He quoted a case where a 3 feet soil crust, the bottom of which touched the water-table, gave a higher yield of wheat than the average and also higher than the surrounding area. MR. N. B. GADRE enquired whether the effect of washing was rapid and Dr. McKenzie-Taylor said it was, provided that leguminous crops followed the process.

MR. N. B. GADRE said that in Bombay rice crops had not been successful for reclamation and sugarcane was better. In reply Dr. McKenzie-Taylor informed him that rice had been found best in the Punjab and suggested that soil conditions in Bombay were not so bad as in the Punjab. Land which has been a long time under "Thur" takes longer to reclaim.

Dealing with the effect of rainfall on the negative pressure in soil, DR. MCKENZIE-TAYLOR said that there was a big response in a well level to the first rainfall, but practically no response to the third rainfall. He said that rain affected a well very rapidly owing to the release of the negative pressure even when the well was 40 feet deep.

MR. A. R. THOMAS referred to the full report of the Punjab Irrigation Research Institute* wherein, in connection with the River Chenab model, it is stated that after 3 trials with time scales 1½ hours, 3 hours and 4½ hours \equiv 1 month, the last was chosen as most suitable as a cut in the upstream bela developed at a corresponding rate.

It would be of value if figures of comparative bed scour and deposition of silt were given. It is found at the Poona Station that bank scour in models may be very rapid and irregular, due to artificial laying compared with natural deposition. The time scales adopted in Poona are based not on the rate of bank erosion, which can be controlled by the intermixing of clay, but on the rate of bed scour, and shoaling of bed material given approximately by the ratio L -scale/ V -scale, when the silt is the same.

In the case of the Chenab model this works out at $1/36$ or 20 hours \equiv 1 month compared with 4½ hours adopted.

MR. THOMAS, drew attention to the statement in the full report of the Punjab Irrigation Research Institute that the time scale for the Panjad model was 1 hour \equiv 1 month. In this model he noted that the object was concerned with bank scour, but suggested that the time scale might be insufficient for correct reproduction of bed changes.

The Punjab Irrigation Research Institute's observations at Rasul Headworks and the conclusions arrived at are similar to those reached in the Sukkur Barrage experiments which are described in the Annual Reports of the Central Irrigation and Hydrodynamic Research Station and in Bombay P. W. D. Technical Papers 45, 46, 52 and 59. The most important factor affecting silt exclusion is the curvature of the river.

Other factors are :-

- (1) V/V_0 ratio inside and outside the pocket where V = velocity; V_0 = non-silting velocity which it is suggested is a more "basic" ratio than B , the ratio $\frac{\text{discharge in left arm of river}}{\text{discharge in canal}}$.
- (2) method of regulation—whether "still pond" or "open flow".

*Not published in this Report.

In connection with the Punjab Irrigation Research Institute's experiments with spurs Mr. THOMAS suggested that the results obtained, though of great interest and particular application in the case concerned are not of general application unless discharge is considered as a factor. The placing of spurs must depend on the natural meander length of the channel which is approximately $\propto \sqrt{Q}$. Thus, the flow lines shown in the photos differ in the case of $l=700'$, $d=2,000'$ from that of $l=500'$; $d=1,500'$, though the l/d ratio is nearly equal.

It would therefore be of value if the discharge of the model during the tests were stated, and also the ratios l/\sqrt{Q} and d/\sqrt{Q} .

MR. LACEY, referring to the statement on page 13 that the P—Q and R—Q relationships derived from observations on regime sites in other canal systems held well for channels in the Gujranwala Division, enquired if this was the result of statistical analysis and was answered in the affirmative.

DR. N. K. BOSE here interjected that the relationships seemed to hold for regime and non-regime channels.

MR. LACEY pointed out that whether the relationships held for regime sites only, or for both regime sites and non-regime sites, the important point to remember was that the two equations— $P \propto Q^{\frac{1}{2}}$ and $R \propto Q^{\frac{1}{2}}$ when solved for V and R led to the simple dynamic relationship $V \propto R^{\frac{1}{2}}$ which he had previously put forward, and was glad to see confirmed.

MR. H. S. KAHAI informed the Committee that in Sind they had examples of bores in which the water rushed up when the soil crust was pierced just as those reported by the Punjab Irrigation Research Institute.

In Sind also their conditions agreed with the Punjab in that the greatest variations in salt content in an un-irrigated area occur in the top five feet of the soil crust. In Sind also soil profiles of high and low salt content can occur side by side showing that the lateral movement of salt is small while the vertical movement may be large.

MR. KAHAI on the subject of silt sampling mentioned some drawbacks in the Puri Siltometer such as a silt sample trapped in one of the cups not returning to the same cup when again passed through the vertical tube, and the obstruction caused by the cone at the base of the vertical tube.

DR. E. MCKENZIE-TAYLOR referred Mr. Kahai to a note on the subject. He said the Vaidhianathan Optical Lever Siltometer corrects for these discrepancies. He also enquired of Mr. Kahai whether he separated particles below 0.075 mm. in diameter before sampling with the Siltometer. Mr. Kahai said he did.

MR. T. BLENCH drew attention to the statement on page 14 that Thur* had appeared in certain villages in the Punjab, and enquired whether all these villages were within about ten miles of the advancing "thur" affected areas shown on the official "thur" map showing an advancing wave of thur.

DR. MCKENZIE-TAYLOR disclaimed knowledge of the official "thur" maps.

MR. N. B. GADRE said that in the Deccan they had not observed the rapid fluctuation of well levels with rain fall and enquired whether it was possible to relate the size of soil particles with this effect of wells recording pressure and not water table.

DR. MCKENZIE-TAYLOR replied that it was not possible, and that the controlling factor was depth of soil crust.

* Land with high salt content usually sodium chloride or sodium sulphate.

SUMMARIZED REPORT OF THE DEVELOPMENT AND RESEARCH DIVISION,
SIND, 1938-39.

1. During the year under report the work of the Development and Research Division was carried out under the following heads :—

- A. Model experiments.
- B. Analysis of hydraulic data in connection with Lacey's silt theory.
- C. Experiments in connection with silt survey of channels :—
 - (i) Channels taking off on the Left Bank of River Indus immediately upstream of the Lloyd Barrage.
 - (ii) Channels taking off the North Western Canal at Khirthar Head R. D. 180,000.
- D. Field experiments to determine the value of coefficient 'C' used in the design of falls in the broad crested weir formal $Q=C. L. H.^{3/2}$.
- E. Experiments to determine absorption and evaporation losses in water courses passing through typical soils in Sind.
- F. Experiments to determine requirements of water for various irrigation units.
- G. Miscellaneous.

A.—MODEL EXPERIMENTS.

2. Before describing the new work done during the year, it is proposed to comment on the results of working of some of the regulators modified as a result of model tests, described in the last annual report.

3. *Pirsher Regulator over Dadu Canal R. D. 250,026.*—The scour hole below the regulator showed considerable improvement in silting.

4. *Head Regulator over Pinyari Canal.*—The scour hole which was 16 feet deep silted up to a depth of 12 feet in one season.

5. *Naundero Fall Regulator over Rice Canal R. D. 190,340.*—A 12 feet deep scour hole silted up to a depth of 6 ft. in one season as a result of modifications carried out on this regulator.

The following model experiments were performed during the year :—

6. *Experiments in connection with the proposed double acting R. C. C. sluice in Ghoraghat Bund at Mile 0/2 in Begari Canals Division.*—Experiments were proposed on a R. C. C. Sluice from Unerwah for flooding a 13 sq. mile compartment of an average depth of about 6 ft. in 45 days by means of the sluice referred to above, discharging 550 cusecs.

The object of the experiment was to determine :—

- (a) The design of protection for the sluice on the compartment side while filling the compartment, with water level in Unerwah at R. L. 227.4, the water level in the compartment which would be empty, gradually rising to R. L. 227.14.
- (b) The design of protection of sluice on the Unerwah side, while emptying out the accumulated water from the compartment through R. C. C. Sluice into the Unerwah with water level in the compartment at 227.14 and that in Unerwah at R. L. 218.1.

A model 1/18th the full size was constructed for an equivalent discharge of 2273 cusecs in Unerwah.

As a result of a large number of experiments suitable protections both on the compartment side and the Unerwah side were determined.

7. *Experiments in connection with the scour hole below Tando Allahyar Regulator on Nasir Branch Ex. Rohri Canal.*—This Regulator started giving trouble from the very start. At first sides scoured below the end of downstream protection. These were pitched dry for 150' on both sides. This resulted in bed scour below Tarungars in a length of about 150'. Eventually model tests were undertaken by this Division at the request of the Executive Engineer.

A model 1/15th the full size was constructed for an equivalent full supply discharge of 1368 cusecs.

A series of experiments were performed and the best conditions for minimum scour with the existing downstream divergence of 1 in 4 were obtained with the following modifications :—

- (1) Two rows of staggered blocks equivalent to 3'-7½" in length, 15" in width and 27" in height above the pavement level spaced 22½" apart at 16'-7" and 20'-4" from the nose of the pier (prototype dimensions).
- (2) Deflector 27" in height above the pavement level with its downstream side at the end of expansion.

8. *Experiments in connection with silling of Kur Hashim Branch.*—Kur Hashim Branch, one of the tail channels of Ghar Branch having a common approach channel with Mirwah on the upstream side of Head Regulator over Chilo Branch gave trouble due to silting every year inspite of regrading it. At the request of the Executive Engineer, Rice Canal Division, a preliminary silt survey was carried out at the site, which showed that Kur Hashim carried a very large percentage of heavy silt and that Mirwah was free from silting trouble inspite of the fact that heavy silt entered the common approach channel.

Model experiments were therefore decided upon to remedy the unsatisfactory distribution of silt. A geometrically similar model 1/12th the full size was constructed. The model was run under original conditions, and it was observed that all the bed water entered Kur Hashim Branch. In all about 10 alternatives were tried in the common approach channel to Mirwah and Kur Hashim to arrive at a proportional silt draw off between the channels.

The final modifications recommended for full supply conditions resulted in the distribution of silt between Chilo Branch, Kur Hashim and Mirwah in the proportion of 46, 25 and 29 per cent respectively which was nearly proportional to the discharge drawn by the respective channels.

9. *Experiments in connection with the proposed Head Regulator over Col. Fife's Channel.*—The Superintending Engineer, Northern Sind Circle desired model experiments to be carried out on a model of Col. Fife's Regulator, which had been designed to carry a discharge of 2225 cusecs with 8 spans of 8.5 ft. each. The experiments were therefore performed to determine the kind and extent of downstream protection required which would result in no scour and uniform distribution of velocities at the normal section on the downstream when the regulator gates worked under-shot, with a maximum cut-off of 8 ft.

A model 1/12th the full size was constructed. The loss of head observed for an equivalent discharge of 2282 cusecs with winding pitching and 2231 with vertical sides on the downstream was 0.20' and 0.28' respectively as against 0.25' designed.

It was, however, thought necessary to reduce the spans from 8 to 6. The crest level was accordingly lowered by .85 ft. and upstream returns were curved. Tests were carried out with different modifications both with winding pitching and vertical walls on the downstream.

In all 26 experiments were performed and the following alternative was finally adopted, with the downstream pavement level at R. L. 194.9 and the downstream glacis extending in an equivalent length of 51.25 ft. from the end of crest.

- (1) Downstream divergence 1 in 27.6 with winding pitching.
- (2) A deflector at the end of pacca pavement equivalent to 1.3' in height, 1.5' in width at an equivalent distance of 85.15' from the downstream noses of piers.

There was no scour at the end of pacca pavement with the above modifications and the loss of head with F. S. L. upstream and downstream was equivalent to 0.09' on the prototype.

10. *Experiments in connection with the proposed additions and alterations to the weir at the tail of Baghar New Cut.*—The experiments on the outfall were carried out last year with the minimum tide level at R. L. 2.0 on the downstream of the weir. It was, however, found during the last inundation season when the weir was worked with the suggested modifications that the minimum tide level was of the order of about R. L. 2.0. The difference of 4 ft. in the lowest tide level shifted the position of the standing wave lower down, which formed on the tarungars, resulting in a considerable scour on the downstream. The Executive Engineer, Karachi Canals Division requested for the model tests to be carried out for the following conditions :—

	Discharge.	App. W. L. up-stream of weir.	W. L. down-stream of weir.
1.	2100 cusecs	9.00	3.50
2.	1600 cusecs	8.50	3.00

A model 1/15th the full size was constructed with the original conditions which existed before the commencement of the last inundation season.

The model was run with an equivalent discharge of 1600 cusecs with water levels upstream and downstream being 8.9 and 3.0 respectively. Standing wave was observed to form at an equivalent distance of 60' from the upstream face of returns and this tallied exactly with that observed on the prototype, confirming the model tests.

The pavement on the downstream was subsequently lowered to R. L. —2.0 and various alternatives were tried. In all 38 experiments were performed and the following modifications gave the best results.

- (1) A baffle equivalent to 1.06' in height and 2.0' in width was removed from its original position and fixed at an equivalent distance of 28 ft. from the foot of the weir.
- (2) Another baffle equivalent to 1.2' in height and 1.0' in width was fitted on the lowered pavement at an equivalent distance of 15' from the foot of glacis.

11. *Experiments in connection with the silting of Choi Branch.*—Choi Branch takes off upstream of the Head Regulator over the Begari Canal and flows during the inundation season only. There was reduction of discharge due to silting of the Branch. Model experiments were therefore undertaken to exclude excessive quantity of heavier grade of silt entering Choi Branch.

A model 1/24th the full size was constructed and it was run with full supply discharge and full supply levels upstream and downstream under original conditions. The observations showed that about 28 per cent of bed water entered Choi Branch which normally should not have exceeded 10 per cent., if the silt were divided proportionately to the discharges drawn by the Begari Canal and Choi Branch at their heads. Water level upstream was raised to H. F. L. thus maintaining a cut off of 8' on the prototype. The percentage of bed water entering Choi Branch was reduced from 28 to 6.6 per cent. This was further confirmed from the L-Sections of the Choi Branch which showed that the maximum silting took place in the beginning of July when there was practically no cut-off at the head.

In all 20 experiments were carried out with different lengths of divide wall and angles of offtake of the approach channel to the Choi Branch. The best results were obtained when about 12.5 per cent. of the bed water entered the Choi Branch as compared to 28 per cent. which entered originally. To confirm these results a measured quantity of silt was injected in the approach channel. The model was run for an equivalent period of 72 hours on the prototype until almost all the silt was washed down. Silt obtained from Choi Branch was 10.7 per cent of the total collected from all the channels. Thus the results obtained with silt injection more or less agreed with those obtained by means of current indicators.

12. *Experiments in connection with the silting of Jamrao Canal.*—The Jamrao Canal which carries a discharge of about 3,000 cusecs was free from silt trouble upto 1933, when it started silting a little after the opening of the Lloyd Barrage and has continued to silt since then.

The silting has been attributed to one or both of the following causes :—

- (1) The canalization of the Eastern Nara and its subsequent running with a steeper gradient than before, picking silt from its bed resulting in an increase in the silt charge.
- (2) The change in the position at which the Jamrao approach channel originally took off from the Eastern Nara. It was considered that the relative layouts of the approach channels to the Jamrao and the Eastern Nara before 1932 were favourable to the former as it took off on the concave side of the curve, thereby drawing a very large portion of top water which was less charged with silt.

Model experiments were therefore proposed to find out the best alignment of the approach channel and suggest means which would reduce the silt trouble in the Jamrao Canal and its offtakes.

A distorted model with a horizontal scale ratio of 1/64 and a vertical scale ratio 1/16 was constructed, representing a little over a mile length of the prototype equivalent to about 100 ft. on the model.

In all 37 experiments were performed with rigid and semi-rigid models and these included two proposals by the Superintending Engineer, Eastern Sind Circle for reducing silt trouble in the Jamrao. The percentage of bed water entering the Jamrao for original conditions was 40.3 per cent.

Alternative No. I of the Superintending Engineer, Eastern Sind Circle, which consisted of a vertical divide wall equivalent to 430 ft. in length was then tried. This gave 31 per cent. of bed water entering the Jamrao approach as against 40.3 before.

A new approach to the Jamrao Head Regulator taking off a little below the commencement of the concave side of the curve, was tried which gave quite satisfactory results as only 18 per cent. of bed water entered the Jamrao.

The alternative No. II of the Superintending Engineer, Eastern Sind Circle, was also tried in which the nose had been pushed up and the channel widened on the right side, immediately upstream of the nose. The results were unsatisfactory, as the percentage of bed water entering the Jamrao approach increased to 32.5 per cent.

Lastly the above modifications were tried with the cutting on the right side omitted. The percentage of bed currents entering the Jamrao was 30.6 as against 40.3 per cent under the original conditions. The improvement thus affected worked out to the tune of 25 per cent.

The Superintending Engineer considered that the improvement resulting in the reduction of silt entering the Jamrao to the extent of 25 per cent. was quite satisfactory. He therefore approved of the last modification of pushing up the nose without cutting the right side, which was recommended for final adoption.

It is proposed to carry out the silt survey of channels at the Jamrao Head after the construction of the nose as proposed above to determine the improvement effected.

B.—ANALYSIS OF HYDRAULIC DATA IN CONNECTION WITH LACEY'S SILT THEORY.

13. Silt and discharge observations were continued on 6 sites of Rohri Canal System during the year under report. About 12 observations were recorded and the data analysed. Four out of six sites showed a tendency either to silt or scour.

There was considerable variation in the two silt factors f_d and f_s given by $f_d = 9.4 \sqrt{d}$ (d =dia. in inches) and $f_s = 89.41 Q^{1/10} S^{3/5}$.

f_s however was more or less constant after 5th and 6th observation for all sites except one. The two regime criteria $P = 2.67Q^{1/2}$ and $V = 16 \cdot \sqrt{R^2 S}$ varied considerably even for the two sites which had a fairly stable bed.

Since four out of six sites did not show a steady bed, and the remaining two, though stable, did not conform to the Lacey's regime criteria, the silt and discharge observations on the Rohri Canal system were discontinued.

C.—EXPERIMENTS IN CONNECTION WITH THE SILT SURVEY OF CHANNELS.

(1) Channels taking off on the Left Bank of River Indus immediately upstream of the Lloyd Barrage.

14. The State Engineer, Khairpur State, apprehended that the silting of Khairpur Feeders, East and West, was due to excessive silt charges being drawn by these canals from the River Indus. He called for an opinion from this Division. A simultaneous silt survey of Khairpur Feeders and the adjoining canals was suggested, to which he agreed.

Two sets of observations one in abkalani and the other in cold weather were taken and the results analysed as under :—

1. that Khairpur Feeder East carried the maximum silt charge of 1693 grains, cft., which was slightly in excess of its due share of silt in proportion to its discharge ;
2. that the average weighted mean dia. of bed silt samples was highest for Eastern Nara with Khairpur Feeder East as a very close second ;
3. that the average weighted mean dia. of silt in suspension was highest for Khairpur Feeder East with Eastern Nara as a close second ;
4. that the Khairpur Feeder West carried the lowest silt charge of 1360 grains per cft., which was less than its due share of silt and the average weighted mean dia. both for bed and suspension silt were also the minimum.

The cold weather observations showed enormous variation in the silt content of water during the abkalani and cold weather seasons. No useful conclusions could therefore be drawn from cold weather observations due to silt charge being very small.

According to another set of silt observations carried out by the Barrage Division in May 1938, silt charge carried by different channels was as under :—

Eastern Nara 1678 grains/cft.
Rohri Canal 1661 grains/cft.
Khairpur Feeder East 1652 grains/cft.

It will be seen that the silt charge in each channel as well as between the channels kept on varying during different parts of the year. There was thus no apparent reason for the silting of Khairpur Feeders unless it was due to the high lands as pointed out by the State Engineer himself.

(ii) Channels taking off the North Western Canal at Khirthar Branch Head R. D. 180,000.

15. Shahdadt Kot Branch which takes off at R. D. 180,000 of the North Western Canal was silting heavily and the Executive Engineer, concerned desired model experiments to be performed. Prior to the model tests a silt survey was considered necessary, which was carried out with a view to determine if the silting was actually due to the excessive quantity of silt flowing into the branch.

The analysis of data conclusively proved that the Shahdadt Kot Branch was carrying the maximum silt charge of 1189 grains/cft., and that the grade of silt in suspension and in bed (both total and harmful) was the coarsest of all the channels taking off at the point.

D.—FIELD EXPERIMENTS TO DETERMINE THE VALUE OF CO-EFFICIENT 'C' USED IN THE BROAD CRESTED WEIR FORMULA FOR DESIGN OF FALLS.

A reference was made by the Superintending Engineer, Rohri Canal Circle, in regard to the value of co-efficient 'C' used in the formula.

$$Q = C.L \{ (H + h_a)^{3/2} - h_a^{3/2} \}$$

According to his observations on certain falls in his circle the value of 'C' worked out to 2.8 as against 3.09 used in the formula. It was therefore proposed to carry out observations on three selected falls to determine the value of 'C' in actual practice. Three sets of experiments were proposed with the following observations :—

- (a) Simultaneous observations of discharges and velocity distribution both upstream and downstream of the falls for 3 days.
- (b) Observation of hydraulic gradient upstream of the fall.
- (c) Observation of water profiles along abutments and end piers.

E.—EXPERIMENTS TO DETERMINE ABSORPTION AND EVAPORATION LOSSES IN WATER-COURSES PASSING THROUGH TYPICAL SOILS IN SIND.

A brief outline of the work was given in the last year's report. About 8 water-courses with discharges varying between 2.0 to 3.7 cusecs were selected originally, but later on 3 were rejected and the observations confined to 5 water courses only. The number of observations was also reduced from 12 to 2.

The results showed that the total absorption and evaporation losses varied from 2.2 to 4.6 cusecs per million sq. ft. of wetted perimeter. It has, however, not been possible to correlate the seepage losses with discharge, depth, temperature or the texture of silt particles collected from the bed of watercourses due to insufficient data. Percentage losses in the watercourses and the loss per mile of a watercourse worked out as under :—

1. The average percentage loss in a watercourse about 3½ miles long for an average discharge of 2.48 cusecs was 14.9 per cent.
2. The average loss in discharge per mile worked out to 3.8 per cent.

Sub-soil water levels were also recorded on either side of the watercourse. The sections showed the presence of a hump in three out of the four watercourses for which the levels were observed. In the fourth also there was a very steep gradient of nearly 1 in 500 in one direction, which indicated the possibility of a source of supply higher up or from the bed of the watercourse to the water table.

F.—EXPERIMENTS TO DETERMINE REQUIREMENTS OF WATER FOR VARIOUS IRRIGATION UNITS.

It has been proposed to perform experiments to determine the requirements of water for different irrigation units, by direct measurement as under :—

- (1) to determine the quantity of water necessary to water to a fixed depth 1/4, 1/2, 3/4 and 1 acre plots in rectangulated lands and in a survey number of say 4 acres in a non-rectangulated area ;
- (2) to determine the quantity of water required to flood adjacent plots having the same area to the same depth through the plots as in (1) above by cutting the common bannas at one or two places. The object of the experiment is to know the relative quantities of water required for flooding an area

directly from a watercourse and through an irrigated field. The quantity of water is to be measured by means of a previously calibrated sharp crested weir.

After a lapse of 30 days from the 1st set of experiments, another set will be started, to see if the results obtained in the first set are confirmed.

In addition to this, moisture content of soil samples obtained from bore holes sunk 10 ft. deep before and after the flooding, will also be determined.

G.—MISCELLANEOUS.

In addition to the work described above, miscellaneous work in the shape of advice in regard to the design of new and remodelling of existing structures and channels, analysis of data for pressure pipes for the Lloyd Barrage floor etc. was carried out during the year.

The usual work of chemical analysis of soil and water samples and mechanical analysis of silt samples was carried out at the Research Laboratory at Kotri.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. A. R. THOMAS drew attention to the experiments on scour below the Tando Allahyar Regulator, and enquired whether the cause of scour was the one-sided flow due to 2 distributaries taking off on the upstream left bank, or whether it persisted even when these were closed.

Ratio of height of blocks to depth of flow is $1/4 \cdot 3$. This height was necessary to force the flow to follow the expansion, and agreed with the ratio $1/4$ found to be the optimum ratio in divergence experiments at Poona.

Isotachs downstream were, however, abnormal, the velocity being high at the sides. Were measures taken for correcting this (e.g. side deflectors) as otherwise bank scour would be expected?

MR. H. S. KAHAI said the scour was due to one sided flow. Although the isotachs downstream in the model were not entirely satisfactory, the improvement was nevertheless considerable, and as the banks were pitched, further measures were not taken.

MR. THOMAS referred to Plate 15 of the full report*, and said the final isotachs in the model tests for additions and alterations to the weir at the tail of Bhaghar New Cut were not very satisfactory. He enquired whether Mr. Kahai had tried different heights and positions of baffles to improve this, and suggested that a deflector at the downstream end of the pavement might improve conditions.

MR. KAHAI replied in the negative, and added that with the isotachs shown the flow was sweet, there being no scouring of bed or banks.

MR. THOMAS pointed out that it appeared from the photographs on sheets 5 and 6 of the full report*, in connection with the group of regulators at the tail of Ghar Branch, that the sides and bed of the model were rigid. Was there a pavement in the prototype at offtake? The shape of the bed would probably be changed by the changes tested, viz., scour and shoaling, and this would influence the results.

MR. KAHAI replied that all their experiments were with rigid models as it was found that with mobile beds the silt got mixed up with the water.

Referring to the model experiments in connection with the proposed Head Regulator over Colonel Fife's Channel, Mr. Thomas asked what accuracy was expected in figures of loss of head, as these were very small in the model. Was V energy taken into account? The isotachs in plate 13(3) are rather distorted. This alternative might lead to bank scour downstream. Alternative III(b) gives best V distribution of the 3.

MR. THOMAS quoted from the full report, on the Jamrao Canal Model, "The flatness of the gradient was attributed to smoothness of the model, resulting in an extremely low value of "Nm"† which worked out to 0.0068 on the model as against the value of 0.0204 for the prototype." Mr. Thomas asked how velocity head was taken into account when calculating gradient.

MR. KAHAI said that $N_m = 0.0068$ (Manning) was based on surface measurement, to which Mr. Thomas responded that this might result in error.

MR. THOMAS said that he was unaware that such a low value of N_m was obtainable, even with completely smooth boundaries.

MR. GERALD LACEY observed that with smooth turbulent flow, such as occurred in smooth pipes when Reynolds critical velocity was exceeded, but roughness had not begun to take effect, it was possible to obtain a value of N_m as low as 0.0068, but this was a nominal value, and as a fact was unconnected with roughness.

The low value showed that there was smooth turbulent flow in the model, and rough turbulent flow in the prototype.

In reply to a question from Dr. N. K. Bose, Mr. Kahai said they obtained their bed velocity directions from pieces of thread attached to wires, the water being clear.

Replying to a question on the experiments to determine absorption losses in water courses Mr. Kahai said that he used weirs which had been volumetrically calibrated. These weirs were all of the same size, and had the same approaches.

MR. T. BLENCH asked whether the kind of soil had been noted, and whether day losses differed from night losses.

MR. KAHAI said that the type of soil was noted, and the moisture content. He had observed no difference between day and night losses.

* Not included in this Report.

† From the formula $V = \frac{1.486K^1}{N_m} S^1$.

SUMMARIZED REPORT OF THE POONA IRRIGATION AND RESEARCH DIVISION, 1938-39.

Since the last Irrigation Research report was introduced in July 1938, the name of the research division has changed from "Irrigation Research Division" to "Poona Irrigation and Research Division", as a result of that Division taking up the running administration work on the Mutha Canals and the Khadakvasla Dam.

2. The Government of Bombay have in March 1939 accepted several recommendations of the Irrigation Inquiry Committee, who, under the Chairmanship of Sir M. Visveswaraya, K.C.I.E., LL.D., had submitted their report in May 1938. Naturally many changes of far-reaching importance will soon take place in the irrigation outlook and administration of the Province, and the field of research carried out in this Division is bound to be affected. Points that would be receiving immediate attention are :—

- (i) Sale of irrigation water on a volumetric basis wherever possible.
- (ii) Expedition of land drainage constructions, and the search for cheaper methods of drainage.
- (iii) Encouragement to cane even in soils where a porous substratum is not met within 8 ft., as with volumetric water supply there is every hope of such irrigation being practised without harm to the lands.

Regarding (i), the Irrigation Inquiry Committee have expressed an opinion that 96 inches of water would be the approximate average requirement of a sugarcane crop and as Rs. 45 per acre is the present cane rate on an acreage basis, negotiations with important consumers are in progress on the basis of Rs. 45 per 96 acre-inches. Regarding (ii), nala-grading will be resorted to in addition to regular drainage schemes, and by discouraging the growth of bullrush and preventing surface water stagnation, the former is likely to be of considerable help in restricting and reducing the damaged area. Regarding (iii), effect of concentrated patches of cane in deep areas on soil condition and subsoil water level is being observed.

3. The research work done by this Division in the effluent zone has been effective in establishing the usefulness of effluent irrigation as a scheme of agricultural welfare, and not only as an alternative method of sewage disposal. Another city in the Province is now contemplating the introduction of effluent irrigation in preference to chemical methods of sewage disposal.

4. A copy of the Research Programme presented at the last year's meeting is already available with all members. As an amount of research work done by this Division is very closely related with agricultural subjects, research programmes (including the one under report) are scrutinised by a "Co-ordination Committee" to avoid duplication of work. As a result of consequent delay, work on some of the items had to be postponed or dropped. The exact manner in which the 26 items mentioned in the programme were disposed can be seen from allocation given on page 27. 25 Notes showing details of work done during the year follow in pages 9 to 84 and a summary is given at pages 4 to 8. In paras. 5 to 8 below, attention is drawn to points of special importance.

5. Rotational running of canals, in addition to eradicating weeds in canals as described in Note No. 2, results in systematising and regularising irrigation and lowering of subsoil water levels, as the dry periods avoid waste and help draining of substrata. With waste avoided, improvement of duties is but natural. When water is sold on a volumetric basis, the onus of its economy will shift from Government to the irrigator, and duties are bound to improve very remarkably. The large amount of waste involved in present methods is evident from details of crop requirements in Note No. 7. It is well known that canal water taken for sugarcane in twelve months even by so-called advanced irrigators is over 150 acre-inches at present, whereas experiments show the need of only about 80.

6. Note No. 3 indicates the great difference in the draining capacity of different materials and justifies the stress laid by this Division on the piercing of Man and Murum in drainage schemes. The necessity of restricting cane in catchments which have no pervious strata within a reasonable depth is also obvious. Results in Note No. 4 will affect the capacity of pipe drains as irrigation from ridge to valley causes greater fluctuation of drainage discharges.

7. This Division aims at control of waterlogging and damage by restricting cane in each sub-catchment to suitable intensities, based on the nature and topography of soils and sub-soils which have been mapped out in detail. But where reasonable intensities

have to be exceeded, as in the case of Sugar Companies, artificial land drainage is inevitable. The same is the case where old irrigation has resulted in extensive damage. Where lands have been damaged for a number of years, simple drainage cannot improve them and artificial reclamation must be resorted to. Irrigators have not yet commenced to work on this conclusion but sugar companies are gradually taking to it. Experiments so far carried out by this Division indicate that leaching must be done where salt is in excess of 2 per cent, but with less salt, Dhaincha as a green manure crop followed by hardy varieties (CO-290, CO-419 and CO-417) of sugarcane will bring about the desired effect. If the soil is not only salt-affected but also sodiunised, addition of gypsum is the best treatment. All other treatments are costlier, either in cash expenditure or in time lost. The amount of gypsum to be added will vary from 1 to 3 tons as pH value of the soil sample varies from 8.5 to 9.5, with salt content brought down below 0.7 per cent, by dilution. Rice has repeatedly failed in the Deccan areas as a reclamation crop as it cannot establish itself.

8. Prejudices of irrigators against effluent have now almost completely worn out, due to systematic experimental work and actual experience in the field higher and prolonged doses of 'N' are no longer resented, and often are they requested for. Note No. 21 opens a new field for practical application, and acreage under 18 months' cane plantation (i.e., Adsali) with its high yields is likely hereafter to spread in the effluent zone, as it has done on other Deccan Canals. Notes No. 18 to 20 indicate varieties that will bring maximum profits to the cultivators under water and manure conditions obtaining in the effluent zone, where effluent irrigation for sugarcane is compulsory and where effluent is most available in Rabi and Hot Weather and less so in the Monsoon. The hardiness and yield of CO-419 is of special interest as this variety is capable of being crushed with an ordinary bullock crusher which is commonly used by small irrigators.

SUMMARY OF RESULTS.

	Note No.
I. UNDER HYDRODYNAMICS.	
63.8 lbs. per c. ft. was found to be the maximum density (at 4°C) of silty water met with in a Deccan river in heavy floods	1
The efficacy of repeated canal closures in weed eradication has once more been proved on the Mutha Right Bank Canal	2
II. UNDER SOIL HYDRAULICS.	
The unsuitability of K/A observations as a reliable measure of permeability has been demonstrated by hundreds of observations systematically taken. It has been shown that $\frac{d}{4x} \cdot \frac{K}{A}$ will be a better index than simple K/A. Attempt has been made to correlate subsoil water gradient with degree of permeability. Thus Mān is 120 times as pervious as Chopan and Murum 320 times	3
The curve of discharge percolating to the nala under different systems of irrigation has been studied in a model. With irrigation going from valley to ridge, the volume of drainage rises suddenly and falls slowly. With irrigation proceeding in the reverse direction, the rates of rise and fall are symmetrical. The limits of fluctuation are ± 28 per cent in the second case but only ± 17 per cent. in the first one, though average is naturally the same in both cases	4
III. UNDER ECONOMY OF WATER.	
Evaporation from surface of Murum Black soil was not found to depend on the salinity of subsoil water or on the stiffness of the soil. In pots kept above ground level it decreased from about 13 inches per month with subsoil water level at 9" to about 5" per month with a subsoil water level at 27". From buried pots the evaporation was about half the above. The rate of evaporation fell considerably and became negligible as subsoil water level dropped from 27" to 40". Evaporation from a cane field was greater than that from an open soil surface in a buried pot even if the latter had its subsoil water level at 9"	5
Evaporation from a cane field was always found to be less than from a plain water surface, and it decreased as cane grew older and shielded the field more effectively	6
Water actually required for a sugarcane crop was worked out with a view to ascertain the excess of water that is being given unnecessarily under the present method. The results were inconclusive	7
IV. UNDER CONTROL OF DAMAGE.	
Salinity of subsoil water was found to depend more on the soil profile type than on the relative position of a bore between the ridge and the valley. Salinity in all profile types in the catchment under observation was found to be decreasing year after year on account of the continuous leaching of salts to the nala	8
Chopan Black soil was found to leach better under heavy irrigation than under light irrigation	9
V. UNDER RECLAMATION.	
162 inches of continuous flooding carried out in 4 months (including evaporation) reduced the salt content in the surface 2 ft. from 3 per cent. to 1 per cent. pH values also decreased near the surface; but they increased below the first foot	10
Dhaincha was found to resist and improve lands more effectively than rice. The latter is almost useless as a reclamation crop. Where even Dhaincha cannot germinate, flooding must be resorted to so as to bring salt content within 2 per cent.	11
Molasses were found ineffective when added directly to the field. That treatment is even worse than useless as it spoils the texture of soil. It is proposed to try mixing of molasses with irrigation water	12
Indore compost was found to be more effective in reducing the pH than sheep manure or Farm Yard Manure. From a crop point of view, however, Farm Yard Manure was superior	13
Gypsum is more effective than lime or sulphur in improving the soil condition of damaged lands. It is also cheaper and hence suitable for adoption on a large scale	14
CO-417, CO-419 and CO-290 were found to be the most suitable varieties of sugarcane for reclaimed lands in the Baramati Experimental Salt Area	15
The same results were obtained in the newly reclaimed lands at Manjri, but the order of relative superiority in the three varieties was reversed. Thus, CO-290 was best, followed by CO-419 and CO-417	16

VI. UNDER EFFLUENT IRRIGATION.

	Note No.
The lighter type of soil (Coarse Murum soil up to 18" depth) gave increased outturn with pre-dosing, i.e. with effluent irrigation prior to plantation. In deeper soils (Murum Black soil 4' deep), POJ-2883 and Pundia gave consistently good results but POJ-2878 and CO-419 gave conflicting results	17
Yields obtained from cane irrigated beyond the age of 10 months with canal water, effluent, and various mixtures of the two, indicated that effluent and canal water could be used in equal proportion without affecting maturity and outturn. This result is of particular advantage where canal water is short	18
Increased outturns were obtainable with increased doses of 'N' in case of POJ-2878 in Coarse Murum soil. In the case of Murum Black soil, however, the results were conflicting and a slight reduction was noticeable with higher doses.	19
Continuation of effluent after the hot weather was found to be injurious in the case of CO-408, CO-417, and Pundia. It had no effect in the case of CO-411, CO-416 and POJ-2883; whereas CO-419, POJ-2878 were positively benefited by continuing effluent up to harvest	20
CO varieties were found to be very suitable for Adsali plantation in the effluent zone, June plantation yielding better results than August plantation. CO-411 yielded 87 tons per acre with June plantation. These observations are of very great importance as no other varieties of cane had succeeded in this tract for Adsali.	21
Continuous effluent irrigation brought about a decided improvement in the texture of Murum Black soils	22

VII. UNDER DRAINAGE CONSTRUCTION.

Temperatures of water in pipe drains remained steady between 25°C and 26°C over a number of months. They did not respond to the wide fluctuations of the atmospheric temperatures outside	23
Cement concrete pipes tested under conditions similar to those met underground <i>in situ</i> remained totally unaffected by such salt water (conductivity 4,000) as is expected to be flowing in drains	24

VIII. UNDER MISCELLANEOUS.

The difficulty in correctly reading the soil sediment volume in the sedimentation tests for sodiumisation was overcome by using a centi-normal solution of KCl instead of distilled water for preparing soil extracts. This yields a quick method for estimating the degree of sodiumisation of a soil sample within about half an hour	25
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Disposal of items in Research Programme (1938-39) circulated at the Research Officer's meeting held at Simla in July 1938.

I. 16 items have been dealt with in the following notes of this report :—

Programme Item No.	This report Note No.	Programme Item No.	This report Note No.
I A/1	17	II B/1	3
I A/2	18	II C/4	4
I A/3	19	III B/1	10
I A/4	„	III B/2	13
I A/5	22	III B/3	12 & 14
I B/I	21	III B/4	11, 15 & 16
II A/1	7	IV A/1	24
II A/2	5 & 6	IV B/1	1

II. Work on 6 items as under is yet in progress and results are not ready :—

II B/2	II C/1	III A/1
II B/3	II C/5	III B/5

III. No work could be undertaken on the following items :—

II A/3, II C/2, II C/3 and III A/2.

IV. Following 6 notes appearing in this report were not on the programme :—

Notes No. 2, 8, 9, 20, 23 and 25.

Total items in programme.	26
Total notes in this report	25

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. N. B. GADRE drew the attention of the Committee to the effectiveness of canal closures in destroying weeds. He said that the bed of the canal must be thoroughly drained when closed, and central drains were constructed for this purpose.

The Mutha Right Bank Canal which was being subjected to the present experiments had a very flat slope e.g. about 1 foot in 3 miles. Since supplies were derived from reservoirs the water is clear in March and April but turbid during Monsoons.

MR. GADRE said that pictures showing the type of aquatic weeds encountered are included in the full report of the Irrigation and Research Division, Poona, for 1938-39*.

MR. W. N. McLEOD observed that the closure method of destroying weeds could not be applied to drains in which for obvious reasons, flow would not be stopped.

MR. S. H. BIGSBY enquired whether the weed nuisance extended to the tails of the canals, and Mr. Gadre informed him that the trouble extended to the tails but was not very bad there.

MR. A. R. THOMAS referred to "Water Weeds and their Eradication from Canals" by Mr. C. C. Inglis† and said that Mr. Inglis' general conclusion was that silty water was the best antidote as compared with the closure method. The closure method was very effective but there were often practical difficulties attending it.

MR. THOMAS referred to the model experiment on the fluctuation of sub-soil water levels and discharges on a drainage catchment under irrigation. He noted that the time scale was taken as 1 to 80, whereby 3 hours constituted a model rotation period against 10 days for the prototype. He enquired how this time scale had been arrived at.

MR. GADRE said they fixed the time scale to suit their convenience.

MR. THOMAS pointed out that in Mr. Gadre's full report* he (Mr. Gadre) had stated that in the flat deep soil areas in the valleys, rain water penetrates to a certain depth during the monsoon but is then evaporated with the result that soluble salts liberated from the decomposition of soils are not leached down but become concentrated in the subsoil layers of the soil. Mr. Thomas wished to know whether this proved that salts originate in the soil itself and are not worked down from ridge to valley.

MR. GADRE replied that on the introduction of irrigation salts are leached down by the irrigation water into the pervious sub-soil and thence to the nalas, and may thus be transferred to other soils.

DR. E. MCKENZIE-TAYLOR said that in the Punjab the normal slope of the land was 1 foot per mile. If the salts are leached into the pervious sub-soil they are carried away. In the soil crust itself the salts move up or down according to conditions of water supply and evaporation, but there was no horizontal movement.

MR. L. VENKATAKRISHNAIYER noted that Mr. Gadre had stated that Dhaincha improved land more effectively than rice, and that the latter crop was almost useless for reclamation in the Deccan. In Madras colingi and pillipasara were used for reclamation, and Mr. Venkatakrisnaier described these crops and the methods of cultivating the same.

Referring to the experiments in effluent irrigation, MR. GERALD LACEY stated that the Delhi Sewage and Water Board had recently constructed a number of irrigation channels to make use of effluent which would otherwise require to be chlorinated before discharge into the practically dry bed of the Jumna River. Mr. Venkatakrisnaier said that in Madras for the last 40 years effluent had been used on grass lands with the result that a profit was made on sewage.

MR. GADRE, in this connection said that 200,000 people produced sufficient effluent at present on a nitrogen basis to suffice for 2,400 acres of sugar-cane. At present about 1,000 acres are annually grown. He added that a piped water supply for drinking, etc. was essential to such schemes.

* Not included in this Report.

† Will eventually be published by the Central Board of Irrigation.

SUMMARIZED REPORT OF UNITED PROVINCES P. W. D. (IRRIGATION)
RESEARCH SECTION, 1938-39.

GENERAL.

During the year under review the entire expenditure on research was Rs. 18,487. Work during the year may be grouped under the following headings ;

- Canal and Gul Losses.
- Lining of Channels and Guls.
- Tube Well Investigations.
- Models.
- Silt Excluding Devices.
- Silt Observations.
- Agricultural Co-operation.
- Miscellaneous and Advisory.

CANAL AND GUL LOSSES.

The results of further determination of canal losses—

- (a) by utilizing calibrated falls.
- (b) by means of statistics.

These two methods have given results consistent with past investigations.

Parshall Flumes have been used for determining losses. In the case of the Agra Park Minor readings were taken every one quarter of an hour day and night from 8 A. M. on the 8th April to 1 A. M. on the 10th April, 1939. The loss per million square feet of wetted surface was 9.57 cusecs.

The observations of losses on cultivators' channels (guls) was continued. In this connection the "Chicken Feed" loss detector has proved to be highly reliable. The apparatus is fully described.

LINING OF CHANNELS AND GULS.

Further investigations have shown that the staunching obtained with Sodium Carbonate is not permanent and is deteriorating with time.

Laboratory experiments have demonstrated that the dosage of Sodium Carbonate should be more than that indicated by the replaceable Calcium in the soil.

Experiments are in progress.

The use of molasses for staunching has been the subject of further experimentation, but without results.

Experimental lining consisting of two inches of lime concrete coated with Mastic No. 2 is still effective after one year.

A further lining under observation consists of a 2-inch base of broken ballast (1 inch) mixed with clay, and an overcoat of $\frac{1}{4}$ inch mastic. It reduces losses by about 90 per cent. and costs Rs. 8-4 per one hundred square feet.

TUBE WELL INVESTIGATIONS.

Certain wells are read once a month for the correlation of ground water fluctuations with rainfall. Representative wells are equipped with six lines of observation pipes radiating from the well at angles of 60°. This is for the study of the sources of sub-soil water supply. Tests on these wells will be carried out twice a year, once in Rabi and once in early Kharif.

Investigations to date show that tube well pumping has not materially changed the correlation between rainfall and the discharge of the Ganges at Narora.

MODEL EXPERIMENTS.

Karon Nadi—This model was for the purpose of evolving an economical design for a 10 feet fall (a) that would pass a flood discharge of 25,000 cusecs with a D. S. water cushion of 12 feet and (b) with a 5,000 cusecs discharge.

A vertical fall with an horizontal talus proved best while the best device for destroying surplus energy appeared to be a cistern. Economical dimensions of the cistern are given.

Combined Bridge and Fall at M. 117-5-140.—Experiments on a model were carried out with dentated cills and baffles. The depth of scour obtained without any device agreed with the prototype. The best results were obtained with a combination of two baffles.

SILT SELECTIVE HEADS.

The reversed curvature type of head known locally as the Russel head has given the best results.

For estimating the efficiency of such heads, in addition to the method proposed in Technical Memo. No. 6, it is now proposed to use Puri's Bottle Sampler and to express the efficiency as the ratio of the silt loads carried by offtaking and parent channel.

Silt sampling at the Sarda Canal Headworks was continued. The silt charge in the canal was found to increase with the rise in the river supplies and with the increase in the discharge through the barrage under-sluiques. The canal water had its least silt charge when the barrage under-sluiques were closed.

SILT OBSERVATIONS.

Silt samples from various parts of the Province were analysed with the Puri Silto-meter.

Inconclusive results were obtained when an attempt was made to establish a relationship between the average diameter of silt particle, and the silt factor calculated from the hydraulic data submitted with the samples.

The recording of canal water temperatures continued. Past records proved extremely valuable in the design of the cooling ponds for the proposed Moradnagar Power House.

AGRICULTURAL CO-OPERATION.

Steps have been taken to start work at the Barabanki Farm on the water requirements of crops under the dual supervision of Irrigation and Agricultural Officers.

MISCELLANEOUS AND ADVISORY.

Deforestation and Floods.—Investigation has shown that the intensity of floods on the Pathri and Ranipur Roads crossing the Ganges Canal has steadily increased during the years 1911-38 as a result of continuous deforestation.

Run-off from Drains.—An analysis was made of the rainfall and discharges of drains of the Lucknow Division in the Barabanki district to determine what percentage of the rain which falls on a given catchment is carried off by drains. It was found that excepting in one case of Deokali drain for which the figure worked out as high as 51 per cent. probably due to defective gauge reading, run-off in other drains varied from 6 per cent to 28 per cent, average being 12 per cent. The catchment of these drains consists mostly of cultivated land and varies from 5 to 33 sq. miles. The average rainfall over the catchment for the last five years for which the figures were worked out was 40 inches.

Calibration of Falls.—Further calibration was done during the year.

Meter Flumes for Canals.—Many enquiries were answered and designs checked.

Evaporation from Reservoirs.—The mean evaporation per month worked out at 6.51 inches compared with 6.62 inches last year.

The Use of Tar for Painting Steel Work.—Tarred surfaces exposed on the Sarda Barrage after two monsoons have compared very favourably with Triple A a very expensive paint.

Observations are being continued.

Dungia Feeder.—The hydraulic data of this feeder were examined and suggestions advanced for preventing the present excessive scour.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

The deterioration of sodium carbonate staunching with time discovered by the United Provinces Research Section provoked a question from Mr. S. H. Brosky who enquired whether the Punjab Irrigation Research Institute's methods of using sodium carbonate had been strictly adhered to.

Mr. HARTLEY replied that he could not say off hand, but briefly the methods of laying the sodium carbonate were :—

- (a) One pound of sodium carbonate was mixed with one gallon of water and sprayed over 20 sq. ft. of the channel bed: (b) a 0.10 per cent. solution of sodium carbonate by weight was formed in the water impounded in the channel and allowed to sink into the ground. (c) The material

forming the bed of the channel was removed to a depth of six inches and mixed with sodium carbonate in the proportion of 1 cwt. of sodium carbonate to 420 cubic feet of earth.* The mixture was then replaced in its former position and thoroughly rammed. Only the bed of the channel was treated: (d) The silt layer on the channel bed was removed. The natural earth under this layer was then treated as in (c). Over the replaced treated natural earth layer the silt was put back in its former position and rammed. Only the bed was treated: (e) as in (c) except that in addition the sides of the channel were also treated by filling narrow trenches dug to the full depth of the berm with the mixture.

One case of each method had been kept under observation since the beginning of 1937.

After the first year all five cases showed greater staunching than resulted immediately after the application, but after the second year the staunching effects had dropped below the initial effect observed; greatly in cases (b) and (d), and considerably in the case of (c) and (e). In the case of (a) the figures are: percentage decrease in losses April 1937 was 25.9 per cent., in March 1938 the figure was 84 per cent., and in March 1939, 23.5 per cent.

MR. GERALD LACEY, with reference to the conflicting results reported in comparing the average diameter of silt particles with the silt factor calculated from hydraulic data, enquired whether the channels studied were in regime. He emphasised the necessity of applying the test regime formula to channels before considering data therefrom. The test formula was $V = 16 R^{1/2} S^{1/3}$ in which the rugosity is implicit and which is applicable to every type of regime alluvial channel from very fine silt to boulders.

In a perfect ideal channel, free from shock, where the bed material varies in average diameter from 0.2 mm. to 0.4 mm. it should be possible to relate the size of material with the silt factor.

MR. LACEY enquired whether the silt dimensions were taken with the Puri Siltometer, and whether the corrections necessary when using this siltometer had been applied. He also wished to know what maximum and minimum diameters were measured.

MR. J. P. JAIN replied that the maximum figure for the average diameter of the silt particles analysed was 0.380 mm. and the minimum diameter 0.032 mm.

MR. LACEY pointed out, after studying the figures handed to him by Mr. Hartley that many of the channels had very low average diameters of the particle such as 0.04 mm. 0.05 mm. etc. It was self evident that such channels were lined with very fine mud and clay of a cohesive character, and that the scouring velocity of such fine particles might be very high. It was essential to examine the data afresh and confine the analysis to the silt of coarser grade.

DR. E. MCKENZIE-TAYLOR said that the greater part of the silt in the Punjab was finer than that mentioned by Mr. Jain. Cohesion will enter the problem when diameters are below 0.075 mm. (roughly). In the Punjab Irrigation Research Institute the distribution curve is based on the results of the constant immersion hydrometer up to 0.075 mm. diameter; for diameters between 0.075 and 0.60 mm. the Vaidhianathan or Puri Siltometers are used; for diameters of silt in excess of 0.60 mm. analysis is done with sieves.

The Punjab Irrigation Research Institute employs methods based on the correlational analysis, and no physical principles have been considered in connection with the equations reproduced in the Annual Report. The S, Q and m relationship has been employed.

DR. MCKENZIE-TAYLOR said they were arriving at nothing fundamental in their analysis of the silt factor and the mean silt diameter, neither did he consider the correlation of Q and P to be fundamental.

MR. LACEY stated that the Punjab experiments had demonstrated two things; that the ratio of the discharge intensity "q" to the wetted perimeter "P" was a constant, and that, within the range of channels examined, the mean velocity varied sensibly as the square root of the hydraulic mean depth, but the Institute had not been able to improve this relation by introducing the diameter of the silt particle as a variable. When however scour in rivers was considered it was agreed by all that there was some correlation between scour and mean diameter and that size entered, in some manner to be determined, as a variable. He suggested that there was something fundamental in the results.

After further discussion the Resolution was moved and carried: *When the silt is exceedingly fine scouring velocities may become a function increasing with fineness, as Dr. Chatley and others have stated.*

When the average diameter of bed silt particles is finer than a certain limit from approximately 0.15 mm. to 0.2 mm., the relatively high percentage of fine particles leads to cohesion, and may thus vitiate conclusions in respect of scouring velocities drawn from the measured grade of silt.

Resolved that existing distribution curves should be examined with the object of determining the percentage of particles below the limit of 0.2 mm. which introduced cohesion as an additional variable. It is recognised that the result of such examination may necessitate the adoption of an ultimate limit other than 0.2 mm. but of the same order.

Dealing with the investigations on Silt Selective Heads, MR. HARTLEY enquired the Committee's views as to whether it was possible to rate the efficiency of these devices by observing silt samples.

DR. MCKENZIE-TAYLOR said that some work had been done on these lines in the Upper Bari Doab Canal.

MR. S. H. BIGSBY said that they had not progressed far enough to be able to determine the efficiencies of silt selective heads by observations of silt samples.

MR. LACEY deprecated the very confusing custom of using the names of people and Divisions, for silt excluding devices, instead of a more rational nomenclature based on the principles employed. As examples he said that the Griffith device was really a cill, and that such devices as the Kings Vanes and the Russell Head come under the principle of reversed curvature.

MR. BIGSBY said that this subject was a very important one and he considered it should be dealt with as a separate item in future.

The following Resolution was moved and carried: *That this committee recommends that the item, "Design of Distributary Heads", be included in future discussions of the Central Board.*

MR. A. R. THOMAS asked for details of the Parshall Flumes used for measuring losses. He used the Crump flume which was eminently satisfactory and worked to within ± 1 per cent.

MR. JAIN said that experiments on a device called the Venturi flume were made in 1915 by V. M. Cone at the hydraulic laboratory of the Colorado Agricultural Experiment Station, U. S. A. Later experiments on the same device were made by Carl Rohwer and R. L. Parshall in 1920. The device had converging entrance and diverging outlet sections, joined by an intermediate throat. The walls were either vertical or inclined outward, and the floor was level. In 1922 Parshall proposed somewhat radical changes in the design of this device—the angles of convergence and divergence were changed, the lengths of these sections were altered, and the floor in the throat was sloped downwards, forming a fixed crest and control at the junction of the converging section and the throat. The walls were made vertical and the floor of the converging section level,

*Q. V. Resolution of the 7th Research Committee, June 1937:—This Committee is of the opinion that the further experiments carried out with Sodium Carbonate have proved the method to be cheap and effective in rendering canal beds less pervious. The best method of application appears at present to be the broadcasting of solid material (Na_2CO_3) on the sub-surface 1 foot below the bed to be treated. The most efficient rate of application is found to be 100 lbs. sodium carbonate per 1,000 sq. ft.

while the floor of the diverging section inclined upward to the lower end of the structure. It is this device that the Irrigation Committee of the American Society of Civil Engineers has named the Parshall measuring Flume.

MR. JAIN said that tests at Lucknow had confirmed the accuracy of this flume. Its particular advantage in his (Mr. Jain's) opinion was the complete absence of curved surfaces, which not only facilitated very accurate reproduction in concrete or plastered brick, but also made it possible to construct wooden flumes capable of transportation from one experiment site to another. Curved surfaces had been the cause of error owing to the difficulties of accurate reproduction on the Left Mohammadpur Distributary on the Upper Ganges Canal System.

CONSIDERATION OF THE SUMMARIZED REPORTS ON IRRIGATION RESEARCH UNDERTAKEN IN INDIA DURING THE YEAR 1938-39, AND THE DISCUSSIONS OF THE RESEARCH COMMITTEE, BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 6TH NOVEMBER, 1939.

MR. A. GORDON, the President, referred to the summarized reports of the research stations, which appear in the preceding pages.

He said he would like to draw attention to the discussions of the Research Committee on those reports, the discussions on model scales being of particular interest.

Continuing, the President pointed out that the Central Irrigation and Hydrodynamic Station (Poona) apparently used Lacey's Theory for fixing scales, while the Punjab Irrigation Research Institute (Lahore) did not.

He regretted that Mr. Inglis, Director of the Central Irrigation and Hydrodynamic Station, was not present at the meeting, having been delayed in his return from leave. Mr. Inglis' views on this question of scales would have been very valuable.

THE PRESIDENT enquired from Dr. McKenzie-Taylor, Director of the Punjab Research Institute, whether he would favour the Board with his remarks.

DR. E. MCKENZIE-TAYLOR said that in the Punjab Research Institute they followed the same methods as were used at the United States Waterways Experiment Station, Vicksburg. Expressed very briefly, their method was to lay out the model, according to the space available, adjust velocities according to Froude's requirements, adjust (verify) the model by adjusting roughness of wetted surfaces until known flow profiles could be accurately reproduced, and then proceed with the investigations of the particular problem in view.

THE PRESIDENT then asked Mr. Lacey for his views.

MR. GERALD LACEY stated that a variety of equations could be employed for calculating *provisional* scales for alluvial models. Whatever equations were employed some slight adjustment was nearly always found subsequently necessary, particularly in respect of slope which was bound up with the precise grade of sand employed and the precise silt charge. Of these equations his own had the merit of great simplicity, and were as accurate as other empirical and more complicated expressions. His equation had, as a fact, been recently employed in determining the vertical scale of a river model in the Punjab. If the same grade of sand were used in the model as in the prototype, the scales of a model were determined thus, assuming that the longitudinal scale adopted was determined from a consideration of the space available for experimentation :—

Longitudinal scale adopted	$1/x$
Vertical scale required	$1/x^3$
Exaggeration in vertical scale	x^3

Those scales meant that if a horizontal scale of 1/1000 were adopted, the vertical scale would be 1/100, and the exaggeration in the vertical scale would be 10 to 1. These scales had the interesting feature that in model and prototype the vertical velocity scale was maintained constant.

THE PRESIDENT said that Rai Bahadur Khosla had just returned from a tour of the United States and the Board would like to hear his views.

RAI BAHADUR A. N. KHOSLA said that no definite conclusions had been reached in America on the question of model scales.

MR. S. H. BIGSBY expressed the opinion that the necessity of verifying a model was universally accepted.

MR. E. O. COX said that in the case of the Trimmu Weir they were now verifying the model.

After further discussion the Board passed the following resolution, "*THE SCALES TO BE USED IN MODEL EXPERIMENTS STILL REQUIRE TO BE CAST IN A FINAL FORM ALTHOUGH CONSIDERABLE ADVANCE HAS BEEN MADE, AND IT IS CLEAR THAT ANY SCALES WHICH MAY BE ADOPTED, MUST SUBSEQUENTLY BE VERIFIED ON THE MODEL.*"

MR. INGLIS, DIRECTOR OF THE CENTRAL IRRIGATION AND HYDRO-DYNAMIC RESEARCH STATION, WAS UNFORTUNATELY NOT PRESENT, BUT IN VIEW OF HIS RECENT VISIT TO THE UNITED STATES OF AMERICA, HE SHOULD BE REQUESTED TO SUBMIT A REPORT, WHICH SHOULD BE CONSIDERED AT A LATER STAGE, TOGETHER WITH ANY OTHER REPORTS ON THE SAME SUBJECT WHICH ARE INVITED."

MR. A. ORAM enquired whether those Provinces which were without a Research Station were obliged to submit their problems to the Central Irrigation and Hydro-dynamic Station.

THE PRESIDENT, "Not obliged but entitled".

Discussion then turned on the difficulties which arose out of the late submission of Research Reports.

THE PRESIDENT said that reports should be printed in good time for the consideration of the Research Committee.

It was resolved that "*THIS BOARD DESIRES TO DRAW THE ATTENTION OF THE PROVINCIAL ADMINISTRATIONS TO THE DIFFICULTIES CAUSED BY THE LATE SUBMISSION OF RESEARCH REPORTS, AND SUGGESTS THAT STEPS BE TAKEN TO SUBMIT SUCH REPORTS EARLIER.*"

THE PRESIDENT said that the various resolutions of the 9th Research Committee* would be considered when the subjects concerned were discussed.

* Vide pages 31, 43, 44, 47, 49, 56, 66, 73, 77, 94, 95, 105, 109, 123.

FIELD RESULTS OF MEASURES ADOPTED AFTER MODEL EXPERIMENTS

PRELIMINARY GENERAL NOTE

At the 3rd Winter Research Committee Meeting held in March 1939,* the following resolution was passed: "This Committee is of the opinion that in order to assess the value of models in solving irrigation and river training problems, more information should be collected on the results obtained from the practical application on the prototype of measures adopted as a result of experiment on models. The Committee recommends that the subject "Field results of measures adopted after model experiment", should be included in the agenda for the annual meeting of the Board and the Research Committee and the Secretary should collect from Provinces all information of value in assessing the value of model experiments".

For this purpose hydraulic models may be classified as being made to:—

- (1) determine discharge over or through structures.
- (2) determine scour below structures.
- (3) determine velocity distributions.
- (4) solve river problems (non-tidal).
- (5) determine sub-surface flow.
- (6) determine sub-surface water pressures.
- (7) determine the effects of silt charge.

The evidence of confirmation from prototypes is not very bulky and a few references will be given under each head.

Discharge over or through Structures.—Observations on the Burnhope Reservoir (Durham County Council) spillway suggest that models underestimate the discharge at corresponding depths of overflow.

The value of n for the models of the Mohawk Tunnels (1 : 40 scale) was found to be 0.0091 which indicates that the models, however smooth mechanically, are nevertheless too rough to simulate conditions in the prototype. (Trans. Am. Soc. C. E., Vol. 103.)

The Leaburg siphon gave a less coefficient of discharge than the model owing to cavitation in the full sized model.†

Models of the sluices of the Assuan Dam and comparison with prototype showed that models can be used to determine the discharge of large sluices with an average accuracy as good as that obtainable by current meter measurements‡.

In the case of the Madden Dam the discharge over the crest of the prototype was apparently greater than that predicted by the model.

Scour below Structures.—Study of this subject reveals that the scour obtained on a model is only relative and does not show the actual scour on the prototype.

Modifications made to the Pirsher Fall Regulator over the Dadu Canal in Sind are said to have prevented scour as predicted by a model.

Determination of Velocity Distribution.—The performance of the hydraulic jump below the Madden Dam has been consistent with the prediction made from the model test. The measured velocity at the toe was less on the prototype which may be attributed to the difference in the roughness of the model and the concrete dam.§

River Problems (non-tidal).—Experiments with models of the Indus and the Lloyd Barrage at Sukkur, of the Brahmaputra and the proposed Eastern Bengal Railway Bridge at Amingaon, and of the Ganges above the Hardinge Bridge, now in progress should be illuminating.

* At the 3rd Winter Research Committee Meeting, the Secretary referred to the Punjab Engineering Congress, Paper No. 227, entitled, "A Study of the River Conditions on a Model of Khanki Headworks and Investigation of Methods for Obtaining Uniform Distribution of Flow and Minimum Silt Entry in the Canal", and said that there appeared to be a lack of faith in such experiments on the part of engineers, which was perhaps attributable to the fact that there was very little information available as to the results of works carried out in the field which had been designed from such experiments.

† Engineering News-Record August 18, 1932.

‡ Proceedings of Inst. of Civil Engrs., Vol. CCXVIII.

§ Trans. Am. Soc. C. E., Vol. 103.

The time required in Nature for structures to become effective differs greatly with the type of stream bed. Thus a spur constructed in 1897 did not make its effect felt until 1911, and another spur constructed in 1901-02 did not fully develop embayment until 1910-11.*

Fahey tells us that the oscillations of the Indus are remarkably regular and that it took about 20 years from the time it commenced to cut the bank at one particular point, to leave this point, and again attack it.†

Models made at the United States Waterways Experiment Station to determine the location of spurs to improve channel conditions show what are termed "ratifying" results with the conditions after the spurs were constructed.‡ In general the surveys showed that the structures were tending to produce the desired results.

Sub-Surface Water Pressures.—The Central Board of Irrigation Publication No. 12 "Design of Weirs on Permeable Foundations" gives examples of satisfactory agreement between pressure pipe observations in models and prototypes.

Sub-Surface Flow.—It is hoped that the recent experiments carried out at the Punjab Irrigation Research Institute may furnish some information on the agreement between the models and actual wells.

Effects of Silt Charge.—Experiments on sand movement in fluvial models described in Vol. 100 (1935) Transactions of American Society of Civil Engineers show that bed-load movements are not directly transferable from the model to the prototype which largely justifies the usual conservative manner in which results of river experiments involving bed-load movement are judged, and is responsible for the acceptance of their qualitative but not of their quantitative results.

POINTS FOR DISCUSSION.

Further examples of comparison between model and prototype.

Time necessary in judging comparison between river models and prototype.

NOTE BY MR. A. R. THOMAS, I.S.E., OFFG. DIRECTOR, CENTRAL IRRIGATION AND HYDRODYNAMIC RESEARCH STATION, POONA, FOR THE 9TH MEETING OF THE CENTRAL BOARD OF IRRIGATION, RESEARCH COMMITTEE, SIMLA, JULY 1939 ON "FIELD RESULTS OF MEASURES ADOPTED AFTER MODEL EXPERIMENTS".

Model experiments are of different types. In some, if the model is made an exact replica of the prototype, and certain rules are followed in its operation, results are obtained which are almost exactly similar to those of the prototype under similar conditions.

Only a small proportion of model experiments fall into this class. In most cases a departure from exact similarity is expected in certain respects.

Two or more models to different scales are often required and deductions have to be made by judgment and experience in knowing what results in the prototype can be expected from observed results in the model, aided also by basic research.

In a paper read before the National Institute of Sciences, India § Mr. Inglis divided model experiments into 8 different types, which classification, it is suggested, may be preferable to the one adopted, as it is based on the degree of similarity to be expected in models :—

- I. Models which are geometrically similar in shape to the prototype and give geometrically similar results.
- II. Models which are geometrically similar in shape ; but do not give geometrically similar results.
- III. Regime models in which conditions of flow are maintained constant, with complete freedom as regards silting and scouring.
- IV. Combined open channel and rigid models.
- V. Rigid and semi-rigid vertically-exaggerated models in which conditions are imposed, e.g., tidal models.
- VI. Models with mobile protection—falling aprons ; spurs, protection round piers, etc.
- VII. Meandering river models.
- VIII. Combined rigid, mobile and meandering river models.

Of these only I gives close similarity of results.

* Punjab Engg. Congress 1939, Paper 227.

† Proceedings of the Inst. of C. E., Vol. LXXI, 1882-83.

‡ Trans. Am. Soc. C. E., Vol. 101.

§ "The Use of Models for Elucidating Flow Problems based on Experience gained in carrying out Model Experiments at the Hydrodynamic Research Station, Poona" by C. C. Inglis, C.I.E., M.Inst.C. E., Proceedings of the National Institute of Sciences of India, 1938.

The above paper, in fact, provides an answer to many of the points at issue in the question under discussion. Examples are given, and it is shown how far models of each type may be expected to reproduce results which would be obtained in the prototype.

A few remarks are given below on the examples mentioned in the programme of the meeting :

The Burnhope Reservoir Spillway would appear to fall into type II. In spillways with sharp curvature of flow, viscosity is an important factor as well as gravity, and results therefore differ with scale. Several models of different scales are usually required, as were used in the experiments with a high coefficient weir for Bhandardara, described in the 1937-38 Annual Report of this Station.

I have not seen the description of the Mohawk Tunnel models, but differences in the relative resistance of smooth surfaces can usually be allowed for, by adjusting slope. Rough surfaces, however, can be reduced to scale and similarity expected, provided the model is large enough for the surface still to be "rough" in the sense used in modern pipe theory.

Regarding siphons, cavitation is not produced to scale, because while pressures in models are scalar, the pressure at which cavitation occurs is not. Provided the equivalent of the cavitation pressure is worked out for the model, however, and pressures are observed, it can easily be determined whether or not cavitation will occur. This also applies to high-coefficient weirs.

The Madden Dam Spillway falls into Class II and the remarks given above regarding the Burnhope Reservoir apply.

In the case of the Assuan Dam sluices, it appears that gravity was the predominant force and the experiments were of type I.

Scour round rigid structures in vertically exaggerated models is not according to the general scale ratios of the model. The question of interpreting scour results is now under investigation at Poona. Experiments with bridge piers have indicated that scour in short geometrically similar models is likely to be approximately to scale when the bed material is the same incoherent fine sand in both prototype and model. The time scale and cohesion of the bed material are often important factors concerning scour in models.

The Pirsher Fall Regulator model was presumably of type IV—combined open channel and rigid models, in which scour in a geometrically similar model may be expected to scale provided the model is short and viscosity is not an appreciable factor in the rigid part.

Velocity distribution may, or may not be similar in a model. Where it is determined mainly by a gravity phenomenon, such as a standing wave, it is reproduced correctly in a geometrically similar model. Close similarity cannot, however, be expected where the distribution is affected by frictional resistance, nor in a vertically exaggerated model. In these cases allowances for divergence have to be made.

River problems present a host of difficulties, as there are so many factors. Vertical exaggeration is essential in long models, though in addition a geometrically similar model of a short length of river may be of great value for the study in detail of the flow at one place. For example, we are now working with three models of the Indus and Sukkur Barrage—two exaggerated and one part-width geometrically similar model.

Silt charge differs very widely between model and prototype, as the natural silt charge increases with size of channel, and this is one reason why similarity in changes of river course are not automatically obtainable in models—scour can be reproduced but silt deposition is always deficient, only indications being obtained. In this connection reference is invited to the account of experiments with the Ganges model in this year's Annual Report.

To sum up, model experiments of the simplest type give results which can be applied directly to the prototype. Experiments of other types require various degrees of interpretation; the conclusions drawn depend not only on the methods followed but on the judgment and ability of the experimenter.

On the one hand, therefore, it is wrong to put implicit trust in model results, but on the other, it is unfair to condemn model experiments in general because of the apparent failure of a few. On the balance model experiments must already have been of enormous benefit, and it is to be remembered that a large amount of basic research is in progress, and the technique of experimenting with models is making rapid strides.

The number of model experiments which have been actually verified in the field is not large, due mainly to the difficulty in verification. As examples I attach in an Appendix, notes on 10 experiments carried out at Poona which have had verification in the field. These were written by Rao Sahib Joglekar, Assistant Engineer.

APPENDIX.

1. *Experiments regarding the design of the sill of the Lloyd Barrage at Sukkur.*—Vide Bombay Public Works Department, Technical Paper 29 “Note on experiments carried out with various designs of piers and sills in connection with the Lloyd Barrage at Sukkur”.

The designed R. L. of the Barrage sill was 176·0, with 1 in 30 upstream and 1 in 70 downstream slopes. Experiments carried out at Poona showed that the sill could be raised to R. L. 177·0, without increasing the afflux, provided the upstream slope was altered to 1 in 5 and the downstream slope was made 1 in 10 down to R. L. 171·0.

The altered design would have the following advantages :—

- (1) With the Barrage gates already ordered, the freeboard of the Eastern Nara Canal could be safely increased from 0·3 ft. to 1·5 ft.
- (2) With a steep downstream glacis to a depth of 5 ft. below the sill, there was no danger of a standing wave forming beyond the pakka pavement under the full range of possible downstream water conditions.
- (3) The alterations proposed in the sill design would not merely enormously improve silt control, but they would also make it possible to use the Barrage as a powerful scouring device ; because the standing wave would always form on the glacis.

The sill was constructed according to the recommendations except that of the undersluices, where the construction was already advanced according to the original design. The Barrage is operating satisfactorily without any scour downstream, except downstream of the undersluices, where it has been found necessary to restrict the head (difference of water levels upstream and downstream) to about 8 ft., so as not to endanger the protection downstream.

2. *Silting of the Right Bank Canals of the Sukkur Barrage.*—Vide Bombay Public Works Department—

Technical Paper 45 “Silt Exclusion from Canals, ‘Still-pond’ versus ‘Open-flow’—Part I”.

Technical Paper 46 “Note on silt exclusion from Canals—Part II”.

Technical Paper 52 “Factors affecting exclusion of bed silt from Canals taking off from alluvial rivers”.

and various notes on silt exclusion experiments.

These experiments were carried out with vertically-exaggerated models during 1930—33.

Conclusions drawn from the experiments were :—

- “ (1) The sand bank (kacha) which used to form in midstream before the Barrage was built, continued to do so.
- (2) There was a marked general trend of silt movement towards the right bank and away from the left bank.
- (3) Scour near the nose of the Left Divide Wall was markedly greater than near the Right Divide Wall nose—due to curved flow carrying the bed water across the nose of the Left Divide Wall. This scour was intensified when the Left Bank Undersluices were kept closed.
- (4) Due to the left bank being concave in plan, there was a curved bed flow across the nose of the Divide Wall, which threw the bed silt away from the Pocket into the River and a deep channel formed along the left bank upstream of the Pocket. Reverse conditions existed along the right bank on account of the convex curve of the bank below Outfall Section. As a consequence bed silt accumulated along the bank and entered the Right Pocket and Canals. Silting occurred much more rapidly in the right pocket than in the left pocket.
- (5) The silt drawn by the Left Bank Canals with “open-flow” was not markedly greater than under “still-pond” conditions ; but in the case of the Right Bank canals, much more silt was drawn with “open-flow” than with “still-pond” conditions.
- (6) When pockets are being scoured, it is essential to close the Canals. If, in order to keep the undersluices clear of silt, it is found necessary to open them in rotation or keep them slightly open continuously, care must be

taken to see that the discharge entering the approach channel does not fluctuate. Similarly, on no account, should a change be made from "still-pond" to "open-flow" without first closing the canals and scouring the silt from the Pocket—otherwise the silt thrown up by the increased, open-flow discharge, will be "roared" into the canals."

The Barrage first came into operation in 1931. The Left Bank sluices were run with semi-open flow and the Right Bank sluices under "still-pond" according to recommendations. The regulation of the Left Pocket was altered to "still-pond" in the beginning of 1938 with the object of checking the tendency of the River to hug the left bank downstream of the Barrage. There has been no trouble regarding silt on the left bank, as shown by the Model. Similarly scour in the river near the nose of the Left Divide Wall increased when regulation of Left Pocket was altered to "still-pond", as shown by the model. On one occasion the Right Bank undersluices were opened inadvertently while the Canals were flowing. This resulted in a large influx of silt into the Canals thus providing an additional verification of the conclusions drawn from the model experiments.

The predicted silt bank along the right bank formed and to prevent this, it was then proposed after model experiments that a long, submerged curved vane of height = 1/3rd depth of water should be constructed upstream of the canals on the right bank, starting from the Outfall section. This, alone, would have tended to pull the main flow of the river across to the right bank, so a similar vane was proposed for the left bank and model experiments showed that, with these, channels would persist along both banks, bed silt being deflected towards midstream. This recommendation was not, however, acted on. Subsequently, in the floods of 1936, the River carried an exceptionally heavy charge of silt, and a large sand bank formed along the right bank from Bunder Station, to the nose of the Right Divide Wall and heavy silting occurred in the North Western Canal. The original solution—a long vane—being no longer possible, another solution of a new Right Bank approach channel is recommended—*vide* figure 9 following page 12 of the Annual Report for the year 1938-39.

Another demonstration by the model of actual results was the adverse effect on silting of the right bank and the N. W. Canal due to relatively more discharge passing through the right Bukkur-Sukkur gorge as in 1936. When the right gorge in the model was closed, the river straightened as in 1938 in the prototype—*vide* figure 7 following page 10 and figure 5 (b) following page 8 of the 1938-39 Annual Report. *

3. *Model experiments on training the River Sarda above the Barrage at Banbassa.*—*Vide* Annual Reports for the years 1936-37, 1937-38 and 1938-39 of the C.I.H.R.

As recommendations as regards protective work according to model results are taken in hand from this year, field results of measures adopted after model experiments are not available; but the model not merely reproduced changes in course which had actually occurred in the prototype, but showed beforehand what was going to happen thus:—

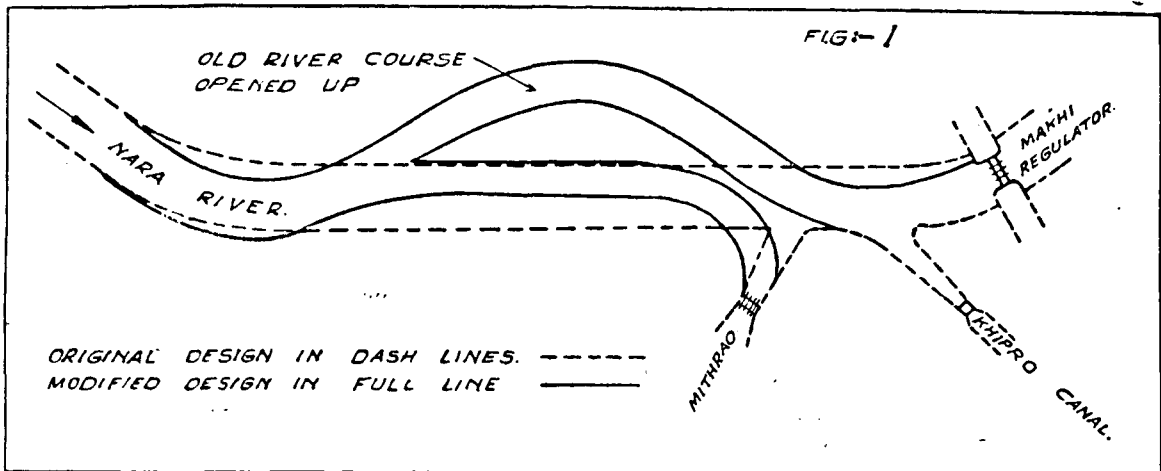
- (1) The model showed that the Western channel would silt up and thus tend to die out. During 1938 floods, the Western channel silted up considerably.
- (2) It was predicted that the boulder bund, which was constructed across the 1937 spill with the object of preventing its further development—shown in figure 12 following page 18 of the 1938-39 Annual Report,* would be washed away. During the 1938 floods, the bund was washed away and the 1937 spill enlarged.
- (3) A cut was made upstream of boulder bund to divert water into the central channel running through the Kala Jala island—see figure referred to in (2) above. The model showed that the cut would be ineffective in developing the central channel. During the 1938 floods, the central channel carried only 2½ per cent. as in previous years.

4. *Remodelling the Mithrao Canal Ex. Nara at Makhi (Sind).*—*Vide* Bombay Public Works Department, Technical Paper 59 "Silt control at Heads of Canals and Distributaries".

Experiments were carried out with a model of the Nara River at Makhi Regulator during 1932-34. The Mithrao Canal derives its supply from the Eastern Nara above the Makhi Regulator; and the Western Nara—which also supplies water to the Jamrao Canal, some miles upstream and the Hiral and other canals downstream was previously a river, which drew its supplies from the Indus at Sukkur. Now it is fed from the Eastern Nara Canal from above the Sukkur Barrage. Coarser silt than previously drawn began to enter the Mithrao in 1932 and the previous drop into the Canal of 2 ft. 6 ins. at Full supply discharge gradually disappeared, so that, command was lost.

*Not included in this Report.

Experiments were therefore carried out to find out how to exclude silt from the Mithrao Canal and the best solution was found to be a separate approach channel for the Mithrao from concave bend upstream—*vide* figure 1.



It was recommended that the old river bed should be partly reopened to carry water to the Makhi Regulator and Khipro Canal; the existing straight channel, after reduction in width, being used as an approach channel to the Mithrao Canal. This lay-out was such that the approach channel took off where the beneficial effect of curvature was a maximum, so that only silt-free, top water entered the Mithrao approach channel, the heavy bed silt being deflected into the river downstream—see figure 1 following page 8 of Part II of the 1937-38 Annual Report of the C.I.H.R.

This recommendation was acted on and “command” was at once restored and the drop into the Mithrao at the Head Regulator gradually increased to 1 ft. 6 ins.

5. *Experiments on training the River Ganges at the Hardinge Bridge (Eastern Bengal Railway).*—*Vide* Bombay Public Works Department, Technical Paper 55 “Investigations carried out by means of model in connection with the protection of the Hardinge Bridge, which spans the River Ganges near Paksey, Eastern Bengal Railway” and the Annual Report for the year 1937-38 of the C.I.H.R.

The 1/500 horizontal scale model reproduced the severe conditions at the head of the Right Guide Bank and also showed the factors which led to these.

Several experiments were done in connection with the Hardinge Bridge, but the only one which it has been possible to verify is the following :—

The model experiments showed that if the Sara Protection Bank were to be abandoned by removing the stones, the flow conditions at the R. G. Bank would markedly improve and the flow would be central to the bridge. Accordingly stones were removed in the prototype before the 1936 floods—*vide* figure 35 following page 38 of the 1938-39 Annual Report*—, and the bank which consists of alternating layers of clay and silt is being allowed to be scoured away. This scour is relatively less rapid in the prototype than in the model, with the results that the flow conditions have not as yet improved to the extent, shown in the model. Qualitative verification has, however, been shown.

6. *Silt exclusion experiments with a model of Faizwah Head Regulator—Ex. West Feeder (Khairpur State, Sind).*—*Vide* Annual Note for 1937-38.

The designed discharge of the Faizwah, which takes off from the Khairpur Feeder West is 310 cusecs. The discharge of the parent channel is 1836 cusecs. The head Regulator of the Faizwah takes off at right angles to the parent channel—*vide* figure 18 following page 10 of Part III of the 1937-38 Annual Report.* Consequently the head reach silted rapidly, the depth of silting in the channel being as much as 2½ ft. and even though the water level in the parent channel was raised by 6 ins., the channel could not pass more than 200 cusecs against its designed discharge of 310 cusecs.

There were two alternative solutions for consideration :—

- (1) a new Head Regulator upstream of the original Head Regulator, taking off just downstream of a concave bend and hence effective in excluding silt,—see figure referred to above.

*Not included in this Report.

(2) remodelling the present Head Regulator.

The 2nd alternative was cheaper than the first, though the former was more safe.

Experiments were carried out with the 2nd alternative.

In the model, which was vertically exaggerated, the left bank was warped to vertical upstream of the head regulator and the channel was made to converge (at 1 in 5 at F. S. L.)—*vide* figure 21 following page 16 of Part III of the 1937-38 Annual Report.* A raised sill was constructed at the entrance of the offtake, at such a level that the depth of water over this was about 0.6 times the depth at F. S. L. in the Khairpur Feeder. The reduced surface width of the parent channel at the downstream end of the offtake was 0.77 times the natural width, due to convergence. The downstream bank diverged at 1 in 10 at the surface and was warped back to natural side slope. This altered design induced curved flow and prevented bed silt from entering the offtake. It was pointed out that although this design of silt excluding head would be successful, provided conditions in the West Feeder did not deteriorate, building a new regulator further upstream on the outside of a bend would provide better and more certain silt exclusion. The latter recommendation was acted on (*i.e.*, a new regulator upstream) and it has been working satisfactorily according to reports from the State Engineer of the Khairpur State.

7. *Remodelling the Dim and Khadro Minors Ex. Jamrao Canal at Mile 17 to exclude silt (Sind).*—The F. S. Q. of the Dim and Khadro Minors taking off from the Jamrao Canal at Mile 17 is 329 cusecs, while the F. S. Q. of the Jamrao Canal above offtakes = 2,760 cusecs. As the minors took off at right angles to the parent channel, they drew excessive bed silt—*vide* figure 2 (a).* Experiments were, therefore, carried out in 1932-33 for remodelling the Head Regulators in order to exclude bed silt.

The vertical exaggeration of the model was 2.5, the horizontal scale ratio being 1/17. A raised sill \cong 85 ft. long was provided in front of the regulators, protruding into the parent channel by \cong 13.5 ft., the surface width of the parent channel being = 136 ft. (or the reduction of waterway = 90 per cent.)—*vide* figure 2 (c). The bed and sides of the Canal were warped to the vertical and back again to $\frac{1}{2} : 1$ in a length of \cong 68 ft. upstream and downstream, so that the convergence at the full supply level, was 1 in 5. Practically no bed silt was then drawn by the minors. In another design, the sill was not protruding but was in line with the toe of the bank—see figure 2(b). This design excluded 50 per cent. of the bed silt, which improvement was considered to be probably more than adequate and hence was recommended.

The modifications were accordingly carried out in August 1933 and in the beginning bed silt was excluded; but in the next year silting began and discharge was reduced thus:—

Dim Minor (designed F. S. Q. = 304 cs. and designed G. R. = 8.2)—

Year.	Maximum	
	G. R.	Q.
1933.	8.7	295
1934.	9.25	285
1935.	9.7	277
1936.	10.5	300
1937.	11.1	272

In this case, therefore, the field results did not agree quantitatively with model results due apparently to wrong interpretation of model results. The remodelling consisted merely of warping the side slopes from $\frac{1}{2} : 1$ to vertical, which would give different results in the prototype, on account of the vertical exaggeration of the model. Thus the reduction in waterway of the main canal was 3 per cent. as against 7 per cent. in the model.

In this case the results of the model were only qualitative, but had the experiments been done now, after more experience with models, the effect of vertical exaggeration would have been allowed for.

8. *Experiments with siphon spillways.*—*Vide* Annual Note for the year 1933-34 for description of siphon experiments with flared outlets.*

Figures 3 and 4 show the full scale 520 cusecs siphon and its 1/8th scale replica, with which experiments were carried out. The flared outlets are shown in dotted lines.

Dynamical similarity with equal Froude No. was obtained in the following respects:—

(a) *Experiments with siphons without flared outlets*—

(1) Discharges in the model and prototype were dynamically similar for relatively the same working heads.

*Not included in this Report.

Experiment No. 1, Original Design
Model of Jamrao Canal at Mile 17
with Head Regulators of Dim and
Khadro Minors.

Scale for plan and section 2' = 1'

Fig. 2 (d) Showing Lines of Flow.

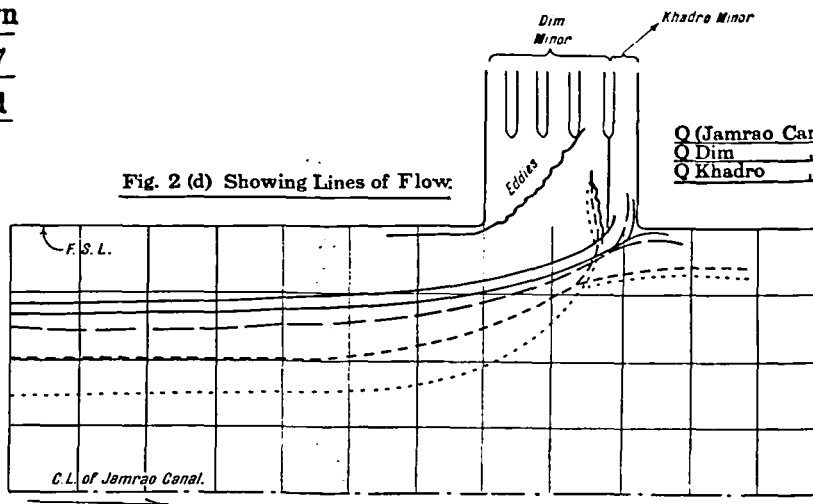
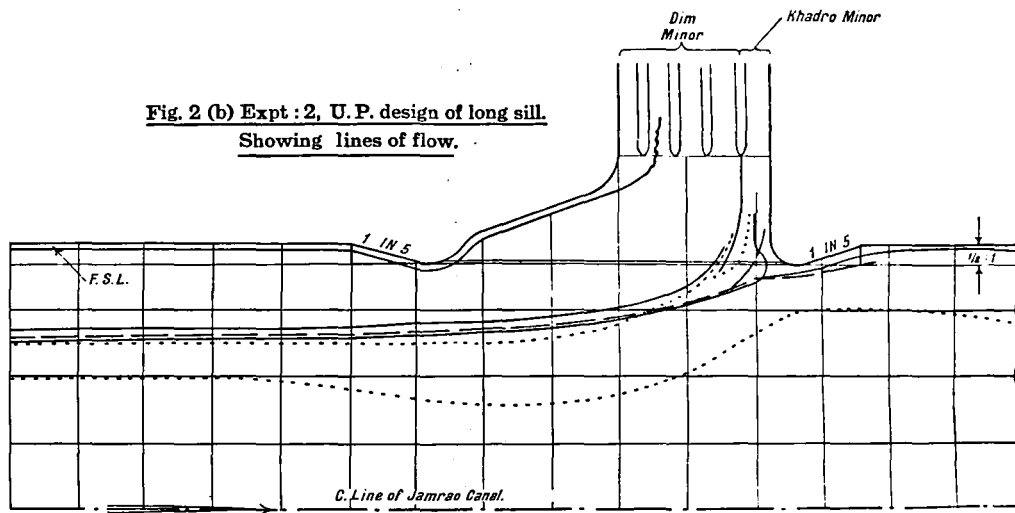
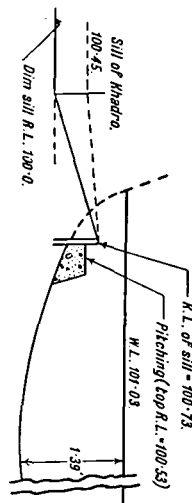
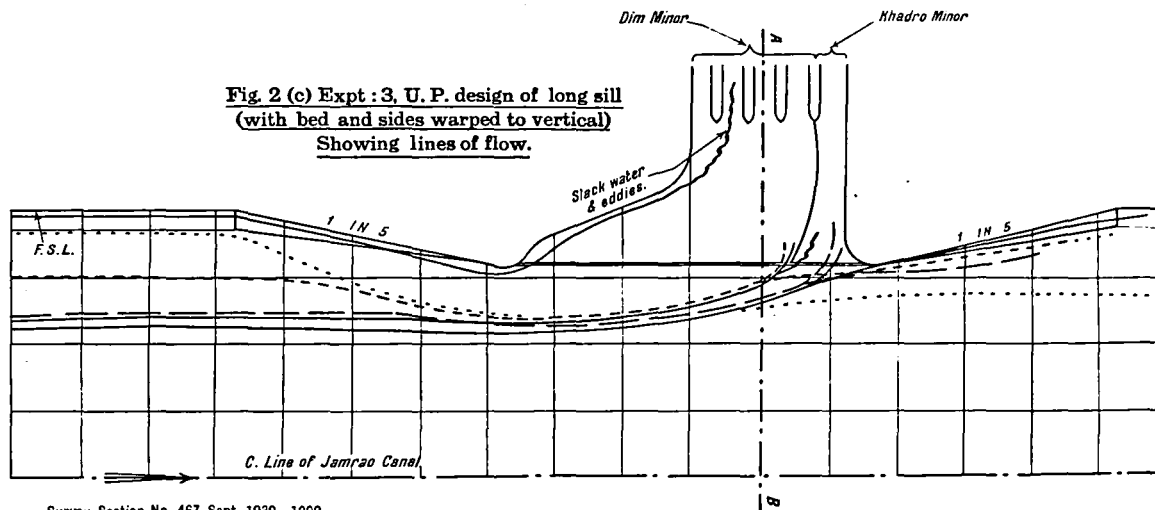


Fig. 2 (b) Expt : 2, U. P. design of long sill.
 Showing lines of flow.



REFERENCES
 Surface
 Mid-depth
 3/4 th depth
 Bed

Fig. 2 (c) Expt : 3, U. P. design of long sill
 (with bed and sides warped to vertical)
 Showing lines of flow.



C. Section on A. B.

FIG : 3, PROTOTYPE

Siphon Spillway at Khadakvasla.

Outer radius = $r_o = 8'$

Inner radius = $r_i = 3'$

$$r_o/r_i = 2.67.$$

Scale $8' = 1''$ (5' dia : X4' width.)

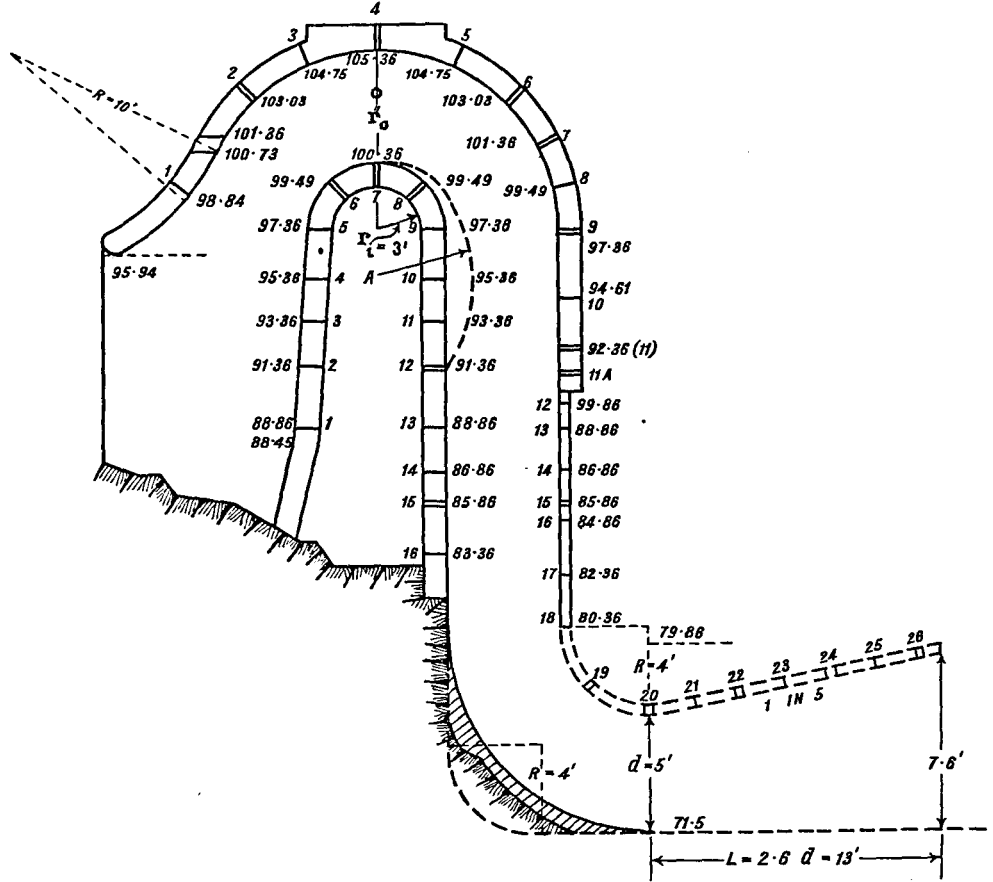
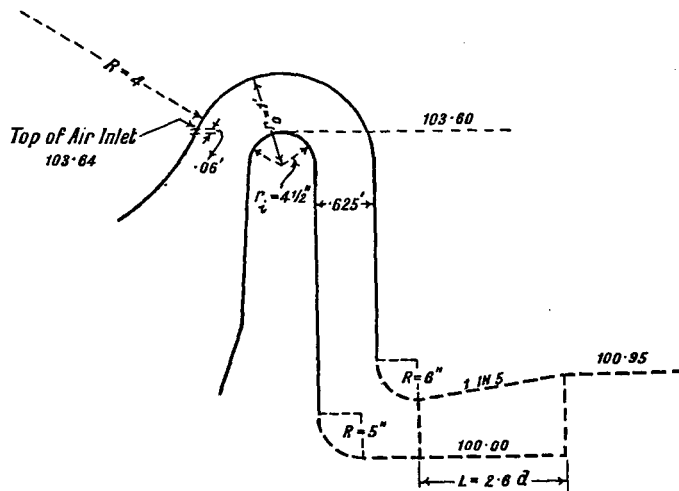


FIG : 4, MODEL (1/8 TH. SCALE.)

3.6' Siphon at Distry : 5. B = 0:5'

$$d = .625'$$

Scale $2' = 1''$



- (2) The pressures observed at various points on the inner shells of the model and full scale siphons nearly corresponded. The pressures on the outer shell were slightly less in the model, but a close approximation to dynamic similarity in pressures was obtained.

The nature of the priming curve was similar in model and prototype (i.e., the curve showing the relationship between priming depth = $\frac{\text{depth u/s over sill of siphon crest at which siphon begins working}}{\text{diameter of siphon}}$, and the vertical

drop or the distance between the lip of the downstream leg of the siphon to downstream water level when siphon primes). Priming was, however, not dynamically similar, the priming depth in the model being relatively greater than in the prototype, other conditions being equal. This was expected as priming depends on the evacuation of air by the flow of water which is not similar under conditions of equal Froude No.

- (b) *Experiments with siphons having flared outlets.*—In the model, when the flared outlet was added, the full supply discharge increased from 2.71 to 3.54 cusecs, i.e., an increase of 30 per cent.; whereas in the prototype, the discharge increased from 503 to 518 cusecs, i.e., an increase of only 3 per cent. That the increase in discharge as a result of flaring would be small in the prototype was foreseen, because the prototype had been designed with the pressure as near the limiting pressure as was considered safe, and it was clear that cavitation would take place if the discharge were increased. Cavitation occurred just downstream of the end of the crown arch at crest, shown at A in figure 3, and no further increase in discharge was possible. Cavitation limits the discharging capacity of siphons but can be reduced by reducing the curvature of the arch.

9. *Experiments with a model of the Head Sluices of the Nira Left Bank Canal (Bombay).*—*Vide* Bombay Public Works Department, Technical Paper 54.

The regulator at the head of the Nira Left Bank Canal (at Vir) consists of 7 spans each span 4 ft. wide, with upstream gates 4 ft. \times 4 ft. The sluices are 9 ft. long and have arched tops. On account of irrigation development, F. S. Q., of the Canal had to be increased from 455 cusecs to 720 cusecs; and according to the original proposal, this was to be done by increasing the number of spans to 10.

Experiments were carried out with a geometrically similar model and it was found that the increased discharge of 720 cusecs could be passed through the existing 7 sluices with a head of only 2 ins., provided a bellmouth upstream and 1 in 10 diverging walls of bed, top and sides downstream were constructed.

The recommended design has been carried out at a cost less than 1/3rd the estimated cost of the first proposal and the prototype results are in agreement with model results.

10. *Tando Mastikhan Fall on Rohri Canal (Sind).*—The fall at Tando Mastikhan is at R. D. 119, 979 ft. on Rohri Canal (Sind) and is combined with a road bridge. The full supply discharge is 10,590 cusecs and the drop in water level is 8.07 ft. It was necessary to design the fall, so as—

- (a) to be able to measure the discharge,
- (b) to ensure proportionality of discharge (i.e., avoid afflux and draw-down),
- (c) to dissipate energy,
- (d) to ensure sweet flow at the surface, d/s of the fall,
- (e) to prevent downstream scour by correct redistribution of velocities, and
- (f) to protect the downstream channel bed and sides.

Model experiments were carried out at Poona in 1928-31 and are described in the Bombay Public Works Department, Technical Paper 44 "Dissipation of energy below falls".

The design adopted was that of proportional Standing Wave Flume Meter Fall with a baffle, cistern and deflector. The ratio of bed width/depth was 20.0 and the permissible side divergence was found, from a model, to be 1 in 10; but as the fall had already been constructed with sides diverging at 1 in 5, experiments showed that vanes in continuation of piers were necessary to fan out the flow properly.

It has been reported that the baffle is effective in dissipating energy and the fall is working satisfactorily, there being no trouble due to bed scour. Similarly in the distribution of velocities downstream of the fall and the wavewash near banks is not, however, obtained in the prototype and model; and this was found to be due to the alignment of vanes in the prototype not being constructed similar to that in the model.

Verification of model results on the prototype.

By H. L. UPPAL.

Comparison of results obtained on the model and those obtained on the prototype after constructing devices recommended from the model study is made in the following three cases. The three cases are very different regarding design of work, discharge, etc.

Panjnad Weir.—At Panjnad deep scour holes occurred every year at the downstream end of the work. On a model of Panjnad weir tests were made to determine the most satisfactory design of protection. On the recommendation of the laboratory certain devices were constructed on the actual in 1935-36. Reports received from the Executive Engineers show that the bed instead of scouring has silted up by the construction of the devices.

Salampur feeder.—Scour holes of about 13—15 ft. depth occurred below rapids on the Salampur Feeder. Model tests also showed heavy scour with a plain floor. When the floor was protected by means of staggered blocks depth of scour was reduced to nil. On constructing the blocks on the actual the downstream of the work silted up.

Mongtanwala Sayadwala Head Regulator.—Line of maximum velocity observations were taken in the presence and in the absence of staggered blocks on the model and on the prototype. Perfect agreement between the two cases is obtained.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

The Chairman, MR. T. M. LYLE, said that the general note gave information from abroad but more information was needed from India.

MR. A. R. THOMAS said that exact similarity between a model and its prototype could not always be expected, and was the exception. The model is a guide. He referred to the results given in his note on pages of these Proceedings.

MR. GERALD LACEY stressed the importance of reproducing in a model the type of turbulence occurring in the prototype.

It was not infrequently assumed that provided the critical Reynolds number, differentiating stream line flow from turbulent flow, was exceeded all was well with the model. This was very far from being the case. The subject had been handled very skilfully in a recent paper presented by Colebrook on Turbulent Flow in Pipes to the Institution of Civil Engineers. There were four types of flow :—

- (1) Viscous stream line flow,
- (2) Smooth turbulent flow,
- (3) Transitional turbulent flow,
- (4) Rough, or fully turbulent, flow.

Of these the third type presented the greatest difficulty in analysis.

ALLEN had also presented a paper to the same Institution on a model of the River Mersey which was so small, that it was evident that he was working in stage (2) in the model whereas in the prototype the third and fourth stages were involved.

MR. THOMAS said it depended on what you were trying to find out. For exact replication the exact Reynolds Number and geometrical similarity were essential.

DR. N. K. BOSE pointed out that such a stipulation would mean that the model would be the same size as the prototype.

MR. THOMAS said that exact replication was rarely necessary. It was usually sufficient to reproduce the same type of turbulence as pointed out by Mr. Lacey.

Even in the case of an open channel the same Reynolds Number could be ensured. However it is not always essential to get exact similarity, and the higher the Reynolds Number the nearer the similarity.

DR. BOSE enquired what Mr. Lacey meant by smooth turbulent flow.

In reply MR. LACEY stated that for the viscous stream line flow the equation—

$$\frac{V^2}{gRS} \propto \frac{(RV)}{N}$$

held good. This equation was that of Poiseuille, and was rigidly correct.

When the flow became turbulent, but before the irregularities had begun to shed eddies, the region of "smooth turbulence" was entered.

For this condition the relation—

$$\frac{V^2}{gRS} = F'' \frac{RV}{N}$$

was correct. It would appear that the function was not an exponential function in pipes but logarithmic. For a limited range of observations however, an exponential function could always be found to fit them.

The exponentials had the common characteristic that if they were written in the form

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

the indices were connected by the equation $a = 3b - 1$, in fact if that relation held good the flow must be in the smooth turbulent region.

The equation of Blasius—

$$V \propto R^{\frac{5}{7}} S^{\frac{4}{7}}$$

was for smooth turbulent flow and satisfied this relation. It was possible also to produce an equation $V \propto R'' S''$, almost indistinguishable from that of Manning, fitting a large range of observations from large smooth pipes which effectively had no roughness coefficient at all.

When flow was fully turbulent in pipes—

$$V \propto \sqrt{gRS F'' \left(\frac{R}{d}\right)}$$

in which R/d denoted the roughness ratio.

If the Prandtl relation for pipes were accepted for open channels the ratio R/d would not be exponential but logarithmic. The transitional stage was one of great difficulty.

DR. BOSE said that what was really being done was the division of the Reynolds Number range into three parts.

MR. LACEY, "Four parts in all, the first part purely viscous, the remaining three parts different types of turbulent flow".

MR. THOMAS, commenting on a diagram drawn on the black-board by Dr. Bose, noted that he (Dr. Bose) had given a figure of 10 as the Reynolds Number at which smooth pipes became rough. Mr. Thomas said this depended on the roughness of the pipes.

MR. THOMAS presented a picture to simplify the concept of turbulent flow. "Imagine a channel of such roughness that it has no laminar layer, the loss of head being proportional to V^2 . Now reduce the roughness until it has no effect, i.e., it is fully covered by the laminar layer. This is smooth turbulent flow, and in between is the transitional range in which both the laminar layer and roughness play a part".

MR. LACEY referred to such models as those of siphons, where cavitation might occur in the prototype and not in the model. He said that in Sweden they had made experiments on turbine models under reduced atmospheric pressure.

MR. THOMAS thought this was an unnecessary refinement, as it was always possible to limit model experiments to pressures corresponding to those at which cavitation would not occur in the prototype.

DR. BOSE referred to Mr. Thomas' statement on scour round rigid structures on page 36. He asked whether scour could be predicted.

MR. THOMAS replied that it is possible, by experimenting with models of two scales, to deduce from the results the extent of scour in the prototype.

DR. BOSE asked if correct scour could be obtained in a distorted model if the water levels were correct. "Not in detail", replied Mr. Thomas.

MR. LACEY said that it was important to consider what it was desired to reproduce. For example in distorted models of the Mississippi River the main consideration was to reproduce stage conditions.

DR. BOSE said that Vogel's experiments on models of the River Mississippi are very interesting and show what can be attained in such experiments with proper care and judicious handling of the model.

A number of model results on the Mississippi carried out at the U. S. Waterways Experimental Station Vicksburg, Mississippi, U. S. A. are quoted by Mr. H. D. Vogel in a paper entitled "Hydraulic Laboratory Results and their verification in Nature". He gives instances of the following models:—

1. The Brooks Point Model.
2. The First Charters Model.
3. The Point Pleasant Model.
4. The Morrison Towhead Model.
5. The Walkers Bar Model.
6. The Stewart Bar Model.
7. The Island No. 9 Model.

The agreement shown in the figures of the model and the prototype is almost complete. Dr. Bose showed here four figures of the Brooks Point Model.

MR. THOMAS referred to figures 26 and 27 of his Annual Report*. These figures are of the Watrak River Model and provide a comparison between a geometrically similar, and a distorted model under similar conditions.

Both DR. BOSE and MR. THOMAS agreed that in general the distorted model is more correct than the geometrically similar model for reproducing rivers.

DR. BOSE referred to the Emerson Barrage model. During construction the river was forced to flow entirely through its right hand channel. The gauges predicted by the distorted model and actually experienced at site are given hereunder:—

Date.	Discharge.	Prototype.	Model.
8th July 1938	85,588 cusecs	486.2 R. L.	485.6 R. L.
28th June 1938	133,433 "	487.19 "	487.0 "
18th May 1938	150,665 "	488.7 "	488.0 "
17th June 1938	105,917 "	487.4 "	487.5 "
13th June 1938	187,809 "	488.4 "	488.3 "
26th July 1938	300,000 "	489.5 "	489.7 "

MR. M. L. MEHTA mentioned the trial fall on the Montgomery-Pakpattan Link, which was tested by model experiments at the Punjab Irrigation Research Institute. The prototype had failed by out-flanking. In the model experiments they had failed to take account of the type of soil in which the fall was to be constructed. Soil conditions should always be studied.

MR. H. S. KAHAI quoted three cases in Sind where scour holes in the prototype had silted up as predicted by model experiments, i.e., (1) the Prishada Division Canal, (2) the Pimiani Canal, and (3) the Anam-dara Fall.

After further discussion it was Resolved that :

"This meeting notes that, in several instances in India, information is available of the success of model experiments as shown by results subsequently obtained in their prototypes. The continued collection of data of field results of measures adopted after model experiments is most desirable.

* Not included in this Report.

In the great majority of experiments concerning erosion, silt movement and river training, the results shown by a model are not similar in all respects to those which would be obtained under corresponding conditions in the prototype, and the qualitative nature of the model results must be recognised.

For canal works it is possible after a period of 12 months to compare the results on the prototype with those obtained on the model.

It is impossible to state the length of the period required for comparison in the case of river models. The necessary observations should be made at the end of each flood season to enable a progressive comparison to be made between the model and the prototype."

CONSIDERATION OF THE SUBJECT "FIELD RESULTS OF MEASURES ADOPTED AFTER MODEL EXPERIMENTS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 9TH NOVEMBER 1939.

MR. A. GORDON, the President, referred to the notes and discussion at the 9th Research Committee contained in the preceding pages. He said that there was considerable evidence of agreement between prototype and model.

DR. E. MCKENZIE-TAYLOR considered it was important to take observations yearly which follows from the resolution of the 9th Research Committee.* He had recommended the recording of cross sections.

MR. E. O. COX remarked on the influence of the presence of clay in a prototype, which might cause results differing from the model predictions. He said that spurs had been placed below the Islam Weir by Messrs. Murphy and Bedford. The summer flow was about 40,000 cusecs and the channel accommodated itself to a waterway of 5 to 6 hundred feet in width. Owing to the presence of clay the model results were not reproduced. They were now proposing to remove the clay, and by next June (1940), he hoped to be in a position to say whether or not the model complied with the prototype.

MR. F. F. HAIGH said that in the case of the Trimmu Weir, certain river discharges were assumed and run on a model. Actual river discharges had since proved quite different to those assumed. He failed to see how correct results could be expected.

DR. MCKENZIE-TAYLOR, "You get an indication".

MR. S. H. BIGSBY stressed the necessity of testing a model again if any change, were made in the prototype design.

MR. T. M. LYLE said that the Central Irrigation and Hydrodynamic Station, Poona, had recommended a certain length of spur for the Sarda River at Bansbassa. He (Mr. Lyle) had accepted the recommendation, but when the construction was three quarters completed, he received a letter from Mr. Inglis, the Director, asking him to increase the length of the spur by 150 feet. This could not be done for both financial reasons, and lack of time before the flood season. Since then, Poona was experimenting further with the shorter spur.

MR. A. ORAM, "If model recommendations cost a lakh, and you have not got it, what is to be done?"

MR. BIGSBY, "I quite agree. Some recommendations made by Research Officers are very expensive."

THE PRESIDENT said it would be interesting to hear how much some of the model work was costing.

DR. MCKENZIE-TAYLOR said that the Khanki model had cost Rs. 20,000; the Islam Rs. 1,500, and the Bias Rs. 1,500.

MR. LYLE said that the first Sarda model made at Poona had cost them Rs. 8,500; the next Rs. 2,500.

MR. F. A. FARQUHARSON considered it necessary to draw up a list of the important prototypes which are being observed, and to keep the list up to date year by year.

MR. BIGSBY said that orders had been issued in the Punjab on reporting the results of models, and he would send a copy to the Board's Secretary.

Resolved "THAT THE RESOLUTION OF THE 9TH RESEARCH COMMITTEE* IS ENDORSED, AND IN ADDITION IT IS RECOMMENDED THAT NO ALTERATIONS IN DESIGN SHOULD BE MADE WITHOUT REFERENCE TO THE EXPERIMENTING OFFICER, AND THE LATTER SHOULD ISSUE INSTRUCTIONS AS TO THE DATA REQUIRED TO BE COLLECTED TO PROVE WHETHER A PROTOTYPE IS BEHAVING AS PREDICTED BY THE MODEL."

* Vide page 43.

DESIGN OF CANAL FALLS

PRELIMINARY GENERAL NOTE

The first resolution, or rather conclusion, reached by the Central Board of Irrigation appears in the Minutes of the 1st Meeting of the Board held in November 1931, and the subject has been discussed and resolutions passed at every subsequent annual Meeting of the Board with the exception of the 1934 Meeting.

Resolutions on the same subject have been passed at the 4th, 5th, 6th and 7th Meetings of the Research Committee of the Board covering the years 1934 to 1937.

This is an indication of the complexity of the subject, and no attempt will be made in this general note to go into details.

Type of Fall Favoured by the Central Board.—The conclusion reached at the 1st Meeting of the Central Board in November 1931 is as follows :—

- (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 a little above and below full supply level.

Notched Falls.—The 2nd Meeting of the Central Board in November 1932 resolved that "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".

Sharp Crested Weirs.—The 1932 Board Meeting also resolved that "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."

Contraction of the Crest.—The 1932 Board Meeting also resolved that "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 shows that radial diaphragms on the glacis are effective for this purpose."

Use of a Deflecting Wall or Baffle.—The 1932 Board Meeting also resolved that "Attention is also invited to a deflecting wall or baffle, described in Bombay Technical Paper No. 44 by C. C. Inglis (S. E., 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."

Type Designs of Falls.—At the 1936 Board Meeting it was "resolved, after consideration of the Resolution of the Research Committee on this subject, passed at the annual meeting in July 1936, that the preparation of type designs of falls should be postponed until such time as a more comprehensive study of the design of such works has been made."

The 1937 Board Meeting resolved that "The Board accepts the opinion of the Research Committee that comprehensive research into the subject of the design of canal falls is desirable, and that until such research has placed the principles of design beyond dispute, it is inadvisable to record any recommendation in favour of any type of design for general application."

Financial Criterion.—The 1938 Board Meeting resolved that "In the opinion of this Board the most satisfactory design of canal fall is one which, while meeting requirements satisfactorily, costs least in terms of capital cost plus capitalized cost of repairs."

Resolutions of Research Committees on the Subject of Canal Falls.—The Resolutions of the Research Committees stress the importance of Mr. Gunn's experiments on the Protection below Khanki Weir (Punjab Irrigation Research Institute Research Publications, Vol. II, No. 8 and Vol. II, No. 12).

For some time it has been considered necessary that a comprehensive note from Mr. Inglis, Director of the Central Irrigation and Hydrodynamic Research Station, was an essential preliminary to further progress, but owing to his onerous duties Mr. Inglis has not yet been able to present the note.

Comparison of Flumed with Full Width Falls and Effects of Varying Cistern Depths.—The 1933 Board Meeting resolved that

- "(i) For the purpose of comparison with the model experiments already complete 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 depth of the channel.
- (ii) Experiments should be conducted as far as possible for the same variations of discharge as were utilised in the former experiments, and to include one at a discharge of about 25 cusecs per foot run of sill in the prototype.
- (iii) The experiments also to include enquiry into the effects of varying cistern depth if time permitted."

The experiments were duly carried out and the results given in the "First Note on Experiments with Falls at Khadakvasla" dated 14th July 1934. No definite conclusion is reached.

Recent Developments.—Three alternative types of flumed fall have been constructed on the new Montgomery-Pakpattan Link in the Punjab. The designers are Messrs. Montagu and Inglis, and the Central Design Office, Haveli Project. The model work in connection with the Inglis design is described in the 1937-38 Annual Report of the Central Irrigation and Hydrodynamic Research Station.

In addition to proving the value of the three types, valuable information is expected to be obtained on the use of models in designing this type of structure.

Successful Falls Constructed in the Past.—In the Information Bureau of the Central Board of Irrigation 74 drawings have been prepared of falls constructed in India which have proved eminently successful in operation.

The discharges vary from 13 cusecs to 10,591 cusecs divided into groups with costs added where available as follows:—

Group.	No. of Falls.	Range of Drop in Feet.	Cost per cusec per ft. drop in rupees.
Under 50 cusecs	6	2.36 to 2.94 .	..
50 to 100 cusecs	4	2 to 6 .	3.6
100 to 200 cusecs	5	0.8 to 9.88 .	1.3 to 9.8
200 to 300 cusecs	9	2.2 to 12.55 .	0.65 to 4.0
300 to 400 cusecs	3	3.4 to 6.45 .	5.0
400 to 500 cusecs	4	4.49 to 6.06 .	6.2 to 10.6
500 to 600 cusecs	5	2.0 to 5.0 .	2.6
600 to 700 cusecs	4	2.0 to 5.52 .	1.75 to 3.8
700 to 800 cusecs	1	6.0	..
800 to 900 cusecs	4	2.99 to 5.05 .	4.7 to 5.7
900 to 1,000 cusecs	3	4 to 8.25 .	4.5

Group.	No. of Falls.	Range of Drop in Feet.	Cost per causee per ft. drop in rupees.
1,000 to 1,500 cusecs	10	2.26 to 16.0 .	0.57 to 5.6
1,500 to 2,000 cusecs	3	2.13 to 8.0 .	1.7
2,000 to 3,000 cusecs	8	2.18 to 11.0 .	0.8 to 1.7
3,000 to 4,000 cusecs	1	3.0 . . . . .	..
4,000 to 5,000 cusecs	2	5 and 5.75 .	1.7
5,000 to 6,000 cusecs	2	1.9 and 4.5 .	1.3 and 4.7
6,000 to 7,000 cusecs	1	6.5	2.6
7,000 to 8,000 cusecs . . . . .	..	.. . . . .	..
8,000 to 9,000 cusecs	1	5.36	1.5
9,000 to 10,000 cusecs	1	6.00	2.3
10,000 to 11,000 cusecs	1	8.07	1.5

The above falls include examples of flumed, notched, baffle wall and cistern protected falls.

POINTS FOR DISCUSSION.

RESULTS OF THE OPERATION OF THE TRIAL FALLS ON THE MONTGOMERY-PAKPATTAN LINK.

The advisability or otherwise of continuing this item on the Agenda of the Research Committee Meetings.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

Dr. N. K. BOSE said they had not been able to run full discharge in the Montgomery-Pakpattan Link to test the three alternative designs of falls. When partial supply was run the lowest or Central Designs fall had failed by out-flanking.

Mr. M. L. MEHTA described the failure of the Central Designs fall. The soil was composed of fine sand with a clay content less than 10 per cent. and a pH value of 10. This soil would not withstand the steep hydraulic gradient of 1 in 6 with which the fall was designed, and failure by out-flanking resulted.

Mr. A. R. THOMAS referred to the model work done at the Central Irrigation and Hydrodynamic Research Station on falls for the Montgomery-Pakpattan Link (*vide* page 9).

Dr. N. K. BOSE enquired how the down stream expansions were calculated.

Mr. THOMAS said they were evolved from the experimental results on two models.

Dr. BOSE pointed out that in models the S curve divergence showed the worst results, whereas in the prototype this form of expansion proved best.

Mr. GERALD LACEY remarked that the degree of divergence, or expansion was properly a function of the channel, that is to say a function of the entire cross section and not of the divergence of the sides. The divergence was a function of scale and small models could work perfectly to a divergence which was inadequate when applied to the prototype. He emphasised the need for fundamental experiment work in this connection.

Mr. T. BLENCH enquired if there had been any experiments to show how glacia slope affected the adhesion of water to the divergence, and was informed that no such experiments had been made.

Mr. BLENCH said he attached importance to the glacia design as a factor affecting spread. Thus the Montagu semi-gravity parabolic design might owe much of its effectiveness to the flat glacia top giving an initial spread to the jet from the throat.

Mr. LACEY mentioned falls which had been flumed on the Mat Branch with an expansion of 1 in 5. The economy had been swallowed up in increased maintenance charges. The floors of the downstream transitions were not lined but merely pitched. Baffles had been suggested to distribute the flow but the nature of the floors precluded their construction.

Dr. J. K. MALHOTRA enquired from Mr. Thomas whether he had carried out any experiments to find the best form of profile for the glacia, as he (Dr. Malhotra) had found by mathematical analysis that the Montagu profile, as given in the Central Board of Irrigation Publication on falls, was based on a fallacy in that in giving a maximum horizontal acceleration to the jet, it did not at all reduce the vertical component of the velocity responsible for downstream scour, which was the object it had tried to achieve.

Mr. THOMAS replied that he had not so far taken the shape of the glacia profile into consideration. The Central Irrigation and Hydrodynamic Station was concentrating on the general principles of falls.

Dr. BOSE said the Punjab Irrigation Research Institute was dealing with the problems which arose downstream of falls.

Mr. LACEY considered that the up-stream conditions of a fall were of great importance, and smooth parallel bell-mouthed entries were essential.

The following Resolutions were proposed and accepted: I. *Resolved that jetting downstream of a fall cannot be referred solely to the angles of the downstream walls, but must be considered with reference to the size of the channel, or effectively to its discharge which determines scale. Experiments should be initiated to determine the manner in which one cross section can be expanded to another in a given length without jetting.*

II. *Resolved that the study of all factors above downstream channel water level, including approach contractions, that contribute to jetting is important. Experiments in this connection such as varying the glacia slope from the horizontal to the vertical for each of a variety of falls, should be undertaken.*

CONSIDERATION OF THE SUBJECT "DESIGN OF CANAL FALLS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 6TH NOVEMBER 1939.

MR. A. GORDON, the President, referred to the proceedings of the 9th annual meeting of the Research Committee contained in the preceding pages.

MR. E. O. COX confirmed the failure of the Central Designs fall on the Montgomery-Pakpattan Link. He said he had seen the Montagu and Inglis falls running at half full supply, and in the former the flow down stream looked smoother. In both falls there was side erosion.

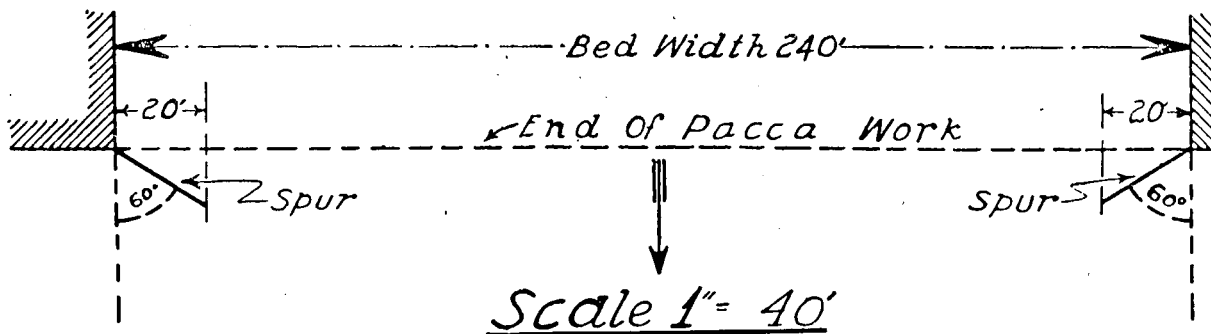
DR. MCKENZIE-TAYLOR said that the failure referred to by Mr. Cox demonstrated the necessity of a careful examination of soil conditions in combination with model experiments. Soil observations on the Montgomery-Pakpattan Link had only been made after the model experiments for the falls were completed.

MR. GERALD LACEY mentioned how falls of identical design on the Sarda Canal system showed varying results according to the soil conditions.

MR. T. M. LYLE said that he had discovered cases of scour down stream of falls which were due to the crests not being perfectly level. Correction of the crest levels had cured the trouble.

THE PRESIDENT referred to the resolution of the 9th Annual Meeting of the Research Committee on the comparison of results on the prototype with those obtained on the model,* and said that in view of this resolution, and the resolution of the 8th Board Meeting,† they had better await further developments on the Montgomery-Pakpattan Link.

MR. COX said he would send further results obtained on these falls to the Secretary for the information of the Board. He said that in the case of other falls in the Punjab where side erosion had occurred downstream, they had stopped the trouble by a pair of spurs at the end of the pacca work as sketched. In the case of the Upper Chenab Canal—240' bed width—these spurs extended 20' into the channel.



MR. COX, continuing, said that they were going to plot the actual velocities downstream of the Montgomery-Pakpattan link falls for comparison with the models.

THE PRESIDENT said a perfectly satisfactory fall could be designed, but the trouble was the side scour. The 4th Board meeting had expressed the opinion that protection against lapping was not susceptible of theoretical treatment and could best be met by a layer of gravel or broken brick a little above and below full supply level.

In reply to a request from the President, Rai Bahadur Khosla said that model tests had been carried out for the falls on the All-American Canal, but the prototypes had not been tested as the Canal had not yet been run. He said he would send the test results to the Secretary.

Resolved "THAT AFTER CONSIDERING THE REPORT OF THE NINTH RESEARCH COMMITTEE MEETING, THIS BOARD CONSIDERS THAT THE SUBJECT OF DESIGN OF FALLS SHOULD CONTINUE AS ONE FOR INVESTIGATION, AND FOR CONSIDERATION BY THE BOARD."

* Vide page 43.

† Vide page 46.

MEANDERING OF RIVERS.

PRELIMINARY GENERAL NOTE.

In October 1938 the Central Board issued a Questionnaire on the Meandering of Rivers.

Factors Affecting Tortuosity.—Very Conflicting evidence was received in reply from which relatively few points emerge in a fairly certain manner. These are :

- (a) that erosion leads to tortuosity
- (b) that the soil composing the banks has a definite influence
- (c) that sudden rises in discharge affect tortuosity
- (d) that obstructions such as weirs or bridges increase tortuosity

Auxiliary points of importance are that the mass of evidence shows :

- (e) that sharp loops in a river are not a sign of decay
- (f) artificial cut-offs are not successful and cause compensatory lengthening of the channel downstream and even upstream
- (g) embankments do not affect tortuosity.

Silt Burden in Relation to Tortuosity.—Evidence on the effect of the silt burden is very conflicting, and the replies to the Questionnaire leave us without a conclusion.

Limiting Width of Meander Belt and Meander Length.—In the National Geographic Magazine for October 1902 there are given data for 23 rivers on flood plains showing that there is a good suggestion of a constant value in the ratio $\frac{\text{Width of meander belt in feet.}}{\text{Width of river in feet.}}$. The mean meander ratio is 17·6.

In the case of incised rivers this ratio is higher and averages 30·6, based on the data from 30 rivers. There is not so much agreement in this type of river. The Seine, Oise and Marne have exceptionally high ratios.

Analysing the data above referred to, Mr. Inglis, Director of the Central Irrigation and Hydrodynamic Research Station, arrives at the conclusion that M_b (the width of the meander belt in feet), M_l (the meander length), and W the river width (*i.e.*, P wetted perimeter) all vary as $Q^{\frac{1}{2}}$ —in other words are scalar—; and that the meander length is of the order of $10 P$ or roughly $25 Q^{\frac{1}{2}}$ to $30 Q^{\frac{1}{2}}$.

No definite information was received from India on these points in reply to the Questionnaire.

Other Influences Affecting Tortuosity.—That some relation exists between river-windings and tributary streams is indicated by studies of the Thames, near London, the Rhone and the Severn (The Geological Magazine, March 1908).

The Questionnaire did not contain any reference to this side of the problem.

POINTS FOR DISCUSSION.

Has further investigation corroborated the apparent relation between meander width and length with width and discharge of a river ?

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

No further information was forthcoming and discussion centred around the definition of meandering.

It was resolved :

"Meandering is defined as the adoption of a continually varying sinuous path by the deep water channel (*thalweg*) of an alluvial river, not imposed by external constraint."

CONSIDERATION OF THE SUBJECT "THE MEANDERING OF RIVERS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 6TH NOVEMBER 1939.

After referring to the note and discussion of the 9th Annual Meeting of the Research Committee dealing with this subject, which appear above, Mr. A. Gordon, the President, asked Mr. Shaw to favour the Board with his remarks.

MR. J. SHAW said that he had a classification, but before laying it before the Board he would like it vetted by Mr. Inglis.

Orissa would like the subject kept open as it was one of great importance to them.

On the average their rivers conformed with Mr. Inglis' conclusions ; that M^2 (the width of the meander belt in feet), M , (the meander length), and W , the river width (i.e., P , wetted perimeter) all vary as $Q^{\frac{1}{2}}$; and that the meander length is of the order of $10 P$, or roughly $25 Q^{\frac{1}{2}}$ to $30 Q^{\frac{1}{2}}$.

Mr. Shaw, continuing, said that in Orissa their embankments are marginal and close to the river.

MR. AITKEN asked how it was possible to lay down the meander belt of a river.

THE PRESIDENT instanced the case of the Indus. According to the formula advanced by Mr. Inglis, the Indus would meander about $17\frac{1}{2}$ miles. This gives the distance to which marginal embankments should be retired. Meandering does not include evulsions.

Resolved " *THAT THIS BOARD ACCEPTS, FOR THE TIME BEING, THE DEFINITION OF MEANDERING SUBMITTED BY THEIR NINTH RESEARCH COMMITTEE.*

FURTHER DISCUSSION ON THIS SUBJECT WILL BE POSTPONED UNTIL AFTER THE RECEIPT OF THE DIGEST OF THE DIRECTOR, CENTRAL IRRIGATION AND HYDRODYNAMIC RESEARCH STATION."

SILTING OF RESERVOIRS.

PRELIMINARY GENERAL NOTE.

Estimating Life for a New Reservoir.—The life of a proposed reservoir may be estimated in two ways :

- (1) By considering river discharge and the percentage of silt contained in the water.
- (2) By comparison with existing reservoirs.

River Discharges and the percentage of Silt Contained in the Water.—The percentage by weight of dry suspended silt has to be converted to volume of silt deposited in the reservoir by applying a factor to convert weight of dry suspended silt to volume of moist silt, such as would compose reservoir deposits.

It is this conversion factor which has been the source of the greatest trouble.

On these lines, assuming that all the silt would be deposited in the Reservoir, the predetermination of the life of the Elephant Butte Reservoir in the U. S. A. varied from 134 to 233 years, i.e., the rate of silting per annum in per cent. of original capacity might vary from 0.75 per cent. to 0.43 per cent. The actual percentage for the first nine years of the reservoir's existence was 0.97 per cent.

No allowance was made for bed load.

The ratio of the mean annual run-off to the original capacity of the reservoir in this case was 0.45.

The life of the Boulder Dam Reservoir was similarly estimated and placed at 202 years.

The ratio of the mean annual run-off to the original capacity of the reservoir in this case is approximately 0.5.

Bed Load.—The bed load is an unknown quantity. In a second calculation for the Boulder Dam they assumed that the suspended load represented 80 per cent. of the total dry load carried by the Colorado in the form of suspended and bed load.

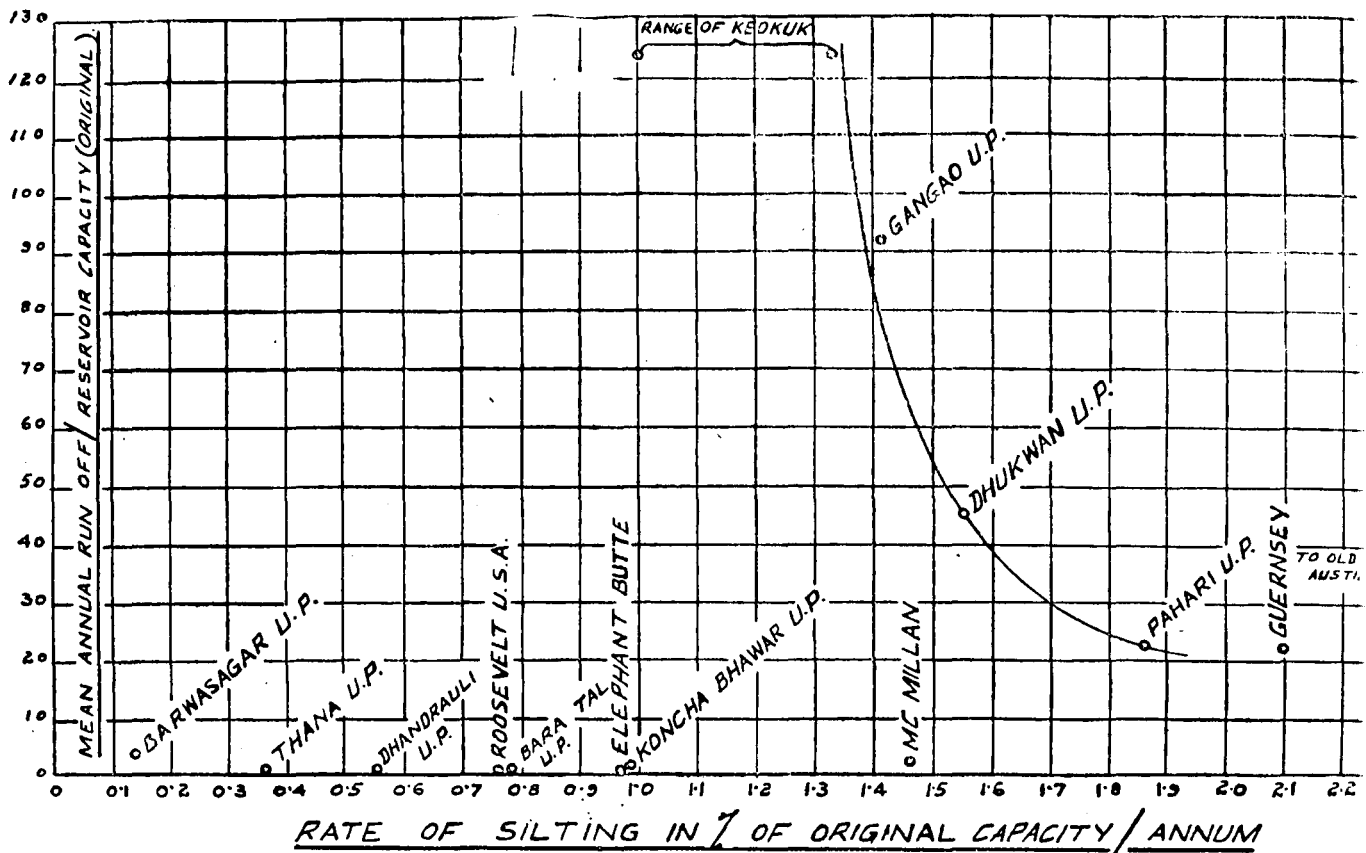
Comparing the actual silting of the Elephant Butte Reservoir with the records of suspended silt in the river (Rio Grande) we are led to believe if the weight in pounds of dry suspended silt is multiplied by a factor $F = 1/47$, the volume of silt in cubic feet which would be deposited in a reservoir on the river in question is arrived at. By the nature of its derivation this factor includes the bed load.

Similar factors could be determined for other rivers on which reservoirs exist.

Estimation of the Life of Proposed Reservoirs by Comparison with Existing Reservoirs.—The determination of factor F on the lines given above and applying it to similar rivers would give us a means of estimating a reservoir's life, provided that the reservoir's capacity exceeded the mean annual run-off of the catchment.

When, as is often the case in India, the reservoir capacity is only a fraction of the mean annual run-off, the best that can be done is to endeavour to find similar reservoirs and see at what rate they have silted. By similar is meant similarity as regards nature of catchment, rainfall and reservoir capacity as compared with the mean annual run-off.

The graph hereunder compiled from the statistics of sixteen reservoirs in India, America and South Africa is of considerable interest because it shows that when the ratio $\frac{\text{Mean annual run-off}}{\text{original capacity of reservoir}}$ exceeds 20, the rate of silting increased with decrease of this ratio in quite a regular manner. But that when the ratio $\frac{\text{Mean annual run-off}}{\text{original capacity of reservoir}}$ is below 5 there is no connection with this ratio and the rate of silting.



Ultimate Capacity of a Reservoir.—A study of existing cases show that a reservoir will continue to silt until channel conditions exist in the silted reservoir upstream. Shuttles could trap water in this channel but the volume so trapped which might be termed the ultimate capacity is relatively very small even with outside shutters. The calculation of this ultimate storage can be made using Lacey's Theory.

Rate of Silting.—Evidence does not show that the rate of silting decreases with the growth of the evil.

Methods of Preventing Silting.—The rate of silting can be checked by afforestation.

For a reservoir that impounds all or a very great proportion of the annual run-off there is no way of preventing silting.

A reservoir impounding only a fraction of the annual run-off can be kept clear of silt by the provision of special facilities for by-passing silt laden flood water as illustrated by the following reservoirs :—

- Amsteg Reservoir in Switzerland.
- Shongweni Reservoir, South Africa.
- Umgeni Reservoir (Proposed), South Africa.
- Nar Nullah Reservoir, India.
- Khushdil Khan Reservoir, India.

The residual storage can be increased by the provision of sufficient gates to lower the flood plane in which case the dam tends to become a barrage.

POINTS FOR DISCUSSION.

The ratio of bed load to suspended load in a river.

The utilization of rates of silting of existing reservoirs in estimating the life of proposed reservoirs.

Note on the silt observation of rivers.

By H. S. KAHAI.

Silt observations are made at the following discharge sites under the control of Government of Sind, twice a week on Tuesdays and Saturdays generally :—

1. Panjnad (on Chenab above confluence) near Daka during the cold season.
2. Mithankot on Indus during the cold season.
3. Saidabad on Indus at Sukkur during the cold season.
4. Outfall on Indus at Sukkur during the whole year.
5. Kotri below Railway bridge on Indus during the whole year.

The section lines at each site along which observations are taken, are generally laid out with pivot and direction pegs marking stations, 100, 50, or 25 ft. apart according to the width of section at each site.

The stations selected for obtaining samples of silt in suspension at the various sites are as under :—

1. *Panjnad at Daka.*—This site is fairly stable and is only changed about 3 or 4 times during the season of discharge observations which is about 8 months.

Discharge section requires to be changed, if any sand banks form above or below it, as this vitiates the angle of flow which we usually try to keep at about right angles.

The discharge site at Panjnad is usually restricted to the width of 900 ft. and if possible less widths are selected ; the reason being that as the discharge sometimes goes very low, velocities become too low for accurate measurement.

The stations on this section for discharge purposes are 50 feet apart and 3 stations are selected equidistant across the section.

For about 6 months out of the 8, there is practically no silt in suspension but if the discharge increases there is certain amount of silt in suspension.

2. *Mithankot.*—Usually 3 stations. The discharge site has to be changed very frequently owing to the formation of sand banks as the river is most unstable at this part. The widths of discharge sections vary from 1,000 feet to 1,600 feet and the number of stations where silt samples are collected vary accordingly.

The stations on this section for discharge work are sometimes 50 feet and sometimes 100 feet apart, depending on the width of the river.

3. *Saidabad.*—Usually 3 stations. This site is also not a stable one. Discharges are observed here for about 7 months out of 12. The site has to be changed usually about 5 or 6 times during the season owing to being vitiated by sand banks and consequent cross channels. The usual widths of this site are between 1,000 feet and 1,500 feet. Usually silt samples are collected at 3 stations about equidistant from one another and from the bank.

At all the above three sites the samples are collected from the surface, 6/10th depth and the bottom.

4. *Outfall.*—This is a stable permanent section of a width of about 3,450 feet. Samples are collected on this section at stations Nos. 6, 12, 17, 22 and 28.

5. *Kotri.*—This is also a stable section with a width of 3,000 feet. The stations selected for silt observation on this section are 7, 12, 17, 22 and 27. Samples are collected from surface, 6/10th depth and bottom at each of the stations of the sections at Outfall and Kotri.

Observations in Field.—The samples are collected from the required positions at each station by means of a metal bottle of 1 litre capacity specially designed to open and close at any required depth.

This bottle is held in a metal framework, by which it is attached to an iron rod which can be lowered to the required depth. The mouth of the bottle is sealed by means of a spring to which a rope is attached. When the bottle has been lowered to the required position tension on the rope raises the spring and opens the mouth of the bottle thus allowing the bottle to be filled with sample water. On releasing the spring the bottle is sealed.

All bed samples are collected as close to the bed as possible.

At each point of sampling velocities are observed and in addition temperatures of water samples and air are also recorded at the time of collection.

Laboratory Work.—The metal bottles containing water samples are taken to office and after properly shaking each bottle the sample is passed through a filter paper which has been previously weighed. The filter papers containing silt are then dried on a steam bath and their weight ascertained. The object aimed at is to ascertain silt in grams per litre. Since each sample is of 1 litre capacity this is readily done, and recorded in column No. 18 of the statement in printed form I. R. C. No. 8 shown on page 55.

Office Work.—The calculations for filling in the columns of the printed form shown on page 55 are made as under :—

1. The weight of silt as ascertained by actually weighing one cubic foot of dry silt is found to be 95 lbs.
2. One c. ft. of water weighs about 62.5 lbs. = 1,000 ounces and 10 ounces sample is $\frac{1}{100}$ of one c. ft. of water = 17.28 cubic inches.
3. Similarly one ounce of water = 437.5 grains.
1 lb. = 7,000 grains.
4. One gram = 15.43 grains.
5. One litre = 1,000 C. C.
6. One C. Ft. = 28.322 litres.

With these basis, figures in each column are filled in as under :—

- Col. 1 to 6 from field observations.
 Col. 7 10 Oz. of water = 4,375 grains.
 Col. 8 Col. 18 \times 4.375.
 Col. 9 Col. 8 to Col. 7.
 Col. 10 Col. 8 \times 100.
 Col. 11 $\frac{1728}{100}$ = 1,728 c. inches.
 Col. 12 Col. 8 \times $\frac{1728}{7,000}$ \times 95.
 Col. 13 Col. 12 to Col. 11.
 Col. 14 Col. 12 \times 100 less .01.

(allowance for the weight of 1 c.ft. of water being a little less than 62.5 lb.)

Col. 15 gives means of 3 samples in Col. 10 for surface, 6/10th depth and bottom for each station.

Col. 16 gives means of 3 samples in Col. 14 of surface, 6/10th depth, and bottom for each station.

Determination of specific gravity.—Col. 17, Specific gravity is determined once in a month-only from samples collected from surface, 6/10th depth and bottom at all the stations selected for silt observations.

After the silt has settled the water is pumped out by means of a pipe syphon. The silt when dry is collected and specific gravity of each sample determined in the Laboratory.

Col. 19 shows the temperatures observed.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

Mr. E. O. Cox said that the Bhakra Dam Project for the irrigation of 4,500,000 acres in the famine areas of the Punjab first came up in 1915. At that time the Sutlej Valley Project was under investigation, and the Government of India refused to sanction the Bhakra Dam until the Sukkur Barrage had been functioning for 10 years.

In the Sutlej Valley Project it was laid down that the Bhakra would take its Kharif supplies from the Sutlej.

In spite of this as there was insufficient flow for the Sutlej Valley Canals, the Bhakra Dam Project would now probably have to rely on storage except for three months in the year when there was ample water in the Sutlej. In the original project samples of water had been taken at Rupal and at the proposed dam site but as the velocities in flood time were from 20 to 30 feet per second it was presumably impossible to take central samples in floods.

There had been various estimates for the rate of silting of the proposed reservoir, but the latest anticipated that the rate of silting would be negligible.

Mr. Cox said he called for information on silting from the Bureau of the Central Board of Irrigation, and after reading this, and Mr. Edgecombe's, "Report on the Silting of Reservoirs," he was alarmed at the prospects.

The proposed canal would have a discharge of 5,000 cusecs from September to June, which involved a reservoir capacity of 2,500,000 A. Ft. given by a 400 feet dam, and they had been up-to-date negotiating with Bilaspur State for permission to build a dam of this height at Bhakra in Bilaspur territory. They were negotiating with Bahawalpur to construct a dam 450 feet in height.

Mr. Cox wished to know at what rate such a reservoir would silt up.

In his opinion silting was related to ;

- (1) total run-off
- (2) state of catchment

INDUS RIVER COMMISSION.

Statement of Silt Observations of the Indus River at _____ for the month of _____ 194 .

Discharge section _____

Observer _____

Computer _____

Station of the Section.	Date.	Gauge M. S. L. of zero.	Total depth of water at station.	Depth from surface of silt specimen.	Velocity of the Indus at observed depth (col. 5.)	DETERMINATION OF SILT BY WEIGHT.				DETERMINATION OF SILT BY VOLUME.				AVERAGE DRY SILT IN ONE C. FT. OF WATER BY		Specific gravity of dry silt.	No. of grains per litre.	Temp.	Remarks.
		Gauge reading.				Weight of water.	Weight of dry silt.	Proportion of dry silt to water.	Weight of silt in one c. ft. of water.	Volume of water.	Volume of dry silt (rammed.)	Proportion of dry silt to water.	Volume of silt in one c. ft. of water.	Weight.	Volume.				
		3				7	8	9	10	11	12	13	14	15	16				
1	2	Ft. dec.	Ft.	Ft.	Ft. per sec.	Grains.	Grains.		Grains.	C. inches.	C. inches.		C. ft.	Grains.	C. inches.				

Forwarded to the Secretary, Indus River Commission, in continuation of this office No. _____ of _____ 193 .

No. _____ of 194 .

Signature _____

Camp _____ 193 .

Rank _____

- (3) slopes of hills
- (4) large flood discharges.
- (5) freshets and floods before the catchment was grassed.

River conditions in Northern India were favourable to the deposition of silt.

MR. COX quoted the Roosevelt Dam in America as an example of freshets causing silting.

The reservoir of the Assuan Dam had not silted because they only stored absolutely clear water.

The proposed Bhakra Reservoir would be 40 miles long. Water entering at a velocity of 15 to 20 feet per second would be retarded to a mean velocity lower than 1 foot per second. In these conditions all the silt would be deposited.

They would not be able to delay storage beyond the 1st August, and all freshets would have to be stored.

MR. F. F. HAIGH wished to know why they could not take silt samples in the river, but Mr. Cox could not give details.

DR. E. MCKENZIE-TAYLOR said that at the Punjab Irrigation Research Institute they used Kennedy's method in taking silt samples in canals. He considered the accuracy of bottle sampling to be very questionable. In his opinion they should also estimate the clay content in silt samples, as it had an important influence on the volume of the deposit.

MR. T. M. LYLE said that in the United Provinces their dams were located in Bundelkhand and were losing considerable capacity by silting as their sluice power was very limited and the reservoirs were full during the greater part of the flood season.

MR. BIGSBY asked if any information was available about the silting of a natural reservoir such as the Wooler Lake. Mr. Cox said there was not.

MR. J. P. JAIN referred to the graph on page 52. He handed round an enlarged graph containing information from 40 reservoirs in addition to those included in the graph on page 52. His graph showed that there was no relation between the rate of silting per annum in per cent. of original capacity, and the mean annual run-off/original reservoir capacity, even when the latter exceeds 20.

MR. GERALD LACEY enquired whether Mr. Cox was considering the sources of silt, i.e., the river tributaries.

MR. COX said he was, and that the cost of an effective retardation works on the tributaries would be 30 lakhs of rupees.

MR. COX suggested that when the reservoir had silted up it would still be possible to generate power, and a water supply could be obtained from tube wells in the area irrigated. For power they needed a minimum head of 200 feet.

MR. N. B. GADRE mentioned Lake Fife in the Bombay Presidency the capacity of which had not changed appreciably in 20 years. He said there was very little soil in the catchment.

MR. L. VENKATKRISHNAIYER said that the silt content of the Cauvery at Mettur in Madras had been analysed. They had consulted Professor Unwin who had advised the provision of bottom storage for silt accumulation.

Discussion then centred around the ratio of bed to suspended silt load in a river. Dr. N. K. Bose though their investigations on the River Ravi at Mukteswar might yield some information.

MR. A. R. B. EDGECOMBE was asked to give more details of the factor $F = 1/47$ referred to on page 51. He said this was some original work he had done in America.*

MR. BIGSBY asked if a similar factor could not be worked out on the Bundelkhand Rivers in the United Provinces on which reservoirs existed and were silting.

"MR. VENKATKRISHNAIYER said that if the silting of reservoirs was recognised dams should be designed to withstand additional pressures as liquid mud sometimes had a specific gravity $2\frac{1}{2}$ times that of water".

After further discussion it was Resolved: *The records from various parts of the world show that the silting of reservoirs may be serious or negligible. The Committee consider that the factors determining silting vary from site to site and must therefore be studied locally.*

The Committee recommend that

- (a) *Investigations regarding silt loads should go on pari passu with enquiries regarding water available for storage.*
- (b) *The main source or sources of the silt load should be determined and steps should be taken so far as possible before dam construction to reduce erosion in the catchment area.*
- (c) *Every opportunity should be taken to study silt accumulation in existing reservoirs with the object of obtaining information regarding the most economical design and method of construction with reference to the life of the reservoir.*
- (d) *Samples of silt in suspension should be taken regularly at existing river gauging sites and at or near any possible dam site. The clay content of the silt should be determined as this may exert an important influence on the volume of the deposited silt.*
- (e) *Samples of deposits from reservoirs should be obtained so that an attempt may be made to estimate the volume of the deposited material with reference to its physical composition.*

Discussion of Mr. H. S. Kahai's Paper, "Silt Observations of Rivers" was then started. Mr. Kahai quoted hydraulic and silt data from the River Indus at Sukkur, and the North-Western Canal, Sind.† These samples were taken with a bottle sampler.

DR. MCKENZIE-TAYLOR said the Punjab Irrigation Research Institute used ounces per cubic foot, whereas Mr. Kahai used grains per cubic foot. Grains per litre is approximately the same as ounces per cubic foot.

MR. GERALD LACEY stated that slopes were frequently quoted as fractions such as $1/6667$, etc., and urged the necessity for expressing slopes in a decimal form or preferably in parts per thousand denoted "S."

MR. F. F. HAIGH enquired if there was any information on the total quantity of silt.

MR. A. R. THOMAS said that the data would be of value to him as the amount of silt in suspension in rivers and canals had an important bearing on models.

DR. MCKENZIE-TAYLOR said they were about to construct a silt trap to compare the results with those obtained from a silt ejector.

MR. COX said it was generally assumed that the silt charge of a river decreases as one proceeds down the river.

**Vide*, "Report on the Silting of Reservoirs and measures taken or projected for its Prevention or Control", by A. R. B. Edgcombe. Government Press, Allahabad, United Provinces. Rs. 12.

† *Vide* pages 29 and 31 of "Report on the work done in the development and Research Division, Sind", for the year ending May 1939.

Mr. LACEY stated that although the silt charge in Northern Indian canals was known to vary, it did not appear to vary to such an extent, during the silt laden period, as to vitiate results.

Mr. THOMAS said the silt load had a very decided effect, but that it was implicit in channel dimensions and was not apparent. The silt load is implicit in your equations Mr. Lacey.

Mr. LACEY suggested that, as he had stated, the variations in silt charge appeared in the Punjab to be insufficient to vitiate results. In Sind, however, not only was all the silt fine, but the amount of fine *suspended* silt was very high, and that therefore in Sind, since it was difficult to exclude fine *suspended* silt, the charge must be of greater importance.

Mr. THOMAS quoted the case of the Mithrao Canal. Silt was excluded and the channel scoured. This proved that silt charge has an effect.

Mr. BIGSBY enquired whether Dr. McKenzie-Taylor had reached any conclusions from the Gugera investigations where serious troubles had been experienced as a result of silt movements. The silt in this case appeared to be very fine and the channels were being choked by the sheer mass of fine soil.

Dr. MCKENZIE-TAYLOR said that a report had been submitted but no conclusions had been reached. The same effects were noticed in the Burala.

Mr. COX enquired what canal slopes obtained in Sind.

Mr. KAHAI said about 1 in 7,000.

CONSIDERATION OF THE SUBJECT "SILTING OF RESERVOIRS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 9TH NOVEMBER, 1939.

Resolved "*THAT THE SUBJECT 'SILTING OF RESERVOIRS,' BE INCLUDED IN FUTURE DISCUSSIONS OF THE BOARD.*"

SILT EXCLUDERS AND EJECTORS.

PRELIMINARY GENERAL NOTE.

Silt Exclusion from Canals.—The employment of all known precautions at the source of supply frequently renders recourse to silt excluders and ejectors unnecessary. Before proceeding, a recapitulation of these precautions will be informative.

Silt Exclusion by Reservoirs.—Reservoirs exclude silt from a canal, themselves silting in the process, but if the offtake of the canal is a considerable distance down stream of the reservoir the stream can pick up a sufficient bed load to nullify the effect of the reservoir.

This is occurring at the Parker Dam on the Colorado River about 150 miles downstream of the Boulder Dam where water is diverted into the All-American Canal.

Selection of Site of Headworks and River Training.—A site for the offtake of the canal on the outer curve of a river is conducive to silt exclusion from the canal. This effect can also be produced by training of the river at lower stages within its flood bed. In the case of the Mithrao Canal in Sind the construction of an approach channel from a concave bend upstream reduced silt entry into the canal.

A great deal can be done by suitable training of a river in the vicinity of the headworks excellent examples of which are afforded by the histories of the Rupar, Khanki Merala and Rasul Headworks in the Punjab.

Use has been made of River Models in dealing with such problems.

Operation of the Barrage Sluices.—The study of the history of the various Indian weirs shows how much can be done in the matter of silt exclusion by the judicious operation of under-sluices, gates, and weir shutters to induce curvature of flow, the still pond method of regulation, and closing the canal at times of heavy silt load in the river.

Design of Barrage and Canal Head Regulator.—The Sarda Canal is a good illustration of the main precautions taken for the exclusion of coarse silt. The undersluices are separated from the rest of the barrage by a divide wall upstream. The Head regulator is splayed at an angle of 110° to the barrage with the object of avoiding turning the water into the canal at too acute an angle and thus creating "eddy" action.

The regulator has a crest raised 6½ feet above the river bed. The regulator gates lower behind this crest thus giving the maximum skimming effect.

Induced Curvature of Flow.—As silt exclusion is to some extent governed by curvature of flow experimental work has been performed to discover the effect of building a curved vane in the river up stream of the pocket formed between the divide wall and canal head regulator. These experiments were performed at what is now the Central Irrigation and Hydrodynamic Research Station of the Government of India, and on a model gave successful results.

At the same station model experiments with King's Vanes were made in connection with the silting of the Mithrao Canal already referred to, and on the model proved effective. The Director of the Research Station has since stated that vanes are of little use in wide channels as they only switched over a portion of the flow in the channel, whereas it is essential to turn the current completely. (Mins. 8th Research Committee p. 2).

Vanes have also been tried on models in connection with the Lloyd Barrage at Sukkur in the Indus.

Silt Excluders and Ejectors.—The former are placed at the head of the canal and the latter some distance down the canal. The basic principle on which these devices operate is that in a flowing stream the silt is more concentrated in the lower layers than in the upper ones. Consequently if the lower layers can be escaped without undue interference with the silt distribution a large proportion of the silt load can be got rid of. Obviously a portion of the supply of water has to be escaped, and in existing extractors the percentage of supply escaped varies greatly up to over 30 per cent.

This escaping means a suitable head must be provided, and an increase in the size of the canal head regulator.

Silt Traps.—These consist essentially of pockets in the canal. An increased section reduces the rate of flow with consequent deposition of silt which is periodically flushed out by an escape provided for the purpose.

Mechanical Extraction of Silt.—At the Head of the All-American Canal the incoming water is detained in 72 circular basins. Silt drops out and is scraped to a central duct by rotary scrapers, whence it discharges back into the parent river under gravity. These basins are designed to deal with a flow of 12,000 cusecs or 80 per cent. of the canal capacity.

The detention period was the outcome of considerable investigation.

Effect of Silt Exclusion on Canal Regime.—Silt exclusion can be so effective as to upset the regime of the canal and cause scouring, as has been noticed in the Upper Bari Doab Canal. One of the major problems of the various forms of excluders is the regulation of the grade and quantity of silt to suit the regime conditions of the canal.

POINTS FOR DISCUSSION.

The optimum percentage of supply to be escaped in silt excluders and ejectors.

The control of the grade of silt excluded or ejected.

Note on the Silt Exclusion arrangements provided at the Trimmu Headworks and proposed for the Kalabagh Headworks

BY F. F. HAIGH.

1. The Trimmu Headworks commands the Rangpur Canal, 2,700 cusecs capacity, on the right bank and the Haveli Main Line, 5,200 cusecs capacity, on the left bank.

2. The former canal is a non-perennial channel which flows through country having a good slope and consequently there is little likelihood of difficulty of command being experienced. An excluder of the Khanki type has been provided at the head and provision has been made in the design of the canal head reach for taking additional water into the canal to operate an extractor at about R. D. 2,000, if this is ever found necessary. This excluder covers one 30' bay of the undersluices only.

3. The more important Haveli Canal is a lined channel with a very flat slope. For full supply conditions Lacey's f is about 1.3, but with low supplies running and the water level headed up at various points to command off-taking channels the velocities will locally be such that only the finest grades of silt will be carried. It is necessary, therefore, to restrict silt entry on this side as much as possible, and with this object the water is passed through three decantation processes before passing down the canal, an excluder being situated in the undersluices pocket and two extractors at R. D. 1,200 and 2,000 of the canal.

4. The pocket excluder covers four bays of the undersluices, the slab being 230' long and extending about 50' above the regulator with its edge parallel to the barrage. The tunnels are very large being generally 34' x 12' though reducing to 30' x 8' at the gate line. The excluder bays are separated from the rest of the undersluices by a divide wall which extends for 300' beyond the excluder slab. Over 200' of this length the pocket floor is paved.

5. The canal excluders are of more stereotyped design comprising tunnels arranged under the canal at such a level as to cause no afflux in the canal supply. Entrance to the tunnels is effected through comparatively small orifices varying in size with the object of distributing the draw-off uniformly, and averaging about 1.5' x 2'. The tunnels roof is cantilevered over the orifices to prevent their draw affecting the silt distribution before the escape is separated from the canal supply. The escape is 1,200 cusecs at R. D. 1,200 and 1,000 at R. D. 2,000. Each extractor is designed to work under a head of 5' and to deliver the escape at the lowest river level likely to occur when the extractors are in use. The canal section from the head to R. D. 1,200 is designed to $f=0.8$ and from R. D. 1,200 to 2,000 to $f=0.7$, these reaches being unlined. Two small extractors were provided instead of one large one for the reasons given in the discussion of multiple extraction below.

6. Before describing the silt excluder arrangements proposed for Kalabagh it will be advisable to discuss briefly the advantages and disadvantages of the different types used at Trimmu.

7. The following advantages are common to all pocket excluders :—

- (a) The head across the barrage is always available for operating them.
- (b) Economy is secured by the use of the barrage gates and cisterns.
- (c) Large orifices unlikely to be choked by rolling or submerged floating debris are easily provided.

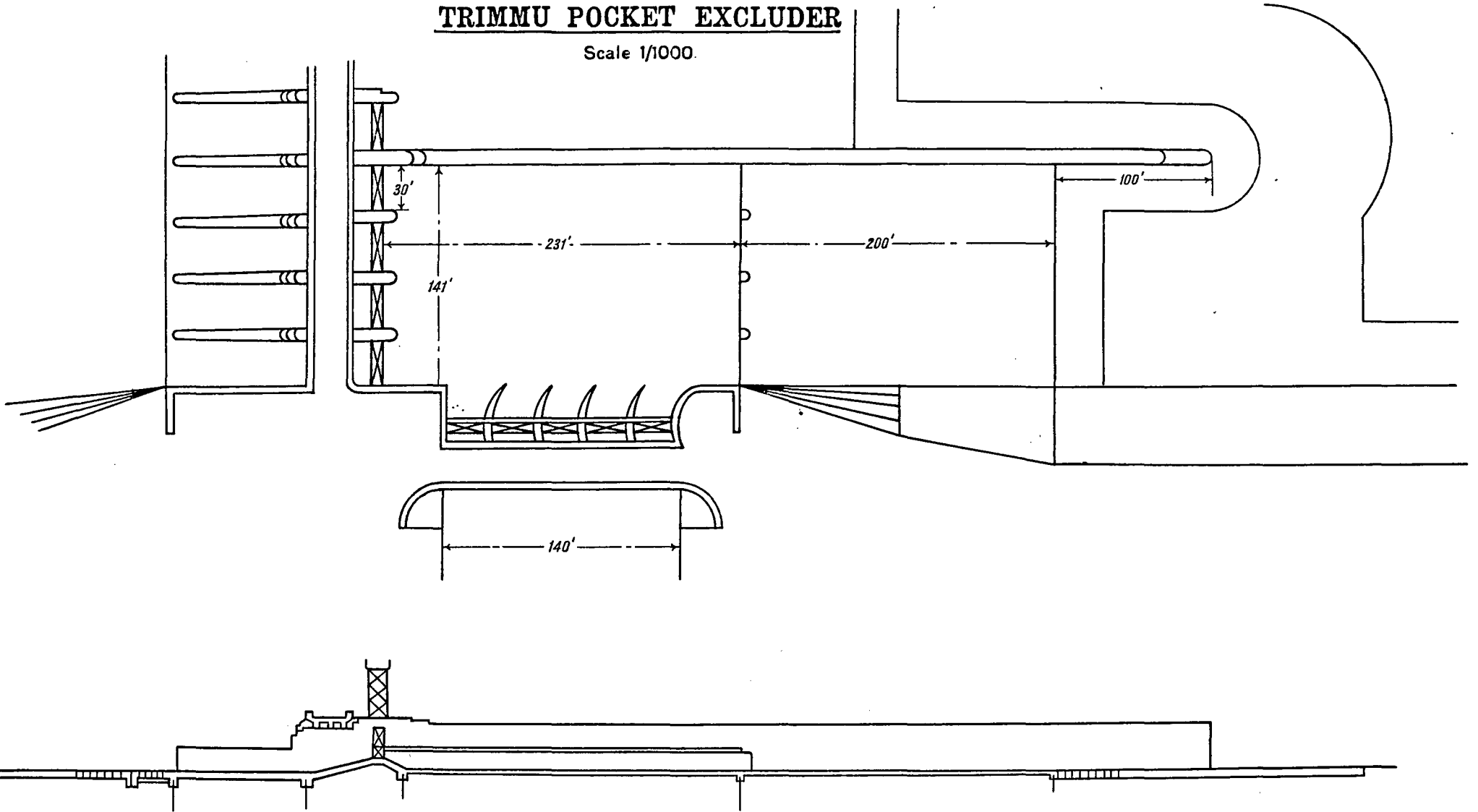
8. The disadvantages of this type are :—

- (d) The difficulty of securing good approach conditions.
- (e) The undersluice bays covered by the excluder cannot be used simultaneously for exclusion and their proper purpose of passing high river discharges.
- (f) The work being subject to river action has to be of very robust construction.

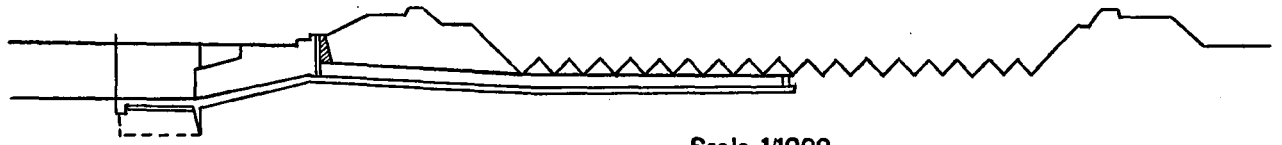
9. The excluder built in the left pocket at Trimmu which has become known as the Kalabagh type, since it was originally designed for that headworks, is an attempt to eliminate the disadvantage (d) above. With the Khanki type the water approaching the excluder has to turn through a large angle and hence must be in a disturbed condition. If a divide wall exists, the approach will generally be *via* an S curve with intense local disturbances at the divide wall nose. The divide wall therefore appears to be definitely disadvantageous with this type. With the Kalabagh type a good approach can be secured if the divide wall is made of sufficient length, but this naturally involves heavy expense. It is doubtful if the length is sufficient to achieve this at Trimmu.

TRIMMU POCKET EXCLUDER

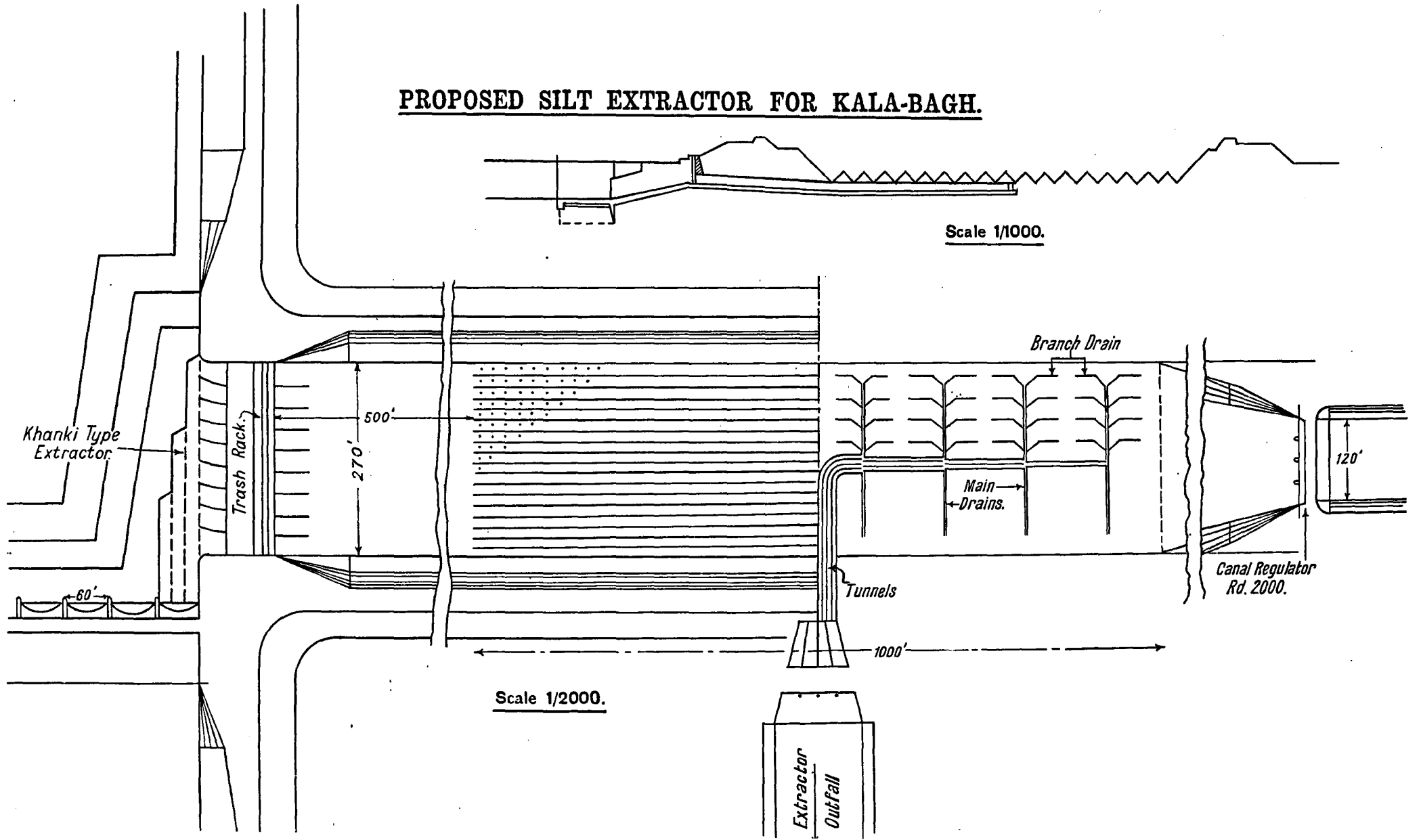
Scale 1/1000.



PROPOSED SILT EXTRACTOR FOR KALA-BAGH.



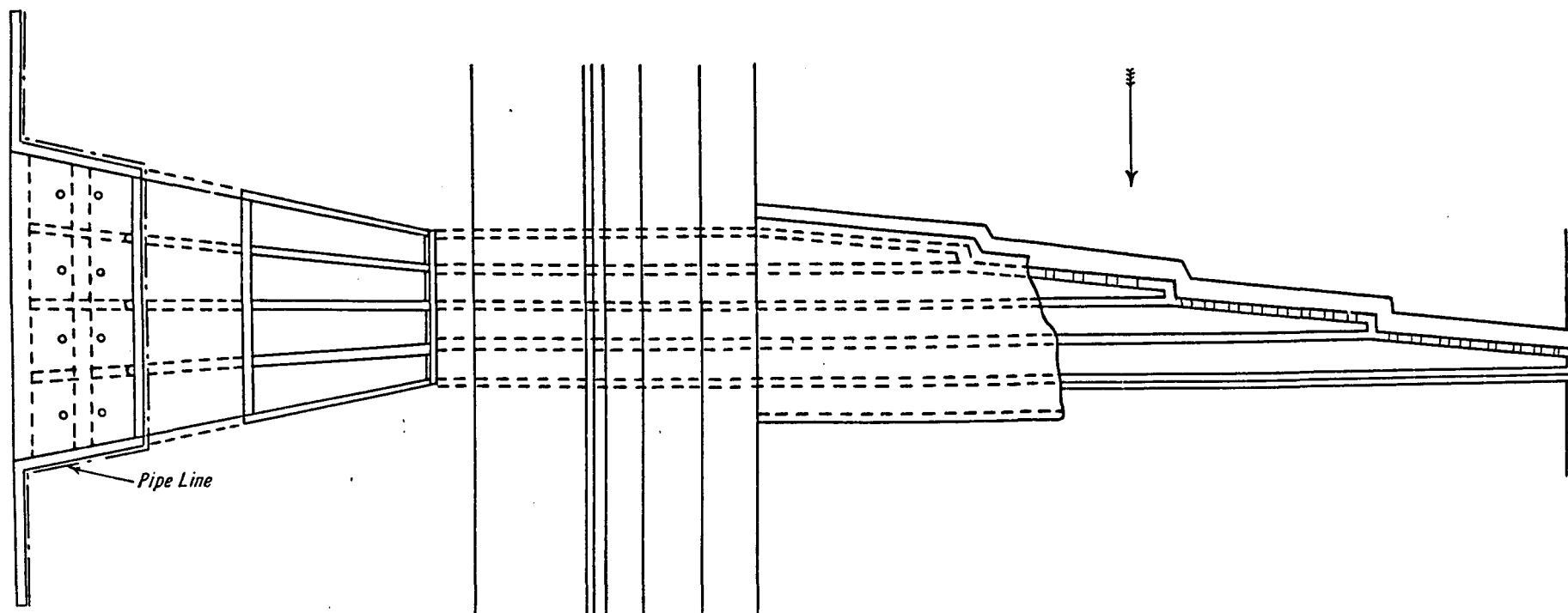
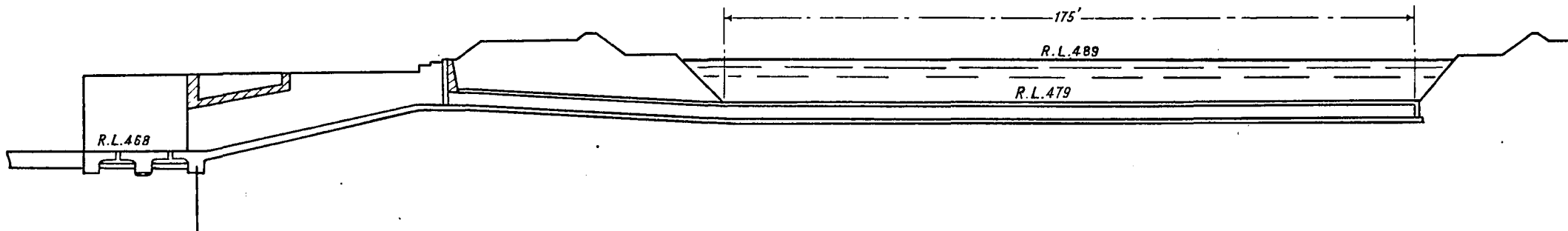
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Scale 1/2000.

TRIMMU CANAL EXTRACTOR

Scale 1/400.



10. A disadvantage of the Kalabagh type as compared with the Khanki type is that the distribution of the canal supply at the edge of the diaphragm is not under control.

11. Turning now to the canal extractors the advantages which can be claimed are :—

- (g) The ease with which good approach conditions can be secured.
- (h) The relative lightness of the work.
- (i) The possibility of multiple extraction.

A long list of disadvantages may be cited such as :—

- (j) The difficulty of securing a working head with high river and low canal supplies.
- (k) The necessity of increasing the size of the head regulator to accommodate the escape.
- (l) The increase in size of the canal section above the extractors necessary to accommodate the escape.
- (m) The necessity of providing separate outfall works.
- (n) The comparatively small orifices are liable to be blocked by sunken debris and may necessitate the provision of a trash rack.

If, however, (j) can be overcome the others are merely a matter of cost and are easily outweighed in comparison with the expense of the Kalabagh type. If, however, (j) presents difficulty and it is necessary to go a long way down the canal to secure the necessary working head (l) may be a serious matter.

13. At Trimmu where the maximum flood level is only 1.5' higher than canal full supply level (j) was not expected to give much trouble, but at the present time as abnormally high levels are prevailing owing to the diversion of the river over the barrage, an adequate working head cannot be secured with high river supplies.

14. Regarding (i) the advantages of multiple extraction are twofold. It has been confirmed in the field that, as might be expected from the fact that the silt intensity increases rapidly in the vicinity of the bed the specific efficiency of small escape is greater than that of large. From this it follows that with a given discharge available for escape it is possible to increase the overall efficiency by dividing this escape between two or more extractors. Secondly, multiple extraction increases the effectiveness of the approach channel. The regime of the approach channel is determined by the grade of silt carried and consequently the degree of concentration of silt of any grade which is possible in the escape stream is limited. A single extractor will, however, reduce the intensity of silt of all grades and the reduction is greater in the case of coarse silt than of fine. In the approach to a second excluder therefore, a further degree of concentration of each grade of silt can be effected, and the overall efficiency is improved.

15. In the case of the two Trimmu extractors the first was placed at a distance of 1200' from the head in order to give time for the optimum silt distribution to be established after the turbulence which occurs downstream of the head regulator. Similarly a distance of 800' was allowed between the two extractors to permit any disturbance set up by the first extractor to disappear. Actually the disturbance created by the first extractor will not be serious since there is no afflux there, and the distance is probably excessive. In any case it should be possible to design an extractor which will not interfere with the silt distribution of the water passing on it and consequently we can reduce the interval between the successive stages of extraction to a minimum giving, in effect, continuous extraction. This it is proposed to attempt at Kalabagh.

16. Another major departure from past practice proposed for Kalabagh is the setting back of the canal head regulator to a suitable distance from the river and locating the extractor in a special flume connecting the two. This flume will be open to the river and consequently the full head across the barrage will always be available for working the extractor. This arrangement it is claimed will have the important advantages of both the pocket and canal location. Its only objections appear to be :—

- (o) The banks of the flume will have to be designed to stand river flood levels.
- (p) The depth in the flume will not be under control in high river stages. (m) and (n) supra will also apply.

As regards (p) it is not anticipated that this condition will have any objectionable effect. With greater depths the velocity in the flume will be reduced and silt will settle probably more effectively through the greater depths in the longer time available.

17. A brief description of the whole scheme for Kalabagh as proposed by the writer is given below :—

At the river edge there will be an excluder of the Khanki type covering one 60' bay of the barrage in three tunnels. This will be controlled by a standard single barrage gate and there will be no pocket divide wall. The diaphragm will be at as high a level as possible limited by the condition that the canal supply can pass into the flume without loss of head. The flume will be 270' wide throughout, the canal discharge being 6000 cusecs. A trash rack will be provided immediately downstream of the head. To secure uniform distribution of discharge over the flume section, the head will be provided with curved vanes and the trash rack piers will be extended to a sufficient length to obviate cross flow. Downstream of the trash rack there will be a settling reach about 500' long designed to $f=0.8$ and with a lined bed the latter being provided to facilitate scouring in the event of excessive deposit in this reach during high flood conditions.

18. The main extractor will cover 1,000' length of the flume. Its bed will be lined and will be formed in longitudinal corrugations with 1 to 1 side slopes of 15' pitch designed to lead deposited silt to the orifices. These will be 1008 in number taking 1 cusec each, uniformly distributed at 18' intervals in each trough. The bed level will be such that the velocity for full supply conditions will correspond with an f of 0.55 at the upstream end and 0.4 at the downstream end, the exclusion of all silt over 0.6 f grade being aimed at. The length of the work is designed to give sufficient time for silt of 0.6 f grade (dia. 0.14 mm.) to settle to 1.5 times the depth in still water. The length is independent of the actual depth since for a fixed width and discharge, velocity and depth are inversely proportional. Actual velocities proposed vary from 2.5'/sec. at entry to 2.0'/sec. at exit.

19. The discharge of the outlets is collected *via* a system of branch and main drains^s in tunnels running downstream in the upper half and upstream in the lower half along the centre line of the flume. After meeting in the centre the tunnels turn under the right bank of the flume and discharge *via* a gated outfall back to the river. The velocity in the escape ducts varies from 2'/sec. at the outlets to 5'/sec. in the tunnels and the total head required to work the excluder is calculated as 2'. The canal head regulator will be situated immediately downstream of the extractor.

Note on the Influence of Very Fine Silt and Cohesion as a Factor in Channel Performance

BY GERALD LACEY.

Of recent years great advances have been made in India in methods of sampling silt and of determining the average diameter of silt particles. The writer, at a time when the correct determination of the average diameter of the silt particle was unknown suggested that the ratio V^2/R characterised silt grade, and that this ratio was a function of the diameter of the silt. For simplicity the relation may be summarised thus :—

$$\text{Silt factor} = f = \frac{3}{4} V^2/R = 8d^{\frac{1}{2}} \dots \dots \dots (1)$$

in which expression d is the average diameter in inches. Later developments go to show that the constant 8, suggested as early as 1930 as a very rough measure is in error and that the correct figure is nearer 9.

2. In the Punjab the decision was very rightly made to measure silt grade rather than employ a silt factor which could only characterise silt grade in an indirect manner. It was found that there was no direct evidence that the silt factor varied as the square root of the mean diameter of the silt particle. Other factors were evidently at work. One curious feature of the experiments made was that a very low silt factor could be associated with a relatively coarse grade of silt. The explanation of this anomaly is "shock". Thus if a channel has very ragged banks more energy is destroyed, and the gross turbulence or agitation of the water is increased. This exposes the coarser grade of silt on the bed but also retards the forward velocity. Before the value of V^2/R could be correctly calculated it would be necessary first to enhance the value of the wetted perimeter employed in the calculation of the hydraulic mean depth on account of the disproportionate part played by the sides in the destruction of energy. It is possible also to conceive of "shock" of a negative character. Considering a channel with glass sides it will be seen that if the sides are omitted in the computation of the hydraulic mean depth the computed value of V^2/R can correctly be associated with the grade of bed silt. If the sides are included the computed value of f will be high for the grade of bed silt encountered. It will thus be seen that with positive "shock" a low silt factor will be associated with a coarse grade of silt, and if negative "shock" is present a high value of the silt factor will be associated with a fine grade of silt. "Shock" plays a part in determining the hydraulic elements of most canals under observation and is sufficient to explain much that would otherwise be obscure. The fact is regarded as of sufficient importance to be mentioned in this note. The most important fact to note however is that in all the work now being undertaken the assumption is implicit that the silt is incoherent and can be picked up almost as readily as it can be deposited.

3. In Sind there is a very high percentage of fine silt, and the persistent silting of channels in Sind in fine silt suggests that cohesion has not been taken sufficiently into account. Having regard to the very fine silt transported by channels in Sind, and their low rugosity they should transport their silt with very low slopes. This does not appear to be the case.

Dr. Chatley in a recent article* makes some very illuminating remarks in connection with cohesion, in rivers and channels transporting fine silt. He observes that in flashy rivers (the statement has also some reference to inundation canals) "the rules connecting slope and soil structure are probably different from those of steady flow since the velocity to keep sediment in motion is much less than that required to disturb old settled sediment". He ascribes this effect to cohesion of the material "which Lacey disregards". It would be more correct to state that the writer had confined himself to channels in which the silt was assumed incoherent, and the channels free from shock.†

Dr. Chatley has shown that if the cohesion between a pair of silt particles compares with the weight of one particle the force required to separate the particles is more significant than their mutual friction, and it is clear that the scouring velocity goes up *not down* with the fineness of the material when the fineness is below a certain limit. The tractive resistance of beds in very fine material will therefore be a direct function of the fineness of the material instead of a function of the coarseness, and unless attention is paid to this aspect of the question equations derived for regime flow based on the size of particles may give very anomalous results.

4. To sum up it may be stated that in all channels of which the silt is reasonably incoherent the non-silting velocities and slopes can be calculated from equations such as those derived by the Punjab Research Institute, in which the average diameter of the silt

*Engineering, December 23, 1938, page 742.
†Procs. Inst. C. E. Vol. 229, page 371.

Plays a part, but in channels transporting very fine silt and cementitious material, the same equations cannot be applied with confidence. The channel dimensions of regime canals transporting incoherent material can be computed from the writer's equations by assigning a silt factor. This silt factor, in channels free from shock, is associated with grades of silt which can be predicted with fair accuracy from the equation

$$f = 1.76 m^{\frac{1}{2}} \dots \dots \dots (2)$$

in which m represents the diameter of the silt particle in millimetres. When the silt is very fine and cohesive the Punjab equations in terms of the diameter of the silt particle break down. Whether the writer's equations, or the Punjab equations are employed, the fineness of the silt plays a part in determining rugosity, and therefore slope, but the fineness of the silt cannot be directly connected with the precise value of V^2/R which must be adopted in order to ensure that the tractive resistance of the fine bed silt is overcome. Effectively, in channels transporting incoherent alluvium, and free from shock, the diameter of the silt particle assigned either by the slope equation, or the equation in terms of V^2/R , should be equal, but if coherence plays a part it will at once be recognised that there will be one value of the silt factor, as a function of pure fineness and smoothness, which will determine the velocity for a given slope, and value of the hydraulic mean depth, and a second value which must be applied to determining the ratio V^2/R , which determines silting and scouring. It is possible therefore to apply in Sind two silt factors, the first a function of the slope and the second a function of the non-silting velocity.

There is therefore nothing anomalous, when due regard is paid to causes, in the fact that in Sind different silt factors are computed from different equations. The correct procedure in future, it appears to the writer, would be to compute values of N_a from the equation

$$V = \frac{1.3458 R^{\frac{1}{2}} S^{\frac{1}{2}}}{N_a}$$

from known values of V , R , and S on the few regime channels that may exist, and in design to refrain from assigning lower values of N_a than obtain in actual practice. In order to avoid silting each channel must also be assigned a definite value of the ratio V^2/R , and this value must not be less than those obtained in practice. Any attempt at computation from the diameter of the silt particle should be avoided since variation in the precise percentage of the fine material may vitiate any conclusions drawn.

The procedure will be somewhat similar to that adopted by Kennedy in which he assigned a value of Kutter's N by experience, and associated with that value an assigned value of the critical velocity.

With incoherent material it is possible to interlink the size of the particle both with the silt factor, and the rugosity coefficient. When the material is coherent the fineness of the particle can be correlated with rugosity, but fineness of the material is no reliable guide in assigning velocities. It is necessary to use a silt factor linked *not* with the fineness of the material, but linked with the 'behaviour' of the precise type and mix of silt to be transported, and that 'behaviour' is best characterised by the ratio V^2/R . It will be observed that any equations in terms of the silt diameter are likely to break down when applied to cohesive material, and that the best method is to assign working values of N_a and the ratio V^2/R . This system at least provides the way out of an *impasse*. The physical aspect of cohesion and the part which varying percentages of fine material play in determining regime velocities remain for investigation.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. F. F. HAIGH introducing his paper said that he had used Lacey's formula $f = 8\sqrt{d}$ to obtain the average size of particle in silt of a certain grade. For $f = 0.6$ this gives $d = 0.14$ mm. He understood that Mr. Lacey had now revised his formula to $f = 9\sqrt{d}$; in which case the diameter becomes 0.11 mm. For this size of particles the rate of falling in still water at 20° C. was 1 foot in 29.4 seconds. Hence, the depth of flume being 12.5, 360 seconds would be required for a particle to fall from the surface to the bed. In checking the approach flume the time allowed for settlement in the suggested design was 667 seconds *i.e.*, 1.84 time the above.

MR. HAIGH had recently received details of the silt excluding arrangements under construction on the All-American Canal off-taking from the Imperial dam on the Colorado river and it was interesting to compare the American data with those suggested for Kalabagh. In the case of the All-American Canal they were attempting to exclude silt down to 0.08 mm. dia. For this grade the settling velocity in still water was 1 ft. in 55 seconds and as the depth was also 12.5' the time of settling from top to bottom was 690 seconds. The total time allowed for settlement was 1260 seconds and the ratio of time allowed to time required 1.83. The chief point of difference was that the velocity of the water during settlement was much higher being 2.25 ft/second in his design against 0.4 ft/second in the case of the American design where the supply was passed through a number of tanks instead of using the canal itself for settling.

MR. HAIGH referred to the paucity of information on the rate of settlement of silt particles in turbulent water. Allan Hazen (Proceedings of the American Society of Civil Engineers)* gave a mathematical formula based on two reasonable assumptions:—

- (a) That a particle reaching the bottom would stay there and
- (b) That the distribution of silt remaining in the water at any time was uniform.

**Vide* Transactions, A. S. C. E., Vol. 53, 1904, page 45; also Transactions, A. S. C. E., Vol. 102, 1937, pages 289—323.

The formula was

$$x = \left(1 - \frac{da}{t}\right) \frac{a}{da}$$

where x is the proportion of silt remaining after time a .

t = the time required for a particle of silt to sink from the surface to the bottom in still water. This formula gives the following values'

$\frac{a}{t}$	1	2	3
$x =$	37%	14%	5%

MR. HAIGH said a doubtful point in connection with the design was whether silt falling between the orifices would be carried forward and escaped or would deposit and form a silt heap of a height depending on the water velocity and the silt grade. He had discussed this with Dr. McKenzie-Taylor who thought that information on this point could be obtained by experiment.

MR. GERALD LACEY said that the equation $f = 8d$ was put forward by him as long ago as 1930 as a "very rough formula" until a "more reliable rule" could be obtained. The numerical value of the constant appeared to be approximately 9. He enquired whether there was any binding clay in the silt.

DR. E. MCKENZIE-TAYLOR was of the opinion that the silt would flow along the corrugations.

In reply to a question from Mr. E. S. CRUMP, Mr. Haigh said that each tunnel would be regulated separately.

MR. T. M. LYLE asked what percentage of the water supply was run to waste, and was given the figure 17 per cent.

MR. S. H. BIGSBY asked Mr. Haigh to explain to the meeting why the exclusion had to be so drastic in this particular case.

MR. HAIGH explained that on the Thal project nearly all the channels would be lined. With a lined section they designed to a high value of "f" as they wanted to be sure that the silt deposited when heading up for command with low supplies would be fine enough to be picked up quickly when the supply was raised.

MR. GERALD LACEY, "You make sure that the flow is turbulent, that is what you mean by designing".

MR. HAIGH agreed.

MR. E. S. CRUMP said that two sets of discharge observations had recently been made on the main line of the Haveli Canal. Using Lacey's formula, the average value of 'N' for four different reaches was consistently higher for the lower of the two discharges observed. In order to reconcile the two sets of results, i.e., give the same value of 'N' it was necessary to adopt a higher value than $\frac{1}{2}$ for the index of R in a formula of the Lacey or Manning Type.

MR. LACEY pointed out that equations of the Manning type were best applied to full stage conditions on channels. If it was desired to obtain an equation that would fit a variety of gaugings at one site, the equation sought was essentially a "stage-discharge" equation and it was possible that an equation of the Bazin type would fit better.

DR. MALHOTRA mentioned that for data obtained from four reaches on the Lined Haveli Canal he had tried Manning and had found it to give approximately as good a fit with the data as Mr. Lacey's formula. *He added that the average observed rugosity by Lacey's formula was about 0.015 against 0.016 adopted in design.

MR. A. R. THOMAS asked if there were any facilities for controlling the slope. Mr. Haigh informed him that there was a regulator on the canal down-stream of the excluder.

DR. E. MCKENZIE-TAYLOR said that in spite of turbulent flow his information was that 80 per cent. of the silt occurred in the bottom 0.2 of the depth.

MR. HAIGH said that in his design Lacey's "f" varied from 0.4 to 0.55 in the extractor reach.

At the request of Mr. BIGSBY, Mr. Crump described the Upper Jhelum Ejectors in the Punjab.

There were five extractors or excluders. The first was about five miles from the head of the canal. It was built in 1935, but was not now operated as it had caused scour in the channel downstream.

The remaining four extractors are located at Miles 25, 28, 37, and 48 of the Upper Jhelum Canal. The first of these is situated at the last of the four points where torrents cross the canal in level crossings and contribute large quantities of heavy silt. In the heavily silted reaches above this point the canal slope was 0.25 per thousand as compared with the designed figure of 0.15%.

The extractor at Mile 28 was built in 1933, and although designed to take 1000 cusecs it was normally run with a maximum of about 250 cusecs. This extractor comprised 36 pipes at 6 feet centres, each pipe 1 foot in diameter. These pipes discharged into an existing culvert in the canal. The canal discharge had declined from 8,700 to 7,100 cusecs owing to silting. As a result of silt extraction, the potential discharge for the same gauge has risen to 10,000 cusecs. The water slope has flattened in the downstream because the extractor has lowered "f".

The extractors at Miles 37 and 48 are designed to discharge 250 and 108 cusecs respectively. Each has nine units on 24 feet centres. Mr. Crump described the design of entries to these units which he said had acted fairly well. At the extractors at miles 28 and 37, each 12 inch pipe has its own sluice valve.

The extractor at Mile 48 is of different design. In this case the 9 Units discharged into a cross duct of expanding section as in Mr. Haigh's design. The designed velocity in this cross duct was 5 feet per second and it was equipped with a single gate at the end.

MR. THOMAS asked whether any preliminary experiments on ducts were carried out.

MR. CRUMP replied that no preliminary experiments were made but the performance of the first structure built was observed. They soon discovered that the smaller the extractor, the more efficiently it worked. It first and foremost takes the heavily silt charged bottom layers of water.

If you extract at all, you take out all the bed silt at the location of the extractor.

MR. CRUMP said that in all his designs he arranged that conditions should be regime conditions, i.e., for the silted bed to remain upstream of the extractor.

MR. BIGSBY said the canal was silted up and something had to be done. The first extractor constructed desilted a portion of the canal, but the process was too slow. They therefore put in a number of extractors to get rid of silt rapidly.

MR. LACEY enquired as to the optimum size of pipes. He was informed by Mr. Crump that results were given in Mr. Haigh's paper No. 211 entitled "Silt Excluders" presented at the Punjab Engineering Congress, 1938. Small extractors were more efficient than large ones, and, if only a small portion of the canal supply could be spared, it was more efficient to construct several units along the canal.

* $N_a = \frac{1.3458}{V} R^{\frac{1}{2}} S^{\frac{1}{3}}$ vide "Stable Channels in Alluvium", by G. Lacey (Equation 20, p. 372) and, "Uniform Flow in Alluvial Rivers and Canals", by G. Lacey (Equation 1, p. 425).

It is essential to arrange for equal draft across the whole width of the canal and so trap all the bed silt. A blockage of one of the extractor pipes was very soon made apparent by the formation of a fid of bed silt downstream.

As regards the proportion of rolling bed silts Mr. CRUMP said that Mr. Benson put the figure at 1 part in 20,000 by volume of the discharge.

Mr. LACEY remarked that as a considerable quantity of the bed silt would be transported by "saltation" or leaping the width of the gap was of importance, and if this was too small, some of the bed silt would "hurdle" the trench crossing the canal at the intakes of the extractor units.

Dr. E. MCKENZIE-TAYLOR, basing his opinion on flume experiments carried out at the Punjab Irrigation Research Institute, said that he did not think hurdling would take place.

Mr. CRUMP said that the extractor constructed on the Upper Jhelum Canal resulted in increased canal discharges. The thirty miles tail reach below the point where the canal bifurcated used to silt up in kharif and thereafter took a long time to cleanse itself. The highest discharge passed at the tail of the reach before 1930 was 6300 cusecs. They now got 7,500 cusecs. On one occasion in 10 days the tail discharge increased by 1,000 cusecs for the same gauge at the head of the reach. Mr. Crump attributed this to the fact that the working level at the tail had always been kept some 2 feet lower than the designed level, so that the tail reach had started scouring from the time the canal was first opened. In the last 10 miles the bed was a solid clay bed, and at a certain stage the silt is wiped off the clay as if the channel had been lined with smooth concrete. With the resulting flattening of the slope the removal of silt from the clay progresses rapidly upstream and as much silt is disposed of in one day as would take months in an ordinary silted channel.

Mr. BIGSBY enquired if data regarding Lacey's "f" could be given. Mr. Crump replied that he could not state results in term of "f".

At Mr. BIGSBY's request Mr. Haigh stressed the point of multiple extraction. In addition to the increase in efficiency obtained by escaping a number of bottom layers there was also the effect on the regime of the approach channel. After one extraction process, the intensity of silt of all grades was reduced and the reduction was greater in the case of coarse silt than fine. The canal supply would therefore have a lower f enabling finer silt to settle and be extracted. In the design under consideration f varied from 0.55 to 0.4 over the extractors.

Dr. MCKENZIE-TAYLOR referred to the Thal Project; and apprehended that if too fine a material was extracted there would be no stanching in the water-courses, and no improvement in the cultivated area, as had been hoped, due to silt deposition.

The slopes of the water courses varied from 1 in 2,000 to 1 in 3,000 and the grade of silt therein would vary from 0.10 to 0.01 mm.

Mr. HAIGH said they aimed at removing silt down to 0.10 mm. diameter, but the relatively high velocities would prevent the fine silt from being escaped.

Mr. LYLE enquired why they proposed only one silt extractor for the Thal Project.

Mr. HAIGH replied that the single structure had seventeen transverse discharging ducts and so was equivalent to seventeen structures of the type which Mr. Crump had been describing.

The duct velocities in the structure varied from 2 feet at entry to 5 feet at exit. The head required to work the extractor was 2 to 3 feet, which would be available at all stages of the river. This advantage was gained by putting the extractor up-stream of the canal regulator.

Mr. BIGSBY enquired about the effectiveness of the control over the proposed Ejector. He understood that a considerable amount of silt would be required in the watercourses on account of the porosity of the soil. It seemed to him that sufficient control would not be obtained.

Mr. HAIGH replied that there were gates on the out fall which gave a simple control over the whole structure, and in addition the upper or lower half of the structure could be closed as found necessary. By reducing the escape the efficiency of the extractor could be reduced to any extent.

Mr. N. B. GADRE enquired whether silt extractors could be used to determine the proportion of bed to suspended load.

Mr. HAIGH said the difficulty was to define the bed and suspended load.

Dr. MCKENZIE-TAYLOR suggested they might compare the results from an extractor with those of a silt trap.

In reply to a question Mr. Haigh said he used the VR relationship ($f=0.73 V^2/R$)* in determining "f".

Mr. CRUMP said it should be recognised that the reduction of the silt load by silt ejectors automatically leads to flattening of the canal slopes downstream, and the forward movement of silt. These results may be embarrassing and must be guarded against.

Steps should be taken to control afflux.

Mr. THOMAS thought it was very important to mention that where possible it is desirable to exclude silt at the head of a canal.

Mr. BIGSBY said that when it came to canals already in existence, such as the Lower Chenab Canal, in which there were large quantities of silt on the bed of all channels, exclusion of silt entry at the head had much the same effect on movement of bed silt in channels as would an ejector from the canal.

It was Resolved that :-

This Committee desires to place on record that silt excluders and ejectors have proved a successful device in the Punjab for the extraction or exclusion of silt from a canal, and that a number of small units is more efficient than a single unit.

The construction on existing canals of such devices leads to secondary problems which require solution.

*This is a slight variation of the constant in the formula quoted on page 431 of the Minutes of the Proceedings of the Inst. of C. E. Vol. 237, Session 1933-34, Part I.

THE COLLECTION OF HYDRAULIC DATA OF TORRENTS IN BOULDER RIVERS AND STREAMS.

PRELIMINARY GENERAL NOTE.

Investigations in Progress.—This subject was proposed for investigation by the Research Committee by Mr. Gerald Lacey at the annual meeting of Committee held in June 1937. Subsequently Mr. Lacey explained the object of collecting such data in a note, dated 20th April 1938, and a letter addressed to the Secretary, Central Board of Irrigation, dated 21st April 1938. Copies of the letter and the note were sent to the officers who attended the next annual meeting of the Committee held in July 1938. Discussion of the subject at the July 1938 meeting of the Committee disclosed the fact that certain amount of data was being collected in the Punjab, and that there is a site in the United Provinces from which data would probably be available. The Chief Engineer, P. W. D., North-West Frontier Province, also informed the Secretary that certain data were collected regarding streams in Waziristan, Baluchistan and North-West Frontier Province for 4 or 5 years subsequent to 1927. After discussion, the following resolution was passed at the last meeting of the Research Committee held in July 1938.

Resolution by the 8th Research Committee of the Central Board of Irrigation.—"Resolved that it is desirable to supplement the existing meagre hydraulic data of boulder and gravel rivers and streams, and that those provinces which in future take observations on boulder rivers and streams as a routine measure should forward annually copies of the information thus obtained to the Secretary, Central Board of Irrigation, who will collate such data for publication.

"Resolved that in future collections of hydraulic data, the value of "Na" the absolute rugosity should be calculated and tabulated instead of Kutter's coefficient. The flow equation from which "Na" is to be computed is $V = \frac{1.3458}{Na} R^{\frac{2}{3}} S^{\frac{1}{2}}$.

"Resolved that in future observations, attempts should be made to assess by actual measurements, the average diameter of the bed material; also by making central surface velocity observations to establish a reliable relationship between the mean velocity and central surface velocity for given values of rugosity and of the hydraulic mean depth".

Proposed Form for Collection of Data.—The attached form* has been drawn up for the consideration of the Research Committee. Data supplied by the Research Officer of the United Provinces has been utilized to fill in the attached form as an example, and also because it contains points on which the opinion of the Committee is necessary.

Information Available on the Subject.—The information at present available in the Information Bureau is very limited and mainly refers to the movement of boulders and gravel.

In the San Gabriel investigations in California a value of $n = .040$ (Kutter's formula) was arrived at for coarse gravel by actual field observations.

In a paper "Recent Experimental Results on Shingle Movement" by Meyer-Peter, Favre and Einstein it is claimed possible to calculate the movement of shingle in a stretch of river with a given discharge. Their experimental results in the laboratory have yet to be verified by observations on rivers.

Meyer-Peter, Favre and Muller in their paper "A contribution to the Calculation of Silt Transport and the Width of Normal Sections of Hill Streams" present results of experiments, but here again data from actual streams is lacking. One of the objects of their investigations was the regrading of shingle transporting streams to arrest the shingle movement.

In the Santa Ana investigations in California the gradient on which various sized material carried by floods is deposited, and the gradient at which it is transported have been analysed from the profile of three principal streams. Boulders will be transported in channels with a gradient of 3.3 per cent. to 3.8 per cent. or greater, and come to repose on gradients of 2.4 per cent. to 3.8 per cent. Gravel appears to be transported on grades of 2.4 per cent. to 2.8 per cent. or over, and appears to come to repose on gradients of 1.4 per cent. to 2.0 per cent. Sand appears to be kept in motion on gradients of 0.3 per cent. to 0.4 per cent. or over and tends to settle on gradients of 0.2 per cent.

Mr. Post from observations on the La Grange River in America informs us that 6 per cent. of the run-off by volume consisted of solids, with velocities from 10 to 15 feet per second, the size of the coarsest material transported being boulders of 2 feet diameter.

POINTS FOR DISCUSSION.

The suitability of the attached form for collecting data.

The relative value of data collected at flood stage and at lower stages.

* Not included in this Report.

Observation of Hydraulic Data from the Boulder Bed of the River Ravi at Mukeswar.

BY DR. N. K. BOSE.

The river Ravi emerges out of the hills at Mukeswar. On the left bank of the river (Fig. 1*) precipitous rocks rise directly from the water while the right bank has a gentle slope culminating in rocky hills. A stretch of the river about 1100 ft. in length has been chosen for observations of hydraulic data and for collection of the bed material. The bed material here varies along the cross-section of the river—being boulders and pebbles on the left, pebbles and shingles in the centre, and shingle and coarse sand on the right.

In low river below 700 cu/sc., the bed is all sand except at the deepest point. At higher discharges 14,000 cu/sc and higher, pebbles of the size 4 or 5 inches have been obtained. The river at this place is in a slight bend—left bank being on the outside of the curve. The rock on the left comes down into the river as spurs.

The following observations are being carried out at the site :—

- (1) Discharge by taking velocities with current meter at .6 depth along 10 verticals.
- (2) Cross-section of the river.
- (3) Slope of the river by observing water surface level at 6 gauges, 3 on either bank of the river, one on the upstream S_2 and S_4 , and one on the downstream 550 ft. away from the site of observation S_1 and S_3 and one at the cross-section itself. There is considerable variation in the slope of the river as worked out from the gauge readings separately. They are given in the table.
- (4) Samples of bed material by means of a special cage prepared for this experiment—modified from a type given by Schaffernak in 'Hydrographie', page 193.
- (5) Temperature of water.

For carrying out these observations special equipment had to be made at this place (see Diagram I.*). Two boulder pillars set in very rich cement had been built one on either bank of the river at a distance of about 450 ft. from each other. One of these pillars is shown in Fig. II*. It shows the arrangement for fixing the rope across the river along the cross-section where the observations are being taken. A special boat (see Fig. III*) (35½' long and 8½' wide) had been prepared for this purpose and equipped with a crab-winch for raising and lowering the sampler cage and the current meter. A long 2½ inch boiler pipe has been fixed to the forefront of the boat provided with a pulley through which a wire rope attached to the sampler or the meter passes to keep the latter in a vertical. A special cage (see Fig. IV*) 24" × 12" × 9" has been prepared whose sides are made of three sheets of wire gauges (½" mesh) overlapping so that the meshes do not allow particles bigger than 1/8" to pass through. The bottom of the sampler is of sheet iron 1/8" thick. This cage is lowered (see Fig. V*) into the water by means of the winch and laid on the bed of the river with its upstream flap kept open. It is left there for about half an hour, the flap is then closed and the cage lifted above water into the boat. Samples, as large as 110 lbs. containing pebbles bigger than 4 or 5 inches even are obtained. Fig. VI* shows one such sample. Whole of the sample is taken out, spread on the left side pillar (see Fig. VII*) and dried. After that they are weighed (see Fig. VIII*) first of all the total weight and then sieved through meshes of different sizes and weighed separately. This gives the distribution curve by weight (see Diag. II*). From this the average diameter has been worked out.

Velocities at .6 depth are taken by current meter, the depths being taken as in Fig. IX*. The direction of the current is noted by a pocket sextant.

Six gauges have been fixed on both banks of the river. They are observed directly by gauge readers on skin boats known as Darrais (Fig. X*). It has been noticed that reading the gauges by a levelling instrument from one bank of the river gives an error of about 5 per cent. as compared to direct reading by the gauge reader.

Fig. X* shews the complete equipment for this experiment. The pillars and the wire rope stretched across is not shown in this figure.

The observations have been started for the last two months and practically the whole of this period has been spent perfecting the arrangements, improving the methods of sampling and overcoming other unforeseen difficulties that are inherent in such work. One of the ever recurring source of danger to the staff employed on such work is the unceasing rush of deodar sleepers that are floated down this river from Kashmir State Forests. These sleepers sometimes got entangled in the wire ropes that keep the cage in position and such is the force of water on these sleepers that the 2½" boiler pipe through which these ropes pass are bent like reeds. Already 4 such pipes have been damaged. Every such occurrence meant in the beginning dislocation of work for about 4 or 5 days. At present duplicate sets are being kept ready at site.

The following table gives the information about this experiment so far obtained.

* Not included in this Report.

Result of discharge observations and analysis of

Serial No.	1	2	3	4	5	6	7	8
Date of Observation	6-5-39	7-5-39	23-5-39	24-5-39	25-5-39	26-5-39	27-5-39	4-6-39
Discharge Q	9,664.52	10,774.49	12,297.95	12,419.06	12,577.54	11,404.70	11,170.64	13,404.0
Area A	2,205.0	2,243.75	2,050.0	2,031.25	2,003.75	1,928.75	1,868.75	2,033.7
Mean Velocity V	4.38	4.80	6.00	6.11	6.28	5.91	5.93	6.50
Wetted Perimeter P	276.43	276.56	276.87	276.43	276.73	276.63	276.55	276.6
Hydraulic Mean Radius R	7.98	8.11	7.41	7.35	7.24	6.97	6.81	7.33
Slope Right Above S_1 . . . . .	.00057	.00057	.00151	.00170	.00170	.00151	.00151	.00
„ „ Below S_2 . . . . .	.00094	.00113	.00094	.00113	.00094	.00094	.00094	.00
„ Left Above S_3 . . . . .	.00019	.00019	.00057	.00094	.00094	.00094	.00094	.00
„ „ Below S_4 . . . . .	.00075	.00075	.00094	.00094	.00094	.00094	.00075	.00
$V/(R S)^{2/3}$ S_1	13.23	14.34	13.76	13.54	14.06	14.12	14.39	15.11
„ S_2	11.20	11.42	16.12	15.52	17.13	16.54	16.85	17.80
„ S_3	19.08	20.68	19.04	16.50	17.13	16.54	16.85	15.19
„ S_4	12.07	13.09	16.12	16.50	17.13	16.54	18.17	19.18
Mean size of sample d (in inches)	1.009	1.249	.44	.66	.59	.40	1.36	1.04
$f_5 = 8\sqrt{d}$	8.040	8.944	5.3064	6.4992	6.1448	5.0600	9.3296	8.19
$S^{1/2} R^{1/2} \frac{10^4}{(370.68)^{1/2}}$ f_1	2.6623	2.6766	4.9720	5.3655	5.3350	4.8715	4.8340	4.95
Do. f_2	3.7161	4.2240	3.6255	4.0882	3.5976	3.5537	3.5264	3.61
Do. f_3	1.2799	1.2868	2.5974	3.6157	3.5976	3.5537	3.5264	4.95
Do. f_4	3.1368	3.2140	3.6255	3.6157	3.5976	3.5537	3.0305	3.110
$\frac{1.3458}{V} R^{1/2} S^{1/2}$ Na 1 . . . . .	.0348	.0322	.0392	.0403	.0388	.0380	.0372	.036
„ Na 2 . . . . .	.0447	.0453	.0312	.0334	.0293	.0300	.0294	.027
„ Na 3 . . . . .	.0201	.0186	.0242	.0305	.0293	.0300	.0294	.030
„ Na 4 . . . . .	.0400	.0369	.0312	.0305	.0293	.0300	.0262	.027
$\frac{1.486}{V} R^{1/2} S^{1/2}$ Nm 1 . . . . .	.0323	.0298	.0366	.0377	.0363	.0357	.0350	.033
„ Nm 2 . . . . .	.0415	.0420	.0292	.0312	.0275	.0282	.0276	.026
„ Nm 3 . . . . .	.0187	.0172	.0226	.0285	.0275	.0282	.0276	.025
„ Nm 4 . . . . .	.0371	.0342	.0292	.0285	.0275	.0282	.0247	.023

samples at Mukeswar (Ravi River).

9	10	11	12	13	14	15	16	17	18
6-6-39	7-6-39	8-6-39	9-6-39	15-6-39	16-6-39	17-6-39	18-6-39	21-6-39	22-6-39
12,754.67	10,508.71	10,292.82	9,588.15	9,943.06	11,036.68	14,461.68	16,004.71	17,175.65	17,774.90
2,051.25	1,947.50	1,938.75	1,862.50	1,851.25	1,925	2,066.25	2,230.00	2,206.25	2,260.0
6.22	5.40	5.31	5.15	5.37	5.73	7.00	7.18	7.78	7.87
276.69	276.56	276.61	276.36	276.44	276.45	276.53	276.85	276.65	276.67
7.41	7.04	7.01	6.74	6.70	6.96	7.47	8.05	7.97	8.17
.00151	.00113	.00113	.00094	.00094	.00113	.00170	.00170	.00226	.00245
.00113	.00075	.00113	.00113	.00094	.00094	.00094	.00113	.00113	.00113
.00113	.00075	.00075	.00038	.00038	.00075	.00113	.00151	.00170	.00208
.00094	.00075	.00113	.00094	.00113	.00151	.00094	.00094	0.00094	.00113
14.26	14.11	13.92	14.74	15.43	15.09	15.35	14.98	14.86	14.39
15.71	16.18	13.92	13.86	15.43	16.05	18.70	17.16	18.72	18.63
15.71	16.18	15.96	19.93	20.86	17.30	17.59	15.58	16.34	15.20
16.71	16.18	13.92	14.74	14.51	13.70	18.70	18.25	19.90	18.63
1.525	.368	.376	.66	.364	.67	.66	.62	.705	.946
9.8792	4.8523	4.9056	6.4992	4.8264	6.5480	6.4992	6.2992	6.7168	7.7808
4.9724	4.0295	4.0236	3.5141	3.5057	4.0145	5.3944	5.5307	6.6664	7.0934
4.0089	3.0659	4.0236	3.9716	3.5057	3.5520	3.6367	4.2141	4.1996	4.2944
4.0089	3.0659	3.0614	1.9218	1.9166	3.0525	4.1102	5.1113	5.5138	6.3599
3.6255	3.0659	4.0236	3.5141	3.9635	4.8692	3.6367	3.7286	3.7145	4.2344
.0378	.0362	.0367	.0336	.0320	.0338	.0358	.0369	.0390	.0409
.0327	.0295	.0267	.0367	.0320	.0309	.0266	.0301	.0276	.0278
.0327	.0295	.0299	.0213	.0203	.0276	.0292	.0348	.0328	.0377
.0298	.0295	.0367	.0336	.351	.0391	.0266	.0275	.0252	.0278
.0353	.0340	.0345	.0316	.0302	.0318	.0334	.0343	.0362	.0379
.0305	.0277	.0345	.0346	.0302	.0290	.0249	.0280	.0256	.0257
.0305	.0277	.0281	.0201	.0192	.0259	.0273	.0323	.0314	.0349
.0278	.0277	.0345	.0316	.0331	.0367	.0249	.0255	.0234	.0257

Note on the Determination of the Average Diameter of the Active Bed of Torrents in Gravel, Shingle, and Boulders.

BY GERALD LACEY.

This note is written in the hope that it may provoke some discussion as to the ways and means by which the average diameter of coarse incoherent bed material may be measured. The modern tendency in the development of hydraulic formulas is to replace co-efficients of roughness such as Kutter's N , N_a etc., with absolute measurements of roughness in terms of the height, or average height of projections from the bed or wetted surface. Relative roughness is denoted by the dimensionless number (R/d) , the ratio of the hydraulic mean depth to the average height of projection. In all recent experimental work on rough pipes with fully turbulent flow values have been assigned to d . It is clear that if ' m ' is the average diameter of the bed material in a boulder river the actual average height of projections will be neither ' m ' nor the radius ' $\frac{1}{2}m$ ' but some fraction of ' m ' which should be a constant for the type of material transported irrespective of precise grade. The fraction remains to be determined, and the first contribution to its determination is the measurement of the average diameter ' m '.

2. Analysis of sandy silt samples has given distribution curves which have certain characteristics. It is not improbable that the average of a great number of such curves would closely approximate to a probability curve. Aeolian or wind blown sands also give distribution curves not far removed from probability curves. It is important to ascertain if distribution curves for boulders, shingle and gravel have the same characteristics as finer material.

If a sample of large transported material can be shown to possess approximately the same characteristics as small samples, equations based on relative roughness derived from small incoherent material can be applied with greater confidence to coarse material. Such equations could also then be treated as 'general' rather than special.

3. The writer has found that if by ' m ' is denoted the average diameter of loose incoherent bed material in millimetres, and allowance is made for shock effect, the silt factor can be deduced from the equation

$$f = \frac{3}{4} V^2 / R = 1.76 m^{\frac{1}{2}}.$$

There is no experimental justification for applying this equation to very small values of m when cohesion will vitiate results, nor can it be applied with confidence to material other than sand. It is however of interest to apply the equation to the limiting condition of "shooting flow" in torrents when the slopes are so severe as to induce flow by "rapids" rather than ordinary turbulent flow. In all torrents and boulder rivers the hydraulic mean depth is sensibly equal to the mean depth D and hence it is permissible to write,

$$V_{lim.} = \sqrt{gD} = \sqrt{gR} = 1.155 \sqrt{fR} \quad \text{and solving for } f,$$

$$f_{lim.} = 24.15.$$

If the equation in terms of the diameter is applied, this limiting value of ' f ' would correspond with an average size of boulder of 188 millimetres or nearly $7\frac{1}{2}$ ". As boulders are far from spherical the maximum dimension of the average boulder involved would be of the order of ten inches. If the writer's equation

$$N_a = 0.225 f^{\frac{1}{2}}$$

is applied the limiting value of N_a is equal to .050.

These extensions of the equation involving f and m are tentative, but show that under limiting conditions of shooting flow the values of N_a and of the boulder diameter are rational and of the correct order. There is by now a mass of evidence to show that the ratio V^2/R is a criterion of regime flow and if values of this ratio can be correlated with values of the average diameter of coarse material a great advance will be made. Whatever may be the views held on this subject the necessity for measuring the mean diameter in order to assess the relative roughness R/d is admitted by all modern authorities.

4. The writer has not been able to obtain any data or literature on the subject of the measurement of the size of boulder material. It is practically impossible to sample a large boulder bed while in flood although samples from a gravel bed should be fairly easy to maintain. A good approximate method for a boulder bed would be to paint or white-wash a "graticule" on a portion of the bed after the flood had somewhat subsided and to photograph it. After the photographs had been taken the entire exposed surface within the limits of the graticule could be carefully painted with some medium and all material thus painted would be removed as a sample. Thereafter the sample could be measured

by volumetric methods, relying on the displacement of water in suitably designed measuring tanks. More than one tank would be required and experience would indicate the most appropriate technique. It would be necessary, in order to reduce labour, to grade the material before measurement. Thus if ten per cent of the sample contained fine gravel, it would be sufficient to select from this graded ten per cent, a few samples obtained by quartation, and to determine for each such sample the average diameter by introducing a counted number of particles, say 10 or 100 into the appropriate volumetric tank and measuring the displacement.

5. Finally it should be possible after sufficient photographs had been collected to reproduce them in such a manner that they could be used as standards of comparison so that a photograph alone would give a quantitative idea of the average diameter of material involved. It might be urged that the correct method of sampling is to remove a sample, say to a uniform depth of one foot from the bed of the channel. It appears to the writer however that in boulder rivers, in which it would appear that relatively few particles of magnitude are in motion at any time that the *surface* sampling is more correct. If the bed is rigid, or rigid within normal conditions of flow, *e. g.*, a cut supplying a head-works, the surface alone is involved and a surface sample should be taken as suggested. The average diameter thus obtained would ultimately be correlated with a theoretical height of projection.

6. As previously stated this note has been written to provoke discussion and to stimulate the sampling of coarse bed material. It is certain that no country in the world presents a better field for the study of boulder rivers and torrents than India.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. GERALD LACEY summarised his note which appears on pages 72-73.

He congratulated the Punjab Irrigation Research Institute on the work they had done at Mukeswar on the River Ravi, where they had produced data of the greatest interest.

MR. LACEY continuing, said that he had deduced that $V = 16.05 (R^2 S)^{\frac{1}{2}}$ *. Mr. Blench had very kindly analysed the Punjab data (pages 70-71) and discovered that the numerical constant in this equation varied from 14 to 18, the average being 16.02. The agreement was very gratifying.

Referring to the Punjab data for the River Ravi at Mukeswar, Mr. Lacey pointed out that there was little difference between the computed values of N_m and N_a . One reason, apt to be overlooked, was that when the values of R were small the difference could not be large, and when the depth was 3.28' equal to one metre the difference was obviously nil.

MR. J. P. JAIN said he had collected data on the Ramganga and the Sarda in the United Provinces where these rivers ran in boulder beds, and he too found very little difference between N_a and N_m .

DR. E. MCKENZIE-TYLOR pointed out that the Mukeswar data (pages 70-71) were obtained on a rising river. He said they would now proceed to collect data from the river when it was falling, in which latter state it was more probably in regime.

MR. LACEY noted that the silt had been sampled by placing a cage on the bed of the river which meant that the observations were of moving material. He said they should endeavour to get at both types of material if possible. He also noticed great daily variations in the grade of bed silt samples *i.e.*, columns 6 and 7 of page 70 whereas R was almost constant. There was a sort of wave in the diameters of the silt. He enquired as to the reasons for excluding silt of less than 1/8 inch diameter. He regretted that central velocity observations had not been made.

DR. MCKENZIE-TAYLOR said they were obliged to omit silt of less than 1/8-inch diameter because so fine mesh offered such resistance to the flow, about 7 feet per second, that they could not work the catching apparatus.

They proposed to approach the problem from another angle. They would calculate the diameter from S and Q and then, applying a reduction factor, relate this diameter to that of the trapped material.

DR. N. K. BOSE explained that at the Mukeswar Site the bed of the Ravi River is not entirely a boulder bed, but that there are patches of sand.

MR. T. BLENCH remarked that the Punjab Irrigation Research Institute took the mean diameter weighted according to mass, *i.e.*, as diameter cubed. American practice was often to take the arithmetic mean *i.e.*, weighted according to number. The difference between these two means was very great for the boulder data under discussion.

DR. MALHOTRA remarked that American practice would give undue weightage to the smaller sizes.

Discussion then centred around the proposed form to be circulated for the collection of data from boulder rivers. Mr. Lacey stressed the importance of observing the central velocity "Vcs." He suggested that latitude and longitude of the site should be stated; that squared paper should be provided with the form for plotting cross sections; that m_1 and m_2 should be stated in a note at the end of the form, wherein should be explained the method of determining these diameters; and that it should be definitely stated whether or not the bed was in movement.

MR. LACEY recommended that the values of the silt factor should be omitted as it could always be computed from the ratio V^2/R if desired. This was accepted, and it was also agreed that the form should be accompanied by a note on the methods of measurement.

The following Resolution was passed.—*Resolved that in view of the valuable work initiated by the Punjab Irrigation Research Institute on the observations of Hydraulic data from Boulder Rivers, a form for collection of Hydraulic Data from India and abroad be compiled by that Institute and sent to the secretary for circulation to the Research Committee with a view to its adoption after the amendment found necessary.*

*Vide "Regime Flown in Incoherent Alluvium" (1939) by G. Lacey, at present in press

NOTE.—Experiments reported in the 1938-39 Annual Report of the Central Irrigation and Hydrodynamic Research Station, Poona (India) confirm this regime test formula.

$$\dagger \text{From the formulæ (1) } V = \frac{1.3458}{N_a} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$(2) V = \frac{1.486}{N_m} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

THE ROLE OF RESERVOIRS IN RIVER FLOOD CONTROL, AND FLOODS AND DEFORESTATION.

PRELIMINARY GENERAL NOTE.

Considerations given to Flood Control by Reservoirs in the Past.—In the past the control of floods by reservoirs has generally been regarded as an uneconomic system of protection.

The cost of reservoirs when constructed purely for flood control exceeds the cost of equivalent protection by levees and by-passes, and only in the vicinity of large towns, where the value of property is high, can reservoirs be utilized for flood control purposes. In studying such costs either the entire space in the reservoir, or some fraction of it, has been allotted to flood control, and at all times except during floods they are to be held empty. This mode of operation means that the entire cost of the storage space allotted to flood control is chargeable to the protective system.

Some think that the construction of large reservoirs for irrigation purposes will diminish the size of floods but in practice unless such reservoirs are especially operated for flood control, they are apt to be partially or completely full when the peak flood arrives.

Thus our present system of reservoirs for irrigation purposes has no particular bearing on flood control unless a special programme is devised for their employment, and for the construction of additional reservoirs for this purpose.

Reservoirs with the Dual Purpose of Flood Control and Irrigation.—Conditions in India in the future will favour the construction of reservoirs. The perennial sources of water have all been tapped and dependence for further supplies will be placed :—

- (1) On reservoirs.
- (2) Prevention of losses (Estimated at over 4,000 cusecs in the Punjab).
- (3) On well irrigation.

Source (1) holds out the greatest promise, and the employment of any reservoirs which may be constructed for flood control in addition to irrigation is a matter of great public interest. In view of this the Federal Government should shoulder a portion of the financial burden of the construction of such dual purpose reservoirs. The purely irrigation reservoirs existing are even now a source of loss to the Provincial Governments.

It appears rather a contradiction to attempt to use reservoirs both for flood control and irrigation. However a detailed analysis of the time of occurrence and volume of flood flows may disclose a procedure for filling reservoirs that will hold in reserve sufficient capacity to absorb floods during the time in which they are likely to occur and progressively release this space for filling as the end of the flood season approaches.

Power Development in Connection with Flood Control.—The possibility of power development must not be overlooked. Reservoirs for flood control may also be utilized for power development and irrigation or either.

Reservoir Sites in Various Provinces and States.—The possibilities of the various Provinces as regards reservoir sites are briefly outlined hereunder. These possibilities were originally explored for power development. For flood control a somewhat different approach is needed but there are points in common.

Assam.—The possibility of good reservoir sites is little explored. The upper plateau between Shillong and Cherrapunji contains sites, but dams would have to be very high, and as the region is very subject to earthquakes, their construction would be hazardous. Reservoir sites in the lower parts are said to be unlikely because the slopes of the rivers and their discharges appear too small.

Bengal and Neighbouring States.—Bengal proper being almost flat offers no suitable sites for reservoirs, but the Himalayan regions bordering on Bengal in the North, for the most part in Sikkim and Bhutan where the rainfall is very heavy and probably contributes a great deal to flooding, offer many sites for reservoirs although as yet little explored.

Flood control in Bengal would probably call for a combination of reservoir control with levees and by-passes. It would appear that reservoirs would have to be devoted entirely to flood control, because irrigation is little needed, and the proximity of coal fields would militate against hydro-electric power.

Bihar and Orissa and Neighbouring States.—The Palamau and Hazaribagh Hills the Ranchi District, the Mayurbhanj State and intervening up-lands have produced many reservoir sites for reconnaissance. In fact there seem to be great possibilities for storage schemes in these Provinces.

Reservoirs may be designed for combined flood control and irrigation as the local coal fields would probably be used for power generation.

Bombay.—There are tremendous possibilities of storage in the Western Ghats where the rainfall is very heavy. The demand for power is large and there is considerable demand for irrigation.

The Nerbudda and Tapti Rivers flow through the Panch Mahals and sites for reservoirs can probably be located.

Burma, with the Shan States and Neighbouring Territories.—These regions are particularly favoured with great possibilities as regards storage sites, but the limestone which forms so large a proportion of the hills is much fissured.

There should be demand for power and irrigation.

Central Provinces and Berar with Neighbouring States.—There are plentiful sites for reservoirs.

It has been held that for any large project the combination of irrigation from the reservoirs should be combined with power and that such a combination may be financially successful. This holds out hopes for combined flood control, irrigation and power reservoirs.

Madras and Neighbouring States.—The hill ranges of Madras offer many possibilities for reservoir sites. Madras is famous for its reservoirs so it is probable that there are many sites for reservoirs for flood control.

The Punjab and Neighbouring States.—The Sutlej, Beas, Ravi, Chenab and Jhelum all have storage possibilities in the hill portions and flood control could be combined with irrigation.

United Provinces and Neighbouring States.—There are great though little explored possibilities in the Himalayan areas which are the main contributors to floods.

An historical example of how a reservoir can affect floods is that of the Gohna Lake caused by an earth slide across the Birahi Ganga Valley in British Garhwal. This slip created a reservoir of estimated capacity 8,000 million cubic feet, and when the barrier burst it created record floods on the Ganges in the United Provinces in August 1894.

The Bundelkhand and Bhaghelkhand areas also have many possibilities for storage works.

In this Province flood control could be combined with irrigation.

Indian States and Territories Adjoining British India.—Storage sites exist in Alwar, Baroda, Benares, Bhopal, Dhar, Hyderabad Deccan, Kapurthala, Kashmir and Jammu, Mandi, Mysore, Sikkim and Suket, but detailed information is not available.

There are other States not mentioned above in which storage sites exist but which have not been investigated.

There must be many sites in Nepal of which nothing is known but we do know that that Kingdom is a source of much flood water.

Sites to-date Investigated from Point of View of Power.—Most of the information in Provinces and States recapitulated above has been taken from the Hydro-Electric Survey of India and the investigation of sites has been made with an eye to power development. Nevertheless it may furnish a key to flood control problems in some cases, and is certainly a guide to the possibilities of flood control by reservoirs in certain areas.

Method of Approach.—In the Information Bureau of the Central Board of Irrigation the problem is being approached in an orderly manner. The first step has been the production of a map of India showing the main rivers, their catchment areas, the sites of gauging stations, and the possible reservoir sites so far investigated, which latter is very far from exhaustive. For each gauging site shown on the map the year from which records date is known.

Information is required as to the rivers which are the greatest contributors to flooding in the various Provinces and States.

The next step will be the examination of hydrographs from these sites to determine what reservoir capacity would be required to absorb flows in excess of say half the maximum flood rate. As the size of floods increases with the interval of time between their occurrence it would appear that absolute protection is impossible, and that the degree of protection desired must be carefully considered. It must be decided whether protection against floods which may occur say once in 25 years will suffice. The results may prove that the necessary storages are outside the bounds of possibility but at least there would be the comfort of finality.

Floods and Deforestation.—The increase of floods with deforestation is recognised and has been the subject of three resolutions by the Central Board of Irrigation pointing out the harmful effects of deforestation and urging Provincial and State Governments to develop and extend the most suitable local machinery to deal with denudation and the allied problems of :—

- (a) better field cultivation.
- (b) better live-stock management.
- (c) afforestation of village waste land.
- (d) conservation of grass land.
- (e) substitution of organized " taungya " for shifting cultivation.

At the recent Inter-Provincial Flood Conference held at Lucknow in January 1939 the Chief Conservator of Forests, United Provinces, described the danger zone in the Himalayas as all forests and waste lands below 9000 feet altitude which are not under adequate protection by an organized Forest Department; in the plains, as all waste and uncultivated lands where domestic grazing is not controlled—particularly ravines, usar and scrub.

POINTS FOR DISCUSSION.

The advisability or otherwise of considering flood control when examining any storage project for irrigation or power.

What rivers are the greatest contributors to disastrous flooding ?

What flood periods should be considered ?

What would be the minimum fraction of the maximum flood flows to be absorbed to have appreciable effect ?

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. T. M. LYLE said that as the most devastating floods frequently occurred in the United Provinces towards the end of September, it would mean that any reservoirs for flood control in these provinces would have to be kept empty until then. This, in his opinion, would make a combination of flood absorption, hydro-electric development and irrigation extremely difficult.

There are two main classes of rivers in the United Provinces, *i.e.*, the rivers in Bundelkhand which rise in the Vindhyan Hills and flow north, and the snow fed rivers flowing south and east from the Himalayas.

Rivers of the former class are not snow fed, and do not usually contribute greatly to catastrophic flooding. Their flood peaks do not as a rule coincide with the flood peaks of the Himalayan rivers. In this tract there are three main rivers, on each of which two reservoirs have been constructed for irrigation storage. Only one further reservoir is required in the near future to make up for the storage lost by the silting of reservoirs on the Dhasan River.

The Himalayan rivers are the chief contributors to disastrous flooding in the United Provinces and Bihar especially the Jumna, Ganges, Gogra, Sarju and Rapti, but the geological formation in the hills does not afford good foundations for dams. The Gogra and Rapti have their sources in Nepal which raises a political difficulty.

MR. LYLE said that Mr. Cox had informed them that it was intended to keep the Bhakra Dam Reservoir empty until early in August. If it started filling in August, and a heavy storm occurred later in September, the reservoir would be of very little use for flood control. Such a case is typical as sufficient water for irrigation could frequently not be impounded unless storage was commenced in August or early September.

Again, if reservoirs could not be kept full, Mr. LYLE failed to see how hydro-electric power could be adequately developed in the circumstances prevalent in the United Provinces without expensive stand-by plant.

The decision to trap or escape a rising flood would be an extremely tricky business as one could not say whether the flood would be likely to cause dangerous flooding or not. Furthermore, if the largest floods were trapped so also would be the largest silt loads. Not only would this silt be an important factor in diminishing the life of the reservoir but the diminution of silt in the river downstream would lessen its usefulness as a fertilizing distributor.

At a previous meeting of the Central Board of Irrigation the Bihar representatives had asked the United Provinces engineers if they could find sites for flood control reservoirs in the U. P. in order to diminish flood damage in Bihar. If such sites were found to be available it would have to be decided who would pay for flood control reservoirs, the benefit of which would not perhaps be confined to one Province or State.

As regards afforestation, Mr. Lyle said that the Central Board had thoroughly discussed the question and the urgency of the matter was being impressed on the United Provinces Government.

DR. E. MCKENZIE-TAYLOR said that the Forest Department in the Punjab were attempting to discover the run-off from forest areas.

MR. L. VENKATAKRISHNAIYER said that in Madras the maximum flood into the Mettur Reservoir was 120,000 cusecs, but the regulating effect of the reservoir was such that the discharge downstream rarely exceeded 55,000 cusecs.

In Madras dams are so designed that the storage level in the reservoir is six feet below the flood storage level. This last six feet is retained purely for flood regulation, and when it is considered that the surface spread of the reservoir is sometimes 44 square miles, an idea can be formed of the immense volume involved. The upper ten feet in the case of the Mettur constitute 20 per cent. of the total storage.

In the Mettur dam the sluices have a capacity of 450,000 cusecs.

An emergency bund is provided, so that should the flood capacity of the reservoir be exceeded this bund would breach.

In Madras there is very little silt in the water.

MR. S. H. BIGSBY said that a point in favour of such projects in Madras was that Government owned both the reservoir site and the areas where the flood damage took place. Such was not the case in some of the other Provinces, and in the Punjab the acquisition of sites from Indian States involved immense sums in compensation.

MR. LYLE said that Mr. Bigsby's remarks applied also to Bundelkhand in the United Provinces where there were a large number of small Indian States.

As an example of the difficulty of assessing floods, Mr. Lyle mentioned a case in Mirzapur in the United Provinces. An earthen dam was designed for a maximum river discharge of 19,000 cusecs. After its construction an extraordinary flood of 55,000 cusecs occurred in 1936, when 22½ inches of rain fell in the catchment in 12 hours. The dam was overtopped, and only just escaped being wrecked.

MR. VENKATAKRISHNAIYER said that they were able to shorten the floods in the Delta. He mentioned that last year in the upper portion of one river a flood lasted for 72 days. Owing to the influence of the reservoir the surplus at the tail end only lasted for 9 days.

MR. BIGSBY also referred to the difficulties and dangers of designing reservoirs for flood control. He instanced a case of flooding in the Agra District and Bharatpur caused by the bursting of a chain of earthen dams.

MR. VENKATAKRISHNAIYER said they had devastating flood trouble in Madras in 1924, when floods were 2½ times as much as the previous maximum. Their records extended back for 60 years.

MR. H. S. KAHAI said that the effect of storage reservoirs on inundation canals should not be overlooked. He referred to the Indus.

MR. BIGSBY said the Indus was the exact reverse of other rivers. Whereas on the Indus floods had to be conserved, floods on the Ganges caused immense damage. Damage by floods in Sind was a very rare occurrence.

The crux of the matter was the minimum fraction of the maximum flood to be observed to have appreciable effect.

MR. KAHAI pointed out that it was desirable to have automatic gauges installed at places where river rating is undertaken.

MR. LYLE said that during the present year, 20 automatic gauges would be fixed on rivers in the United Provinces.

After further discussion it was

“Resolved that for the consideration of the research Committee, the Secretary take two typical cases, one of a river in Central India, and the other of a Himalayan river, both equipped with rating Stations, and calculate the storages necessary to reduce by 20 per cent. the peak of a 30 year flood.”

CONSIDERATION OF THE SUBJECT “THE ROLE OF RESERVOIRS IN RIVER FLOOD CONTROL” BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI—9th NOVEMBER 1939.

MR. A. GORDON, the President, referred to the notes and discussion at the 9th Research Committee contained in the preceding pages.

One of the main issues was the silting of reservoirs,* continued the President, and the meeting would like to hear the latest American information from Rai Bahadur Khosla.

RAI BAHADUR A. N. KHOSLA said he had not as yet had time to write his report on the subject, but would do so shortly, and send it to the Secretary for distribution to Members of the Board.

MR. S. C. MAJUMDAR said that floods were most destructive in Bengal, but at the same time the very fine silt which they carried was of immense value. From Bengal's point of view this point has to be remembered in considering the control of floods by means of reservoirs. Another difficulty was that all the sites for such reservoirs were outside the limits of Bengal.

Mr. Majumdar said that their records of the silt contents of rivers were negligible, and the collection of such information was important.

Discussion then turned on silt sampling on rivers.†

MR. E. O. COX failed to see why such investigations should go on ‘ad infinitum’. If silt sampling at any particular gauging site was continued over a period of 5 years, the information gathered should, in his opinion, suffice.

MR. COX failed to see the advantage of taking silt samples a hundred miles below a possible dam site.

MR. S. H. BIGSBY replied that the value of taking silt samples at a site far removed from a possible reservoir site was in connection with silt entry into canals. The process of regularly observing silt samples was expensive. Based on the work at several head-works in the Punjab, the cost was Rs. 1,500 per annum per site. Furthermore the observing of samples was a difficult work, and even hazardous in the case of hill torrents.

THE PRESIDENT demurred over the cost quoted by Mr. Bigsby, but thought that at this stage the Board should ask the Provinces at which river gauging sites silt sampling was being done.

* Vide pages 51-57 in this Report,

† Further information on this subject will be found on pages 53-56.

DR. R. M. GORRIE asked if he might draw attention to the resolution of the 9th Research Committee on the silting of reservoirs.* Paragraph (b) of the resolution read thus, "The main source or sources of the silt load should be determined, and steps should be taken, so far as possible, before dam construction, to reduce erosion in the catchment area".

Dr. Gorrie said that in Uhl Valley, Punjab, they were attempting to work out a simple method of reducing the silt load. The catchment was 150 square miles. He suggested that the Uhl Valley investigations might contribute something to the solution of the problem.

After further discussion it was resolved—

" THAT THE TITLE OF THIS SUBJECT BE CHANGED TO, " THE COLLECTION AND STUDY OF STATISTICAL DATA PERTAINING TO RIVER FLOOD CONTROL."

THE SECRETARY IS INSTRUCTED TO FORWARD TO EACH PROVINCE A MAP SHOWING RIVER GAUGING SITES, AND POSSIBLE SITES FOR DAMS, AND REQUEST THE PROVINCES TO INFORM HIM AT WHICH OF THE SITES SILT SAMPLING IS REGULARLY, OR ABOUT TO BE, UNDERTAKEN.

THIS INFORMATION WILL THEN BE CIRCULATED TO ALL PROVINCES.

IN VIEW OF THE IMPORTANCE OF THIS INFORMATION, ESPECIALLY IN THE SELECTION OF RESERVOIR SITES, THE BOARD IS OF THE OPINION THAT SILT SAMPLING SHOULD BE UNDERTAKEN BY THE PROVINCES CONCERNED AT AS MANY SITES AS WILL GIVE THE NECESSARY INFORMATION."

* Vide page 56.

CANAL LOSSES AND MEANS OF CONSERVING IRRIGATION WATER (STAUNCHING OF CANALS).

PRELIMINARY GENERAL NOTE.

Measurement of Canal losses.—The measurement of canal losses has been attempted along lines which may be termed direct and indirect.

Direct Methods of Measurement.—The direct methods include (a) the observing of discharges at the head and tail of the reach under investigation and (b) the rate of loss of water from compartments.

The 6th Research Committee held in July 1933 resolved that :—

- (i) the best method of measuring the losses in water courses is by the compartment method as adopted in the United Provinces.
- (ii) this same method can be used for determining losses in channels up to say 300 cusecs by selecting and bunding off typical reaches of 100 feet length.
- (iii) in larger channels, this method is not practicable and the most suitable method at present appears to be the determination of losses by the measurement of discharge at the head and tail of the reach.

Since these resolutions have been passed doubts have been raised as to the efficiency of the compartment method as it gives the purely local rate of loss.

In very small channels a chicken feed apparatus has been used in conjunction with the compartment for determining the rate of loss.

Accuracy of Measurements.—The discharge observations have been made with current meters, rods, and by calibrated falls. The accuracy of individual discharge observations is a very moot point. At the 6th Research Committee Meeting it was stated that 900 observations would be necessary to attain anything like accurate results. Working from an assumption that an individual discharge observation was within ± 3 per cent. of the true discharge another Member produced mathematical proof that nine observations would reduce the probable error to ± 1 per cent., and 36 observations to ± 0.5 per cent.

Accuracy of Rod Measurements.—The question of the accuracy of rods and their accuracy as compared with current meters for the observation of discharges has also arisen. The first series of experiments in this connection are those carried out by Major Cunningham who deduced that a rod whose length was 0.94 times the depth travelled at the mean velocity of the water in that particular vertical. Major Cunningham limited the use of rods to depths of 15 feet.

As a result of his experiments the probable error may be placed at ± 5 per cent. for rod discharges provided every precaution is taken.

Accuracy of Current Meters.—The accuracy of meters was the subject of an exhaustive series of tests at the Colorado Experiment Station in 1933. The Price, Ott, Fteley-Stearns, and Ritchie-Haskell were tested and the former was the most satisfactory.

The probable error in replicating velocity determinations at different velocities increases as the velocity decreases but in no case did the error exceed 0.5 per cent. when using a Price meter. This meter gave the most accurate results using the 2 and 8 tenths method.

Results in shallow flumes show that current meters are inaccurate under this condition and that the errors increase, in general, as the depth decreases.

British Standard Specification No. 599—1935 says that the probable error in discharge observations by current meters is ± 3 to 4 per cent. provided every precaution is taken and the water flows in an open conduit of smooth and regular section free from serious disturbances such as cross currents and eddies.

Accuracy of Flumes and Falls.—Calibrated flumes and falls have been used to determine discharges and hence losses.

The discharge formula of such falls are determined empirically and again the percentage error is unknown. Inaccuracies are mitigated by measuring volumes of water over long periods of steady flow.

Parshall flumes have been used in smaller channels and the results are consistent. One hundred and eighteen observations on this form of meter show that the mean deviation between the measured and computed discharges is + 0.5 per cent. The discharges were measured with current meters which Parshall says have a probable error from 2 to 3 per cent. even when used by experienced operators.

The Jesson metering flume has also been used. Tests on this flume have been made in the Punjab but the results are not as yet available in the Central Board Information Bureau.

Canal Losses by Indirect Methods.—Dealing with the determination of losses by indirect methods, this has been attempted by observing the slope of the sub-soil water in the vicinity of canals and combining this with the transmission co-efficient of the soil thus arriving at the rate of subterranean flow from the canal.

The rate of subterranean flow has also been attempted by chemical means.

Another method of considerable interest is the closure loss method using manometric tubes sunk in the berm.

Attempts have also been made to utilize statistics maintained as a routine on various canal systems. Such statistics extend back over a long period of years and they appear to warrant a more searching analysis than has yet been made.

Investigations have been made to determine how the losses are distributed between the bed and sides of a canal. Direct loss through the canal bed has been measured by a tube driven into the bed in which a head of water is maintained equal to the depth in the canal at the time.

Canal Losses and Conditions Affecting them.—A mass of data on the rate of loss of water from channels is available and space prohibits a recapitulation in this note. The data covers all sizes of channels from cultivators, ditches carrying half a cusec to canals discharging ten thousand cusecs.

The data signifies :—

- (a) a decreased rate of loss with an increase in the size of channel.
- (b) a decrease of loss with a decrease of gauge.
- (c) an increase in loss with increase of depth to sub-soil water up to a limit after which the loss decreases with increased depth to sub-soil water.
- (d) an increase of loss with temperature.

Loss Variations with Temperature.—In connection with (d) the 8th Research Committee (July 1938) of the Central Board of Irrigation, passed the following resolution :—

“ This Committee is of the opinion that it is of vital importance to record the temperature of the water when measuring seepage losses from canals ”.

The resolution is not very clearly expressed. It may be taken as referring to the canal water or the underground water in its vicinity or both. The underground water temperature is of great importance as the rate of subterranean flow varies directly as the viscosity.

Loss Variations with Soil Types.—Losses have been found to vary with the type of soil. The ratio of losses appears to be using the U. P. nomenclature of soil as follows :—

Usar	1
Matiar	1.4
Loam	2
Dumat	2.4
Bhur	3

This nomenclature covers mechanical and chemical composition of the soil. As might be expected the correlation of losses with the purely mechanical structure of the soil has proved abortive.

Prevention and Reduction of Losses.—Dealing with the prevention or reduction of losses we may divide the methods attempted into the following four classes.

- (1) Lining the channel.
- (2) Reducing the full supply level of the channel.
- (3) Chemical treatment of the soil of the channel.
- (4) Adjustment of the slope of the channel.

Lining has been attempted with bitumen, earth stabilized with bitumen, brick (plain, reinforced and combined with bitumen), and concrete (plain, reinforced and gunited).

American practice favours concrete plain and reinforced.

The largest system of lining undertaken in India, the Haveli Project, has used brick. This is a new work and will be watched with interest.

Recent experiments in Bengal with bitumen may produce useful results.

Successive Research Committees of the Central Board have been unable to recommend any specific type of lining as being pre-eminently suitable for general use.

Warrantable Capital Outlay on Lining.—We have numerous estimates of the capital expenditure permissible on canal lining based on the value of the cusec, the rate of loss, the life of the lining, annual repairs, and the return on capital expenditure; a complicated actuarial problem. In the United Provinces for such calculations it has been laid down that no return is required on the capital expenditure; that 3½ per cent. interest should be allowed for borrowing money, that depreciation should be calculated according to the formula :—

$$\text{Depreciation} = \frac{100}{\text{life}},$$

and that 1 per cent. should be allowed for annual repairs. The evaluation of the cusec day has been left largely to the individual choice of the officer making the investigation.

Reduction of Losses by Lowering Full Supply Level.—There are several examples in India of attempts to reduce losses by reducing the full supply level of channels chief among which may be mentioned the Ganges Canal, and the Deg Diversion. The results have been beneficial but figures are not available as to the actual reductions of loss.

Chemical Processes for Loss Reduction.—The outstanding chemical process for the reduction of canal losses is the Sodium Carbonate process. Field tests of the amount of reduction secured are on a small scale and confined to compartment methods. To date they show that the losses are reduced by approximately 40 per cent. and that the staunching persists.

The costs of treating channels by the sodium carbonate process vary from As. 5 to Rs. 1-8-0 per cent. sq. ft. according to the locality and size of channel.

Past Research Committees of the Central Board of Irrigation have passed resolutions on the sodium carbonate process which are quoted hereunder.

“Regarding the lining of canals, it is resolved that the method recently investigated in the Punjab Irrigation Research Institute at Lahore, of applying to a canal bed a dilute solution of sodium carbonate, to prevent or reduce seepage is of considerable interest and of great potential value, not only in respect to the staunching of channels but also in connection with all works, into the design of which, the flow of water through the sub-soil enters. It is expected that channels, the beds of which contain even only a small amount of calcium clay can be improved by the addition of sodium carbonate which converts a calcium clay into an impermeable sodium clay. The sodium clay renders the canal bed less pervious. Further tests of this method should be carried out in the field in order to compare results with those obtained in the laboratory, and to determine the conditions under which it will be beneficial. The exceptionally low cost of this method compared with any other form of lining and the ease with which it can be used, are factors of considerable importance”.

“This Committee is of the opinion that the further experiments carried out with sodium carbonate have proved the method to be cheap and effective in rendering canal beds less pervious. The best method of application appears at present to be the broadcasting of solid material (Na₂CO₃) on the subsurface 1 foot below the bed to be treated. The most efficient rate of application is found to be 100 lbs. sodium carbonate per 1000 sq. ft.”

The Joosten Process of chemical consolidation has been investigated with a view to its application to staunching canals. It is particularly applicable to sandy soils but costs are high (about 13s. per square yard in England).

Reduction of Losses by Silt Deposit.—The reduction of losses by adjusting the grade of canals to encourage a deposit of staunching silt has been tried in the United Provinces and results are being observed.

Practicability of Canal Lining.—Finally the following resolution of the 4th Research Committee of the Central Board of Irrigation is quoted.

“(a) This Committee having considered the question from a point of view of lining to check absorption losses, is of the opinion that the lining of existing large channels is economically impracticable apart from the administrative difficulty of closures to permit of the work being done,

(b) the lining of small channels and water courses appears to be practicable. Since the largest losses take place in such channels, it is desirable that a large scale experiment should be carried out”.

Sale of Water.—Before terminating this note, and as it affects the conserving of irrigation waters the following resolution of the 6th Research Committee of the Central Board of Irrigation is quoted.

“ This Committee is of the opinion that the sale of water by volume is not a practical proposition for general application in this country, but this method has been found practicable in some cases of large holdings. Up to the present no device for the measurement of water for small holdings which meets all the requirements of this country, and which could be used for the sale of water by volume has been brought to the notice of this Committee. The Committee is also of the opinion that the volumetric method of charging for water on canals would not afford greater protection to the cultivator than he enjoys at present, without additional cost to him ”.

POINTS FOR DISCUSSION.

- What is the error in discharge observations ?
- Do rods give a smaller or greater error than current meters ?
- Do existing canal statistics enable us to arrive at losses ?
- What is the best method of rapidly ascertaining losses on a system ?
- How do canal temperatures compare with sub-soil water temperatures ?
- Does the effect of the sodium carbonate treatment diminish with age ?
- What is the additional cost of lining a new canal as compared with constructing an unlined canal of the same discharge capacity ?
- Define the value of a cusec day ?

Report on Studies of Seepage Losses from Canals,

By T. BLENCH.

1. *Introduction.*—A most important addition to the water-table following the construction of canals is the seepage from them. As the Punjab information had not been collected and studied, and there is negligible extraneous published information on the subject, the subject has been one of the main studies of Waterlogging Investigation.

As with most other work undertaken in the investigation, considerable valuable data already existed and only required collation and analysis. It is not possible to acknowledge all sources of information; but it is fair to state that even the year's special investigation now described would be very incomplete were it not for the large number of officers who have disinterestedly collected information in the past.

The principal channels studied were those of the Upper Chenab and Lower Chenab Canal systems, as they lay in the Rechna Doab (between the Chenab and Ravi) where waterlogging is causing embarrassment.

The general physical conditions affecting the problem are: (i) A clayey crust, some 12 feet average thickness, with occasional high values such as 40 feet and occasional low ones of two or three, of varying degrees of impermeability. (ii) A sandy sub-stratum of great depth with occasional layers of kankar (nodular limestone), and lenticles of clay. (iii) A water-table about 5 feet deep, practically stable in the most waterlogged areas, and over 40 feet deep rising over 1 ft. per year in the southern arid areas. (iv) A dry climate, except for a well-defined monsoon and very light winter rains.

At Lyallpur, in the middle of the distributing system of the Lower Chenab Canal, winter evaporation is of the order of 1/8 inch rising very rapidly in April and May to some 2/3", dropping to about 1/2" during the monsoon months, and declining fairly evenly, thereafter, to a minimum in Dec.-Feb.

2. *Main Line and Branch Seepages.*—These form a separate sub-head, because they are not vitiated, in the manner of distributaries, by unavoidable differences between the methods of measuring head and offtake discharges.

(a) *L. C. C. Branches.*—Discharge Division recently collected regulating site and offtake discharges for every month for 20 years, using the data of gauge registers. The results were averaged by months and, although individual results were very different from each other, the 20 years' monthly means, when plotted, fell on quite definite curves with slight scatter except for Upper Gugera Branch and the Main Line L. C. C. Apart from choosing full supply periods for analysis, and spreading correction factors (of which there was official record) over the data, both legitimate processes, no selection or adjustment of information was made.

To decide the value to be placed on the averages, the results had to be considered both statistically and physically. The following branches were selected, Burala, Lower Gugera and Jhang with remote water-tables, and Rakh and Upper Gugera with high water-tables over parts of them. Physically, the former group should be expected to seep at a rate independent of water-table depth; the latter at a rate proportional to its depth from the water-surface.

In statistical analysis it is required, firstly, to find whether the seepages fluctuate about a fixed mean, or about a curve which is a function of time. Accordingly the yearly means of each Branch were plotted against time. As expected, the former group of Branches did not indicate that they had suffered any significant change in seepage during 20 years. Upper Gugera Branch also showed this peculiarity, whilst Rakh Branch showed a definite tendency to increase its seepage rate since about 10 years ago. The behaviour of the latter can be explained in terms of the phenomenon that seepage increases suddenly when the watertable reaches such a height that the capillary fringe touches the channel bed and establishes saturated flow conditions. After this sudden increase, seepage drops again with further rises, of water-table. As the Rakh Branch became progressively waterlogged from the head downwards, it can be concluded that the added seepages due to the former cause exceeded the reductions due to the second. On the Upper Gugera, however, about 1/4 was waterlogged 20 years ago, and about 1/2 is waterlogged now. The steadiness of seepage, therefore, is reasonably attributable to the counter-balancing of the two factors mentioned.

Before proceeding with statistical work, however, it was necessary to remove a source of constant error, in that during the last 10 years certain channels possessing metered heads had had those heads recalibrated to suit current-meter observations. Old velocity-rod calibrations were compared with later current meter ones and it was found that the differences introduced were comparable with the seepages. As the offtakes had not generally, nor so early, suffered current meter calibration the head tables

were corrected to the velocity rod calibrations. Whatever the merits of the two systems of calibration, it is obviously essential to obtain consistence.

Having corrected the tables, and verified the constancy of average seepage throughout the 20 years as corrected, the standard test for the "normal law" of error was made. That is, the deviations of every monthly result from the 20 years' mean, were grouped in intervals of 10 cusecs, plotted in histogram form, and compared with the "normal curves" drawn from the calculated standard deviations. The normal curves were found a fairly good fit to the histograms, so that the acceptance of arithmetic means as the most probable results was justified mathematically, as well as from the commonsense considerations that the results plotted uniformly, and that the number of causes of error was considerable.

Having established the normal law, the accuracy of the results could be found immediately. It was found that, although the standard deviation of a single monthly result was about fifty percent (with extremes greater than hundred per cent for certain months on certain channels), the 20 years' monthly means had only about $1/\sqrt{20}$ of this standard deviation, i.e., about 11 per cent. with extremes over 22 per cent. The worst grand mean, i.e., mean of the whole 20×12 results, had a standard deviation of 5 per cent.

Having found the s. ds. of the monthly means the latter were plotted against time (in months) and the standard deviation band was added. This limited the shape of curve closely. The Branches of remote water-table were all of a type, giving about 60 per cent. more percolation in mid-summer than in mid-winter. Temperature curves were obtained for other canals, and they showed a range of 10°C to 30°C . The seepages of two branches out of three showed some 60 per cent. more percolation in mid-summer than in mid-winter, corresponding very closely to the *viscosity range for the above temperatures as D'Arcy's Law required*. The third, Burala Branch showed a very much larger range. Its summer discharge was, however, much greater than its winter one, and an analysis of how its discharge table was framed showed that its winter seepage ought to be increased by about 50 per cent. to obtain truth. The discrepancy after making that correction was not incompatible with the fact that berms were probably flooded badly in summer.

The Upper Gugera Branch points initially indicated a very bad scatter about a horizontal line; but when the s.d. band was plotted it was found that the points really lay on a curve with a double maximum. This was reasonably explained by the fact that water-table is high in summer, and the peak that ought to occur due to temperature is converted into a trough by the preponderating negative effect of water-table rise.

The Rakh Branch was treated separately by drawing a smoothing curve by eye through the more recent results. As it was desired to know the value of water saved by lining, the monthly total winter seepages of the system were plotted with their s. d. limits. The whole analysis was summarised in a table giving the essentials, particularly the s. ds.

The Main Line was not analysed as it did not at the time seem relevant to the main purpose of Waterlogging Investigation, and because its paucity of offtakes and absence of a meter head made the results seem of doubtful value.

A most interesting sequel to the analysis was the discovery that, in very recent years, the Lower Gugera Branch had been equipped throughout with standard flumes and regulators calibrated on standard lines. This has removed most of the sources of error which make statistical analysis compulsory. The local Executive Engineer has calculated seepages from the records of these flumes for one year and the points agree very closely with the 20 years' monthly means.

(b)

L. C. C. Main Line.	}	Drainage Method.
U. C. C. Main Line.		

A main line that lacks meters and sufficient offtakes is not generally suitable for statistical analysis unless exactly comparable discharge methods are in regular use. The main lines in question have not that advantage, and have the further complication that they are so waterlogged as to run as drains in closure. Such a high water-table causes great irregularities in seepage by its fluctuations and consequent alterations in seepage head.

Mr. Crump suggested that the difficulties be removed permanently by providing means of observing seepage heads, and measuring the drainage flow during closures. Both canals were, therefore, fitted at mile intervals with B.S.P. Pipes, i.e., pipes sunk sufficiently deeply to record the water-table level remote from the channel. The difference in level between pipe and canal/drainage water gives a permanent measure of exfiltration/infiltration head producing flow. During closure bridges were closed except for one bay each and the daily drainage discharges and heads were observed in them. When steady conditions were reached the increase (or decrease beyond the infiltration reach) of discharge per unit head per million square feet was calculated for each reach and corrected

to 20°C by D'Arcy's Law. The values (σ) so obtained are now on record and the seepage any day of the year, for steady conditions, can now be calculated merely by observing the pipes.

One valuable feature of the method is that, whereas most methods of finding seepage are based on taking the difference of big quantities to find small ones, it measures a quantity comparable with what is to be found.

To test results the Lower Chenab Canal ones were compared in mid January with the Discharge Division results [see (a)] for December and January. The agreement was good, although considerable deviation would have been admissible because of the abnormally bad scatter of the statistical data, and their paucity—several years' results were missing.

To test the Upper Chenab Canal results they were compared with a curve that had been drawn previously plotting seepage against discharge. This curve showed a range of over 1,000 cusecs loss between 8,000 and 12,000 cusecs discharge. It had not initially a reliable zero as head and tail discharges had been found by inconsistent methods. The x-axis was estimated by finding, roughly, from the special well-line records, at what discharge the efflux head was zero. Again the agreement was reasonable.

Just as method (a) showed considerable differences between one Branch and another, method (b) showed enormous differences between one reach and another. Geological sections observed during sinking the B. S. P. pipes showed why. Where the canal cuts through the clay crust into silt or sand the losses are enormous. As much as 25 cusecs per million sq. ft. per foot head at 20°C may be reached. A couple of feet of clay will reduce the losses below 1 cus/mill/ft.

Part of the Jhang Branch was treated similarly, and the results agreed with what is locally accepted. Here the rate of loss was small but the heads were large.

(c) *Special Broad-Crested Weirs.*—Fourteen miles of the abandoned tail of the Upper Chenab Canal Lower (originally about 250 feet bed-width) now carries a small feeder of 500 cusecs and about 50 feet bed-width. There are no oftakes. The reach was split into three by building three identical broad-crested weirs in old bridges, and one b. c. weir, not much different from the others, at the tail. The tables of these weirs were prepared theoretically, allowing for friction; and it was assumed that the similarity of the weirs would cause any error in calibration to cancel in calculating seepages.

Because of impervious soil and high water-table, the losses which, being for the whole 250 feet bed-width, were expected to be large were actually small—about 20 cusecs over the whole 14 miles.

The difficulties in obtaining useful results were, therefore, very great; and it was not till double gauge wells had been fitted, the masonry dressed, and the approaches improved that good results were obtained. The difficulty of fluctuating water-table was avoided by calculating losses per ft. head from B. S. P. pipes.

An interesting peculiarity was that when the results were analysed it was found that a disturbance common to all reaches completely swamped the time-lag effect. This cause appears to have been the high temperature variation of the flooded, dead-water berm. To avoid the error caused by being unable to assess time-lag, steady periods, or as many periods following rising discharge as there were following falling discharge, had to be taken—and the discharge level had to be about the same for these conditions. This increased the magnitude of random error and necessitated averaging more results.

In spite of all the difficulties, seepage intensities were obtained with about 10 per cent. standard deviation, and they agreed with what to expect from (b) for clay soil.

The point of practical value is that large reaches of even a Main Line in a waterlogged area may be contributing very little to that waterlogging. The water-table behaves as a viscous fluid, and what happens at one point on it is determined by the additions all over it, not solely by the additions at that point.

The experiment was started before Waterlogging Investigation was sanctioned, and the difficulties mentioned have been of value in showing that the method is satisfactory with a few precautions whenever the losses give a readable gauge difference.

(d) *Special Sharp-Crested Weirs.*—Before Waterlogging Investigation was started a reach of 12½ miles on the Kasur Branch Lower was equipped with three sharp-crested weirs at approximately equal intervals and a broad-crested weir 6½ miles below the last. Discharge was about 840 cusecs and there was no offtake. At one weir was a mill by-pass. The metal work was done and fitted by the Amritsar Workshops, who also fitted very accurate vernier Hook gauges reading to 0.001 of a foot. The weirs were identical except, initially, as to aeration. This omission was rectified later.

Gauge setting was rather troublesome, and the obtaining of suitable gauge-well holes also caused some difficulty. Even after removing every conceivable defect and surveying the water-surface profiles with great accuracy to check the identical behaviour of the weirs, it was still found that the gauge-wells on opposite sides did not give the

same readings. The differences change sign, and are due to small irregularities from upstream, etc. In fact, they merely justify the use of double gauge wells.

The results obtained are most consistent and agree with analysis of a long series of current meter observations by the R. I.

The b. c. weir was not suitable for use with the sharp-crested ones.

As with (c) the difficulties experienced were merely due to the newness of the work, and show that the method is satisfactory after observing certain precautions. The reach above the mill showed an unexpected surge effect.

(e) *Direct Discharge Observations (Bikaner Canal).*—The method consists of repeated measurements of discharge at the head and tail of a reach without oftakes. The methods and the sections, including approaches, should be identical and the observers with instruments should be interchanged at intervals. The Bikaner Canal was chosen as it was lined with concrete. As the loss in 55 miles was of the order of 38 cusecs on 2,000 cusecs discharge a great number of results had to be averaged to obtain the seepage with reasonable accuracy. The mathematical analysis was complicated by the fact that steady discharge conditions were unobtainable, so not only temperature but also perimeter, combined personal and instrument bias, and time-lag were variables. Complete statistical analysis of 51 selected observational pairs gave a seepage at 20°C of 1.5 ± 0.25 cusecs/million. It is interesting to note that the combined instrumental and personal error difference at 2,000 cusecs was 113 cusecs for one pair of observers and 27 for another; whilst the seepage at 20°C and full supply perimeter is 38 cusecs.

Mathematically the work was of considerable interest; practically it shows how badly vitiated seepage results can be when the precaution of eliminating personal and instrumental errors is not observed.

The concrete lining material was tested in a seepage tester and gave some 3 cus/million under 12 feet head. It may have been damaged in removal from the parent material; but its general appearance was porous (it was kankar lime and aggregate concrete), and it does seem that the losses found at site are the result of resistance of lining plus resistance of soil.

(f) *Tank Method. U. C. C.*—One mile of the abandoned tail mentioned in (c) was bunded and treated as a tank. Seepage was assessed during filling from a specially built meter flume, whilst the tank was maintained full at a constant level, and at other levels. The water was visibly clean. The usual great seepage was noticed at first, while the soil was saturating, but ultimate staunching was slow and tended to a value of about 1 cusec/mill/ft. head in good agreement with the results from experiment (c) immediately upstream.

Provided water is visibly clean it seems that a tank experiment gives results comparable with those in flowing water.

(g) *Point Method.*—A 10" diameter pipe of thin steel was driven at a point in the bed of the above tank. Water in it was maintained at outside water-level by means of a pipette—the pipe contained a magnifying device that magnified 1,800 times, so a pipette was adequate for the tiny amount of water required. Seepage was calculated for this and other similar pipes.

The results agreed very well with the tank ones. This was surprising because the same method in distributaries gives low results owing to compaction of the bed material during driving the pipe. There are two possible explanations (i) the driving did not need to be deep as there was no flow outside to scour the bed (ii) the clay was tough and may have been already thoroughly compacted, or deflocculated.

These experiments cover most of the work on Feeder Channels.

3. *Distributaries.*—Here the work has been tedious but has not covered a wide field. The great difficulty about the particular work is that head discharges are assessed by one method and outlet discharges by a method that is, for the present purpose, open to doubt. There are two principal types of outlets, the open flume (O. F.) and the A. P. M. Whatever the size, type of approach, quality of masonry, or velocity of approach, the coefficient for the O. F. is assumed as 3.0 or some similar value, depending on the circle of administration. For the A. P. M. it is assumed at 7.3 in some circles, 7.5 in others. Now theoretical considerations make 3.0 for the O. F. seem low, and for a well made A. P. M. 7.8 is about the theoretical value if it is the size it purports to be. As the orifices are cast iron, and 0.20 feet is a common nominal size it is customary to allow a little margin, which increases the discharge some $7\frac{1}{2}$ per cent. on an average. If, however, the approaches are bad and cause shock loss. or if there are tiny defects of masonry the discharges can drop very noticeably.

In short, there is considerable evidence that coefficients of both the principal outlets are rather low, say about 5 per cent. allowing for the differences between one outlet and another; but they may be correct in an old area with standards of design and construction and maintenance a bit below average. For distribution purposes there is no harm

whatever in this ; but as it is customary to design distributaries successfully on the assumption that 10 per cent. is required for absorption it follows that when the seepage itself is being studied a 5 per cent. error in average outlet coefficient means that it is customary to assume seepage twice as great as it really is.

Further, distributary head discharges are usually obtained by velocity rod. There seems no better way of doing it, but one always feels some doubt about discharges taken in small channels as it is not easy to make a rod the requisite length without its striking the bed.

To avoid the colossal task of calibrating the outlets of many distributaries, the tank and point methods described in section 2 have been tried also. The former is reliable but is very expensive and requires to be done immediately after flow ; consequently observations can only be done at long intervals of time and short intervals of space. The point method gives results of relative value, but the absolute values agree very badly with those obtained by other methods, presumably because of soil compaction during driving. However, work of some scientific value has been done and is described below :—

(a) *Water-Account Method. Awagat and Pauliani Distributaries.*—The former 50 cusec distributary is peculiar in having a carbonated bed and having silted to about half its previous size (when it carried much more discharge). The latter 100 cusec channel is more normal but is in partial filling.

Both channels had their outlets calibrated by a portable flume rated against a tank. The former had special velocity rod observations done at its head only. The latter had its flumes at head and 38,000 R. D. calibrated. As they were not of much different sizes any errors in calibration should cancel in finding seepage, so the results of that reach are very reliable.

Outlet and flume gauges have been read daily since last October, and water temperature observed. The result of the former need not be discussed now as they reflect the abnormalities of the channel rather than the general seepage phenomena of distributaries.

The daily plot of the Pauliani results, corrected for temperature according to D'Arcy's Law, showed reasonable steadiness for three months till light winter rain occurred. The seepage (at 20°C) then dropped some 15 per cent. It recovered with fine weather and has increased recently with the start of the hot weather.

The immediately obvious explanation was that a marked proportion of seepage passes through the banks, and under them and back to the ground to be evaporated. Fortunately the near-by Lyallpur Agricultural College had daily evaporation figures and the exact effect of evaporation will be studied quantitatively from them after the monsoon.

It is found that evaporation keeps fairly steady in winter and increases rapidly to a maximum during April and May. It maintains this till the monsoon breaks and then drops to a lesser value from which it steadily declines with the setting in, of the cold weather. A water temperature curve, on the contrary, increases regularly from January to a turning point about September, after which it falls rather rapidly. It follows that a seepage curve for a distributary in which the bank loss (which is controlled by evaporation) is large either because of embankment or small size of channel, should be expected to be square-topped. This is exactly what local Divisions find.

The rate of percolation loss from Pauliani Disty was about 8 cus/million. This is about the average for branches of the Lower Chenab Canal, and several other distributaries will require analysis before general conclusions can be drawn.

(b) *Tank Method.*—This has been adopted extensively on Awagat Distributary, and partially on Pauliani. In the former it was extensive enough to check method (a). In the latter it was consistent, but not extensive enough to be called a check.

On Pauliani 2,000 feet of tanks were observed day and night for 2 consecutive days and nights to test the bank loss effect. It was expected that if that effect were really in existence as suggested by (a) then night losses should be less than day ones. It was found that they were 75 ± 2 per cent. of the day ones during the particular winter nights chosen.

(c) *Point Method.*—This has been tried on several distributaries including Awagat and Pauliani. On the last two it gave results about 1/2 of what was indicated by other methods.

So far no channel has shown losses approaching those of Pauliani.

One great difficulty in the method is that a small pipe compacts the soil very badly, whilst a big pipe compacts it fairly badly and causes so much bed disturbance that deep driving is necessary and even then the bed scour gives such a short "leakage path" that great care has to be taken to fix a stabilisation level in the pipe.

Further experiments are in hand, especially with regard to evaporation from banks.

Note on the Approximate Computation of Channel Losses in Re-Modelling and Project Work.

By GERALD LACEY.

This note is intended primarily to show the important part which losses play in determining channel efficiency. It is not intended as an original contribution to the theory of losses which is still under investigation. The simple assumption is made that it is possible to express the losses for a given soil in terms of cusecs per million square feet of wetted surface, approximately, and that the wetted perimeter can also be expressed approximately as a function of the discharge. On the basis of these elementary simplifying assumptions some interesting equations can be derived which may assist some practical engineers in getting channel losses and "irrigation intensity" in correct perspective. The equations were worked out some years ago by the writer, and that for the length of a channel in terms of its irrigation intensity and losses factor was recently derived independently by Mr. G. E. Hartley, Irrigation Research Officer, United Provinces.

2. It is now generally admitted that the wetted perimeter of a channel designed on modern principles is given approximately by the equation $P=C Q^{\frac{1}{2}}$: the losses in cusecs per million square feet of wetted surface may be denoted by a variable K , for which a different constant may be assigned for any given section of a channel system.

Assuming a rational value for the constant C :—

$$\begin{aligned} &\text{Losses per mile in cusecs—} \\ &\quad \frac{2.67 \times 5280 \times K Q^{\frac{1}{2}}}{1,000,000} \\ &= .0141 K Q^{\frac{1}{2}} = k Q^{\frac{1}{2}} \quad \dots (1) \end{aligned}$$

As it is impossible to assign the value of K with very great accuracy, or the value of C , it matters little whether the English mile, or the Punjab mile of 5000' is adopted. If for K an approximate value of 7.0 is adopted, the value of k is approximately 0.10, and the following table can be prepared :

TABLE I.

K	k	Remarks.
3.50	0.05	Clay.
7.00	0.10	Intermediate, clay.
10.50	0.15	Average soil.
14.00	0.20	Intermediate, sand.
17.50	0.25	Sand.

The remarks are purely descriptive and indicate the type of soil encountered. In the United Provinces the losses on the large canals and branches are of the order of 7.00 cusecs per million, and on the distributaries and minors, in average soil, of order of 10.50 cusecs per million.

A very simple approximate equation for the losses on main canals per mile is

$$\text{Losses per mile} = 0.1 Q^{\frac{1}{2}}$$

Thus a channel with a discharge of 3600 cusecs would have losses of 6 cusecs per mile, or 300 cusecs in a fifty mile reach. This figure agrees closely with losses on the Hardoi Branch of the Sarada Canal.

3. If the area commanded per mile of a distributary is treated as uniform within the section considered, the discharge abstracted per mile in cusecs, z , will remain constant. Treating the losses factor as constant also

$$dq = z \cdot dl + k q^{\frac{1}{2}} \cdot dl$$

It is not possible to integrate this expression so as to obtain the discharge as a function of z , l and k . Approximate integration leads to the expression

$$Q = zl + \frac{2}{3} kl (zl)^{\frac{1}{2}} + \frac{1}{6} (kl)^2 \dots \dots \dots (2)$$

Thus if z the outlet draw-off per mile is two cusecs, the theoretical length of the channel 5 miles, and the losses factor 'k' equal to 0.15 we have

$$zl = 10; \frac{2}{3} kl = 0.50; (zl)^{\frac{1}{2}} = 3.16;$$

$$\frac{1}{6} (kl)^2 = .09$$

10.00	
1.58	
0.09	1.67
<hr style="width: 50%; margin-left: 0;"/>	
11.67	

The losses on this small channel would amount to 14.30 per cent. of the head discharge of 11.67 cusecs.

If the channel is made 18 miles long instead of 5, the losses are greatly increased. The head discharge consists of the following three items :—

36.00	
10.80	
1.22	12.02
<hr style="width: 50%; margin-left: 0;"/>	
48.02	

The losses on this long straggling channel would amount to 25.0 per cent. of the head discharge of 48.00 cusecs. Whatever the soil factor may be the same principles obtain, and it is evident that any system of design which assumes a constant ratio of losses to head discharge is in error.

4. If the expression given in paragraph 3 is integrated for the length,

$$l = \frac{2}{k} \left[Q^{\frac{1}{2}} - \frac{z}{k} \log_e \left(1 + \frac{k}{z} Q^{\frac{1}{2}} \right) \right] \dots \dots (3)$$

This equation is correct but requires rather careful computation as it involves a difference which may be very small. It is possible by its proper use to calculate the correct head discharge of any complicated system of which the commanded areas, and the soil factors are known.

The length is theoretical to an elementary tail.

In practice the channel will terminate with a tail gul, or tail cluster of outlets with an assigned discharge, and for this discharge an equivalent length must be computed, as a constant of integration from equation (3).

As an example the equivalent length may be computed for a channel of head discharge 48 cusecs, outlet draw off 'z' or 2.0 cusecs per mile, and losses factor 'k' of 0.15.

The difference reduces to 1.349 and the length to $\frac{2 \times 1.349}{0.15}$ equal to 17.99 miles, which is almost exactly the 18 miles given in the previous example.

5. It would be a simple matter to prepare diagrams which would supply all the necessary information, and which would permit of determining the most economical layout for any system for which a fixed head discharge has been earmarked. The first requirement is to calculate values of the function within the square brackets for values of Q and the ratio z/k . The writer will leave that labour to others. There is little doubt that if this system were applied in the first instance to the layout of projects in sandy tracts such as commanded by the Bahawalpur canals that the nature of the problem to be faced would be appreciated at the commencement of construction rather than on completion.

Note on the Replacement of the Kutter Equation by a Simpler Exponential Formula.

By GERALD LACEY.

That the complicated Kutter equation is still employed in India is due largely to the fact that practical engineers rely on diagrams and tables computed from the Kutter relation. One great advantage of the equation which it has obtained through continued use is that most practical engineers have acquired some facility in estimating approximate values of Kutter's rugosity coefficient N . The coefficient has now a world wide significance as a measure of roughness. There are however other and simpler equations which employ a coefficient of essentially the same character. Thus, employing metrical units the three following equations :—

$$\begin{array}{ll}
 V = 1/N R^{1/2} S^{1/2} & \text{Manning—Strickler-Gauckler.} \\
 V = 1/N R^{.70} S^{1/2} & \text{Barnes—Forchheimer.} \\
 V = 1/N R^{1/2} S^{1/2} & \text{Lea—Lacey.}
 \end{array}$$

employ the same coefficient of roughness. When the hydraulic mean depth is unity in the metrical system, *i.e.*, 3.28', all three equations, and also the Kutter equation, give identical results. There is thus no radical departure from tradition and those who assessed Kutter's N in the past can assess values of N for any one of these exponential equations. In practice the values so assessed are almost indistinguishable.

2. Buckley states very correctly that although Manning's coefficients *in extreme cases* differ from Kutter's materially, *in moderate cases* the difference between them is small. A closer study of the subject shows that if imaginary values of the slopes are assigned comparative values of the coefficients of Kutter, and Manning, when tabulated show great discrepancies, whereas if rational and actual slopes are employed of the type encountered in actual practice in alluvial channels the agreement is close. If slopes of the same order as regime slopes are employed the agreement is very close indeed.

3. In the following table metrical units have been employed. The value of Kutter's rugosity coefficient N has been taken as .0225 throughout and the corresponding values of Manning's N calculated. Rational slopes appropriate to the rugosity have been computed from the equation $S = .000200 R^{-1/2}$, the hydraulic mean depth being expressed in metres :—

TABLE I.

R feet.	R metres.	S	C	Kutter's N	Manning's N
1.64	0.500	.000280	38.20	.0225	.0234
3.28	1.000	.000200	44.44	.0225	.0225
6.56	2.000	.000140	50.90	.0225	.0222
9.84	3.000	.000115	54.90	.0225	.0219
13.12	4.000	.000100	57.70	.0225	.0218
16.40	5.000	.000090	60.30	.0225	.0217

A glance at this table shows that it is quite immaterial whether the simple Manning equation or the more complicated Kutter equation is employed. The coefficients are practically identical, and they remain practically identical provided rational slopes, from the view point of the canal engineer are employed. If greater slopes are assumed for values of the hydraulic mean depth in excess of one metre, the result is merely that the Manning coefficient more closely approximates to that of Kutter. For example, if for a hydraulic mean depth of 5 metres the high value for the slope of .000155 is adopted, Chezy's coefficient is reduced to 58.10 and that of Manning becomes exactly .0225. If lesser slopes than those in the table are assumed the value of Manning's N will be slightly reduced. The table establishes beyond a doubt the superior merits of the Manning equation on grounds of great simplicity and equal accuracy.

4. As it is a very common practice to calculate flood discharges by employing a rough "estimate" of Kutter's N, and thereafter computing velocities from Kutter's equation it is of interest to compare the Manning coefficients. In the following table Kutter's N has been assumed as .045 throughout, a value appropriate to large boulders and shingle, and rational values of the slope calculated from the equation $S = .0125 R^{-1}$.

TABLE II.

R feet.	R metres.	S	C	Kutter's N	Manning's N
1.64	0.500	.0180	18.30	.0450	.0485
3.28	1.000	.0125	22.22	.0450	.0450
6.56	2.000	.0090	26.20	.0450	.0430
9.84	3.000	.0070	28.30	.0450	.0425
13.12	4.000	.0060	29.80	.0450	.0422
16.4	5.000	.0055	31.00	.0450	.0421

This table also shows that there is little to choose between the two equations, in which case the simpler claims preference. Rugosity coefficients are always assumed in round numbers such as .035, .040 or .045 when dealing with torrents, and meticulous accuracy is obviously out of the question.

5. From what has been said it is clear that the Manning equation has everything to commend it as a useful exponential substitute for that of Kutter. It is clear also that it gives almost identical results. The fact has long been recognised in Egypt where the Manning equation is universally employed. Engineering practice in India has been inclined to recognise that, quite apart from the bed material, the size of a channel, in other words the value of the hydraulic mean depth, plays a part in the precise value of Kutter's N which should be adopted. Thus Buckley refers to the fact that a value of N of .0225 is frequently assigned to small channels and .020 assigned to large ones. Sir John Benton recommended a value of .020 for canals of large size and in fairly good order. Kennedy suggested .0225 for small channels such as distributaries and .0200 for large canals. Buckley quotes values of Manning's N of .020 and .017 for small and large channels respectively in Egypt. There is thus considerable evidence, in respect of the Kutter equation, that the value of N to be assigned diminishes, other things being equal, with increase in the value of the hydraulic mean depth R. Now the Kutter equation is replaced very closely by that of Manning, and it therefore follows that the necessity to adjust the value of N, with either the Kutter or Manning equation, must vanish if the power assigned to R in the exponential equation (*vide* paragraph 1) is appropriately increased. Effectively formulas such as the Forchheimer or the Lea-Lacey equation, both afford this adjustment which is made in modern engineering practice.

6. In tables I and II it was necessary to assume rational values of the slope in order to compute the values of Chezy's C from Kutter's equation. In any comparison of exponential formulas of the Manning type it is unnecessary to tabulate the slope since this does not enter as a variable.

Writing

$$V = \frac{1}{N} R^{\frac{1}{2}} S^{\frac{1}{2}} = \frac{1}{N_a} R^{\frac{1}{2}} S^{\frac{1}{2}}$$

$$N = N_a / R^{\frac{1}{2}}$$

Assuming that the value of N_a is maintained constant the following table is obtained:—

TABLE III.

R feet.	R metres.	N_a	N (Manning).
1.64	0.500	0.0225	0.0238
3.28	1.000	0.0225	0.0225
6.56	2.000	0.0225	0.0212
9.84	3.000	0.0225	0.0205
13.12	4.000	0.0225	0.0200
16.40	5.000	0.0225	0.0196

It will be noted that when the hydraulic mean depth is approximately ten feet and over, corresponding to very large canals, the value of Manning's N is approximately 0.0200, whereas for small channels with a hydraulic mean depth of approximately three feet the value of N is approximately 0.0225. It thus follows from the three tables that the Manning equation is a very close approximation to that of Kutter, and further if it is the practice to diminish the value of N with increase in size, it would be better to recognise the variation of N with R, modify the power of R slightly and adopt the Lea-Lacey equation.

7. To sum up, it is contended that the Kutter equation is unnecessarily complicated, and to use the words of Unwin appears to have "no advantage over simpler equations". If it is desired to replace the Kutter equation as closely as possible by an exponential equation it is firmly established beyond all doubt that the Manning equation is the best substitute to employ. If, on the other hand it is contended that both the Kutter and Manning equations require some *slight* adjustment by canal engineers when assessing the value of N on large canals, then, clearly and indisputably that adjustment is best made by slightly modifying the power of R, and employing the Lea-Lacey equation instead. It is certainly time that practical engineers in India came forward into the open and expressed their opinions on the subject.

8. This note is confined to a discussion of whether it is possible to replace the Kutter equation, now in use in India, by a simple exponential equation, and having put forward the Manning equation in this connection to discuss whether any other exponential equation might represent the facts more accurately. Opinions having been elicited on that subject it may then be necessary to discuss other formulas for flow. Thus the Prandtl-von-Karman flow equation for full turbulence in rough pipes takes the form

$$V = K \log (R/d) \times (gRS)^{\frac{1}{2}}$$

an equation which is logarithmic in form.

It is customary when the relative merits of the Kutter and exponential equations are discussed for some critics to throw the whole problem back into the melting pot by drawing attention to the work of Prandtl, and thus discrediting "empirical equations" without making any constructive proposals. The fact remains that the question whether the Kutter equation can be replaced by a simple exponential equation must be determined on its merits, and can be determined now, without waiting for the last word to be said on the problem of flow. Similarly whether the Manning equation as an exponential formula most accurately represents conditions on canals in India must also be decided, and can be decided now on its merits.

9. Whether the Prandtl-von-Karman equation most accurately represents conditions in open channels or whether in open alluvial channels the exponential type of equation is more accurate is yet an open question. It is sufficient to record here that if the Prandtl-von-Karman equation is differentiated it will be found that the curve can be fitted with a succession of chords all of the type

$$V = \frac{1}{N} R^{.75} S^{\frac{1}{2}}$$

$$V = \frac{1}{N} R^{.70} S^{\frac{1}{2}}$$

$$V = \frac{1}{N} R^{.65} S^{\frac{1}{2}}, \text{ etc.}$$

Within the normal range of observations on rivers and canals the Manning equation, and the Lea-Lacey equation are both close approximations to the Prandtl-von-Karman fundamental equation for pipes. The equations being exponential are easier to manipulate than an equation of a logarithmic form, and there is every reason why equations of this type should be adopted now *in preference to the Kutter equation*, the determination of the ultimate equation, most satisfactory from a physical viewpoint, being left an open question. This note is intended as a practical contribution for the consideration of practical engineers.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MESSRS. GERALD LACEY and T. BLENCH briefly summarised their papers (*vide* pages 83, 88, 90).

MR. BLENCH, dealing with the value of canal statistics in assessing seepage, tabled copies of Plates I and V of the Waterlogging Investigations Division, Lower Chenab Canal Absorption Report.* He maintained that these plates showed that statistics are excellent if arranged over a period of some 20 years. Major discrepancies of discharge methods have to be reconciled if "constant errors" are to be removed.

DR. N. K. BOSE said that Mr. Lacey, in assigning the value of "k", had not taken into account the effects of the position of the water table.

MR. LACEY stated that the value of "k" would have to be assigned with reference to the known type soil in the reach in question, anticipated spring level, etc.

MR. H. S. KAHAI said that channels in Sind were designed for a loss of 8 cusecs per million square feet wetted perimeter.

MR. W. N. McLEOD said he thought Mr. Blench's careful examination of the statistical method had proved its value in the case concerned.

* Not included in this Report.

MR. S.H. BIGSBY asked whether Dr. McKenzie-Taylor had anything to say on Mr. Blench's statistical-method.

DR. E. MCKENZIE-TAYLOR referred to Mr. Blench's statement, "The point of practical value is that large reaches of even a Main Line in a waterlogged area may be contributing very little to that waterlogging". (Vide page 85). Dr. McKenzie-Taylor maintained that it did not matter which section was taken; over the whole of the Doab the rate of rise of the water-table was about 1 foot per year. The question was whether the rise would be arrested by lining the main canal or its branches. Mr. Blench's statement quoted above indicates that seepage losses have little effect on the general rise of water-table. Dr. McKenzie-Taylor suggested that the results of the Haveli lining be watched, for which purpose pipes had been inserted.

DR. MCKENZIE-TAYLOR also referred to Mr. Blench's statement "xxx xxx corresponding very closely to the viscosity range for the above temperatures as D'Arcy's Law required". (Vide page 81). Dr. McKenzie-Taylor emphasised that D'Arcy's Law applies only to saturated flow, whereas in the Poliani Distributary the water table is low.

DR. MCKENZIE-TAYLOR said he would very much like to see the data. In statistical work it was of paramount importance to use only good data, and it looked rather as if Mr. Blench had converted bad into good data. In the Punjab Irrigation Research Institute they had examined similar data, and its quality was such that they could have used it as an argument both for and against canal lining.

One observation used by Mr. Blench had a probable error of ± 50 per cent. "I feel", added Dr. McKenzie-Taylor, "that the application of statistical methods to the data available is open to question".

DR. MCKENZIE-TAYLOR noticed with astonishment that Mr. Blench had discovered a loss of 25 cusecs per million square feet of wetted perimeter per foot of head (vide page 85). The biggest loss he (Dr. McKenzie-Taylor) had observed was 13 cusecs per million square feet.

MR. BLENCH explained that he obtained the rate of loss quoted by Dr. McKenzie-Taylor in two small reaches by the drainage method.

MR. McLEOD pointed out that Mr. Blench had specified very clearly where this loss had occurred.

DR. BOSE questioned the drainage method. He thought that the stream line configuration would differ for inflow and outflow.

MR. BLENCH exhibited Plate V from his "Report on Seepage Losses of the Upper Chenab Canal" which showed that the stream line configuration was practically identical in both cases. It showed the result of Hele-Shaw observations made by the Punjab Irrigation Research Institute.

MR. E. S. CRUMP said that observation pipes were driven down into the stream line system. There was no great difference in the stream lines when the canal was running as a drain or as a canal, particularly for a wide canal. The drainage method depended on this similarity in the stream line system.

MR. BLENCH said that the method was correct according to Muskat.**

On the question of the relation between canal and watertable temperatures Mr. Blench said that, as far as he was aware, there was no precise information. Page 14 of the Waterlogging Investigations Division, Lower Chenab Canal Absorption Report* shows that the ratios of summer to winter seepage for the three deep water-table Branches of Plate I, are 4.0, 1.7 and 1.8. The viscosity theory based on a reasonable temperature range (taken from an adjacent canal) indicates 1.62. The figure of 4.0 for the Burala Branch is reduced to 2.67 when error of winter discharge table is estimated, and the remaining discrepancy is not unreasonably attributable to flooding of berms due to the high supplies run in summer. In his (Mr. Blench's) opinion, canal temperature is a good first approximation.

MR. CRUMP described his observations for losses on the Kasur Branch as a preliminary to lining. The reach was 20 miles long. It was split up into three sections by four meters. The upper three meters consisted of sharp crested weirs, and the lower meter was a standard board crested weir.

The sharp crested weirs had free overfalls, and particular attention was paid to correct aeration of the nappe, a phenomenon which could make difference of as much as 12 per cent. in the discharge.

REHBOCK'S condition were carefully observed as regards the position of the gauge wells, and the height of the crest, and the maximum gauge readings H were within the range of Rehbock's experiments. The empirical formula $Q = 88 \times H^{1.69}$ was adopted and agreed very closely with the values of the coefficient given by Rehbock for similar conditions.

MR. CRUMP dealt with reaches A and B, between the three sharp crested weirs. He obtained 57 results each result being an average for a day of 17 readings. He allowed for time lag. The standard deviation was worked out. The probable error of an individual observation in A reach was 7.1 per cent. and in B reach 7.8 per cent. The probable error of the mean was 0.94 per cent. for A reach and 1.03 per cent. for B reach.

MR. CRUMP considered he was correct in dividing Δ by \times , and asserting that he knew his losses with an accuracy of 1 per cent.

DR. MALHOTRA stated that Mr. Crump was perfectly justified in his assertion so long as the number of observations from which the probable error of the mean was deduced was stated. This was necessary to guard, against a confusion between the 'probable error of the mean', and 'probable error of an individual observation', as the former would diminish for a constant value of the latter, as the number of observations was increased.

MR. CRUMP said that when this reach is lined, he would have to take another 57 observations to determine the reduction of losses by the lining.

MR. CRUMP said his results on the Kasur Branch confirmed the results obtained by Mr. Malhotra. Mr. Malhotra found a loss of 75 cusecs over the 20 miles in June, or 10 cusecs per million square feet of wetted perimeter. He (Mr. Malhotra) had stated that his probable error was 10 per cent., as compared with his (Mr. Crump's) error of 1 per cent.

MR. BLENCH, in reply to Dr. McKenzie-Taylor's criticisms explained that the general rise of water table was attributable not only to the general distribution of seeping branches over the Doab but also to the fact that the water-table behaved as a viscous fluid and therefore its rise or fall at one site was due not only to local causes but also to remoter ones. He gave the analogy of a bath fitted with taps of which some were running and some closed. It would not be logical to deduce that because certain taps were closed therefore all were closed and the rise of bath water was attributable to an entirely different source. He disputed Dr. McKenzie-Taylor's opinion on his use of statistical methods, whose object was to find the value of the data. Plate V of his L. C. C. report plotted all the data in histogram form and recorded the Normal Curves on the same diagram. It was a matter of fact that the curves fitted the histograms quite well enough to justify their use in assessing the value of averages. He retabled Plate V to show that this was so. It was to be noticed that individual results were not for use, but averages of many of these results, and the averages had very small standard deviations.

At this stage of the discussion Mr. Lacey asked if he might introduce his note on the desirability of using Manning in preference to Kutter. In his view, within the normal range of slope and material encountered in alluvial channels in India, the Kutter's equation can be replaced very accurately by that of Manning.

* Not included in this Report.

** "The Flow of Homogeneous Fluids through Porous Media" by M. Muskat.

Mr. BLENCH stated that although the Manning's equation might be the best substitute for that of Kutter he personally preferred the equation of Mr. Lacey, in which the power of "R" was made 3/4 instead of 2/3 as in the Manning's equation. He based his preference on physical grounds. After some discussion it was Resolved that the Research Departments of the different Provinces should examine the existing data from canal and rivers with a view to ascertaining the most probable exponential or other relationship.

Mr. S. H. BIGSBY enquired whether the sodium carbonate treatment for staunching channels diminished with time.

Mr. G. E. HARTLEY said that experiments in the United Provinces made it appear that the staunching decreased with time, but that the results were not conclusive.

Mr. J. P. JAIN described how the sodium carbonate was used for lining (*vide* page 30 of these Proceedings).

Mr. BIGSBY wished to know if in the United Provinces trials they analysed the soil for exchangeable calcium before laying the lining, and whether the work was carried out in accordance with the latest specifications of the Punjab Research Institute.

Mr. JAIN said the soil had been so analysed, and that the figures for exchangeable calcium were quoted in Technical Memorandum No. 6 of the United Provinces Research Section.*

The amount of exchangeable calcium found in the soil before treatment in case (b), described on page 22 of these Proceedings, was 0.01 grammes per 10 grammes of soil.

Dr. MCKENZIE-TAYLOR said that they had discovered that if a wet sodium clay is used it does not disintegrate whereas the dry clay does. On the Okara Farm they lined the channels with sodium carbonate treated earth. No measurements were made of the discharge, but the area under cultivation increased by 25 to 30 per cent.

In the Montgomery Division a 6 cusec channel had been treated with sodium carbonate with good results.

Failures were reported of the sodium carbonate process on tube wells. In these cases sodium carbonate had merely been scattered on the beds of the channels, and samples showed very patchy results.

Dr. MCKENZIE-TAYLOR repeated that the amount of sodium carbonate to use was that necessary to create a pH value of 10.8 (see also page 15).

Mr. BLENCH pointed out that to reclaim sodium clay calcium was used. As there is a certain amount of calcium in irrigation water he wondered whether this would slowly destroy the staunching effect of sodium carbonate.

Mr. KAHAI said that there was calcium in the water in Sind.

Dr. MCKENZIE-TAYLOR said that with such quantities of calcium as existed in irrigation water there would be no reaction. 60 parts per 100,000 was the absolute maximum contents of solids in irrigation water.

Mr. L. VENKATAKRISHNAIYER said they were analysing clays in Madras and were using sodium carbonate for staunching. He hoped that by next year they would be able to give results.

Mr. BIGSBY pointed out that one year is hardly sufficient time to judge. He also considered that when examining results it was necessary to know what method had been employed in making the lining. It was clear that the later technique was far in advance of the earlier.

Mr. BLENCH said the principal field examples in the Punjab are the Awagat Distributary of 50 cusecs capacity the bed of which was lined in December 1937, and tubewell watercourses at Qadian. In both cases water went round the edges of the lining, and the seepage results were therefore inconclusive.

Discussion then centred round the error in discharge observations. Mr. Blench produced the following tables giving the results of some observations:—

Kasur Branch.

Observers	Punjab Research Institute.
Instruments	Price Current Meters.
Approximate Discharge	900 cusecs.
Probable Error	1.5 per cent.
Difference of—	
Personal Errors	21 cusecs.
Instrument Errors	26 cusecs.
Percolation losses	72 cusecs.
Remarks	Calculated by Waterlogging Investigation Division but not checked by Research Institute.

Jhang Branch.

Observers	Punjab Research Institute.
Instruments	Price Current Meters.
Approximate Discharge	2,900 cusecs.
Probable Error	1.3 per cent.
Difference of—	
Personal Errors . . . . .	....
Instrument Errors . . . . .	....
Percolation Losses . . . . .	....
Remarks	Calculated by the Waterlogging Investigation Division but not checked by Research Institute.

* Not included in these Proceedings.

Bikaner Canal.

Observers	W. I. Overseers.
Instruments	Price Current Meters.
Approximate Discharge	800 to 1,500 cusecs.
Probable Error	2.1 per cent.
Difference of—	
Personal Errors	27 and 113 cusecs (combined instrument and personal).
Instrument Errors . . . . .	....
Percolation Losses	40 cusecs.
Remarks	Error includes that due to time lag being neglected.

Upper Chenab Canal Tail.

Observers	Many overseers.
Instruments	Velocity Rods.
Approximate Discharge	4,500 to 7,000 cusecs.
Probable Error	1.97 per cent. to 1.42 per cent.
Difference of—	
Personal Errors . . . . .	....
Instrument Errors . . . . .	....
Percolation Losses . . . . .	....
Remarks	Routine observations of many years with occasional check by S. D. Os.

MR. BLENCH tabled copies of Plates III and III-A of the Waterlogging Investigations Division's Report on Absorption of Branches of the Lower Chenab Canal* to show that velocity rods give less percentage error than current meters.

He thought it fair to say that first class current meter canal observations of flows from 1,000 to 7,000 cusecs give about 1½ per cent. error, and that it can be inferred from the ordinary results that velocity rods should give less than 1 per cent. error under first class conditions.

After further discussion the following Resolution was proposed and carried: *Resolved that the subject "Accuracy of the different methods of taking discharges" be placed on the Agenda for future meetings of the Research Committee of the Central Board of Irrigation.*

CONSIDERATION OF THE SUBJECT "STAUNCHING OF CANALS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 9TH NOVEMBER 1939.

MR. A. GORDON, the President, referred to the notes and discussion at the 9th Research Committee contained in the preceding pages.

The President requested Mr. Cox to favour the Meeting with the latest information on the Haveli Lining.

MR. E. O. COX opened his remarks by saying that losses on the lined Bikaner Canal were 1.5 cusecs per million square feet of wetted perimeter.† On the Haveli Main Canal losses were now 1/2 cusec per million square feet.

Continuing, Mr. Cox said they had one or two isolated leaks, but the lining had stood up very well. There was no cracking although expansion joints had not been made.

The lining of the Haveli Main Canal had taught them a lot: For example Mr. Cox thought that the use of clay puddling behind the lining was a mistake. The puddle had dried out and left a gap of about an inch. This gap eventually filled with water and caused the lining to bulge in places. The total bulging was 250 feet long a small length considering that 45 miles had been lined. The bulging was not serious as the reinforcement held.

Based on the Haveli experience, they proposed to use the same form of lining on the Thal Project, but in the latter case they would omit reinforcement of the bed section. The all-in cost of the lining for the Thal Project was estimated at Rs. 20-8 per one hundred square feet.

* Not included in this Report.

† *Vide* page 86 for further details of observations and nature and condition of lining.

Lining required heavy maintenance. Banks and drains must be maintained. It was essential to provide a very big hydraulic gradient behind the lining, as a breach might carry away a big fid of lining. On the Haveli Main Canal a permanent staff of 8 men per mile of canal was employed to look after the lining.

DR. E. MCKENZIE-TAYLOR expressed the opinion that sand backing to lining would be preferable to clay puddle.

THE PRESIDENT, "Our scientific advisers are still divided in their opinions as to whether canal seepage or rain is the chief contributor to a general rise of the water table. I understand that you, Dr. McKenzie-Taylor consider that rainfall is the main factor. Would you kindly favour us with your reasons in brief?"

DR. MCKENZIE-TAYLOR in reply said that it was a very difficult question to decide.

MR. A. ORAM enquired the increase in the capital cost of the Haveli Project due to lining.

MR. F. F. HAIGH replied that the original estimate was so heavy that it was difficult to determine the actual increase due to lining. He estimated that the canal portion cost 30 per cent. more than it would have cost if unlined.

MR. COX informed the meeting that on the Thal Project they estimated a saving of 1,250 cusecs due to lining, and that although the lining would cost something in the region of 2½ crores of rupees the net result would show a profit.

In the case of the Bikaner Canal, Mr. Foy had informed him (Mr. Cox) that the lining had proved very remunerative. On that canal the original loss of water was at the rate of 8 cusecs/million square feet, which lining had reduced to 1½ cusecs. On the average the Bikaner rates for irrigation were Rs. 2 per acre less than the Punjab rates.

MR. BIGSBY said that in dealing with Bikaner results it must be remembered that most of the area irrigated by the canal was crown waste and the financial results were bound to be very favourable.

In his (Mr. Bigsby's) opinion the smaller channels, *i.e.*, 2,000 cusec channels as compared with 10,000 cusec channels, were worth lining from the economic point of view. The difficulty of lining existing main canals was almost insuperable owing to the long closures which it would necessitate.

Furthermore in the upper reaches of unlined canals there were frequently serious complications owing to spring level being above the bed of the canal.

THE PRESIDENT requested Dr. McKenzie-Taylor to give his opinion on the use of sodium carbonate for staunching.

DR. MCKENZIE-TAYLOR said that the staunching value of sodium carbonate was exemplified by the Thal practice of digging 5 or 6 feet under the soil surface, and lining channels with the natural sodium clay there found.

Major Prideau had lined tributary systems with sodium carbonate, and had reported a 30 per cent. increase in the area irrigated.

Continuing, Dr. McKenzie-Taylor said that the Punjab Irrigation Research Institute were considering a form of lining with molasses, in which the sugar is precipitated in the soil by the use of lime. This would produce a hard surface, and would probably be even cheaper than sodium carbonate.

On the Karo Farm the lining made with molasses two years ago was still in good condition.

DR. MCKENZIE-TAYLOR said that in some cases the sodium carbonate lining had reduced silt clearance.

MR. T. M. LYLE, "The experimental work in the United Provinces seems to indicate that sodium carbonate lining deteriorates with age."*

MR. BIGSBY referred to the sodium carbonate *plaster lining*,** and said that water courses had been lined with plaster at Rs. 22 per mile using free labour. Major Prideau had told him that, based on the time taken to irrigate his area, he had saved 33 per cent. of the water by using sodium carbonate plaster.

Major Prideau says that with this form of lining it was essential to ensure a certain correct velocity, and that a surface velocity of 1.5 feet per second was suitable. He used a lot of bhusa (straw) to prevent cracking.

MR. BIGSBY explained that the oldest watercourses were only two years old. It was, therefore, impossible to state the life to be expected for this plaster. Visual examination showed little or no deterioration and it was quite safe to say that plaster would last for 3 years as an absolute minimum.

* Vide pages 29—31 for further details of observations, and nature and condition of lining.

** Vide page 12.

The plaster was not easily damaged by cattle inasmuch as it is self healing. Cattle find great difficulty in extricating themselves from a watercourse lined in this manner and soon learn to avoid crossing the watercourse. The plaster is very effective in stopping weed growth and improves the silt carrying capacity of the watercourses.

Resolved "*THAT IN VIEW OF THE LARGE VOLUME OF WORK WHICH HAS BEEN DONE RECENTLY IN LINING CANALS, ETC., AND OF THE FACT THAT SOME YEARS MUST ELAPSE BEFORE THE EFFECTS CAN BE PROPERLY ANALYZED, CONSIDERATION OF THIS SUBJECT REQUIRES TO BE CONTINUED, BUT IT IS NOW CLEAR THAT UNDER CERTAIN CONDITIONS THERE ARE ECONOMICAL METHODS OF STAUNCHING AVAILABLE.*"

WATERLOGGING AND LAND RECLAMATION.

PRELIMINARY GENERAL NOTE.

The following resolutions have been passed by the Central Board of Irrigation.

Board Meeting November 1931.—"The Board records 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.—" (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 on 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. When 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 1938.—"This Board is of the opinion that in view of the lack of definite information regarding losses from canals, and their effect on the sub-soil water tables it would be a grave danger to undertake any large works to alleviate water-logging problems which had not received confirmation by thorough professional investigation."

The only resolution passed by a Research Committee with a bearing on the subject was passed at the 4th Meeting in 1934. It reads as follows:—

"(a) This Committee considers the researches of Dr. McKenzie-Taylor on the limit of salinity to prevent deterioration of the soil to be of the highest value.

(b) This Committee hopes that the results will be included in a memoir of the Research Institute and so made available for circulation."

In September 1938 the Board issued Publication No. 17 entitled "Notes on Water-logging and Land Reclamation in the form of a Questionnaire". Information received from the various Provinces is listed under the following 26 questions appertaining to Waterlogging and 23 questions concerning Land Reclamation.

WATERLOGGING.

1. What is the definition of waterlogged land ?
2. What is the minimum depth from the surface to which the water table must rise before the tract can be considered in danger of waterlogging ?
3. Is "local" rise in water-table in the vicinity of irrigation channels distinct from "general" rise of water table of an irrigated tract ?
4. What is the best method of recording the sub-soil water levels ?
5. What are the factors responsible for the infertility of waterlogged soils ?
6. To what extent are the water requirements of crops affected by the nearness of the sub-soil water level to the surface ?
7. If the sub-soil water does not contain an excess of soluble salts what is the minimum depth from the surface to which water may rise, to permit the following crops to be grown ?
 - (a) Wheat.
 - (b) Cotton.
 - (c) Rice.

- (d) Sugarcane.
- (e) Fodder crops.
8. (a) Do those depths apply if the sub-soil water is flowing ?
 (b) How is it possible to ascertain whether sub-soil water is flowing ?
 (c) What is the minimum rate of flow to which those depths refer ?
9. To obtain maximum out-turn from these crops is it better for the sub-soil water level to fluctuate or remain stationary.
10. (a) If chemical and physical properties of the soil affect the growth of crops in water-logged soils what tests are necessary to ascertain these properties ?
 (b) What are the deciding factors ?
 (c) To what depth should samples be taken ?
 (d) At what intervals of distance should samples be taken ?
 (e) Is it necessary to take samples periodically ?
11. (a) What are the causes of waterlogging ?
 (b) Is it possible to state the relative extent to which these causes are responsible ?
12. (a) What is the most practicable method of measuring seepage from canals ?
 (b) By what method is it economically possible to ascertain whether there is heavy seepage even in a short length of canals ?
 (c) Is there evidence to show that in general seepage is greater through the bed of a canal than through the banks ?
13. Is there anything to show that seepage depends on (i) supply level in the channel, (ii) the difference between the supply level and the sub-soil water level, and (iii) the age of the channel ?
14. What is the maximum depth of sub-soil water from which moisture can be brought to the surface by capillary action and other forces ?
15. Is there any relation between the depth of water table and the rate of movement of moisture by capillarity ?
16. How is the relation in Question 15 affected by the characteristics of the soils ?
17. Is there any method of determining whether a rise in water-table will lead to the accumulation of salts in the surface soil ?
18. Is there any information available on the production and destruction of nitrates in waterlogged soils ?
19. Is the lowering of the Full Supply Level in a channel an effective method of preventing or curing waterlogging ?
20. (a) Is it desirable in mixed crop areas to restrict cultivation on crops which need large quantities of water, *e.g.*, rice ?
 (b) By what methods can this be achieved ?
21. (a) Is it possible before constructing a canal to ascertain where seepage is likely to be excessive ?
 (b) If so, how can it be avoided ?
22. What is the effect on the sub-soil water table of the opening of an irrigation system ?
23. (a) Does the introduction of rice irrigation tend to cause a rise in the water table ?
 (b) If such a rise occurs, is the practice of drawing off the water during plant growth a contributory factor ?
 (c) What are the remedies ?
24. How is it possible to prevent excessive use, or waste, of water ?
25. What are the best methods of controlling the rise of the water-table ?
26. Can the effect of any measure intended to combat the rise of the water table be (i) predicted, or (ii) ascertained at any stage of operation of the cure, in case it is being tried (a) alone, or (b) in conjunction with other cures ?

LAND RECLAMATION.

1. (a) What tests are necessary to ascertain whether land is suitable for irrigation ?
 (b) What are the best methods for making those tests and how should samples be taken ?
 (c) To what depth and at what interval should samples be taken ?
 (d) Can the soils be definitely classified ?

2. (a) Which soils are suitable for irrigation with special treatment, and what treatment do they require ?
 (b) Are some of those soils suitable for growing certain crops only, and if so, which crops ?
 (c) Is it possible to define maximum intensities of irrigation and cultivation for different types of land ?
3. Are some soils only suitable for irrigation with water of a particular quality, and can those soils and qualities be defined ?
4. (a) How is land damaged by irrigation water apart from "logging" it ?
 (b) Is it possible to state which soils are liable to be so damaged ?
 (c) What are the other causes for land going out of cultivation ?
 (d) Is it possible to state the extent to which each of these causes is responsible for land going out of cultivation ?
5. If the sub-soil water contains excessive salts, is it possible to state the minimum depth from the surface to which it may safely be allowed to rise in various types of soil ?
6. (a) What classes of soil prevent seed germination ?
 (b) What classes of soil prevent growth of crops which have taken root ?
7. At what intervals of time it is necessary to analyse—
 (a) Surface soil,
 (b) Sub-soil,
 (c) Sub-soil water ?
8. Is it economically possible to prevent excessive evaporation by mulching, tilling, etc.?
9. Is it possible to prescribe suitable crop rotations or manurial treatments for different types of soils which are damaged or liable to be damaged, or have been reclaimed after having been damaged ?
10. (a) What types of land can be economically reclaimed, and on what water supply ?
 (b) Can land be reclaimed or prevented from being damaged by the application of chemicals, and if so, is it possible to define the types of soil, and chemicals required in each case ?
 (c) If land can be prevented from deteriorating by the use of chemicals, how often is an application of the chemical necessary, and what is the probable cost per acre per annum ?
 (d) Is it possible for the zamindars to use such chemicals, if so, what organization is necessary to promote the use of them ?
11. (a) Is leaching on the surface or through the sub-soil a suitable method of reclamation ?
 (b) Is the latter possible without artificial sub-surface drainage, and if so, is it possible to define which land is amenable to that treatment ?
12. What is the best agency for carrying out reclamation when :—
 (a) Small areas within zemindars' estates have been damaged,
 (b) Larger areas belonging to big landlords or to Government have gone out of cultivation ?
13. Is scrapping a practical and economical method of reclamation ?
14. If water which is saline is suitable for irrigating certain soils, can the properties of the water and soils be defined ?
15. (a) Is it possible to state from an analysis of the soil what fertilizers are necessary ?
 (b) What is the best method of analysis ?
 (c) How often should the soil be analysed ?
16. Has the quantity and quality of silt carried by canal water any relation to the maintenance of fertility or to the deterioration of land irrigated by that water ?
17. What are the factors governing the movement of salts in soils ?
18. Does the type of salt present in the soil influence (a) the rate of deterioration, (b) the rate of reclamation, (c) the appearance of salt at the surface with reference to depth of water-table ?

19. What depth of soil profile should be considered when dealing with the possible deterioration of soil due to concentration of salt at the surface with rise of water table ?

20. To what depth can harmful salts in the soil be removed by irrigation, and how can they be prevented from returning ?

21. If surface leaching is resorted to, what should be the concentration of the salts in water necessitating change of water ?

22. What salts are present in the canal irrigated tracts and what is their relative importance ?

23. What are the effects on land where sub-soil water has risen, of the conversion of perennial channels into Kharif channels ?

The mass of information precludes recapitulation in this general note.

POINTS FOR DISCUSSION.

Points on which further information is forthcoming or on which further discussion is required will be decided at the Meeting by Members of the Research Committee.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. S. H. BIGSBY said there was no satisfactory definition, and there were grave objections to attempting to define waterlogging in any other manner than in the Central Board of Irrigation Publication No. 17*.

DR. E. MCKENZIE-TAYLOR said that waterlogging could be better defined with reference to the field moisture capacity of the soil. In waterlogged land the soil crust is maintained at field moisture capacity almost to the surface.

He (DR. MCKENZIE-TAYLOR) stated that in the Punjab if the water-table was within 6 feet of the surface then there was practically no moisture gradient between the water-table and the soil surface since this depth of soil would be at field moisture capacity. As the depth of water-table increases, the depth of soil in which a steep moisture gradient is present begins to appear at the soil surface. The maximum depth of this zone of steep moisture gradient appears to be about 5 feet in the Punjab. It follows that when the water-table is situated at a depth of 11 feet (5 feet of steep moisture gradient soil and 6 feet of constant moisture gradient soil) it is producing no influence on the surface conditions of the soil and, therefore, with a water-table at a depth of 11 feet the land could not be waterlogged.

MR. W. N. MCLEOD considered it was important to dispel the idea that waterlogging is connected with the appearance of salt in the land surface.

MR. BIGSBY drew attention to question 4, page 98: "What is the best method of recording the sub-soil water levels ?"

MR. N. B. GADRE said that in Bombay they recorded the sub-soil water levels in bore holes. Observations were taken every month, and in some cases every three months.

DR. MCKENZIE-TAYLOR said that further investigations had changed our outlook. As an example he quoted question 5, page 100: "If the sub-soil water contains excessive salts, is it possible to state the minimum depth from the surface to which it may safely be allowed to rise in various types of soil ?"

MR. BIGSBY pointed out that it is because our outlook is changing that this item "Waterlogging and Land Reclamation" is kept on the agenda. He thought one way of dealing with the question of recording ground water levels would be to ask the Research Officers to prepare a note for the next Board Meeting.

MR. GADRE gave information on the depth of water-table and the rate of movement of moisture by capillarity (*vide* question 15, page 99). He quoted from the table opposite page 30 of his full report.†

Soil type.	Description of water.	Depth to sub-soil water in inches.	Average Monthly Evaporation in inches.
Stiff Murum Black Soil	Canal Water	27	4.3
Stiff Murum Black Soil	Canal Water	18	7.8
Stiff Murum Black Soil	Canal Water	9	13.2
Stiff Murum Black Soil	Saline Water	27	5.35
Stiff Murum Black Soil	Saline Water	18	8.7
Stiff Murum Black Soil	Saline Water	9	13.0
Fine Murum Black Soil	Canal Water	27	5.3
Fine Murum Black Soil	Canal Water	18	8.33
Fine Murum Black Soil	Canal Water	9	14.3
Fine Murum Black Soil	Saline Water	27	5.41
Fine Murum Black Soil	Saline Water	18	8.7
Fine Murum Black Soil	Saline Water	9	12.6

*" Land may be classified as waterlogged when the water table is permanently located at ground level. The approach of this condition is indicated when the yield of crops commonly grown in the locality is reduced by the rise of the water table, below the normal that would be expected from the soil type of that area".

† "Report on Irrigation Research 1938-39" not included in this Report.

MR. GADRE said that experiments were done in 40 gallon oil drums. Evaporation losses were determined by weighing. There was not much loss when the soil depth exceeded 40 inches.

No attempt was made to control temperature.

MR. GADRE could not state off-hand whether the soil in the drums was specially tamped, and said that his figures were really comparative for different soils.

DR. MCKENZIE-TAYLOR drew attention to the June 1939 issue of "Current Science" wherein experiments performed at Poona are described. Soil evaporimeters were used. The soil was packed uniformly into the vertical cylinders. Losses were determined by weighing and replenishing.

The time taken by water to rise up to the top of the different soil columns in the different soils (this is indicated by the appearance of wetness at the surface and also verified from the daily evaporation losses) is given in the following table:—

Type of soil.	Height of soil column.				
	6-in.	1 ft.	1½ ft.	2 ft.	3 ft.
Poona soil	1 day .	2 days .	6 days .	15 days .	Not wet even after 3 months. 21 days.
Punjab soil (normal) '	1½ days .	3 days .	5 days .	10 days .	
"Bari" (alkali) soil from the Punjab	3 days .	Not wet even after three months.			

The following table gives the actual loss of moisture in inches during January, February and March 1939, as well as the mean daily evaporation in inches from a Piche evaporimeter kept at 4 feet above the ground.

Month.	Type of soil.	Mean daily evaporation in inches from the top of soil columns with depths of					Piche evaporimeter 4 ft. above ground.
		6-in.	1 ft.	1½ ft.	2 ft.	3 ft.	
January 1939 .	Poona soil30	.27	.18	.12	.01	.45
	"Bari" soil from Punjab.	.05	.02	.02	.01	.01	
	Punjab soil (normal)	.29	.23	.21	.18	.09	
February 1939	Poona soil38	.34	.22	.15	.02	.56
	"Bari" soil from Punjab.	.06	.02	.02	.02	.01	
	Punjab soil (normal) .	.37	.26	.22	.18	.09	
March 1939 .	Poona soil48	.41	.23	.16	.02	.71
	"Bari" soil from Punjab.	.05	.03	.03	.02	.01	
	Punjab soil (normal) .	.43	.30	.21	.17	.08	

DR. MCKENZIE-TAYLOR said he had plotted these results with reference to depth in an attempt to discover at what depth to sub-soil water surface evaporation ceases. He found that evaporation ceased at 4 feet depth for the Punjab and at 3 feet for the Poona soil.

KEEN* gave a figure of 6 feet, but he only observed water levels in a pipe, and pipe measurements give an exaggerated loss.

MR. BLENCH suggested that the height of the capillary† fringe should be determined, as a high fringe would allow evaporation to occur from greater depths than would be possible with a low one.

*The reference to Keen's work is "G. J. Symon's Memorial lecture before the Royal Meteorological Society on March 16th, 1932", 'Nature', March 26th, 1932, page 463.

†At the 3rd Winter Meeting of the Research Committee, 1939, MR. H. S. KAHAI raised the question of determination of the capillary fringe, and said he would like to know the Committee's definition of it, and their opinion as to how it could be determined. Mr. Crump said that he looked upon the capillary fringe as the layer above the water table (as measured in a bore which tapped the sand below the clay crust) in which the degree of saturation (by water drawn from the water table by capillary action) was such as to produce a pressure transmitting continuum of water in which the pressure was capable of being measured by means of a manometer tapping the capillary fringe. He would define the upper limit of the capillary fringe as the surface above which the preponderance of contained air rendered it impossible to record a water pressure by means of a manometer tapping the soil at the point under consideration.

DR. MCKENZIE-TAYLOR said he was of the opinion that the true water table or phreatic surface was not at the level of water standing in an observation pipe and referred to the experiments in progress at the Research Institute, Lahore, which showed that when drops of water, such as rainfall, fell on to damp soil, there was a sudden rise of the water in the observation pipe which could not possibly be accounted for by the addition of the small quantity of water to the water table. He said that a sudden rise of one or two feet had been recorded in some investigations carried out in the field, and that in his opinion this was the true level of the phreatic surface.

After further discussion, the Committee decided that before the next Research Committee Meeting, Research Officers should be asked to examine the problem with a view to obtaining a definition of the phreatic surface, and to specifying the correct method of its measurement.

Mr. BIGSBY asked, "What is the water-table?" He said there were two views in the Punjab *i.e.* Dr. MCKENZIE-TAYLOR's view based on saturation, and Mr. Crump's view based on the ability to transmit pressure. He asked Mr. Crump to state his definition.

Mr. CRUMP said that he wished to make the property of pressure transmission a criterion. In expanding his explanation Mr. Crump said that if a manometer were inserted into the soil crust it would register a certain absolute pressure. If now this pressure were reduced and water drawn into the manometer tube then in his (Mr. Crump's) opinion the soil at that point would be saturated. If, on the other hand, a reduction in pressures resulted in air being drawn in, then the soil at that point would not be saturated.

Dr. MCKENZIE-TAYLOR stated that it was impossible to measure any pressure that might be transmitted in an unsaturated medium by means of a manometer. It follows from this that a water-table cannot be present unless the soil is saturated. The moisture contents of soil samples and their saturation values can be determined in the laboratory. In the field it can be ascertained whether the soil is below or above the field moisture capacity. There was, therefore, no need to consider pressure transmission when the determination of moisture content can give the required information regarding the presence or the absence of free water in the soil. If free water is absent no water-table could be present.

Mr. BIGSBY informed the meeting that the practical point connected with this discussion was the observation of well levels in the Punjab. They wanted to know whether their wells showed the water-table, or whether they merely registered pressure: If the former, then the ground water was within the range of surface evaporation.

Dr. MCKENZIE-TAYLOR produced actual soil specimens totalling 10 in number. The complete series was taken at various depths from the surface to 12 feet below ground level.

These samples are tabulated hereunder:—

Exhibit.	Depth (feet).	Appearance.	Clay content.	
G	Top	Dry powdery	0 ft. to 1 ft.	23.5
		Dry	1 ft. to 2 ft.	20.4
E	2	Dry	2 ft. to 3 ft.	21.7
C	3	Fairly dry	3 ft. to 4 ft.	23.8
		Dry	4 ft. to 5 ft.	19.4
F	5	Dry	5 ft. to 6 ft.	19.9
		Damp	6 ft. to 7 ft.	20.9
A	7	Damp clay	7 ft. to 8 ft.	23.2
D	8	Fairly dry	8 ft. to 9 ft.	17.9
B	9	Damp clay	9 ft. to 10 ft.	17.12
		Dampish	10 ft. to 11 ft.	19.40
H	11	Dampish	11 ft. to 12 ft.	6.6

Below the 12 feet depth the ground water was under pressure.

Dr. MCKENZIE-TAYLOR said that in addition to taking these samples they put down a series of pipes to depths of 6 ft., 8 ft., 9 ft., etc. down to the water-table.

Free water appeared in the first pipe but the second and third were dry.

The day after these pipes were installed it rained, so Dr. McKenzie-Taylor put in an inverted cone and obtained a complete series. Five days after sampling the results were:

6 feet depth	dry.
7 feet	water present.
8 feet	small quantity of water.
9 feet	water present.
10 feet	water present.
11 feet	small quantity of water present.
12 feet	dry.

Referring to the soil samples Dr. McKenzie-Taylor pointed out that some were so dry that he could not imagine a water-table was present.

The ground water in the locality is under pressure since there is a canal nearby, and Dr. McKenzie-Taylor thought that there were two water-tables, one derived from the canal through a permeable layer about 6 feet from the surface and the second under pressure below the 12th foot. He did not think a manometer would register pressure except at the 7th foot.

Dr. MCKENZIE-TAYLOR pointed out that the canal had been running since 1896 and that, therefore, the soil samples should have been saturated in this long period if it was possible to saturate the soil. The moisture determinations and the appearance of the samples showed that they were much below saturation values and, therefore, no water-table was present in the soil at the time of sampling. He also pointed out that a distinction should be drawn between saturation at the time of sampling and the appearance of water some time after sampling. If water appeared in a bore and at the time of sampling the soil was unsaturated it meant that the soil crust *remaining* was not able to withstand the uplift pressure of water and did not mean that under natural conditions, with a complete soil crust present, free water was present at this depth.

Mr. CRUMP pointed out that some of Dr. MCKENZIE-TAYLOR's bores had shown free water, some of them having reached stability. He based his remarks on the diagram exhibited by Dr. McKenzie-Taylor. They showed a decrease of pressure with elevation.

DR. MCKENZIE-TAYLOR, pointing to the samples on the table, said he could not conceive that free water was present in the soils exhibited. He further pointed out that in the deepest bore no water was present. In the bore at the 11th foot a very small quantity of water had appeared while in the shallow bores the water-table was already at a considerable height. The water in the shallow bores could not have passed upwards through the soil underlying the bores on account of the low rate of transmission indicated by the bore at the 11th foot and the dry condition of the bore at the 12th foot. If there had been a connection between the water in the shallow bores and the water underlying the soil crust then the water should have risen more rapidly in the deep bores than it did in those which were shallow. A conclusion to be drawn from these observations was that there was no connection between the water-table in the sand underlying the soil crust and the water which was present in the shallow bores.

On the request of Mr. Bigsby, Dr. McKenzie-Taylor described another case. He put down a pipe to find the ground water level. Alongside this pipe they dug a pit. The water table in the bore was 3 feet above the bottom of the pit, and the latter was dry except for some leaks in the sides. This was 60 feet from a canal.

DR. MCKENZIE-TAYLOR referred to the Journal* of Agricultural Science in which it is stated that clays may have zero permeability with quite considerable porosity. In his (Dr. McKenzie-Taylor's) opinion, such was the case in the Punjab.

MR. GERALD LACEY asked if Dr. McKenzie-Taylor classed the water-table as the underside of the impermeable roof. Dr. McKenzie-Taylor replied in the affirmative.

MR. T. M. LYLE did not consider that the definition of free water-table applied to artesian conditions.

MR. BLENCH suggested that the disagreement between authorities was due to their choosing, quite reasonably, different definitions for the term "water-table". In general use the term "Water-table" meant the free-surface of the soil-water. When the soil-water was confined under pressure by impermeable material no water-table, therefore, existed. In the Punjab case under consideration the "saturated zone" of the soil-water was stabilised by evaporation before it reached the surface, so Artesian effects did not occur; but the determination of the free surface was rendered difficult by the fact that this stabilisation only occurred when the soil-water had risen through the sand and entered the relatively impervious soil-crust of clay. If the observer were willing to wait days or weeks for water to rise in his boreholes in the crust he could determine the water-table according to conventional definition, provided it had been steady. Obviously, therefore, the determination of water-table by the usual method of boring, was not suitable in a clay material. Tolman† acknowledged the difficulty by classifying soils as aquifuges, aquicludes, and aquifers according as they were absolutely impermeable, highly impermeable although able to hold much fluid, or permeable enough to yield a commercial water-supply. The types of these materials may be taken as rock, clay, and sand. Tolman† gave an example of a capillary fringe of 10 ft. taking 475 days to establish itself in a clay and it had apparently not reached its limit of rise.

In view of the facts given Mr. Blench was not surprised that the boreholes quoted by Dr. McKenzie-Taylor did not yield water appreciably after 5 days' wait. It seemed fairly obvious that a highly impermeable site had been chosen and that such sites could not be general—if they were, then rain would find its descent as difficult as the ascent of water-table water and would not show the results on the water-table that were generally obtained.

In actual fact the level to which water will rise in a bore made into the sand is not much different from the level of the free-water surface in the clay. The difference is the loss in head due to the fact that the water is not static, but is moving at a rate normally determined by evaporation, viz. about 5" per year. That this small velocity can produce a loss of head of an inch or two is due to the very low transmission constant of clay soil. Tolman gives it in terms of velocities under 1% gradient, and shows 0 to 0.001 ft. per day for clays. Waterlogging Investigation Division has been carrying out experiments under Mr. Crump's instructions, using a special manometer that records pressures without using anything more than a trifle of water, and the transmission constant found near D. I. R's site, when used with the measured loss of head, indicates a velocity of flow of the order of evaporation flow (which equals the rate of well rise before that rise was stopped by contact of soil-water with the soil-crust and the consequent establishment of a capillary fringe from whose surface evaporation is possible). The idea behind this experiment had already been suggested independently by Tolman, who thought of the phenomenon in terms of the reduction in capillary fringe height due to dynamic head gradient and suggested that the loss in height might be used as a measure of evaporation rate.

MR. BLENCH dealt with Dr. McKenzie-Taylor's point about pressure transmission in unsaturated soil by stating that there were, in this aspect, two kinds of non-saturation—Tolman, realising this, refers to the under-saturated zone instead of the unsaturated one. If the under-saturation was of the type called funicular by Keen there was continuous water throughout in tubes bounded partly by soil surfaces and partly by capillary films, and a continuous system of air passage also existed. Pressure transmission occurred, however. Another type of under-saturation was when a capillary fringe moved upwards. In doing this it preferred some passages to others with the result that some pores could be isolated and left full of air. Here there is a continuity of completely saturated pores, but contained air-pockets exist. Pressure recording in this is simple, and Waterlogging Investigation Division had performed experiments on such a rising and falling fringe in a 45 gallon oil drum of sand. Effective porosity on the falling conditions was 20%, but on the rising only 10%. The difference represents entrapped air, but does not prevent the manometer, whose end was in the capillary fringe (at less than atmospheric pressure) from recording continuous change. However, if a saturated sand were allowed to drain freely till all drainage stopped there would still be bound water round the points of contact of the soil-particles, but pressure transmission would obviously be impossible, as the continuity of the water had been broken.

Thus the mere fact of partial saturation as found in the laboratory by comparing contained water with dry pore space is no proof that pressure transmission is impossible. An Australian Government Research reference actually gave examples of under-saturation below the water table, merely because of included air bubbles which no more broke the fluid continuity than did the soil-particles themselves.

MR. BLENCH opined that there was, in view of the fact given, no intellectual difficulty in using the ordinary water-table definition when dealing with an aquiclude, but that, owing to the very slow motion of water in such a medium, special instruments such as Mr. Crump's (or a Chattock manometer) were required to find it instead of the crude method of inserting a pipe and waiting for weeks. In view of the small difference between true water-table and the level recorded by boreholes through the crust into sand, he thought it would be good enough to accept ordinary well-levels for practical work in the Punjab plains where there was no Artesian effect. Whether either, or any other, definition were accepted was not of very great consequence so long as everyone accepted the same. But an acceptable definition should not be repugnant to the one in general use for water in an aquifer.

DR. MCKENZIE-TAYLOR informed the Meeting that the field moisture capacity in the Punjab varied from 23 to 25%.

He said that if well levels are showing pressures, the calculations for additions to sub-soil water by canals were wrong.

MR. A. R. THOMAS enquired whether he was correct in assuming that open wells may not normally register correct water-table levels, but that they do so after rain.

DR. MCKENZIE-TAYLOR said Mr. Thomas was correct in his assumption.

* "Permeability of Saturated Sands, Soils and Clays" by P. C. Carman, Journal of Agricultural Science Vol. XXIX, pages 262-273.

† "Ground Water" by Tolman.

Referring to the appearance of salts on the land surface Mr. Bigsby said that they now knew that the lowering of the water table is not a cure for alkaline soil. He drew attention to the resolution passed at the Board Meeting in November 1931 (*vide* page 98 of this Report). After discussion the following resolution was passed:

"Resolved that the committee draw the attention of the Board to their Resolution on 'Waterlogging and Land Reclamation' passed at the 2nd Board Meeting in November 1931, and recommend that the Board reconsider the question and frame a new resolution thereon in the light of present day knowledge."

CONSIDERATION OF THE SUBJECT "WATERLOGGING AND LAND RECLAMATION" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 9TH NOVEMBER 1939.

MR. A. GORDON, the President, referred to the notes and discussion at the 9th Research Committee contained in the preceding pages, and said that apparently the provisional opinion recorded by the 1931 Board meeting was no longer tenable.*

MR. S. H. BIGSBY reported cases in the Punjab where salts had risen to the ground surface although the water table was 40 feet down. He said such cases showed that the appearance of alkali at the surface was quite unconnected with the water table.

Continuing, Mr. Bigsby said that the lowering of the water table had not cured the appearance of salts. He understood there were similar cases in the United Provinces.

KHAN BAHADUR ABDUL AZIZ, "There are cases in the United Provinces".

DR. MCKENZIE-TAYLOR maintained that the two subjects, water table, and salt appearance, should be treated separately. In the Thal, salt was in evidence with a water table 30 feet below the surface, and no irrigation had ever been done there. He found that the appearance of salt was independent of the depth to water table.

MR. W. N. MCLEOD considered it unfortunate that the term waterlogging had been associated with high water table, and the appearance of salt.

MR. A. ORAM said it appeared that waterlogging, and soil deterioration, were not interdependent.

MR. BIGSBY stated that in the Punjab there are tracts which are to all intents and purposes water-logged but are still fertile inasmuch as they bear crops. He also explained that the Irrigation Branch, Punjab, did not possess a complete survey of alkaline lands. Special surveys were only carried out when deterioration was sufficiently severe to cause serious complaints. In such areas surveys were carried out twice a year. Little information was available about areas not subject to this Special Gurdawari. The lack of information had, in many cases, hampered the enquiries. Unfortunately Government had not been able to finance the aerial survey advocated by the Irrigation Branch.

MR. E. O. COX expressed the opinion that the whole country should be chemically examined.

DR. MCKENZIE-TAYLOR suggested aerial surveys as a rapid and efficient method of recording salt affected areas. Such surveys should be carried out in the cold weather at which season the salt was more visible.

Resolved "THAT THE BOARD CONSIDERS THAT THE PROVISIONAL OPINION OF THE BOARD RECORDED IN 1931 REGARDING THE RECLAMATION OF ALKALINE SOIL BY LOWERING THE WATER TABLE IS OPEN TO CONSIDERABLE DOUBT IN VIEW OF THE RESULT OF RESEARCH WORK SINCE CARRIED OUT.*

THE SUBJECT IS STILL BEING STUDIED INTENSIVELY, AND IT IS PREMATURE FOR THE BOARD TO EXPRESS ANY FURTHER OPINION AT THIS STAGE. THE BOARD CONSIDERS THAT THE QUESTIONNAIRE ON LAND RECLAMATION† SHOULD BE BROUGHT UP TO DATE."

* *Vide* page 98.

† *Vide* page 99.

THE DESIGN OF DRAINS IN IRRIGATED AREAS.

PRELIMINARY GENERAL NOTE.

No resolutions on this subject have been passed by the Central Board of Irrigation or the Research Committees of the Board.

A " Questionnaire on Drainage Systems in Irrigated Areas " was recently issued and replies have been received from the various Provinces.

The questions numbering 71 are listed hereunder.

Drains to deal with high water-table.

1. If the level of the sub-soil water is to be lowered, what are the best methods of doing it, and to what level should it be lowered ?

If the level be lowered, what measures should be taken to dispose of the water ?

2. What forms of drainage to deal with High Water-Table have been adopted in your Province, and under what conditions have they been successful or unsuccessful ?

3. What is the best method of determining the sub-soil discharge for which a drain is to be designed ? Should it be determined with reference to actual observations such as :—

- (a) Annual residual rise in the water-table,
- (b) Maximum rate of rise,

or by simply assuming a discharge per mile length of the drain ? Are the data available, and have seasons been indicated ?

4. Is there any experimental or actual data available showing the sub-soil water discharge for various depression heads and bed widths for :—

- (a) Clay,
- (b) Silt, and
- (c) Sandy soils ?

5. What are the factors influencing the distance between drains in different types of soil ?

6. What is the approximate distance for which a drain is effective in :—

- (a) Clay,
- (b) Silt, and
- (c) Sandy soils ?

7. Is there any information available showing the relationship between sub-soil discharge and bed width of a drain for the same depression head ?

8. What information is available regarding the amount of moisture retained by various types of soil ? (It should be stated whether the experiments were with soil in the natural state or laboratory treated).

9. What information is available as to actual discharges in drains compared with those for which they were designed ?

10. What are the methods adopted for selecting the best lines for sub-soil drains ?

11. Which type of drain is the more efficient, an open or covered drain ?

12. What side slopes are necessary for open drains in different types of soils ? What is the best cross section for this type of drain ?

13. In cases where sub-surface drainage has been installed, what methods have been adopted for the disposal of drainage water ?

14. Is sub-surface drainage an economical method of lowering the sub-soil water-table and what is the economic limit of cost of sub-surface drainage ?

15. What records are kept of the chemical analysis of the water in the drains ?

Drains to deal with surface and storm water.

16. What methods have been adopted in the Province or area under consideration for disposing of surface and storm water ?

17. What methods, formulae, rugosity co-efficient, etc., were employed to calculate the discharge for which the drains were designed.
18. What rainfall intensity, duration and distribution were assumed ?
19. What allowance was made for absorption and evaporation ?
20. What run-off was assumed ?
21. What is the nature of the catchment areas, *e.g.*, are they steep, rocky, covered with vegetation, etc.
22. Were the drains designed to take excess irrigation water and river spills in addition to rain water ? If so, for what quantity ?
23. Were the drains designed to take the full discharge anticipated from all sources or was allowance made for temporary flooding in the vicinity of the drain ?
24. How were the dimensions of the drain calculated ?
25. For what discharge were the masonry works designed, and were their foundations lower than normally to allow for the possibility of scour ?
26. Do the catchments or drainage lines contain any ponds or depressions which may delay action of floods ? If so, what allowance was made ?
27. What information is available as to the working of the drains, *i.e.*, are there any data of actual discharges, rainfall and run-off compared with those for which the drains were designed ?
28. Is there any information regarding the effect of this type of drain on the sub-soil water-table and the area under agriculture ?
29. Where a drain is given a new alignment across a depression, in what circumstances is it obligatory to maintain banks to prevent spills ?
30. Where drains follow natural depressions, under what circumstances is it better to adhere to the depression or to straighten out the alignment with cut-offs ?
31. Has a rise in the water table ever been traced to the diversion of surface water across depressions with a drain confined within banks ? If so, can any subsequent action be taken to arrest this rise ?
32. In flat country when is it better to cut across a doab to make an outfall, and when is it better to carry the drain parallel to the rivers in the natural depression to the confluence of the two rivers ?
33. Where town drainage has, by custom, been discharged into a natural drain, is this detrimental to the efficient working of a surface water drain ?
34. For what periods of time in cases of heavy rains do low lying tracts drained by your drains remain submerged, and what is the maximum period permissible ?
35. Was the cost of your drains debited to irrigation budget, agricultural, contribution or otherwise ?
36. To what heads are the annual repairs of your drains debited ?

Drains to deal with Seepage from Canals.

37. What is the definition of a Seepage Drain ?
38. How far from the canal is the seepage drain located ?
39. What is the average difference in level of the water surface in the canal and in the drain per mile ?
40. What is the bed width of the drain ?
41. What is the slope of the drain ?
42. How are the capacities of the drain calculated ?
43. What actual discharges are experienced in the seepage drains? (Best answered in discharge per unit length, say one mile of drain). How do the discharges vary with the season and the discharge run in the canal ?
44. What is the geological formation of the land through which the seepage drain runs ? (If geological sections are not available, pits should be dug at intervals along the course of the drains extending 5 feet below the bed).
45. (a) Are there any observations indicating the variation in sub-soil water levels in the vicinity of the drains ? If so, please give a brief note thereon.
(b) Does this type of drain affect the sub-soil water-table ?
46. How far have seepage drains, constructed parallel to a canal, been successful in relieving waterlogging due to excessive seepage from the canal ?
47. At what stage of retardation of flow in a seepage drain do you consider clearance necessary.

48. Have you examples of seepage drains in which the discharge is gradually decreasing or increasing ? If so, to what do you attribute this phenomenon ?

49. What determines the maximum depth of the bed of the drain below the water-table ? Is there an optimum depth at which the side slopes can be retained, and at which the inflow is enough to justify digging the drain ?

50. Can seepage drains be operated efficiently as small units to supplement canal supplies ? If so, what is the economical size when considering such factors as pumping charges, cost of maintenance of drain, and discharge ?

51. In what circumstances will it pay to shore up sides of drains in bad soil and how can this be done ?

52. Are seepage drains effective means of removing seepage water ?

53. Do they tend to increase seepage from the Canals ?

54. Is the nature of the soil a factor in the practicability of seepage drains, *e.g.*, are they practicable in sandy soils ?

55. What is the minimum distance from the canal at which a seepage drain should be excavated ?

56. What information is available regarding the success or otherwise of seepage drains in your Province ?

57. How much do you expend per mile on the clearance and repairs of seepage drains, and have you any special agency, such as labour gangs, of dealing with the repairs ?

Surface-cum-seepage drains.

58. What is the definition of Surface-cum-seepage drains ?

59. Should such drains be considered a temporary expedient to be replaced by separate seepage drains when funds are available ?

60. Can a drain be given a suitable slope and section to function both as a surface water and a seepage drain ?

61. If the drain is doing good by removing seepage in its upper reaches, is it depositing this seepage lower down and thereby causing damage in the lower reaches ?

62. Can local flooding from storm water be prevented satisfactorily while not obstructing seepage flow by the use of non-return flap valves ?

General.

63. Are you troubled with the growth of weeds in drains ? If so, how do you keep them down ? What minimum depth and velocity are necessary in drains to prevent growth of weeds ?

64. If conditions are such that weeds cannot be excluded by design, what other methods are used ?

65. What methods are employed for measuring discharges of drains ?

66. Is it necessary to maintain a service road along either or both surface and seepage water drains ?

67. Is it fundamentally sound to use the rivers as outfalls for drains ? Could the water be put to any better use such as flood irrigation or drain-cum-canal irrigation ?

68. Has experience shown that it is feasible to make a drain in an upper portion of a 'doab' work satisfactorily as an irrigation channel for lower areas ?

69. Should such a scheme be primarily a drainage undertaking with irrigation as a subsidiary matter or by-product, or can both be given the same importance ?

70. What factors determine the cost of maintenance of :—

(a) Drains to deal with high water-table,

(b) Drains to deal with surface and storm water,

(c) Drains to deal with seepage from canals, and

(d) Surface-cum-seepage drains ?

71. (a) Is it desirable from the point of view of waterlogging danger to encourage zamindars to connect their field drains with the drainage system maintained by Government ?

(b) Have any rules been framed according to which the zamindar can connect his drains with those maintained by Government ?

The mass of information precludes recapitulations in this general note.

POINTS FOR DISCUSSION.

POINTS ON WHICH INFORMATION IS REQUIRED OR IS FORTHCOMING WILL BE RAISED AT THE MEETING BY MEMBERS OF THE RESEARCH COMMITTEE.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

MR. J. P. JAIN referred to the figures on page 30 for the monsoon run-off carried by drains in the Barabanki and Lucknow Districts of the United Provinces. He said that discharges were taken from gauge discharge curves.

MR. W. N. McLEOD said they experienced great difficulty in observing the peak floods in drains.

MR. A. R. THOMAS said that, in Bombay, flood discharges had been calculated from H. W. L. markings on culverts assuming free flow downstream. This method of course did not give the duration of the flood.

MR. S. H. BIGSBY asked if anyone could say how the efficiency of a drain was tested.

MR. G. E. HARTLEY said that in the United Provinces they based the efficiency of a drain on the time taken to remove standing water from the catchment. They allowed 5 days submersion of the deeper parts of depressions.

MR. L. VENKATAKRISHNA IYER said that in Madras they allowed a six days submersion of rice areas. They allowed for a run-off of 3 inches in 24 hours.

MR. MEHTA said that the only crops likely to suffer are those that are grown during the Kharif season or reclaimed waterlogged areas.

Observations at Chakanwali Reclamation Farm showed that if the rainfall is heavy, and water stands in the fields on account of the overflowing of drains, the submersion periods for different crops were as follows:

Maize—The crop dies if water stands for more than 8 to 10 hours in the field.

Cotton and Toria—The maximum submersion period is 24 hours.

Sugarcane—A submersion exceeding 48 hours considerably reduces the yield.

Rice—This crop can stand an aerobic conditions for longer periods than those given above. If however the water-table, or the water in the field is in motion, the yields of rice are high.

MR. McLEOD pointed out that the more the water-table rises and land goes out of cultivation, the greater the need for surface drains to deal with the increased run-off.

MR. BIGSBY said they were allowing for a run-off of from 1 to 4 cusecs per square mile in the big Punjab Scheme now in progress. This postulates flooding of cotton for 5 days and of rice for 8 days.

He asked what diversity factor should be used in a collecting drain of which they had a large number. Such drains sometimes cross drainages which are in embankment. So far the choice has been governed by financial considerations.

MR. BIGSBY said they had some drains which only ran full when there was an exceptional storm such as might be called an act of God.

MR. McLEOD explained that they had to construct collecting drains, whereas in the United Provinces natural stream beds served this purpose.

MR. BIGSBY said that the recorded run-off varied immensely. Thus in 1936 a run-off of 96 cusecs per sq. mile from an area of 9 sq. miles was recorded from a catchment intensively cultivated, the main crop being sugarcane. In the sixties of the last century large tracts of the Western Jumna Canal area in the Punjab were badly waterlogged. After controversy lasting for several years, the Government of India issued orders for the construction of drains, for changes in the location of channels, and for the reduction of intensity of irrigation. These orders were carried out, and waterlogging was very largely cured. The records available were somewhat scanty, and it was not possible to allocate credit for this success with any certainty as between the remedies applied.

DR. E. MCKENZIE-TAYLOR said that there were cases of water in drains causing the land on either side to go salt. The first flush of water in a drain in some parts of India was exceedingly salty, and for such water a large capacity drain was essential.

MR. VENKATAKRISHNA IYER referred to question 68 on page 108 and said that at Koradilla in Madras they use a drain for irrigating areas lower down the catchment.

The system concerned is 2,000 years old, and they were now trying to operate the drains from the canals.

MR. McLEOD said that on the Dipalpur Canal in the Punjab they allowed the seepage drains to discharge back into the canal.

After further discussion the following Resolution was passed:—

Resolved that the replies received from the Provinces to the Questionnaire on "The design of drains in irrigated areas" be circulated to the members of the Research Committee for information, and with a view to the modification of the existing questions, and the inclusion of new questions, in the light of further experience.

Also resolved that the replies and amendments be brought before the Board at the 10th Annual Meeting to be held in the autumn, 1939.

CONSIDERATION OF THE SUBJECT "DRAINAGE SYSTEMS IN IRRIGATED AREAS" BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 9TH NOVEMBER 1939.

Resolved "THAT THE REPLIES TO THE QUESTIONNAIRE* BE REFERRED BACK TO THOSE PROVINCES WHICH HAVE NOT SUBMITTED PROVINCIAL REPLIES. THEREAFTER THE QUESTIONNAIRE TO BE PRINTED FOR THE INFORMATION OF THE BOARD."

* Vide pages 106-108.

1939-40 Programme of the Central Irrigation and Hydrodynamic Research Station, Poona.

PROGRAMME OF EXPERIMENTAL WORK FOR THE YEAR 1939-1940.

The following is a provisional list of experiments with models to be carried out:—

I.—SPECIFIC EXPERIMENTS.

Experiments on behalf of the Railway Board.

1. With 1/500 scale model of the Ganges and Hardinge Bridge for investigating the movements of the River (continued).
2. With models of the piers of the Hardinge Bridge to investigate scour and the behaviour of stone protection (continued).

Experiments for the Central Government.

3. Training of the River Jumna near Delhi Gate Pumping Station (continued).
4. Protection of the proposed Road between the Delhi Gate Pumping Station and the Okhla weir by means of spurs etc.

Experiments for the United Provinces Government.

5. Training the River Sarda at Banbassa and protection of the Right Afflux Bund (continued).
6. Methods of preventing scour and protecting the floor downstream of the Sarda Barrage.

Experiments for the Government of Sind.

7. With 1/300 scale model of the River Indus above the Sukkur Barrage to find the effect of river curvature on silt charge, and proportion of discharge in two gorges and experiments with the proposed new right bank approach channel designed to exclude silt from the Right Bank Canals (continued).
8. With 1/150 scale model of the River Indus above the Sukkur Barrage for comparison of results with those of the 1/300 scale model and observing the effect of model scales on results (continued).
9. With 1/40 scale, geometrically similar, part-width model of the River Indus above the Sukkur Barrage and the proposed new Right Bank Approach Channel to compare results of the geometrically similar model and vertically exaggerated models in (7) and (8) and to find out scour at the nose of the Divide Bank of the approach channel and at the raised sill of the offtaking channel.

Experiments for the Government of Bengal.

10. Scour round piers of the proposed bridge at Burdwan across the Damodar River and stone protection round piers.

Experiments for the Central Provinces Government.

11. Factors affecting stability of the decking slabs of submersible bridges (continued).

Experiments for the Orissa Government.

12. With a model of the Mahanadi River on flood control by embankments.
13. With a model of the Brahmani River on flood control by embankments.

Experiments for the Government of Bombay.

14. To prevent jetting downstream of Aqueduct No. 3 of the Girna Canal.

II.—BASIC EXPERIMENTS.

15. Investigating bed movements with various types of sand and silt, under controlled conditions (continued).
16. Laboratory experiments to determine factors affecting seepage from Canals (continued).
17. Dissipation of energy below falls (continued).

18. Standardisation of the design of S. W. Flumes.
19. Rate of abrasion of silt (continued).
20. Scale effects of rigid structures in geometrically similar and vertically exaggerated models (continued).
21. With various types of spurs to see the effect on bed scour and throw-off.
22. Standardisation of design of high coefficient weirs (continued).
23. Experiments with Head Regulators to ascertain factors causing loss of head (continued).
24. Divergence experiments for determining optimum conditions ensuring stable flow (continued).
25. Venturi flume experiments—to produce type designs and calibrate them (continued).
26. Scour round piers and the behaviour of stone protection (continued).
27. Factors affecting meanders of rivers.

1940-41 Programme* of the Punjab Irrigation Research Institute.

CHEMICAL SECTION.

1. *The Lining of Channels.*

The Chief Engineer has approved the design of an experiment on lining which is to be carried out on the Pauliani Distributary with sodium carbonate treated soil. In this case the sides will be lined as well as the bed, the method of dealing with the sides having been suggested by Mr. Jesson.

On certain estates, minors and water-courses have been lined with sodium carbonate treated soil. The treatment in some instances was without the addition of cement. The treated water-courses will be kept under observation.

A recent development in the production of a kacha lining is the precipitation of the sugar contained in molasses by lime in a sodium carbonate treated soil. The resultant material sets hard in approximately two days and is much cheaper than the plaster already tested in which cement was incorporated. This new material will be further investigated.

2. *The Effect of the Soil Crust on the Rise in Water-table.*

An account of the work already carried out has been given in the Annual Report.

Each month a certain number of well records are examined and the depth of the soil crust in the neighbourhood of the wells is determined. The water levels in the bores made during the examination of the soil crust are recorded. This work will be continued.

Observation pits have been dug and will be kept under examination. Pipe observations are also being made with reference to water-table which are under pressure and the determination of the true water-table level.

Laboratory experiments on the rise of water from a water-table in soils are being conducted. These experiments will be continued with the object of determining factors which control the rate of rise.

3. *Movements of Salts and Moisture in the Soil Crust.*

For the past three years a series of plots at the field laboratory have been under examination to determine the movement of moisture and salts in the soil crust under non-irrigated conditions. The Chief Engineer has sanctioned a small water-supply so that these plots can now be irrigated. It has been shown under the non-irrigated conditions that over a complete period of the seasons the salt content of the various layers of the soil remains the same. The effect of different intensities of irrigation on the salt movement will now be studied.

4. *Dispersion of Clay.*

This subject is of considerable importance in both engineering and agricultural problems. Examples of its effect in engineering are the failure of the Fall at R. D. 40,280, Pakpattan Link, the condition of certain canal banks and the breaches in these which occur. A study of the nature of this dispersion and its control will be made.

5. *Earth Roads.*

A programme of research on earth roads has been drawn up in collaboration with the Consulting Engineer to the Government of India. This programme has already been sent to the Chief Engineer by the Consulting Engineer to the Government of India.

6. *Analytical Methods.*

With the object of reducing the time required for analytical work, the development of new rapid methods of analysis will be continued.

PHYSICS SECTION.

1. *Seepage from Canals.*

The Officer on Special Duty, Waterlogging Investigation, has used the measurement of the seepage into a canal when it is acting as a drain to determine the seepage from a canal when it is running full supply. The justification for adopting this method has been the model experiments in the Hydraulic Laboratory. These experiments will be extended in the Physical Section with the object of obtaining further information on the subject.

*Subject to approval of the Chief Engineer, Punjab.

This programme was actually drawn up after the Ninth Research Committee Meeting. *Vide also* Dr. McKenzie Taylor's remarks on page 123.

2. *Silt Investigation.*

These will be carried out in collaboration with the Mathematical and Statistical Sections. The programme of work of the subject is given in the Mathematical Section.

3. *Negative Pressures in an Unsaturated Soil above the Water-table.*

This subject has been discussed in the Annual Reports of the Physics and the Land Reclamation Sections for 1939. Field observations are now being made on wells in which the water-table is at varying depths below the soil surface. Rainfall records are being obtained in the neighbourhood of these wells and the effects of rain on the well readings are being observed. The effect of evaporation on the development of negative pressure will be studied in the laboratory.

4. *Cavities under weirs.*

Two methods for the detection of cavities under weirs have been under examination.

The vibrometer method was being studied at Rasul during the cold weather of 1938-39, but it had to be discontinued owing to the rise of the river downstream. As soon as the river levels permit this will be continued.

The wireless wave method for the determination of cavities is still under development in the laboratory. Considerable progress has been made in the construction of the apparatus and it is hoped that it will be sufficiently advanced to test in the field during the coming cold weather.

5. *The Physics of Soils unsaturated with water.*

In the Punjab under the conditions of a rising water-table, stability of the water-table seems to be reached when it touches the underneath side of the soil crust. The suggestion was made in the Annual Report of 1937 that after this stage had been reached, the wells instead of recording water level recorded pressures. The transmission of this pressure through an unsaturated soil will be investigated. The investigations will have an important bearing on the pressures on retaining walls under unsaturated soil conditions.

MATHEMATICAL SECTION.

1. *Experiments on the Tractive Force of Beds consisting of different Grades of Silt.*

The work on this subject which had already been carried out is discussed on pages 55-58 of the Annual Report for the year ending April 1939 (manuscript copy). The resistance offered to flow by the small glass sides and bottom of a flume is being determined in terms of the resistance offered by still air. When these results have been obtained, the experiments to investigate the resistance offered by different grades of silt will be carried out under varying hydraulic conditions. In all these experiments the resistance to flow of still air will be taken as standard. An attempt will be made to correlate bed resistance with a characteristic of the silt and the usual hydraulic elements.

2. *Observations of Hydraulic Data at Regime Sites on Canals.*

A memoir (Volume II, No. 23) describes the previous research work on this subject and gives the conclusions reached. It is now proposed to test the S-Q-m formula at new sites and to determine whether the P-Q and the R-Q relationships hold also for non-regime sites.* An attempt will be made to develop a method for estimating the total bed and floating silt load with the object of examining the effect of this load on regime conditions.

3. *Collection of Hydraulic Data for some Steady Sites in Rivers.*

An examination of the application of the Punjab S-Q-m formula to regime conditions on the Mississippi river has been made and was reported on pages 51-55 of the Annual Report for the year ending April 1939 (manuscript copy). Observations will now be made in Punjab rivers to obtain evidence as to whether the formula can be further applied.

4. *Collection of Hydraulic Data for Boulder Rivers.*

A site at Mukeswar on the River Ravi is under examination. A note describing the site and giving samples of data that had been collected was presented to the Research Officers Meeting at Simla in July 1939†. In accordance with the resolution on this subject passed at this meeting, a form for recording the data has been drawn up. The analysis of the data will be undertaken on the lines discussed at that meeting.

5. *Falls.*

This subject has been discussed at the Central Board of Irrigation Meetings on a number of occasions and has been examined at the Irrigation Research Institute in connection with the Haveli Project‡. Experiments will be undertaken to investigate jetting on the lines resolved at the 9th Meeting of the Research Committee of the Central Board of Irrigation.

*Vide page 13 of this Report.

†Vide page 63 of this Report.

‡Vide page 16 of this Report.

6. Rivers and River Training.

A resolution in which meandering was defined was passed at the 9th Meeting of the Research Committee of the Central Board of Irrigation.* It is proposed to study the effect of discharge, silt load and grade, slope and bank resistance on meandering at a site on the Ravi River near Lahore.

7. High Dams.

The Chief Engineer has suggested that preliminary work should be undertaken to study the conditions of stress and strain in dams in preparation for the Bhakra Project. A review of the literature is now being made and when completed a detailed programme of research will be submitted to the Chief Engineer for approval.

STATISTICAL SECTION.

1. Factors affecting the Rise and Fall of Water-Table in various Parts of the Punjab.

A study of the changes of water-table in relation to rainfall has been carried out for a part of Rechna Doab. The conclusions derived from this study are now under consideration in the light of the work done on the subject by the Waterlogging Investigation Officer.

The study was primarily for an area where the rainfall is high. The remaining zones of the Doab will be investigated on similar lines, and the work extended to other parts of the Province.

2. Silt and Scour as evidence in Regime and other Channels.

The statistical examination of the data collected on regime channels is being published as a Memoir of the Institute. A number of old channels have, however, been given up and new zones selected in their place. Data from these is being collected.

As some of the formulae derived from regime data appear to apply equally well to non-regime sites, the data from some of the non-regime channels will also be examined in order to distinguish between the real regime formulae and the quasi-regime formulae. The surface width and mean depth of the channel will also be correlated with the discharge to see if they yield as good results as the wetted perimeter and hydraulic mean depth formulae.

3. An examination of Kutter, Lacey and Manning formulae with special reference to Punjab channels.

The Research Committee of the Central Board of Irrigation have passed a resolution that the hydraulic data be examined in each province to find if Kutter's formula cannot be replaced by a simpler formula of the exponential type as formulated by Manning or Lacey.†

It is proposed to survey some channels in each division, in addition to the regime channels under regular observation, to ascertain if they were designed on Kutter and, if so, with what value of the Coefficient. The data will next be analysed so as to determine firstly if the Kutter formula is less easy of application than Manning or Lacey, taking into consideration the tables and charts already in use, and secondly if an exponential formula can fit the data equally well. In the latter case the indices will be compared with Manning and Lacey and their probable errors determined.

4. Silt diameter and Lacey's "f".

There has been no attempt yet made in the Punjab to find the connection between these two qualities. It was stated by the U. P. Research Officer at the Central Board of Irrigation Research meeting in July 1939 that no such relation could be discovered for U. P. data‡.

The connection between the silt diameter and Lacey's 'f' will be investigated from the available data.

5. Studies in subsoil flow as applied to problems of weir design.

A Memoir on the subject is under preparation. The effect of sloping the toe-wall has also been fully worked out and will be included in the Memoir.

The results obtained from the works in the field will be compared with theory and the observed effects of silt and temperature will be investigated from the theoretical and statistical view points. Several new forms including more than two lines of sheet piles will also be investigated.

The empirical formulae derived from a study of experimental data, which will be embodied in a separate memoir will be examined statistically to see if the coefficients can be improved.

* Vide page 49 of this Report.

† Vide page 94 of this Report.

‡ Vide page 30 of this Report.

A collection of the profiles of all existing Punjab weirs will also be made and the theoretical pressures worked out and collected in one place for future reference.

6. *Silt Investigation.*

Bed samples in the Punjab canals generally contain silt between 0.05 mm. and 0.6 mm. diameter and the relationship between slope, discharge and average bed silt diameter

$$S \times 10^3 = 2.029 \frac{m^{.86}}{Q^{.21}}$$

is based on these bed samples.

It is well known that when the silt is very fine it introduces some cohesive forces and it is expected that for such bed silt a different slope will be required. This will now be investigated for the existing data by analysing the bed silt distribution curves and later on by choosing some sites where the bed silts have been rendered very fine by silt exclusion at the head.

7. *Hydraulic elements for boulder and gravel rivers.*

Dr. Bose selected the Mukesar site for investigation and data are being obtained and tabulated. A preliminary note by him on the work done so far has been considered by the Research Committee of the Central Board of Irrigation at their July 1939 meeting.*

The data will be analysed in collaboration with the Mathematical Section.

8. *Seepage losses from Canals.*

A note on losses from the L. C. C. has been prepared by the Waterlogging Investigation Office. The data are being examined in the Statistical Section with a view to elimination of the changes from month to month and year to year, which the above note has taken as part of the random variation.

The elimination of these changes will be carried out and an attempt made to frame more reliable estimates of the seepage. If successful the method will be extended to other systems.

9. *Silt entry at Headworks.*

The data from a number of Headworks laboratories is being received and tabulated. A detailed examination has been possible in only a few cases.

The examination will be extended and brought up-to-date.

10. *River supplies, soil erosion and run-off.*

A preliminary study of changes on supply in the river Ravi at Madhopur was carried out in 1936. The relation between plant cover and run-off and erosion has been studied for experimental trays at Nurpur and Madhopur. Data for the trays are still being received.

The slow changes in river supplies will be examined for some other sites, if time permits. A memoir on the tray results is planned in collaboration with Land Reclamation Officer.

11. *Shape of Glacis profile in weirs and falls.*

A note was written examining the Bose and Montagu profiles. It was shown that these profiles do not reduce the vertical velocity responsible for D/S scour. The mathematics of Montagu profile was also shown to be incorrect.†

Attempts will be made in conjunction with the Hydraulic Section to develop a more satisfactory form of glacis.

12. *Road condition and size of material.*

A formula connecting particle size and height of capillary water column has been already given to the chemical section, and criteria for good and bad roads in regard to clay percentages and material size have been evaluated. These are described by Dr. Puri in his article in 'Indian Roads'.

It is hoped to examine the data for more road sites in the coming year to improve the formulae and criteria and then write a note on all the work done by the section so far.

HYDRAULIC SECTION.

1. Chief Engineer has ordered the following works to be undertaken :—

1. *Ferozepur Weir*—to determine the effect of raising the downstream floor on the scour and the protection that will be required.

*Vide page 68 of this Report.

†Vide page 47 of this Report.

2. *Rasul Weir Undersluices*—to determine the alterations that must be made to ensure that the standing wave will form at a safe position.

3. *Rupar Weir*—to examine the conditions under which the scour takes place and the method to be adopted for its control.

4. *Tughial Rapid of the Upper Bari Doab Canal*—to determine the effect of raising the crest on the scour downstream and the steps to be taken for its control.

5. The design to be adopted to replace the Needle Regulator on the Upper Gugera Branch, Lower Chenab Canal.

6. To determine the steps to be taken to control retrogression downstream of Jaba Level Crossing, Upper Jhelum Canal.

The work on the Ferozepur Weir and the Jaba Level Crossing will be completed at an early date. Experiments at Rasul Undersluices are now being carried on. The remaining work will be commenced during the next year.

2. *Investigations of Models of Rivers with Canal Headworks.*

Experiments on the models of the river Sutlej at Panjnad have been completed. Experiments on the model of the river Chenab upstream of Khanki are in progress at Malikpur. A model of the river Sutlej upstream of Islam Weir will be further examined to determine the effect of the belas in the pocket on the development of the river in 1938-39.

A model of the pocket at Madhopur Headworks on the Ravi is under construction to determine the effect of a divide wall in front of the undersluices and a cantilever platform on shingle exclusion.

3. *River Training Works.*

Work has already been carried out on river training on the Sutlej above Islam and downstream of the Panjnad Headworks. Experiments are to be undertaken to determine the measures necessary to prevent further erosion of the banks of the Beas river in the neighbourhood of Sri Gobindpur.

4. *Design of Canal Falls.*

The following problems have been under investigation during the past year :—

1. Determination of a satisfactory glacis slope for the fall.
 2. Determination of the most satisfactory approach to the crest.
 3. Determination of the satisfactory side curves downstream of the crest from the point of view of jetting.
 4. Determination of a suitable length of cistern with reference to the depth of flow downstream and the head over the crest.
 5. Determination of the effect of lowering the floor on jetting downstream.
- The above work will be continued.

5. *Design of Silt Ejectors.*

This work will be carried out on a model of the head reach of the Upper Bari Doab Canal for the control of the silt in that canal system.

6. *Determination of rolling Silt in Channels.*

Experiments on a two feet wide trench in the Hafizabad Distributary are being carried out. Laboratory experiments in flume have already been undertaken and photographs were exhibited at the last Research Officers Meeting at Simla.

It is proposed to investigate trenches of varying widths to determine the most satisfactory size for measuring the quantity of silt rolling on the bed of the channel.

7. *The Silt Survey of the Lower Chenab Canal will be continued.*

Observations of shingle and silt entering the Head Regulator of the Upper Bari Doab Canal will be continued.

So far as possible a silt survey of the Upper Bari Doab Canal will be repeated.

LAND RECLAMATION SECTION.

1. *The Effect of Irrigation on the Rise of Water-Table and the Movement of Salts in the Soil Profile.*

A. *Unsaturated Soil Conditions.*

(i) *Rise in Water-Table.*—A series of cross and longitudinal sections of the sub-soil water-table of the Rechna Doab at different periods of irrigation have shown that the rate of rise throughout the lower portion of the doab is the same. This indicates that

a factor of uniform intensity is responsible for the rise of water-table. Rainfall and irrigation are the two widespread factors that seem to be responsible for the rise in water-table.

It is proposed to examine the rainfall plus irrigation load in detail.

In order to determine the actual contribution to the water-table made by fieldirrigation a block of land with a water-table situated at 33 feet from the natural surface has been selected in the Lower Bari Doab Colony. It is proposed to divide the area into plots with different intensities of irrigation. The bores in the field will be determined by measuring the rise in the moisture content of the soil profile and by observing the rise in water-table in observation pipes which will be installed.

Soil profiles in irrigated and un-irrigated fields in deep water-table areas of the Sirhind Canal will be examined to determine the maximum depth at which irrigation applied at the surface is able to affect the water-table.

(ii) *Movement of Salts in the Soil Profile.*—Investigations will be carried out to determine the position of the zone of accumulation of salts in the soil crust with reference to the total irrigation load and system of cropping, and to determine the limit of irrigation at which the zone of accumulation remains stationary or has a balance of movement in a downward direction at the end of the Rabi season.

Experiments will also be carried out to determine the conditions of the formation of a zone of salt accumulation which will prove harmful when the zone reaches the soil surface.

B. Saturated Soil Conditions.

The experiments started at Jaranwala to study the effect of perennial irrigation, Kharif irrigation alone, and Rabi irrigation alone, on the water-table and also on the direction of the movement of salts will be continued.

For investigations on the zone of accumulation of salts in a soil where the conditions of flow approach those of saturation it is proposed to start experiments on an entirely new area near the farm.

2. Prevention of Land Deterioration.

Experiments on the use of gypsum for the prevention of land deterioration will be continued.

3. Reclamation of Thur Lands.

Reclamation is now in progress at the following sites :—

(i) *Lower Chenab Canal*—

Chaks 112, 113, 114 and 115 R. B.

(ii) *Lower Jhelum Canal*—

Chaks 188 N. B., 190 N. B. and Sher Mohd. Wala.

(iii) *Lower Bari Doab Canal*—

(a) Renala Estate.

(b) Military Farm, Okara.

(c) Shergarh.

(d) 97/9 L.

Reclamation on these sites will be continued.

Any other sites that are sanctioned by the Chief Engineer and for which staff is provided will be taken up for reclamation.

4. Soil Surveys.

(i) A soil survey of the undeveloped Thal desert has been sanctioned by Government. This will be carried out to determine—

(a) The irrigation boundaries.

(b) The sites for distributary heads.

(c) The duty of water.

(d) The suitability of soil for agriculture.

(e) The possibility of deterioration of the soil due to salts and waterlogging.

(ii) Proposals for a soil survey to determine areas liable to deteriorate in the Lower part of the Lyallpur colony have been submitted to Government. Work will be undertaken if sanction is received.

(iii) Special Thur Girdawris will be continued and will be extended to ascertain the total area that goes out of cultivation due to the appearance of Thur in the Rechna Doab.

5. *Miscellaneous.*

(i) *Effect of Release of Negative Pressure on the Rise of Water-table.*—Experiments are in progress to determine the immediate effect of rain on the rise of water-table in areas having water-tables at different depths. An examination of the soil profile is made to determine the minimum rainfall that will release the negative pressure and cause the apparent rise in the water-table. These investigations will be continued in the year 1940-41.

6. *Tube-well Irrigation.*

A study of the economics of the zemindars' practice of tube-well irrigation will be carried out.

GENERAL SECTION.

1. *Examination of Soils from Deteriorated Areas with special reference to the Presence of Trace Elements and their Effects on Crop Yields.*

An examination of soils from wheat areas has just been concluded. It is proposed to extend this investigation to soils under rice. The object of the investigation is to bring out factors which affect the yield of rice and to see which of these soil factors are affected most as deterioration proceeds.

2. *To Study the Effect of Manganese and Phosphate contents of Soils on the Crop Production under Field Conditions.*

Interesting results had been obtained in the laboratory regarding the effect of manganese and phosphate content of soils on yield of wheat. It is proposed to extend this investigation to the field.

3. *The Movement of Bases in Soils at Low Moisture Content.*

It had been found possible in the laboratory to bring about transference of bases by electro-dialysis from soils at low moisture content (*i.e.*, about 8 to 10 per cent.). It is proposed to study the comparative movement of different bases present in the exchange complex of soils.

4. *Examination of Soils and Waters.*

1939-40 Programme of the Development and Research Division, Sind.

It is proposed to carry out the following work in the Development and Research Division during the current year :—

- (i) Hydrodynamic work.
- (ii) Field Experiments to determine the value of coefficient ' C ' used in the design of Falls in the broad crested weir formula $Q = CLH^{3/2}$
- (iii) Experiments in connection with silt survey of channels at—
 - (a) Jamrao Head
 - (b) Makhi weir
 - (c) 3rd mile Khipro Canal
 - (d) 3rd mile Mithrao Canal
 - (e) Channels taking off the Jamrao Canal at miles 17, 32, 47, 82 and 88.

The data collected *vide* items (a) and (b) will be analysed in regard to the comparative silt draw-off by the different channels taking off at Jamrao Head and Makhi weir due to the modifications introduced on the upstream of Jamrao Head for excluding excessive charge of heavy silt from the Jamrao.

Items (c) to (e) will be confined to the determination of quantity and quality of silt passing through different channels *ex* the Jamrao Canal and other allied problems connected with the movement of silt.

- (iv) Experiments to determine the requirements of water for various irrigation units.
- (v) Investigations to determine—
 - (a) The relationship between the central surface velocity and the mean velocity for the whole cross section.
 - (b) The correct position of mean velocity on each vertical.
 - (c) Relationship between velocity and silt charge at any point in a vertical on a cross section.
- (vi) Investigations into the movements of sub-soil water-table and soil classification.
- (vii) Other miscellaneous work.

1939-40 Programme of the Poona Irrigation and Research Division,
Poona.

Research work in this Division Concerns :—

- I. Economy of Water.
- II. Control of Damage.
- III. Land Drainage.
- IV. Reclamation.
- V. Effluent Irrigation.
- VI. Miscellaneous.

Research during 1939-40 will be carried out on the following points :—

NOTE :—Items marked with asterisk are continuation of last year's work.

I. *Economy of water.*

1. Suitability of different drainage waters for irrigation.
2. Cost of pumping water for irrigation.

II. *Control of Damage.*

- *3. Evaporation from cropped and uncropped soils with sub-soil water level at different depths.
- *4. Measurement of irrigation water that goes to the sub-soil water-table.
- *5. Variation of the salinity of sub-soil waters.
 6. Effect of heavy irrigation on sub-soil water-table in deep soils.
- *7. Surface and sub-soil water account of an undrained catchment.
8. Efficacy of nala grading in control of damage.
9. Eradication of Bulrush.

III. *Land Drainage.*

- *10. Model experiments on the flow of sub-soil water.
- *11. Effect on Cement Concrete pipes of saline drain water.
12. Money value of soil preservation resulting from drainage.

IV. *Reclamation.*

13. Reaction of chemicals on soil structure.
14. Cultural methods for establishing crops in salt lands.
- *15. Selection of resistant varieties of crops.
16. Improvement of soil tilth by—
 - **(i)* Cropping.
 - **(ii)* Green manuring.
 - **(iii)* Organic acids.
 - **(iv)* Chemicals.
 - **(v)* Bulky manures.
 - **(vi)* Commercial wastes (molasses, etc.).
 - (vii)* Combinations of above.

V. *Effluent Irrigation.*

- *17. Utility of preparatory doses of effluent.
- *18. Effect of continuing effluent irrigation to cane beyond ten months age, up to harvest.
- *19. Effect of increasing doses of effluent.
- *20. Effect of altering seasons in which effluent is applied to cane.

- *21. Advisability of adsali cane plantation in effluent zone (It can consume more effluent in Rabi).
- 22. Effect of effluent irrigation on different soil types (Particularly deep soils).
- 23. Comparative benefits of effluent to different green manure crops.
- 24. Comparative benefit of effluent to different fruit crops.

VI. *Miscellaneous.*

- *25. Silt load of flood waters in Deccan areas.
- *26. Eradication of weeds in Canals.

1939-40 Programme of the United Provinces Research Section (Irrigation).

The work of the Research Section will be mainly confined to the following groups :—

1. *Staunching of Canals and Guls*—

(a) Experiments on channel lining will continue. Mastic lining which was tried on a small gul near the Research flume in 1937 and which was kept under observation this year will be tried in the field on a large scale, as it is quite cheap and effective in reducing losses.

Lining with Bitumals (W. R. M.) grade carried out on another gul near the Research flume in March this year will be kept under observation.

(b) Experiments being carried out at the Lucknow University in developing the technique of sodium carbonate lining are proposed to be completed.

Agra Park Minor of which losses have been observed recently once again will be lined with sodium carbonate by dry method if investigation of present losses indicates that this would be promising.

Lining of Itaujja disty. from M. 3—7 to M. 11—1 with sodium carbonate which was approved by the S. E. and for which an estimate was submitted to the S. E. will be carried out this year as soon as a closure of sufficient duration to complete the work is available.

(c) Work on Molasses will be taken up as soon as the experiments with sodium carbonate lining referred to above are finished.

2. *Losses on Main Canal and Branches.*

(a) Losses for Main Canal and Branches will be determined by field measurements and also by the method of standard Irrigation Branch returns as advocated in Tech. Memo. 7. This work, however, depends upon the specific enquiries received from circles.

(b) Calibration work of the falls M. 115—4 Kheri Br. and M. 108—4 Lucknow Br. which is in hand will be completed.

3. *Losses in Guls.*

(a) Experiments on gul losses will continue and information as to the type of soil and clay content will be collected in each case with a view to establish a relation between the losses and the type of soil.

(b) Experiments will also be carried out to test the relative merits of the compartment method and discharge method as advocated by the Sind Engineers for observing gul losses.

4. *Tube-well Investigations.*

(a) Work on the study of sub-soil water in the Tube-well area and the connected problems taken up last year will be continued and the data analysed as soon as observations have been taken in accordance with the proposals contained in the note by A. R. O. on tube-well records, and received in the Research office.

(b) Work on the analysis of discharge record at Hardwar and Narora and the rainfall records over the tube-well areas and their correlation for the last fifty years will be taken up as soon as the scheme prepared in consultation with Prof. Mahalanobis of Statistical Institute, Calcutta, has been approved by the Chief Engineer.

5. *Agricultural Cooperation.*

Proposals contained in the Technical Memo. 7 in this connection having been approved by the Chief Engineer and the Director of Agriculture, work will be taken up shortly on the lines indicated in the note.

6. *Silt Observations.*

(a) Work under this head is largely dictated by the number of enquiries received from Divisions.

(b) Attempts will be made to establish a relationship between the mean diameter of silt particles and the Lacey's silt factor by the analysis of data collected so far.

(c) Hydraulic observations will be taken of stable channels by the Research section to prove how far Lacey's theory is applicable in this Province.

(d) Records will continue to be kept of the temperature of canal water.

7. *Silt Selective Heads.*

- (a) The various designs constructed in the field will be kept under observation.
- (b) Work on the silt sampling of the Sarda river will continue.
- (c) Tests on existing heads to determine efficiency will be instituted.

8. *Model Work.*

It depends upon the specific problems received from the divisions and circles. It is suggested that divisions be asked to send up their problems by the 1st week of July so that work on model experiments can be regulated.

9. *Measurement of Water.*

- (a) Experiments will be carried out to evolve standard methods of discharge observations of known accuracy.
- (b) Experiments will be carried out to evolve standard methods of calibrating falls and issue type designs of known accuracy.

10. *Miscellaneous and Advisory.*

Work under this head depends on enquiries. One of the chief items to be taken up under this head will be the development of formulæ for determination of factors at heads of distributaries.

DISCUSSION BY 9TH RESEARCH COMMITTEE, JULY 1939.

At the final session the chair was again taken by Mr. S. H. BIGSBY.

The programmes of research at the various centres were discussed.

DR. E. MCKENZIE-TAYLOR said his programme was the same as last year, and that he did not submit his programme to the Punjab Government until September 1st. He would like to suggest that drawing up programmes for the Research Committee Meeting was hardly worth while, because Research Officers needed to take into account what had been done at the Meeting.

The other Research Officers agreed and the following Resolution was passed :—

Resolved that the subject " Discussion of Research Programmes " for the Research Committee meetings be changed to " Current Research Activities."

Resolved also that a recommendation be made to the Board that the Research Programmes, revised as a result of discussions at the Research Committee meeting, be brought before the succeeding meeting of the Board.

Votes of thanks were passed to the Chairmen of the meetings, and to the Secretary.

CONSIDERATION OF THE SUBJECT TO BE INVESTIGATED DURING THE ENSUING YEAR AND QUESTION OF REVISED RESEARCH PROGRAMMES BY THE CENTRAL BOARD OF IRRIGATION AT THE ANNUAL MEETING AT DELHI, 10TH NOVEMBER 1939.

Resolved—THAT THE BOARD ACCEPTS THE RECOMMENDATION OF THE 9TH RESEARCH COMMITTEE, THAT THE RESEARCH PROGRAMMES, REVISED AS A RESULT OF DISCUSSIONS AT THE RESEARCH COMMITTEE MEETING, BE BROUGHT BEFORE THE SUCCEEDING MEETING OF THE BOARD.

THE DESIGN OF CHANNELS IN ALLUVIUM.

PRELIMINARY GENERAL NOTE FOR GUIDANCE OF 10TH BOARD MEETING.

The first meeting at which this subject was brought to the notice of the Board was the 6th meeting held in November 1935 when Mr. Gerald Lacey delivered a paper on "Regime Flow".

At the 7th Board Meeting in November 1936 Mr. Lacey submitted two notes entitled "Viscosity as a Factor in the Flow of Water in Open Channels" and "An Improved Regime Slope Formula".

The matter was referred to the Research Committee for consideration, and the Board passed the following resolution :

" This Board notes, with great satisfaction, the advance made by Mr. Gerald Lacey in the solution of the problem of design of channels in alluvium, and the extent to which his theory is supported by independent investigations. "

At the 8th Board Meeting in November 1937 a resolution was passed that the United Provinces Government be asked to place Mr. Lacey on special duty to write up a complete note on his researches for publication by the Board.

The reasons given for this request were : The difficulty experienced by engineers in using Mr. Lacey's work owing to its being scattered in several publications ; the great advantage of focussing attention to divergences of views on details of application known to exist among irrigation engineers ; and the stimulus to further research in this most vital subject which such a publication would produce.

It was recognised at the 9th Board meeting in November 1938 that further progress in discussing the subject of the Design of Channels in Alluvium could not be made until the aforementioned publication was available.

It appeared that generally speaking the Punjab investigations showed agreement with those formulæ of Mr. Lacey's which did not involve the silt factor ' f '.

Mr. Lacey has since written his paper which he has entitled " Regime Flow in Incoherent Alluvium " and the publication is now in the press. It was hoped to have the publication distributed before this 10th Board Meeting. As this has proved impossible the conclusions reached by Mr. Lacey are quoted hereunder :

" In all regime channels in incoherent alluvium the primary fundamental variables are the mean velocity, the hydraulic mean depth, the water surface slope, and the bed silt grade.

Of the four variables, V, R, S and f two only are necessary in order to obtain the third and fourth.

The first equation is

$$V = (4/3)^{1/2} \sqrt{fR}$$

In this equation when the value of the silt factor is unity the grade of sand has a rugosity coefficient N_a of .0225, and standard sand is thus defined. When the hydraulic mean depth is equal to one metre (3.2808, ft.) the value of N_a is identical numerically with the value of N assigned by the Kutter, Manning or Forchheimer equations for flow.

The second equation is

$$V = 16.05 (R^2 S)^{1/3}$$

In this general regime equation the rugosity is implicit, and the equation is applicable to every type of regime alluvial channel from very fine silt to boulders.

From these two fundamental equations a variety of other equations can be derived. If a flow equation of the Manning or Forchheimer type is sought it must take the form

$$V = \frac{1.3458 R^{2/3} S^{1/3}}{N_a}$$

The value of N_a is given by the equation

$$N_a = .0225 f^{1/2}$$

If it is desired to apply the flow equation to non-regime channels in which shock and channel conditions play a part the flow equation takes the form

$$V = \frac{1.3458 R^{2/3} (S - s)^{1/3}}{N_a}$$

in which ' s ' represents the fraction of the gross slope destroyed by shock.

In regime channels, free from shock, and of which the silt is of standard incoherence, the silt factor and mean bed silt grade are correlated by the equation

$$f_r = 1.76 m_r^{\frac{1}{2}}$$

the diameter ' m ' being measured in millimeters.

If shock is present in a regime channel as a variable the silt factor becomes an inverse function of the silt grade and

$$m_r^{\frac{1}{2}} f_r = m^{\frac{1}{2}} f = m'^{\frac{1}{2}} f' \text{ etc.}$$

In the modified Bose relation

$$S \propto m^{5/6} / q^{1/3}$$

the slope is a function of bed silt grade and the discharge intensity ' q '. the shock being implicit.

In the equivalent expression of the writer

$$S \propto f_r^{5/3} (f_r/f)^{5/3} / q^{1/3}$$

the shock is explicit.

When there is no shock the expressions are identical.

The modified Bose equation applies to silt of a standard coherence. The equation of the writer

$$S \propto f^{5/3} / q^{1/3}$$

when shock is absent is applicable irrespective of the precise coherence, coherence being implicit.

The simplest dimensioned expression for the writer's general regime equation is the Lacey-Malhotra equation.

$$\frac{V}{\nu} \propto (RS/m)^{\frac{1}{2}}$$

in which the kinematic viscosity is implicit.

Under ideal conditions when all the variables are equally free to vary the wetted perimeter and discharge are correlated by the writer's expression

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

From this equation coupled with the two first fundamental equations in terms of V, R, S, and f all other regime relations flow.

The unique determination of channel dimensions postulated by the writer's regime equations connotes a fundamental and implicit similarity in all regime channels. If P and l represent the wetted perimeter and length of a given channel and q its discharge intensity, also if P', l' and q' are the values for any second channel, the fundamental requirement for energy similarity is that the ratio $\frac{P}{l}$ shall be equal to $\frac{P'}{l'}$ and the ratio $\frac{P}{q}$ equal to $\frac{P'}{q'}$.

In large regime channels of the same silt grade the slopes are sensibly proportional to the exaggeration in the vertical scale. In all regime channels, large or small, of the same silt grade the slopes vary as the ratio $\frac{R}{P}$, if similarity is preserved. If by E is denoted the ratio of the wetted perimeter to the water surface width, the exaggeration in the vertical scale of a model, with reference to the scale of the cross section, is given by the expression

$$\left(\frac{E'}{E''} \right)^2 \left(\frac{R' P'}{P'' P} \right)$$

in which E', R', P' and E'', R'', P'' have reference to the exaggerated model and prototype respectively.

From this equation coupled with the writer's equations for the diameter of the silt particle follow the derived equations necessary to model experiments."

At every meeting since its inception the Research Committee of the Board has discussed Mr. Lacey's formulæ on the basis of data produced by research officers. The relevant decisions of the Research Committee as embodied in their various resolutions on the subject may be summarized as follows.

(a) Lacey's P_w —Q relationship may be said to be established.

(b) That no physical relationship has yet been established between the Lacey silt factor ' f ' and actual silts.

The Research Committee are now devoting their attention to two very important points.

(I) The examination of existing distribution curves to determine the percentage of particles below the limit of 0.2 mm. which introduce cohesion as an additional variable.

(II) The examination of existing data from canals and rivers with a view to ascertaining the most probable exponential or other relationship.

Mr. A. GORDON, the President, referred to the brief note in the preceding pages.

He said he would like to draw attention to the verification of Mr. Lacey's regime test formula $V = 16.05 (R^2 S)^{1/2}$.

He enquired whether the Board was prepared to accept Mr. Lacey's theory, as it had been accepted in the United Provinces.

The President invited Mr. Lacey to give the Board his views.

MR. GERALD LACEY said that he would briefly discuss the equations obtained by the Punjab Research Institute, and his own equations, indicating the very gratifying measure of confirmation of his own equations so far obtained and explaining in what respects they differed, and why.

The following table compared the equations.

Equation No.	Lacey.	Punjab.
1	$P = 2.67Q^{1/2}$	$P = 2.80 Q^{1/2}$
2	$R = 0.47 (Q/f)^{1/2}$	$R = 0.47 Q^{1/2}$
3	$V = 1.155 f^{1/2} R^{1/2}$	$V = 1.12 R^{1/2}$
4	$S^* = .391 f^{1/2} / Q^{1/2}$	$S^* = 2.09 m^{.66} / Q^{.21}$

NOTE.— S^* = slope in parts per thousand.

The first equation of the Punjab entirely confirmed the Lacey equation. In neither equation did the silt factor or the silt diameter enter. The only difference was a slight difference in the numerical constant. Much evidently depended on the ratio of the average active discharge to the maximum or "full-discharge." This equation was the first fundamental in all model work.

Equations (2) and (3) were lined together. Equation (2) could be obtained from equations (1) and (3), or alternatively equation (3) could be obtained from equations (1) and (2). The superficial resemblance of the Punjab and Lacey equations was most striking, and showed a great degree of *basic* confirmation of the form of the Lacey equations, with the very important proviso that it had not been found possible in the Punjab to improve the correlation by the introduction of the silt grade as a variable. The average silt grade of the Punjab data corresponded closely to a silt factor of unity.

The fourth equation was of the greatest interest because in the one equation the silt factor entered, and in the other the silt grade. Further it was very clear that each should perform the same function. The power of Q of 0.21 was of no great moment. Earlier work in the Punjab gave to this index values of 0.30 and 0.25 respectively and the power might well reduce finally to 1/6.

If this slightly modified power was employed it was clear that the silt factor varied as the square root of the diameter of the average bed silt sample, as he, Mr. Lacey, had contended in 1930.

The fact however remained that the Punjab data, unless some new theory was evolved as an explanation, failed to confirm the Lacey theory, which was almost self evident, that the ratio V^2/R steadily increased with increase in bed silt grade. The fourth equation (Lacey) was merely the equation

$$V = 16.05 (R^2 S)^{1/2}$$

written in a different manner, and for that equation there was a great mass of data over a great range of material.

The curious feature of the Punjab data was that frequently the silt factor was an inverse function of the silt grade. This phenomenon was due to the introduction of "shock" into a regime channel. When shock was present, and ragged banks could create shock, an increased slope was demanded and more energy was destroyed which was dissipated by increased eddying motion.

This shock retarded the velocity but, by virtue of the increased eddies, exposed a coarser grade of silt on the bed. In the Punjab equation the degree of shock was faithfully reflected in the grade of bed silt and shock was therefore implicit in the Punjab equation. Although the shock was implicit in the Punjab equation the fact that shock was present was demonstrated by a *low* value of 'f' being associated with a *high* value of 'm' and this was the basis of the new shock theory.

* Vide page 124.

Briefly if f_r and m_r represented values free from shock, and shock were applied, the shock theory was that

$$m_r^{\frac{1}{2}} f_r = m^{\frac{1}{2}} f$$

As a general rule shock was present to some extent and that accounted for the fact that it was impossible to derive hitherto from the relatively small range of bed silt of the Punjab data any equation correlating f and m . As soon as the shock theory was introduced a correlation was possible; for silt of average coherence the equation appeared to be

$$f_r = 1.76 m_r^{\frac{1}{2}}$$

THE PRESIDENT thanked Mr. Lacey for his valuable remarks, and then called on Dr. McKenzie-Taylor to favour the Board with his views.

DR. E. MCKENZIE-TAYLOR said that the Punjab Irrigation Research Institute had recently issued a memoir on the subject* which was at present in the press.

He said that the Punjab equations, listed by Mr. Lacey above, applied only to those canals which they had investigated with the use of a particular form of siltometer.

MR. LACEY said that the verification of his formula $V = 16 (R^2S)^{\frac{1}{2}}$, referred to by the President, was obtained by the Punjab workers for boulder rivers. This equation was independent of silt grade.

THE PRESIDENT enquired from Rai Bahadur Khosla as to what the general opinion was in the United States.

RAI BAHADUR KHOSLA said that general opinion in that country was in favour of Lacey's theory.

THE PRESIDENT said that the Board was very grateful to Mr. Lacey and to Dr. McKenzie-Taylor for the work they had done. The formulæ arrived at were a great advance on *anything they had* had before, and fewer points were left for investigation. What was now required was more knowledge of the lower limits of fineness of silt to which these formulæ applied.

DR. MCKENZIE-TAYLOR said that investigations on the lines referred to by the President were being carried out in the Punjab.

Mr. Lacey and Dr. McKenzie-Taylor in collaboration then proposed the following resolution, which was approved and adopted by the Board.

Resolved—“*THAT ONE OF THE DIFFICULTIES IN THE PAST HAS BEEN THE DIRECT CORRELATION OF 'f' THE LACEY SILT FACTOR, AND 'm' THE MEAN DIAMETER OF THE BED SILT PARTICLES. THE INTRODUCTION OF THE CONCEPTION OF SHOCK BY MR. LACEY HAS LED TO A SECONDARY INVERSE RELATIONSHIP BETWEEN 'f' AND 'm' ON THEORETICAL GROUNDS, WHICH IS SUSCEPTIBLE OF EXPERIMENTAL STUDIES. THESE SHOULD NOW BE UNDERTAKEN.*”

THE FACT THAT THE PUNJAB RESEARCH INSTITUTE HAS CONFIRMED THE LACEY BASIC RELATIONSHIP BETWEEN THE VELOCITY AND THE HYDRAULIC MEAN DEPTH,† BUT, DESPITE THE RELATIVELY LARGE RANGE OF 'm' FOR CANAL SYSTEMS (FROM 0.2 TO 0.4 m.m. APPROXIMATELY) HAS NOT BEEN ABLE TO INTRODUCE 'm' AS A VARIABLE CAN BE ADEQUATELY AND FULLY EXPLAINED IN TERMS OF THE NEW LACEY SHOCK THEORY SHOULD IT PROVE TO BE CORRECT.”

MR. S. H. BIGSBY said he would like to congratulate Mr. Lacey and Dr. McKenzie-Taylor for the agreement they had reached.

In replying DR. MCKENZIE-TAYLOR said that the range of silt covered by his (Mr. Lacey's) theory was limited for Mr. Lacey's purposes, but the range nevertheless covered most of the slopes which were encountered in canal design.

* “An Investigation of the Inter-Relation of Silt Indices and Discharge Elements for some Regime Channels in the Punjab” by Bose and Malhotra; Research Publication, Vol. 11, No. 23, Punjab Irrigation Research Institute. Price: Rs. 1-10-0 or 2s. 5d.

† The basic relationship connecting the velocity and hydraulic mean depth is

$$V = c R^{\frac{1}{2}}$$

for channels transporting silt of sensibly the same grade. The Punjab Research Institute obtained by statistical analysis the equation

$$V = 1.12 R^{\frac{1}{2}}$$

for the entire collection of Punjab regime data from 24 channels under observation. The bed silt grade encountered varied between 0.20 and 0.40 millimetres in diameter. The silt was thus all silt of the same order, sandy silt, but varied in fineness. It was not possible to improve the correlation of the equation

$$V = 1.12 R^{\frac{1}{2}}$$

by the introduction of the precise silt grade as a variable, and this was due to the presence of shock, which sets up an inverse relationship between the silt factor and the silt grade, instead of a direct relationship. When the variation in grade is great for example, when a comparison is made between the values of c obtained for fine sand, and gravel respectively, the fact that the silt grade must enter is immediately recognised. G. L.

SOIL DENUDATION AS AN ADVERSE FACTOR ON RIVER SUPPLIES AND AGRICULTURE.

PRELIMINARY GENERAL NOTE FOR GUIDANCE OF 10TH BOARD MEETING.

The subject originally appeared under the heading "The Effects of Deforestation on Irrigation Projects."

At the 8th meeting of the Board in 1937 attention was directed to the dangers of deforestation as the member for the United Provinces suggested that this was the primary cause of heavy floods. The meeting passed the following resolution :

"The Central Board of Irrigation desires to draw attention to the Proceedings of the British Empire Forestry Conference, South Africa, 1935, with particular reference to the possible dangerous effects of deforestation on irrigation in India.

These effects are :—

- (a) the increase of intensity of floods,*
- (b) the decrease of the dry weather flow in rivers. The former would mean greater capital expenditure and more expensive maintenance on canal headworks, thus possibly making otherwise productive projects unproductive, and difficult to finance. The possibility of damage to existing works should also not be overlooked. In addition, and what is most important of all, there is the greater tendency to flooding of vast tracts of country.*

A decrease in the dry weather flow of rivers would have most serious effect on those cultivators who rely on canal supplies to mature their crops. Even those who rely on irrigation from wells might be affected by lowering of the sub-soil water table.

These detrimental effects have already been noticed in some of the smaller river basins. Although there is no absolute proof of the larger rivers yet having been affected by deforestation, the Board is of the opinion that India cannot afford to neglect the experience of other countries.

The problem is not usually a Provincial one, as most of the basins of larger rivers lie in more than one Province or State, and deforestation in one administration may produce most serious results in another.

The Forest Department has from time to time drawn attention to the dangerous effects of deforestation on rivers, and the Board desires to endorse those warnings."

Further discussion took place at the 9th meeting of the Board held last year (1938) and it was at that meeting that the title "Soil Denudation as an Adverse Factor on River Supplies and Agriculture" was adopted.

It was obvious from the discussion that there was ample evidence that denudation was taking place on a large scale in India. The Imperial Council of Agricultural Research and the Forest Department were fully aware of the situation, but no national concerted action to arrest the evil was either planned or in progress, although local efforts were being made on a small scale in the Punjab and United Provinces.

Individual members advanced proposals. The member for Bengal advised the formation of a River Commission, Dr. Gorrie suggested that each Province should undertake surveys on the same lines as were adopted in the Punjab and which he briefly described.

The meeting finally adopted the following resolution :

"This Board is convinced that the evils of denudation in India are so serious and widespread that action for its further prevention should be taken without further delay. Denudation causes high floods in summer and low river levels and small supplies in winter, which result in—

- (i) damage to canal systems through interference with the regularity of canal supplies.*
- (ii) harmful deposits of sand,*
- (iii) interference with river navigation, and*
- (iv) wide spread damage to the country-side.*

Methods which have been found effective depend on the local conditions. They include—

- (a) better field cultivation in order to reduce erosion from plough land,*
- (b) better live-stock management in order to reduce erosion from grazing lands,*

- (c) afforestation of such village waste land as can be devoted to the production of timber, fuel and fodder trees,
- (d) the conservation of grass land,
- (e) the substitution of organized taungya for shifting cultivation.

The Board considers that all Provincial and State Governments should be urged to develop and extend the most suitable local machinery to deal with further denudation and the above mentioned allied problems."

This resolution was circulated to the contributing Provinces and States for such action as they might consider necessary. Replies from the Provinces and States are still awaited.

A reply has been received from the Imperial Council of Agricultural Research to whom a copy of the resolution was also sent. They state that the question of prevention of erosion and allied matters were considered by the Central Fodder and Grazing Committee at their meetings held in 1937 and 1938.

At the first meeting of this Committee in 1937 the improvement of grasslands was discussed and experiments thereon suggested. This has a connection with erosion prevention.

No information was forthcoming at the second meeting of the Committee in 1938 as to whether these experiments had been undertaken, but the Committee expressed the desirability of conducting more experiments on contour-bunding and on contour-trenching to reduce run-off in grassland areas.

DISCUSSION BY THE 10TH BOARD MEETING, NOVEMBER 1939.

MR. A. GORDON, the President, referred to the note in the preceding pages.

THE PRESIDENT requested Dr. Gorrie to favour the Board with an account of his experience in the Punjab.

DR. GORRIE then delivered the following Address :—

" GENTLEMEN,

I will first read to you from Lord Hailey's book "An African Survey", pages 1061-62 :

' Springs and wells are fed by reserves of water stored in the sub-soil or rock underground. If these reserves dwindle, then wells dry up, springs are reduced to a trickle, and rivers that once flowed strongly all the year round fail altogether during dry periods and run only during and immediately after periods of rain. The more water lost as run-off, the less is available for underground storage : One of the most serious effects of increased surface run-off, therefore, is a fall in the level of the ground water-table. Such falls have been observed, and to some extent measured, in many parts of the United States¹ ; in Africa the same phenomena of falling water-tables and dwindling rivers exist, although accurate measurements appear to be lacking. Examples of rivers which flowed all the year round twenty or thirty, or even ten years ago, and now consist of a chain of waterholes in dry weather and a muddy torrent in wet, have been quoted from almost all African territories. Apart from the Saharan examples², the cause of which is a subject of some contention, there are many others. Dr. Robert Laws has listed twenty large streams that have ceased to flow in the Mombera District of Nyasaland since he first took up his residence there, nearly fifty years ago. The level of lakes in Uganda is steadily falling, especially Lakes George, Edward and Kioga³, and in Kenya many once perennial streams have now become seasonal.⁴

A corollary to the dwindling of rivers and streams during dry seasons is the increase of flooding in wet seasons. Storm waters, no longer checked by forest and bush, flow down gullies and hill-sides into the river-beds ; and streams, suddenly swollen, become converted from feeble trickles into rushing torrents heavily charged with silt. It is now an accepted thesis that such flooding is greatly augmented, and in some cases caused, by deforestation of the watershed. In France, for example, the correlation between floods and deforestation has been demonstrated in the Savoy region. Between 1738 and 1912, 21 per cent. of the forests of this region were destroyed ; and whereas during the eighteenth century only eight floods occurred in the area affected, in the nineteenth

¹ W. R. Chapline, ' Range Research in the United States ', *Herbage Reviews*, Vol. V, No. 1, 1937, pp. 1-13.

² E. P. Stebbing, ' The Threat of the Sahara ', *Extra Supplement, Journal of the Royal African Society*, May 25, 1937, p. 7.

³ V. E. Fuchs, *Report of Cambridge Scientific Expedition to the East African Lakes, 1930-31*.

⁴ H. L. Sikes, *The Underground Water Resources of Kenya Colony, 1934*, p. 10.

century the number of floods rose to thirty-eight.¹ It is at the time of such flooding that irreparable damage is done by the removal of soil in the form of silt. Evidence from many parts of Africa points to the fact that within the last twenty or thirty years such sudden floods, which often subside as quickly as they arise, have become more numerous and more extreme.

The question of a falling water-table needs special consideration in view of the fact that in many parts of Africa action is being taken, by the sinking of new boreholes, and the deepening of existing wells, to extend the water supplies available to man and beast; and indeed it has been suggested that a part of the solution of the overstocking problem lies in opening up new areas for grazing by the provision of wells.² It is obvious that if the demands made on the underground water-store increase, while available supplies continue to shrink and recede, wells provided by governments at considerable cost, with the idea that they will constitute permanent sources of supply, will afford only temporary relief, and will indeed create an even worse position. Catchment tanks and dams might be preferable to wells, as being cheaper and easier to construct and maintain.

The conviction appears to be held now by a majority of competent engineers that the decrease of dry weather flow is becoming a more recognisable phenomenon than the increase in intensity of floods. Both phenomena are accepted as established though only in a very few cases do river readings go back far enough to provide accurate data which can prove these as facts.

These trends fit in so well with what we know of denudation and misuse of land in Indian catchments, that it is impossible to avoid the conclusion that the balance of seepage run-off is inevitably deteriorating. It has already been stressed, at meetings of this Board that deterioration of run-off conditions is due to destruction of plant cover, and the causes of this destruction have been classified under plough land and waste land. The value of these two lines of attack depends upon ratio of cultivation to itinerant or local grazing.

Our experience to date in the Punjab foothills shows that the problem of waste land can be met by concentrating upon the value of grass as a crop. The gradual substitution of grass cutting instead of uncontrolled grazing, brings to the peasant a realisation that a few fat cattle are a better proposition than a lot of thin ones. The run-off condition in the foothills reacts surprisingly quickly to a restored grassland. Unfortunately we have not been so successful in handling the plough land problem, and the only way to effect any radical and widespread improvement appears to be for Government to grant an appreciable reduction in land revenue payment to the peasants wherever *wattbandi* or efficient terracing is carried out by them. The zone which is particularly badly in need of attention for *wattbandi* is the rolling, slightly hummocky and rather sandy uplands which lie along the base of the Siwaliks. Much of this land grows *ekfasli* wheat, and is bare fallow through the summer and earlier half of the rains, ploughing normally beginning in September after the bare surface has suffered excessively from sheet erosion. The cure here is comparatively simple and obvious, namely ploughing 2 or 3 times during the summer and earlier monsoon storms, and thorough repair of *wattbandi* at each of these ploughings. This would improve the absorptive capacity of the soil enormously, and reduce the sheet erosion, thus correcting the present heavy load of silt which is taken to the rivers from such land. Such land unfortunately is outside the present activities of the Agriculture Department.

A point which I think has not been stressed previously in the discussion of denudation and river supplies, is the amount of serious erosion and gulying which takes place along the lower fringe of the snow belt. The rate of melting and consequent run-off from snow beds depends largely upon the condition of the soil surface or plant cover on which the snow rests. Melting is exceedingly rapid from bare ground and slower from grassland and scrub jungle. Banks of wet snow lying on a slope of poorly terraced cultivated land have been seen to cause deep gullies in the potato fields of the Uhl valley, in exactly the same way as in the notorious Palouse hummocky wheat lands of Washington and Idaho.

Our experiments with *contour trenches* in the Siwaliks indicate an immediate improvement in flood conditions. Out of two small catchments of about 25 acres each at Polian above Jaijon, one was more or less completely trenched with accurately levelled trenches, each 10 foot trench holding 25 gallons of water. Trenches cost 2 annas each and the cost per acre of trenching, gully plugging, and planting and sowing grass and trees was about Rs. 8.

Run-off measurements were taken but only one severe storm occurred this monsoon. In it 2½ inches of rain in 8 hours gave a peak flow of 4.7 cusecs and a yield of 78,000 cubic feet over a period of 10 hours from the untrenched nala, but no measurable yield whatever from the trenched area. Considering that the trenches were new and that

¹ A. Magnein, Communication read to the Upstream Engineering Conference, Washington, D. C., 1936 p. 228.

² Sir F. Stockdale, Report on his Visit to East Africa, C. A. C. 345, 1937, pp. 83ff.

practically no fresh vegetation had yet come in on the berms, this result gives a satisfactory indication of much better future figures. The impetus to grass and bush growth given by the moisture held up by such contour trenches is most valuable and results in a much more lush and luxuriant plant cover. Similar work in the Wasatch plateau of Utah has given enormously valuable results in stopping detritus deposits from being cut from the hills and dumped upon orchard land on the Salt Lake plains below.

Measurements from Bani in the Pabbi Hills show that 6,000 lbs. of soil per acre was lost from poorly covered grass land from a storm of about 2" in 3½ hours. The ratio of loss of soil varies from 1/6th to 1/30th for individual storms between clipped cover and conserved grass growth. The effectiveness of cover is greater in the Eastern than in the Western Punjab experiments for heavy individual storms, as one would expect from the knowledge that the grassland cover is so much thicker in better distributed rainfall.

I suggest as a resolution (A) that some form of central executive control of inter-provincial catchments should supplement the purely advisory work now being taken by Imperial Council of Agricultural Research.

(B) That the two main lines of attack are (1) improvement of grassland or scrub jungle and (2) improvement of field cultivation by *watbandi* and contour ridging. For the latter the help of the revenue authorities is essential in order to obtain executive action to improve the layout and levelling of fields on sloping land."

THE PRESIDENT enquired as to the annual rainfall in the areas dealt with by Dr. Gorrie.

DR. GORRIE said that the rainfalls recorded by the nearest registered stations, which were not very reliable, were : Jhelum and Kharian 23 inches, but fall is less in the Pabbi Hills between these ; Hoshiarpur 40 inches.

MR. S. H. BIGSBY said that some 30 years ago he measured a fall of 4 inches in 3/4 hours in the Pabbi Hills.

THE PRESIDENT enquired what the minimum rainfall should be to enable conservation by grass growth to be attempted.

DR. GORRIE said somewhere in the neighbourhood of 20 inches. With very suitable soil and good conservation it might be done with an annual rainfall as low as 12 inches.

MR. E. O. COX enquired the cost of such work.

DR. GORRIE said that it costs Rs. 8 per acre for two-thirds trenching and one-third gully plugging, together with sowing and planting.

MR. W. G. CAME asked if the upkeep was expensive.

DR. GORRIE said that very little upkeep was required once trenches had been dug and plants established. The silviculturists had disapproved of the claims made that such work in Bihar altered the climate of the neighbourhood because the meteorological data from Bihar was insufficient.

MR. BIGSBY asked if there was any local advantage from the expenditure of Rs. 8 per acre.

DR. GORRIE said that after the first year there was an appreciable income from grass cutting, and in some places bhabar grass was grown for paper making. This grass fetched ten annas per maund* as compared with eight annas for fodder grasses. Twenty-five maunds was the general yield per acre, a very good revenue. It was therefore an economic proposition where grass could be sold for paper making in addition to fodder. Where grass could only be used for fodder, the revenue obtainable depended on local conditions.

MR. E. O. COX asked if a district once closed to grazing could ever be reopened.

DR. GORRIE said they were trying opening for grazing by rotation, allowing 3 to 8 acres per cow, according to the district. The results were, that in the end the number of cows per acre might be higher than before the area was closed but they were better fed.

MR. E. O. COX said that the catchment areas of the proposed Bhakra and Balehu Dams were mainly composed of bare slopes. As a result these reservoirs would lose capacity by silting. Mr. Parker, late Chief Conservator of Forests, Punjab, had said that silt would be reduced to one-tenth if the catchments were closed to grazing.

MR. A VIPAN asked if there was much trouble from fire.

DR. GORRIE said that jungles are deliberately fired, with disastrous results. In Chil pine areas departmental protective burning is done to reduce the damage.

MR. A. ORAM enquired how the people were compensated against closure to grazing.

DR. GORRIE said that the Chota Nagpur Government offered the bigger land owners a share in the profits accruing from closure.

DR. GORRIE then handed round photographs, four of which, with explanatory notes are reproduced.

* 1 maund = 80 pounds.



An open type of contour trench which has given good results in water-catching and encouragement of vegetation. Dimensions :—

12 feet lengths between cross-partitions which are lower than the main berm ; 1½ feet deep and 1½ feet wide at bottom, but sloped off on both sides and with berm built to form gentle slope on down hill side.



Contour trenches at Dholbaha in head of Paphial Cho, with their first catch of rain water. Planted bhabbar grass cannot be seen but vestiges of original anjan and daulu grasses are already profiting by moisture.



This shows that contour trenches are not straight lines, but must be laid out accurately level so as to catch maximum of water. Squad below is building a checkdam in the nala bottom.



A good catch of rain in the contour trenches continues to seep into the ground for several days after the storm and long after untrenched slopes are again bone-dry.

MR. ORAM enquired whether the photographs were of forest reserves.

DR. GORRIE said the land was not forest reserve, but private land, subject to the Chos Act. Under this Act, the breaking of fresh cultivation could be stopped, but existing cultivation could not be interfered with. Dr. Gorrie strongly recommended a study of the Chos Act.

MR. F. A. FARQUHARSON asked if the value of bhabar grass did not depend on a supply of wood pulp in addition.

DR. GORRIE said that newspaper was wood pulp, but that bamboo or bhabar grass was generally used without wood pulp for manufacturing writing paper.

MR. E. O. COX asked whether people were interested in reclaiming their own land.

DR. GORRIE said that the propaganda basis of stopping erosion was not good enough if one hundred per cent. control of land use was needed by the Irrigation Departments.

MR. T. M. LYLE, "I understand you are of opinion that the control of erosion in the upper parts of a catchment does not cause any risk of damage in the lower reaches of the river."

DR. GORRIE, "The risk is extremely small compared with the benefit."

MR. LYLE, "Are the owners of the local areas in which control measures are exercised, recompensed for handing over their land by the benefits that accrue to their land?"

DR. GORRIE, "Yes."

MR. LYLE, "Bengal wants silt but does not want floods. How is this to be arranged?"

DR. GORRIE, "I do not think it is feasible to expect silt without floods."

MR. BIGSBY pointed out that Rs. 8 per acre was equivalent to about 50 lakhs of rupees for a thousand square miles catchment. He said the proposition was not an economic one from the point of view of the Irrigation Departments.

DR. GORRIE said he did not suggest doing this work over thousands of square miles. It should be restricted to demonstration areas or small but vitally important catchments.

THE PRESIDENT said that the problem was both provincial, and inter-provincial. It was necessary to impress on the Government of India the necessity of pursuing a strong policy for preserving catchment areas.

MR. LYLE said that this had been done by means of the resolution passed at the 8th meeting of the Board in 1937.*

THE PRESIDENT expressed the opinion that something more definite was required.

THE PRESIDENT moved: "That the best thanks of the Board be accorded to Dr. Gorrie for his Address, and for the valuable assistance he had given us in the discussion." He was sure that the discussions on this subject would have an ultimate effect, even if immediate results were not forthcoming.

The motion was carried by acclamation.

MR. ORAM proposed the following resolution which was duly accepted by the Board:

Resolved—"*THAT THE BOARD REQUEST THE CENTRAL GOVERNMENT TO REFER TO THE BOARD'S RESOLUTIONS PASSED AT THE 1937 AND 1938 ANNUAL MEETINGS,† AND AGAIN WISH TO EMPHASIZE THE IMPORTANCE OF THE SUBJECT.*

THE MATTER IS NOT PROVINCIAL, BECAUSE THE VITAL INTERESTS OF MORE THAN ONE PROVINCE OR STATE ARE BOUND UP IN THE WATER YIELD FROM ANY ONE OF THE LARGE NATURAL DRAINAGE SYSTEMS OF INDIA.

IN AREAS WHERE SOIL DENUDATION CAN BE PREVENTED, THERE SHOULD BE BENEFITS TO LOCAL INHABITANTS, AND TO THE PROVINCIAL GOVERNMENTS WITHIN WHOSE TERRITORIES SUCH AREAS ARE SITUATED.

THE BOARD CONSIDER THAT LOCAL BENEFITS SHOULD BE SECONDARY OR SUBORDINATE TO THE MAIN OBJECTIVE, WHICH IS THE CONSERVATION OF THE WATER YIELD IN THE INTERESTS OF THE INHABITANTS OF ALL PROVINCES WHOSE EXISTENCE DEPENDS ON THE SUPPLY OF IRRIGATION WATER BEING MAINTAINED, FROM CATCHMENT AREAS WHICH, IN MANY CASES, EXTEND BEYOND THE LIMITS OF CONTROL OF ANY PROVINCIAL GOVERNMENT.

* Vide page 128.

† Vide page 128.

BY THE COURTESY OF THE FOREST DEPARTMENT INFORMATION HAS BEEN PLACED BEFORE THE BOARD, AT ITS 10TH ANNUAL MEETING, OF WORK UNDERTAKEN, IN THE PUNJAB, ON THE PREVENTION OF SOIL DENUDATION. THE RESULTS, SO FAR OBTAINED, ARE ENCOURAGING, AND IT SEEMS THAT A MEASURE OF PREVENTION OF SOIL DENUDATION, AND CONSEQUENT CONSERVATION OF WATER YIELD, IS PRACTICABLE.

AN APPRECIABLE PART OF THE ANNUAL RAINFALL, AFFECTING THIS QUESTION, IS PRECIPITATED WITHIN AREAS UNDER THE CONTROL OF THE CENTRAL GOVERNMENT. THE BOARD ARE OF THE OPINION THAT IF MEASURES TO PREVENT SOIL DENUDATION COULD BE EXTENDED TO ALL DETERIORATED AREAS, WITHIN THESE LIMITS, A DEGREE OF INSURANCE FOR THE FUTURE WOULD BE OBTAINED.

IN ORDER TO ACHIEVE THIS, ESPECIALLY IN ITEMS OF COST, ASSESSMENT OF LOCAL AND GENERAL BENEFITS BETWEEN PROVINCES, ETC., THE ACTIVE PARTICIPATION OF THE CENTRAL GOVERNMENT APPEARS TO THE BOARD TO BE NECESSARY."

THE FAIR INCIDENCE OF THE COST OF IRRIGATION WATER ON DIFFERENT CLASSES OF CROPS.

PRELIMINARY GENERAL NOTE FOR GUIDANCE OF 10TH BOARD MEETING.

The subject first came before the Board at their 7th Annual Meeting in November 1936.

Of primary importance in this connection is the water requirements of crops ; a subject that has assumed first place in the discussions under "Means to Secure the Equitable Distribution of Irrigation Water". There has therefore been considerable repetition in the discussion.

An introductory note was written by Mr. T. M. Lyle in 1936. Mr. Lyle gave reasons for the impracticability of a flat rate and of volumetric charge. He favoured the acreage rate but modified to avoid the anomalies which at present exist. In his opinion the fairest way of fixing the acreage rates would be to make them a certain percentage of the increased values of the crops due to irrigation only. He went on to show that in the United Provinces approximately 1/3rd the gross value of an irrigated crop was due to irrigation and claimed that 1/6th the gross value of an irrigated crop could therefore fairly be claimed as payment for irrigation facilities. Existing rates in the United Provinces were in all cases lower than 1/6th the gross value of the irrigated crop.

The meeting passed the following Resolution :—

"The Board is of the opinion that there appears to be a necessity for introducing a more satisfactory method of assessing water rates for crops, which will afford encouragement to the zemindar to cultivate in a more scientific manner, and the rates should bear more relation to the value of the crops, and their water requirements. In regard to the latter, further investigations are desirable by the Irrigation and Agricultural Departments to ascertain more precisely the water requirements of particular crops."

At the 8th Board Meeting in November 1937 the discussion dealt mainly with the adjustment of assessment to encourage better methods of cultivation, and the sale of water by contract.

It was felt that little progress could be made until more information was forthcoming on the water requirements of crops, but that the subject should be discussed by the Board every year as it was one of considerable importance.

From the discussion at the 9th Annual Board Meeting in November 1938 it appears that there was a proposal before the Sind Government to introduce a sliding scale with the present rates as a minimum.

The provision of a sliding scale was also being investigated in the Punjab in connection with the revision of the Irrigation Act in that Province.

Further reference was made at this Meeting to the contract system of water supply.

Since the last Board Meeting the Imperial Council of Agricultural Research has published a "Bibliography of the Water Requirements of Plants." Omitting any references from abroad an outline is given hereunder on the water requirements of wheat. In making this outline we have also consulted the bibliography prepared by the Bureau of Information for Irrigation.

Water Requirements of Wheat.

Name of Province.	Locality within Province.	Average rainfall in inches.	Number of preliminary waterings.	Number of waterings after sowing.	Duty.	Average Depth of water per irrigation watering in feet.	Total irrigation depth in inches.	Yield of grain per acre.	Type of Soil.	Remarks.
1	2	3	4	5	6	7	8	9	10	11
Baluchistan	Quetta	10·15	1	Nil	..	....	..	17·75 mds.	..	Better yield than is obtained with the usual six or seven irrigations.
Punjab . . .	Various	20	1	2	..	1st watering 0·268 2nd watering 0·251 3rd watering 0·217	9	16 mds., 11 seers.	Old cultivation.	Further watering decreases yield.
Punjab . . .	Upper Bari Doab Canal, Sirhind Canal, W. Jumna Canal.	20	1	2	..	....	..	..	Very old Mature cultivation.	
Sind . . .	Various	4	1	Nil	200	....	12·8	18 mds., 21 seers.	Sweet Land.	Subsequent waterings after the preliminary waterings do not increase yield.
							to 14·4		Kalar Land.	
United Provinces	Cawnpore and Saharanpur	38	1	1	..	0·25	Reduction below this depth not conducive to best yields.

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CENTRAL BOARD OF IRRIGATION.

Correction slip No. 1.

Central Board of Irrigation Publication No. 22 "Annual Report (Technical) of the Central Board of Irrigation, India, for 1938-39".

Page 137.—"Water Requirements of Wheat". Delete entries against Sind and insert the following data in columns 2 to 11 instead :—

2	3	4	5	6	7	8	9	10	11
Sakrand	4	Early sown crop two waterings of 4" each. Late sown crop one watering of 6".	Three	200 (200 is the water-course head duty assumed for design in the Barrage Project).	Preliminary watering 6" — 8". Three subsequent waterings of 3".	15" to 17" (See note in column 11).	Yield at Sakrand 1140 lbs. per acre.	Loamy.	These results were obtained in small plot experiments under ideal conditions i.e. with no water-course losses and level plots. They do not represent field conditions. Further, if the 3 subsequent waterings are reduced yields decrease.

Simla,

Dated 17th April 1942.

A. R. THOMAS,

Secretary, Central Board of Irrigation.

Reverting to the question of increased yield due to irrigation it should be noted that the yield of irrigated and unirrigated crops for all the Provinces of British India appear in the "Agricultural Statistics of India," a publication which has appeared annually since 1886.

DISCUSSION BY THE 10TH BOARD MEETING, NOVEMBER 1939.

THE PRESIDENT referred the meeting to the note on the subject (on the preceding pages), and to the note on, "Means to Secure the Equitable Distribution of Irrigation Water," on pages 141 to 146. He added, "You will share my satisfaction in noticing the increased co-operation between the Agricultural and Irrigation Departments, particularly on the United Provinces tube wells. This is a direct outcome of the Board's recommendations, and the interest displayed by Dr. Burns, Agricultural Commissioner with the Government of India, Imperial Council of Agricultural Research".

KHAN BAHADUR ABDUL AZIZ said that in the United Provinces they had started a five-year plan for the collection of data from tube wells. This year they were collecting data relative to sugarcane.

Mr. S. H. BIGSBY said that the Punjab Government were launching a big experiment at the Lyallpur College which would be spread over ten years. The engineering lay out, in the form of pumping equipment, overhead tanks, etc., was costing Rs. 60,000.

THE PRESIDENT enquired whether Mr. Farquharson had anything to say on the subject of a sliding scale of charges.

Mr. F. A. FARQUHARSON informed the meeting that the Punjab Canal Act Committee had decided against the sliding scale. The present sliding scale, varying with prices, was only applied to land revenue in the Punjab, and its application had greatly reduced revenue.

Mr. BIGSBY furnished particulars of remissions, etc.

THE PRESIDENT read the following letter, recently received from the Chief Engineer of Gwalior State :—

FROM

THE CHIEF ENGINEER,
PUBLIC WORKS DEPARTMENT,
GWALIOR GOVERNMENT,
GWALIOR.

TO

THE SECRETARY,
CENTRAL BOARD OF IRRIGATION,
SIMLA, W.C.

No. 9665 of 1939, dated 30th October 1939.

DEAR SIR,

With reference to your letter No. 4825-J.-151, dated the 19th September, 1939, I beg to state that the system of charging eight annas per bigha for each watering, was in force in 1921, but it has been discontinued from the year 1924 on account of the difficulty encountered in recording correctly, the number of times that water was given to each field.

Moreover, this system gave rise to complaints by the cultivators about the number of waterings taken by them. In investigating these complaints no reliable evidence could be secured as to the number of waterings given.

Since the Rabi season of 1924 we are charging full rates for each kind of crop, irrespective of the number of waterings given.

It is considered that the system of charging proportionate rate per bigha per watering is not practicable or desirable in the interest of the State.

Yours faithfully,

(Sd.) S. N. BHADURI,

30-10-39.

Chief Engineer,

P. W. D., Gwalior Government.

Commenting on this letter Mr. BIGSBY said that in some areas in Rajputana and probably in Gwalior there was frequently not enough water stored to permit the full number of waterings. In some localities a smaller charge was then made. This system was unsatisfactory as it led to corruption which was difficult to detect.

KHAN BAHADUR ABDUL AZIZ said that they had sold water by volume on tube wells. Cultivators on tube wells opposed the crop rate, and were in favour of a charge per watering, even at an enhanced rate.

MR. BIGSBY then proceeded to describe the contract system of charges in the Punjab. The cultivators on this system are charged according to outlet capacity, irrespective of the volume of water they actually utilize. The system works reasonably well, except in cases where there are a large number of holders on an outlet.

KHAN BAHADUR ABDUL AZIZ said the contract system was tried on the Eastern Jumna Canal in the 60's of last century. It failed for the same reason mentioned by Mr. Bigsby.

MR. A. ORAM said that in the North-West Frontier Province they had tried the contract system. Five-year contracts are in force, for the irrigation of three estates, under which the owners pay a lump sum per crop which is the average of what they paid per crop during the five crops previous to the beginning of the contract.

THE PRESIDENT said that if a good system of assessment could be discovered, the advantage would be great.

Resolved "*THAT SUGGESTIONS HAVE BEEN ADVANCED THAT PAYMENT SHOULD BE MADE PER WATERING, BUT THE BOARD CONSIDERS THAT THIS METHOD OF ASSESSMENT IS IMPRACTICABLE FOR A PERENNIAL CANAL SYSTEM.*"

IT IS ESSENTIAL, FOR THE FURTHER CONSIDERATION OF THIS QUESTION, THAT THERE SHOULD BE CLOSE CO-OPERATION BETWEEN THE REVENUE, AGRICULTURAL, AND IRRIGATION DEPARTMENTS, AND IT IS PLEASING TO OBSERVE THAT SUBSTANTIAL DEVELOPMENT IS TAKING PLACE ON THESE LINES."

After passing the above resolution, the meeting discussed the methods of assessing water charges.

MR. F. A. FARQUHARSON said that in parts of the Punjab water was sold on the Contract System, but so far only to individual outlet owners.

The opinions of all the Non-Official Members of the recent Canal Act Committee was that, unless a Contract System could be devised which would be acceptable by all outlet share-holders, the present system for individual outlet owners should be abolished as it constituted a loss to Government, the System being adopted only where the irrigators stood to gain thereby.

Continuing Mr. Farquharson said that a New Panchayat Bill was before the Punjab Legislative Assembly whereby it was proposed to introduce the Panchayat System throughout the Province. It would be part of the duties of the Panchayat to distribute the water supplies to outlet owners, and it might then be possible to introduce the Contract System for the sale of water to all irrigation outlets.

MR. E. O. COX enquired if a note on the system could be sent to all Provinces.

THE PRESIDENT said that the Sind Government had laid down that the Canal Act should not apply to cases where one land owner cultivated the whole area served by an outlet. He had not received figures to see whether there was a loss to the Government as a result of this.

MR. COX said that under the contract system, a contract is binding for 3 years. Rates are based on the average value of the cusec in the division concerned. Remissions were not ordinarily given, but the cultivators received calamity remissions.

MR. BIGSBY said that many of the large estates on the contract system had reduced their irrigated crop areas. This was rather an extraordinary effect.

MR. ORAM presumed that the contract system was only applicable to established canals, and was informed that such was the case.

MR. GORDON said that in the case of Government waste land the cultivators were given a certain amount of water to cover such waste land.

MR. FARQUHARSON promised to prepare a note on the contract system for the information of the Board,

THE DESIGN OF DISTRIBUTARY HEADS.

PRELIMINARY GENERAL NOTE FOR GUIDANCE OF 10TH BOARD MEETING.

At the 9th Research Committee Meeting held in July 1939, arising out of the discussions of the United Provinces Research Report, it was resolved that :—

“ This Committee recommends that the item ‘ Design of Distributary Heads, ’ be included in future discussions of the Central Board.”

The main point is the design of heads from the point of view of silt control.

DISCUSSION BY THE 10TH BOARD MEETING, NOVEMBER 1939.

THE PRESIDENT referred to the resolution of the 9th Research Committee.*

He said that in Sind they make alterations to heads on the results obtained from models, and the method was extraordinarily successful. Without fail the prototype had agreed with the model, and the President gave details of the Nara experiment.

The President said that as a result of the work done in Sind, that province might be able to suggest certain rules for the design of distributary heads.

MR. F. A. FARQUHARSON said that in the Punjab considerable remodellings and alterations to the design of distributary heads had been carried out in the past, but due to proper histories of channels not having been maintained it was not possible now to study the effect of those changes due to the information required not being forthcoming.

MR. T. M. LYLE said that histories of channels had been started some years ago in the United Provinces.

Resolved *“ THAT THIS BOARD ACCEPTS THE RECOMMENDATIONS OF THE 9TH MEETING OF THE RESEARCH COMMITTEE TO INCLUDE THE IMPORTANT SUBJECT OF THE DESIGN OF DISTRIBUTARY HEADS IN THE BOARD'S FUTURE AGENDA.*

THE SECRETARY SHOULD COMMUNICATE WITH THE PROVINCES WITH A VIEW TO ASCERTAINING WHETHER THEY ARE ABLE TO SUPPLY INFORMATION FOR THE COMPILATION OF A GENERAL NOTE ON THE SUBJECT FOR EXAMINATION BY THE RESEARCH OFFICERS.”

**Vide* page 31.

MEANS TO SECURE THE EQUITABLE DISTRIBUTION OF IRRIGATION WATER.

PRELIMINARY GENERAL NOTE FOR GUIDANCE OF 10TH BOARD MEETING.

At the Fourth Annual Meeting of the Central Board of Irrigation, held in November 1933, the publication of a paper entitled "Distribution of Irrigation Water" was discussed. A draft of the paper was subsequently distributed, and a great deal of information collected from the Provinces, but a final draft has not yet been compiled owing to the complexity of the problem.

Omitting the above discussion, the subject "Means to Secure the Equitable Distribution of Irrigation Water" first appeared as a result of a discussion on water Rights at the Fifth Board Meeting in November 1934.

The Board at that time was considerably concerned over the position of water rights under the new constitution, as between provinces and states. It was affirmed by certain members that the cultivator had no definite legal right to his supply of irrigation water enforceable in the civil courts. This was felt to be a highly unsatisfactory state of affairs, but no definite solution to the problem was forthcoming. A tentative suggestion was made by one member that the formation of a Water Rights Board might afford a solution.

The Board passed the following resolution :—

" Resolved that this Board is exercised as to the means to secure the equitable distribution of irrigation water in the future ; that members should consider means suitable to their own Provinces, with a view to discussion at the next meeting of the Board."

The origin of this item as a subject for discussion is of great importance as it will be observed that subsequent discussions have strayed from the strict intention thereof and the discussion has latterly become one more concerned with the water requirements of crops. This is undoubtedly a factor of importance but by no means the only factor. It would appear that the water requirements of different regions should be laid down taking into consideration primarily the local rainfall, and the nature of the soil. On such a basis the total surface and subsurface water supplies utilized and unutilized could theoretically be apportioned amongst all the districts of India irrespective of whether such supplies could be delivered to or utilized by a particular district immediately or in the future. In this way no abstraction of surface or subsurface water would be permitted until the theoretical requirements of all the districts linked to that particular source of supply had been considered and only rejected if supply was completely and for ever outside the bounds of practicality.

At the next, the sixth, Board Meeting in November 1935 the main object of the subject was lost sight of and discussion devolved into an argument between the protagonists of volumetric sale of water and the sale of water on the basis of matured acreage.

The following Resolution was passed :—

" 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."

The Research Committee duly considered the question of charging for irrigation water and passed a resolution to the effect that the volumetric method was neither practical nor could it afford greater protection to the cultivator without additional cost to him.

At the seventh Board Meeting held in November 1936 the Board ratified the Research Committee's reply and enlarged on it as will be seen from the following resolution :—

" It is resolved that at present the sale of water by volume is not a practical proposition for general application in this country though the method has been found practicable in some cases of large holdings. No device for the measurement of water for small holdings which meets all the requirements of this country, and which could be used for the sale of water by volume on ordinary canal systems, has been brought to the notice of the Board."

The Board is of the opinion that the existing system of distribution of water based on crop requirements is most suitable, but that further knowledge on the subject of water requirements of crops is desirable."

Discussion was based on second paragraph of the above resolution when the subject " Means to Secure the Equitable Distribution of Irrigation Water " was discussed by the Board at its 8th Annual Meeting in November 1937 thus completely masking the original intent of the subject.

The entire discussion centred around the canal and well water requirements of crops, and the question of the fertility of silt even obtruded itself. The resolution framed took the following form :—

" This Board is of the opinion that the question of water requirements of crops and manurial value of silt is of great importance, and should be one of the first investigations undertaken at a Central Research Station for Irrigation, if and when established."

At last year's (1938) meeting of the Board discussion centred on the water requirements of crops and the part played in this respect by the Agriculture Department. The general opinion was that the Irrigation Departments and the Agriculture Department viewed the problem from different angles. Additional specific cases which from the irrigation viewpoint needed investigation by the Agriculture Department were mentioned such as the maximum outturn per cusec of water ; the rotation which would give the best results in an intensity of 35 acres out of 100 acres in the cold weather ; and the relative values of different numbers of waterings.

It was considered that the quantities of water utilized from tube wells might yield information of value.

The part which would be played by a Central Research Station for Irrigation appeared to be rather that of a central clearing station for information rather than actual experimentation which would be of limited value owing to the tremendous variety in climates found in different parts of India.

The need for consultation between Agriculture and Irrigation Officers was emphasized and although certain suggestions were made nothing definite was decided upon.

As a result of these discussions a scheme for determining the relation between water duty and yield of sugarcane and wheat crops in the Western United Provinces has been prepared and submitted for approval of the Local Government. The Irrigation and Agriculture Departments will co-operate and data will be collected from tube wells. Details of the scheme and connected correspondence are reproduced on pages 143 to 146.

Preliminary construction work in connection with a scheme for research on the water requirements of crops is being carried out by the Department of Agriculture, Punjab, in conjunction with the Imperial Council of Agricultural Research. No final results of the investigations are likely to be available for several years.

The following schemes financed by the Imperial Council of Agricultural Research for the study of water requirements of crops are in progress :—

- (1) Rice Research Scheme, Central Provinces, Raipur.
- (2) Rice Research Scheme, Bengal, Chinsurah and Bankura.
- (3) Rice Research Scheme, Bihar, Sabour.
- (4) Rice Research Scheme, United Provinces, Nagina.
- (5) Water requirements of Crop in the Punjab, Risalewala.
- (6) Oilseed Research Scheme, Punjab, Lyallpur.
- (7) Sugarcane Research Scheme, Bombay-Deccan, Padegaon.
- (8) Sugarcane Research Scheme, Madras, Anakapalle.
- (9) Sugarcane Research Scheme, Madras, Gudiyattam.
- (10) Sugarcane Research Scheme, Punjab (Risalewala, Lyallpur and Jullundur).
- (11) Sugarcane Research Scheme, Bihar, Pusa.
- (12) Sugarcane Research Scheme, United Provinces (Shahjahanpur and Muzaffarnagar).

Progress reports from these stations have been abstracted and will appear in the Board's Quarterly Bulletin No. 15. All future progress reports will be similarly treated.

The Central Board has sent proposals to the Imperial Council of Agricultural Research with respect to this subject. The proposals were submitted to the Board by the United Provinces, Sind and Bombay.

In order to strengthen the liaison between the Agricultural and Irrigation Departments the Vice-Chairman of the Imperial Council of Agricultural Research has decided that the Secretary, Central Board of Irrigation will in future be invited as a visitor to attend the meetings of the Advisory Board and its committees discussing matters of common interest.

COPY OF A LETTER NO. 15234-J. H./164-B-355W/1939 OF 1939, DATED THE 30TH AUGUST, 1939, FROM KHAN BAHADUR M. ABDUL AZIZ SAHIB, C.I.E., I.S.E., CHIEF ENGINEER, UNITED PROVINCES, PUBLIC WORKS DEPARTMENT, IRRIGATION BRANCH LUCKNOW, TO THE SECRETARY TO GOVERNMENT UNITED PROVINCES, PUBLIC WORKS DEPARTMENT, LUCKNOW.

"I have the honour to state that the Central Board of Irrigation at its meeting held on October 29 to November 4, 1938, drew attention to the experiments on the water requirements of some crops conducted by the Irrigation Department, United Provinces, and desired that the available data should be examined by the Statistician to the Imperial Council of Agricultural Research. On January 21, 1939, Rao Bahadur Vidyathan, the statistician to the Council visited the tube well No. T. 1. A in the Irrigation Development Division (West) and examined the tube well and crop yield figures available. It was found that these figures were not likely to give any useful information on the water requirements of sugarcane. The Technical Adviser to the Imperial Council of Agricultural Research therefore advised that a small scheme on the desired investigation should be drawn up by the joint deliberations of the Agriculture and the Irrigation Departments.

2. Accordingly a meeting represented by officers of the two departments was held at Lucknow on May 7, 1939, and it was decided to lay out the experiment on crop yield figures for sugarcane crop in five localities namely the State tube well zones of Bijnor, Moradabad, Budaun, Meerut-Muzaffarnagar, and Bulandshahr and the experimental results available from similar experiments conducted by the Agricultural Department in the past at Nagina, Shahjahanpur, and Muzaffarnagar should also be utilised in fixing the irrigation treatments to be examined in the proposed experiments under cultivator's field conditions. A copy of the Director of Agriculture letter No. 29569/1-135C., dated June 26, 1939, together with a copy of the scheme is sent herewith for perusal.

3. So far as the Irrigation Branch is concerned the following help in the shape of extra establishment or waiving of water dues will be necessary :—

- (i) Five tube wells in each of the five districts of Bijnor, Moradabad, Budaun, Meerut-Muzaffarnagar, and Bulandshahr will have to be selected for these tests and also ten fields of nearly uniform soil conditions will have to be selected for the laying down of the selected sugarcane crop to be treated with the five variations of irrigation. The cultivators of these selected plots will have to be persuaded to agree to these experiments and an experienced ziladar's services for this preliminary work will be necessary. He should be able to complete the work in all the five districts in three months, *e.g.*, October—December in each year. The help of the local revenue staff should of course be available to him in addition.
- (ii) The tube well operators should be able to regulate the irrigations under the supervision of the local ziladars and no extra staff for this work is necessary.
- (iii) For the harvesting of the samples and their weighing and record the Director of Agriculture suggests that one ziladar with two kamdars should be appointed for each tube well and for all the 25 tube wells, 25 such units will be necessary. The period for which each unit will work is expected to be five days. As it is not possible to have so many ziladars for such a short period, one ziladar per district assisted by fiveamins and ten patrols ought to be able to complete the work satisfactorily. The staff will also require training in the selection of the sample plots, the proper methods of cutting and weighing, etc., and the engagement of the staff for two weeks for the whole operation should be sufficient.

(iv) The following will therefore be the expenditure in Irrigation Branch on the establishment proposed :—

1 Ziladar 4th grade for 3 months at Rs. 75 plus Rs. 50 for Travelling Allowance .	375
5 Ziladars 4th grade for 14 days at Rs. 75 plus Rs. 30 for travelling allowance each	245
25 Amins for 14 days at Rs. 25 each	292
50 patrols for 14 days at Rs. 12 each	280
	1,192
For 5 years	5,960
say Rs.	6,000

(v) The Director of Agriculture has also proposed a free supply of water for any irrigations beyond four in order to induce cultivators to agree to give more water than what is considered necessary by them at present. Out of a maximum 1,500 waterings for the 250 plots selected for the tests at the most 450 waterings may have to be given free. Assuming that the area of the plots would be 1.5 acres on average, the cost will be Rs. $1.5 + 3.5 =$ Rs. 2,362-8-0.

As some waterings will have to be skipped owing to timely rainfall in some localities, it may be assumed that about Rs. 2,000 per year or Rs. 10,000 for the full five years may have to be foregone on this account.

4. I have therefore to request that the approval of Government may be accorded to the incurring of the expenditure in this Department for this scheme which has been sponsored by the Director of Agriculture and described in detail in the letter a copy of which has been enclosed herewith. The collection of the data and the statistical examination thereof will be conducted by the Director of Agriculture and he will no doubt come up separately for the approval of the expenditure in his department and the sanctioning of the scheme in its entirety."

COPY OF LETTER FROM BISHNU SAHAY, ESQ., I.C.S., DIRECTOR OF AGRICULTURE, U. P., LUCKNOW, TO THE CHIEF ENGINEER, U. P., P. W. D., IRRIGATION BRANCH (WESTERN CANALS), LUCKNOW, No. 29569/1-135-C., DATED JUNE 26, 1939.

"I have the honour to forward herewith a copy of the scheme for determining the interaction between water duty and yield of sugarcane and wheat crops in the Western part of the United Provinces for information and comments if any."

Scheme for determining the interaction between water duty and yield of sugarcane and wheat Crops in the Western U. P.

INTRODUCTION.

The Central Board of Irrigation at its meeting held on October 29th to 4th November 1938, drew attention to the experiments on the water requirements of some crops conducted by the Irrigation Department in the U. P., and it was desired that the available data should be examined by the Statistician to the Imperial Council of Agricultural Research.

After scrutiny of the data, it was felt that although records on quantity of water supplied to the crops could be utilised for giving vague indications of the water requirements, no data pertaining to the yield of the crops in question was maintained. The available data, therefore, did not permit of any correlation studies of water supply with yield which is a very important aspect of the problem.

It was later realized that a suitable scheme on the desired investigation should be drawn up by the joint deliberations of the Agricultural Department and the Irrigation Department in the U. P. Accordingly, at the meeting, represented by officers of the two Departments, held on 7th May, 1939, it was decided to layout the experiment in five

localities namely, the State Tube Zones of Bijnor, Moradabad, Badaun, Meerut-Muzaffarnagar, and Bulandshahr, and the experimental results available from similar experiments conducted by the Agricultural Department in the past at Nagina, Shahjahanpur and Muzaffarnagar should be utilized in fixing the irrigation treatments to be examined in the proposed experiments under cultivator's field conditions. The results of the experiments conducted on Government Farms although more reliable and precise could not be safely applicable to crops grown under cultivators' conditions.

Present Proposals.

The object of the present scheme is :—

- (I) to find out the optimum water requirements of sugarcane and wheat crops in the western parts of U. P.
- (II) to determine the extent of correlation between water duty and yield of the two crops.

Central Procedure of Work.

It is proposed that only a few of those districts in which sugarcane and wheat crops are of major importance should be selected for experimentation to start with. In each of the selected districts, five villages are to be selected at random and ten fields of almost uniform soil conditions to be selected in each village. Villages will be selected at random within the Tube Well Zone provided they are known to be sugarcane or wheat (as the case may be) growing villages in which the crop is of not less than average importance. For minimising loss of water through seepage in the *guls*, the selection of the fields will be restricted to areas near the Tube Wells. The experimental fields should receive as far as practicable uniform cultural (barring irrigational) and manurial treatments.

Sugarcane.

In the case of sugarcane, manuring may be done at the rate of say—250 mds. of farm-yard manure to an acre. Sowing of the experimental fields should be taken up in the 3rd week of February and completed within as short a period as possible but not exceeding one week.

The irrigation treatments may be 3 + 1, 4 + 1, 5 + 1, 5 + 2, and 6 + 1; the first figure in each case representing premonsoon and second figure post-monsoon number of irrigations at 88,000 gallons of water (4" per acre per irrigation).

Out of the ten fields in each village, two will be selected at random for each treatment. Thus in any one particular village there will be two fields for each treatment and the five villages in each locality will provide ten replicates in each experiment.

It is proposed to sow one variety of cane in all the fields in a locality but should the interaction between water duty and different varieties of cane be also desired to be estimated, a split-plot design of layout will have to be adopted.

The proposed irrigation treatments should be timed as tabulated below :—

Serial No.	No. of irrigation.		Data.						
	Pre-monsoon.	Post-monsoon.							
I	3	1	3rd week February.	3rd week March.	2nd week May.	End October.			
II	4	1	Do. .	Do. .	1st week May.	1st week June.	End October.		
III	5	1	Do. .	Do. .	3rd week April.	2nd week May.	1st week June.	End October.	
IV	5	2	Do. .	Do. .	Do. .	Do. .	Do. .	Do. .	Mid December.
V	6	1	Do. .	Do. .	2nd week April.	1st week May.	4th week May.	2nd week June.	End October.

At each Tube Well commanding the experimental plots, a rain gauge will be maintained for obtaining accurate rainfall data. Any amount of rainfall received within the interval period of each irrigation treatment will be deducted from the proposed quantity of subsequent irrigation (*i.e.*, 88,000 gallon or 4" per acre).

Sampling of the plots for yield determinations.

The yield per acre of the experimental fields will be estimated by such standard sampling method as may be suggested by the Statistician to the Imperial Council of Agricultural Research. This will necessitate harvesting of a number of

samples of uniform size and shape by the approved method and their weighment and record separately. The experiment in any particular locality should be harvested within as short a period as possible but not exceeding one week.

Some compensation will be necessary to ensure the ready co-operation of the growers in allowing the experiments to be laid out in their fields, sampling of their crops or for delaying their harvest. It is suggested that where the premonsoon irrigation treatments are four or below, a compensation at the rate of 0-2-0 per maund of cane sampled out be given and where the premonsoon treatments are above four, the grower will be considered as compensated in the shape of free supply of water given to him for any irrigations beyond four. This higher rate of compensation per maund on cane sampled out is suggested as the growers receiving lower irrigational treatments are likely to obtain comparatively lower yields.

Staff and other provision.

It is proposed that the irrigational treatments will be conducted and supervised by the Tube Well Operator and the harvesting of samples from each field for yield determinations will be supervised by the Ziladars of the Irrigation Department. In addition to this, it will also be necessary that some responsible officer either a senior Ziladar or a Sub-divisional Officer should direct and exercise general supervision over the conduct of the experiment in each locality (district).

The extent of supervision, labour and time required for harvesting can not be accurately estimated without any knowledge of the approved method of sampling to be adopted. It may be assumed, however, that a unit of one Ziladar and two kamdars will normally be able to sample two fields per day. The time taken for ten fields in each village will, therefore, be five days. To deal, at one time with the proposed total of 50 fields per locality, five such units of workers will be needed. The same strength will be required for the experiments in the remaining four localities (districts).

It will also be necessary to provide for the statistical examination of the experimental data, and a certain amount for compensation and contingencies. The expenditure may be roughly detailed as under :—

Recurring—

	Rs.
One Statistical Assistant at Rs 150 per mensem for 4 months	600
Compensation to cultivators	1,000
Other contingencies	400
	2,000

Non-recurring—

Harvesting and weighing equipments, chains, poles, pegs, 50 weighing balances, and 50 measuring tapes one for each unit of workers, etc.	2,500
Total	4,500

Total expenditure required for 5 years of work = Rs. 22,500.

The experiment will be repeated over a period of at least 5 years and it is proposed that the Statistical part of the work may be carried out by the Statistical Section of Imperial Council of Agricultural Research by employing temporarily, each year, the officer provided for above.

A similar scheme of work can be drafted out for the wheat crop as well.

DISCUSSION BY THE 10TH BOARD MEETING, NOVEMBER 1939.

THE PRESIDENT referred to the preceding note, and said that the discussions at the various Board meetings appeared to have wandered from the original intent of the subject.

Resolved. " *THAT THE OPINION OF THE BOARD IS THAT THE INTER-PROVINCIAL DISTRIBUTION OF WATER IS NOT TO BE CONSIDERED, AND THAT THE TITLE, " MEANS TO SECURE THE EQUITABLE DISTRIBUTION OF IRRIGATION WATER", BE CHANGED TO, " THE EQUITABLE DISTRIBUTION OF IRRIGATION WATER ON A CANAL SYSTEM."*

APPENDIX I.

VISIT OF THE CENTRAL BOARD TO THE IMPERIAL AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI.

The party composed of Board Members and Officers attending the 10th Board Meeting arrived at the Imperial Agricultural Research Institute, New Delhi, at 8 A.M., on 9th November 1939, and were received by Rao Bahadur Viswa Nath, the Director.

After inspecting the Institute's library the party was taken to inspect the experimental plots.

At the top block they were shown the layout of the fields and arrangements for irrigation. The water was not measured but applied to the fields as required.

A standing crop of berseem was viewed. Experiments on this crop had extended over two years and the results obtained were as follows :

Average yield per acre in maunds* of berseem fodder for the different intervals of irrigation.

Description of treatments.	Average yield per acre in Maunds.	
	1937-38.	1938-39.
8 days' interval	896.08	770.49
10 " 	884.77	654.57
12 " 	807.09	751.01
16 " 	568.07	645.37
20 " 	673.86	587.46

Conclusions.—In both the years, the yield of green fodder with 12 days' irrigation interval does not differ significantly from that obtained from 8 days' and 10 days' irrigation intervals.

The party was then taken to plots Nos. 1, 2 and 3, where they saw a germinating crop of oats, and irrigation arrangements. The Institute was moved to Delhi from Pusa some four years ago, and a great deal of levelling had to be done with scrapers. The plots viewed occupied ground which had been scraped. After scraping, oats were sown in rabi 1936, followed by jowar for green fodder in kharif 1937 ; oats were grown in rabi 1938 and the crop viewed by the party was again oats, sown after a green manure crop.

The yields obtained were as follows :—

Plot No.	Oats 1936-37.	Green jowar 1937-38.	Oats 1938-39.
	Mds. per acre.	Mds. per acre.	Mds. per acre.
1	18.78	126.20	27.34
2	23.94	134.66	29.07
3	20.30	84.28	27.79

The party was then conducted along the first watercourse to the experiment area (middle block), when they were shown experiments with different rabi fodder crops as alternative to berseem. These experiments were designed to see whether any alternatives to berseem could be found, as berseem is very costly in irrigation as well as in seed.

Last year's results were as follows :—

	Yield of green fodder per acre.	No. of cuts	No. of irrigations given.
	(Mds.)		
Berseem	730.64	6	21
Senji (<i>Melilotus parviflora</i>)	185.37	2	12
Methra (<i>Trigonella sp.</i>)	166.60	2	10
Kerao (<i>Pisum arvense</i>)	327.17	1	6
Khesari (<i>Lathyrus sativus</i>)	258.80	1	6
Barley and Kerao	330.04	1	7

* 1 maund = 80 lbs.

The party was informed that this year, in addition to the number of irrigations required to grow these crops, records of the volumes of water used were also kept. The volume of water used up to date was as follows :—

	Gallons per acre.
1st irrigation	76,942
2nd irrigation	54,635
3rd irrigation	50,473
4th irrigation	46,176

Adjacent to this experiment, was the manurial experiment. The results obtained with a crop of maize grown in this experiment in the preceding kharif* are given below. When viewed, barley had just been sown to see the residual effect.

Treatments per acre.	Average yield per acre in maunds.
1. No manure	13.559
2. Farmyard manure 40 lb. N.	13.753
3. Activated sludge 40 lb. N.	15.597
4. Rape cake 40 lb. N.	15.791
5. Farmyard manure 40 lb. N. + 50 lb. P_2O_5 + 50 lb. K_2O	13.692
6. Activated sludge Do. + Do. + Do.	15.026
7. Rape cake Do. + Do. + Do.	15.281
8. Compost 40 lb. N.	15.417
9. Compost 20 lb. N. + 20 lb. N as Amm. Sulph.	15.791
10. Farmyard manure 20 lb. N. + 20 lb. N. as Amm. Sulph.	17.889
11. Farmyard manure 120 lb. N., once in 3 years	15.573
12. Complete artificials (40 lb. N. + 50 lb. P_2O_5 + 50 lb. K_2O)	16.300

The Officer conducting the party described the wheat varietal yield trials. He quoted the following varieties and yields :—

Variety.	Mean yield per acre in maunds 1938-39.
P. 4	24.34
P. 80-5	22.56
P. 114	21.96
P. 125	22.02
Local	24.91
C. 518	24.63
P. 12	28.18
P. 111	26.48
P. 120	23.78
P. 165	25.58
BA	26.07
C. 591	25.12

Sugarcane varieties growing under irrigation were inspected. These had been planted in March 1939, and had received, on an average, one irrigation per month.

In discussing what had been seen, MR. A. GORDON said that in Sind he preferred plots of $\frac{1}{4}$ acres, whereas those they had been shown were in some cases $\frac{1}{40}$ th acre.

In reply to a question from MR. T. M. LYLE, the conducting Officer informed the party that lucerne was not good for milch cattle. Berseem was proving more favourable and, provided there was adequate water, was the best rabi fodder crop. Berseem was much superior to Napier grass. He said they fed cattle on the various crops and tested the milk yield.

RAO BAHADUR VISWA NATH explained that the farm had never been under irrigation before they occupied it, and they were studying the effect of irrigation on the sub-soil water.

The party were then conducted to the Botanical Laboratory where Dr. Pal, the Economic Botanist, showed photographs and gave figures for yields which, he claimed, showed the beneficial effect of scraping off the top soil. This caused the party some surprise as they had recently been discussing the evils of denudation.

* In India the year is split into two seasons or "fals"; namely the "rabi" from 1st October to 31st March and the "kharif" from 1st April to 30th September. Wheat, barley, peas and gram are the chief rabi crops, and rice and maize the chief kharif crops, while sugarcane grows throughout the year.

MR. LYLE asked whether it was beneficial to plough in ' sun '.*

He was informed that it was beneficial, but the ' sun ' must be ploughed in at the right time which was just before flowering. This was most important, and it must be ploughed in at least two months before the following crop is sown. ' Sun ' can be grown at any time, and should be ploughed in before the first rains.

MR. LYLE said that in the United Provinces, the new Director of Agriculture was not satisfied that ' sun ' was best for green manure.

The party then proceeded to the Soil Laboratory. Here the Director, Rao Bahadur Viswa Nath, and Dr. Dass explained soil survey work which was being carried out in India. A preliminary soil map of India† was exhibited showing the location of the eight types of soil, *i.e.*

- (1) Alluvial
- (2) Coarse Alluvial
- (3) Red Soils Lying on Metamorphic Rocks.
- (4) Laterites.
- (5) Black Soils.
- (6) Deep Black Soils or Regur.
- (7) Light Soils on Trap.
- (8) Deep Black Alluvial Soils.

In an interesting discussion on whether climatic or geological factors predominated in determining the soil types, Rao Bahadur Viswa Nath exhibited a map‡ showing how India was divided into four zones by lines running approximately north to south. On the extreme west was the arid zone, followed by the semi-arid zone, the humid zone, and finally the wet zone including parts of Bengal and Assam to the extreme east. On the map, dots indicate places from which soil samples have been taken for obtaining soil data.

These divisions agree approximately with the geographical distribution of the three basic crops ; rice, wheat, and millets. The geographical distribution of these crops was shown on maps.§

Other maps and diagrams exhibited were :

- ||(1) Sugar Map of India showing areas under sugar and a list of sugar factories.
- ||(2) Graphs showing percolation and capillary rise.
- ||(3) Map of India showing salt content and rainfall.

* Hemp.

† Copy on record in the Bureau of Information for Irrigation. Acc. No. 571.

‡ Copy on record in the Bureau of Information for Irrigation, Acc. No. 572.

§ Copy on record in the Bureau of Information for Irrigation, Acc. No. P. F. III.

|| Not available in the Bureau of Information for Irrigation.

APPENDIX II.

VISIT OF THE CENTRAL BOARD TO THE MALARIA INSTITUTE OF INDIA, DELHI.

The party, composed of Board Members and Officers attending the 10th Board Meeting, visited the Institute on the morning of November 10th, 1939, and were conducted by Lieutenant-Colonel Gordon Covell, C.I.E., I.M.S., Director.

The party were shown various types of oil sprays, and paris green blowers, and given details of the various mixtures used: All insecticides must have pyrethrum as a base, the party was informed. A chamber for testing the efficiency of insecticides was seen.

Methods of transporting live mosquitoes for test purposes were exhibited. In a special type of box exhibited, it is possible to keep mosquitoes alive for two weeks.

Tests of the yellow fever carrying power of the common mosquito were explained. It is fairly well proved that the mosquito can carry this disease, and the Malaria Institute of India is guarding against the contingency.

A model of a mosquito proof house was inspected. The need of electricity and fans, and of wiring in verandahs, was stressed by the Director. He said the best gauze to use was 14 mesh to the inch, composed of 28 to 30 S. W. G. bronze wire.

Photographs were exhibited showing engineering features in the design of drains, and construction of borrow pits, to prevent the breeding of mosquitoes; and of the effects of irrigation on mosquito breeding.

It was explained that the main trouble occurred on the Western Jumna Canal, which tails off at Delhi, when there were closures. To prevent the larvæ being carried down stream, a filter boom with oil behind it was used.

Mosquitoes were dusted to be identified, and hence the distance they travelled determined. At Delhi they travel about $\frac{1}{2}$ mile, but the distance varies with the species.

The Lido method of littoral work for preventing mosquito breeding was explained.

Other things viewed included larvæ eating fish; mosquito proof water tanks; and a mechanical insecticide mixer.

The party was informed that cinchona was introduced into Spain in 1640, and the quinine isolated from it in 1820. The cultivation of cinchona was started in India in 1860, but a slump followed, and the Dutch East Indies now produce over 90 per cent. of the world's quinine.

Lt.-Col. Covell, explaining the stages of growth of a mosquito, said they remain in the larva stage for three weeks. Females only drink blood, and are not fertile if they do not. The males feed on fruit and sweet things. Of the 44 anopheles only 7 were important propagators of malaria, and a map of India was exhibited showing the distribution of anopheles. It was important not to clear jungle in swampy places without first ascertaining the type of mosquito in the locality, as shade was obnoxious to certain types. Stagnant swamps were harmless.

Lt.-Col. Covell observed that, in planning anti-malarial measures in Delhi, it was essential that the liability of that part of India to periodical visitations of the disease in what was known as its regional, or fulminant, epidemic form be constantly kept in mind. Failure to do so was to court disaster.

In certain years, and in certain areas in particular years, the usual increase in malaria prevalence which occurred every autumn was enormously exaggerated. The total number of deaths occurring in areas coming within the epidemic zone might then be from 10 to 20, or even 30, times the normal. Fortunately, epidemics of such terrible intensity were rare, and no major epidemic had visited Delhi since 1908. There were, however, minor epidemics, which occurred at intervals of about from 5 to 7 years, in which the prevalence of malaria was very markedly increased, and became a public-health problem of considerable gravity. In an epidemic year, not only was there a great increase in the number of malaria cases, but the actual virulence of the infection was much enhanced, so that attacks of fever were much more severe than in other years. Furthermore, there was a great increase, not only in the number of mosquitoes, but also in the percentage of mosquitoes which were infected with malaria parasites. Epidemics tended to occur especially in years of excessive monsoon rainfall following a series of years in which the rainfall had been in defect, provided also that the level of the general immunity of the population against malaria was low. For that last reason, they did not occur in the same locality at intervals of less than 5 years, even in years of high rainfall. After the lapse of 5 or more years since the last epidemic a large number of children were present in the community who had never been exposed to malarial infection, whilst those who had been infected during the last epidemic had lost practically all their immunity. Conditions were therefore suitable for the advent of another fulminant outbreak. In Delhi the last two epidemics occurred in 1926 and 1933. The monsoon rainfall in 1937 and 1938 was abnormally low, so that an epidemic of malaria was very likely to occur in the next year in which there was a copious monsoon rainfall.

Malaria-control measures could be divided into two classes : namely, permanent works designed to eliminate breeding places ; and recurring measures, such as the application of larvicides and minor levelling and draining operations, which had to be continued year after year, just as streets had to be scavenged, or fruit-trees sprayed to kill insect pests. It was primarily for the mitigation of epidemic malaria that the programme of permanent anti-malaria works in Delhi was planned in 1936. It was hoped that when they were completed the incidence of the disease would be kept in check by recurring measures, even in an epidemic year. About half of the programme had been executed, but until it had been completed it could not be said that the problem of malaria-control in Delhi had been adequately tackled. It had been hoped that the entire programme would have been completed before the advent of the next epidemic year, but unfortunately financial stringency had held it up, and it was practically certain that Delhi would experience another epidemic before the remaining works were taken in hand. The completion of the programme was of more than local interest, since it would provide an indication of the extent to which permanent engineering works could influence epidemic malaria.

In conclusion, Lt.-Col. Covell said the Malaria Institute of India were constantly issuing publications which, as a body, represented the best text book available. He said that no fixed text book was possible.

APPENDIX III.

STATE TUBE-WELL SCHEME IN THE WESTERN DISTRICTS OF THE UNITED PROVINCES.

Address delivered by Mr. Ram Chandra Sahai, I.S.E. Executive Engineer, to the Central Board of Irrigation, during the Board's inspection of tube-wells on the 7th November 1939, with comments by Mr. F. H. Hutchinson, I.S.E., Superintending Engineer, United Provinces.

The seven falls on the Ganges Canal harnessed for generation of hydro-electric power and one steam-power station at Chandausi develop between them 23,000 kilowatts or 40,000 H. P. The peak-load last winter and in summer mounted to 23,000 kilowatts and approximately 16,000 kilowatts or a little more than half was used for irrigation-pumping by means of (a) river pumps on the Ramganga (Bijnor District) and the Kali Nadi (in Bulandshahr and Etah districts) and (b) some 1,478 State Tube-wells and about 200 privately-owned zamindari Tube-wells. Of the remaining, 5,000 kilowatts is used for minor industries in towns and villages and 2,000 for domestic purposes, mainly in the 80 odd towns which are electrified under the Scheme in the ten western districts.

2. *Scope of the Project.*—The 1,478 State Tube-wells have been sunk in the districts of Saharanpur, Muzaffarnagar, Meerut, Bulandshahr, Aligarh, Bijnor, Moradabad, Budaon and Bareilly in dry tracts which had hitherto remained without canal irrigation due to the seasonal shortage of water in the rivers feeding the canal systems of the Ganges, Jumna and Ramganga. Between them these wells protect one and a half million acres. Another 100 wells have been recently surveyed and 60 are being bored.

3. *Extent of the Division.*—The West Division takes up the area on the west of the Ganges river and 512 wells have already been completed in the Ganges-Jumna doab and 46 are being sunk. These 558 wells take up a culturable command of 5,40,000 acres or 840 sq. miles and the system has enabled the reservoir underlying these areas at a depth varying from 15' to 45' to be utilised for the widespread system of irrigation.

4. *Types of wells adopted and strainers used.*—Wells on this side have been sunk with an average 1·3 cusecs discharge. Borings go down 250' to 330' and 100 feet of 6" strainers have been lowered in good water-bearing strata of coarse or good medium sands. Each well commands 1,000 acres or 1·5 sq. miles on an average. The subsoil extraction has, therefore, been one cusec per sq. mile. The types of strainers experienced with were Ashford, Tej and Agricultural. The former were used on about 12 wells but were found expensive in comparison and their use was consequently abandoned.

The Tej strainers were used in 3", 5" and 7" sizes. For shallow wells sunk upto 200 feet, 40 feet of 3" and 16 feet of 5" diameter strainers yielded on the average 18,000 G. P. H. with a depression of 10 to 12 feet. The 3" size strainers sunk in such wells showed a tendency to diminishing yields and their use was discontinued. Moreover the capital cost of installing a larger number of small capacity wells over a given area with the additional outlay in electrifying a larger number of points militated against the employment of the smaller type. The operating costs also proved higher in proportion. The 5" strainer well with 70' length of strainer pipe gradually developed into the 1·5 cusec standard well which has now been generally adopted.

The Tej strainer has been the monopoly of the Reliable Water Supply Service of India Ltd., and is made out of brass sheets 1/8" thick bent round to form a 6" tube, the vertical joints being brazed. These are in 8 feet lengths and have a particular advantage in extraction and resinking in case if a tube-well fails for any reason.

The other type is known as "Agricultural". It consists of a copper mesh cloth wound over a perforated wrought iron tube and aperture of the mesh varying between .008" to .0115" to suit the different grades of sand met in the area.

The Tej strainers bought in large quantities have cost Rs. 12 per foot although in the initial stages as much as Rs. 20 per foot were paid for a 5" size.

The Agricultural type 6" strainers cost Rs. 5 to 5-8-0 per foot including the 6" perforated pipe (96 holes 14/16" dia. per foot).

The only objection against this type is its use in strata having a high acid or alkaline content and its liability to electrolytic action due to the presence of two metals, iron and copper. The soils in the Gangetic doab of these Provinces are generally free from alkaline or excessive acidic contents and hence this disadvantage does not come into action. This type has been preferred to all others on grounds of economy and facility of local manufacture. Out of 512 wells operating at present, 400 have the Agricultural type strainers lowered into positions.

Cavity wells.—Towards the southern portion of Bulandshar district and in Atrauli Tehsil of Aligarh district, the borings revealed the predominance of clay strata in the subsoil as also finer texture of sands. The success of strainer wells in this tract seemed problematical and the discharges actually obtained were disappointing. It has been

endeavoured to abstract water from the fine medium sand strata underlying the thicker and adhesive clay beds by means of cavity wells. It has been observed that cavities developed below 100' gave better results as regards their yield. These wells have given between 27,000 and 35,000 G. P. H. with 12.5 H. P. centrifugal pumpsets and in order to preserve the cavities, the depression has been restricted to 10 ft.

Twelve such wells have been sunk. The life of such wells will depend to a large extent on the care bestowed in working them.

5. *Rainfall*.—For the last two years rainfall in the Western districts has been in defect of the normal and this has naturally led to the lowering of spring-levels. In 1936-37, it amounted to 24.3", 1937-38 had only 22.8" while during 1938-39 there was only 13.8 inches on the average compared to 28 inches normal. The drop in spring-level has averaged 3 to 5 feet in the various Canal and Tube-well areas. In Kharif 1939, the rainfall averaged 16.4 inches but it was unevenly distributed. It will be seen that this part of these Provinces has consequently passed through 3 successive years of scanty rainfall and the pressure on Tube-wells was great both as regards crop requirements as also the draw-downs. Before the effects of deficient rainfall are discussed, it would be interesting to mention the results achieved during the dry years. For this purpose I will take up years 1937-'38, 1938-'39 and the last Kharif.

6. *Review of results achieved. Kharif 1937*.—465 wells worked. Average rainfall was 19.8 inches.

Sugarcane area irrigated was	Acres.
	35,623
Cotton area irrigated was	10,399
Maize area irrigated was	14,174
Miscellaneous area irrigated was	8,098
	<hr/>
Total	68,294
	<hr/>

Sugarcane took 2.9 waterings and consumed 103,257 gallons per acre-watering corresponding to a field depth of 4.6 inches or 1.12' for the fasl. The rate worked out to Rs. 3-10-0 per acre-watering and Rs. 10-7-0 for the fasl.

Cotton took 1.4 waterings and consumed 85,293 gallons per acre-watering or a field depth of 3½ inches per watering and 5.2" in the fasl. The rate worked out to Rs. 3-2-0 per acre-watering or Rs. 4-5-0 for the fasl.

Rabi 1937-38.—489 wells were running. September '37 had heavy rainfall—4.2 inches to 6.5 inches and there was no demand for Rabi paleo. Between October and March '38, the winter rainfall averaged 3 inches.

Rabi area irrigated from Tube-wells was 75,866 acres which took 98,300 acre-waterings or the number of waterings was 1.3 only. Each acre-watering consumed 91,798 gallons or 4.1" in field. The total volume used for crop maturity was 1,20,000 gallons or the equivalent 5.4" in the field. The assessment came to Rs. 2-10-0 per acre-watering or Rs. 3-6-0 for the fasl. This was pretty low as compared to the Canal rate of Rs. 5 per acre. As has been mentioned above, the number of waterings was only 1.3 for the fasl on account of good winter rainfall and the absence of demand for paleo.

Kharif 1938.—Wells in commission were 496. Average rainfall in the fasl was only 11.4 inches compared to 19.8 inches of the preceding fasl and was unevenly distributed. Monsoon had set late in June and withdrew early in August. The month of September was wholly dry. Area sown under cane decreased to 31,165 acres on account of the slump in price of "gur" during the winter of 1938 and the crop-pests that had ravaged the standing crop and reduced its sucrose content. Total area irrigated was 90,901 acres. Particulars of areas and crops were:—

(i) Sugarcane—

Area	31,165 acres.
Acre-watering	1,23,859
No. of waterings	3.9
Gallons used per acre-watering	104,228 or 4.8" field depth.
Gallons used per acre	336,920 or 14.7"
	Rs. A. P.
Rate per acre-watering	3 14 0
Rate per acre	15 3 0

These details for sugarcane include paleo in Rabi 1937-38, Kharif irrigation in 1938 and late irrigation in Rabi 1938-39.

(ii) Cotton—

Area irrigated	19,461 acres.
Acre waterings	34,758
No. of waterings	1.8
Gallons used per acre watering	81,217 or 3.5" depth.
Gallons used per acre	142,376 or 6.25".
	Rs. A. P.
Rate per acre watering	2 6 0
Rate per acre	4 3 0

(iii) Other Kharif—

Area irrigated	44,045 acres.
Acre waterings	74,904
No. of waterings	1.7
Gallons used per acre watering	88,694 or 3.8".
Gallons used per acre	160,616 or 6.58".
	Rs. A. P.
Rate per acre watering	2 5 0
Rate per acre	4 3 0

Lighter waterings were given in view of drought and the mutual anxiety to save sugarcane.

Rabi 1938-39.—504 wells worked. Average rainfall late in February was 2.3 inches and total irrigation covered 1,75,000 acres.

(i) Wheat—

Area irrigated	107,445 acres.
Acre waterings	257,288
No. of waterings	2.4
Gallons used per acre watering	97,303 or 4" depth.
Gallons used per acre	212,088 or 10".
	More water was used as soil was dry.
	Rs. A. P.
Rate per acre watering	2 8 0
Rate per acre	5 15 0

(ii) Other Rabi—

Area	52,459 acres.
Acre waterings	130,571
No. of waterings	2.3
Gallons used per acre watering	81,766 or 3.8".
Gallons used per acre	183,619 or 10".
	Rs. A. P.
Rate per acre watering	2 4 0
Rate per acre	5 10 0

Kharif 1939.—510 wells ran. Rainfall, again has been on the low side and its distribution was not even. The month of August was dry but September rainfall has been timely and better distributed. Average rainfall has been 16.4 inches. Total area irrigated was 91,621 acres. Cropwise areas were :—

Sugarcane—

Area irrigated	31,786 acres.
Acre waterings	127,623
No. of waterings	4.0
Gallons used per acre watering	118,800 or 5.2".
Gallons used per acre	472,000 or 20.8".
	Rs. A. P.
Rate per acre watering	4 6 0
Rate per acre	17 8 0

Cotton—

Area irrigated	14,107 acres.
Acre waterings	22,292
No. of waterings	1.6
Gallons used per acre watering	94,000 or 4.1".
Gallons used per acre	150,400 or 6.8".
	Rs. A. P.
Rate per acre watering	2 8 0
Rate per acre	4 0 0

Other Kharif—

Area irrigated	45,728 acres.
Acre waterings	82,658
No. of waterings	1.8
Gallons used per acre watering	96,500 or 4.2".
Gallons used per acre	174,000 or 7.5".
	Rs. A. P.
Rate per acre watering	2 9 0
Rate per acre	4 8 0

7. *Irrigation factors.*—In working out the financial forecast of the Tube-well Project when it had fully developed by the year 1941-42, it was hoped that each individual well would be able to irrigate :—

Rabi	240 acres .	24 per cent. of the culturable command.
Sugarcane	125 acres .	12.5 per cent. of the culturable command.
Rabi + Sugarcane	365 acres .	36.5 per cent. of the culturable command.
Other Kharif	60 acres .	16 per cent. of the culturable command.
Total annual	425 acres .	52.5 per cent. of the culturable command.

When compared to the canal irrigated areas in four of the intensely irrigated western districts, *i.e.* Muzaffarnagar, Meerut, Bulandshahr and Aligarh, the latter percentages obtaining now after 80 years of the running of canals are :—

Rabi	40 per cent.
Sugarcane	25 per cent.
Rabi + Sugarcane	65 per cent.
Other Kharif	17 per cent.
Annual Total	82 per cent.

It would interest the members of the Board to know the percentages actually achieved for the seasons enumerated earlier.

Kharif 1937.—Rabi *plus* sugarcane irrigated was 111,489 acres and Other Kharif 32,671 acres. Culturable command was 424,772 acres.

Rabi + Sugarcane was, therefore, 26 per cent. and other Kharif 8 per cent. Annual total 34 per cent.

1938-39—

Rabi crops irrigated covered	1,57,282 acres.
Sugarcane irrigated covered	31,165 acres.
Other Kharif irrigated covered	63,506 acres.
Rabi was, therefore.	37.2 per cent.
Sugarcane	7.5 per cent.
Other Kharif	15.0 per cent.
Annual Total	59.7 per cent.

It would be seen that the percentages allowed in the forecast were modest and the development even in the initial stages has been quicker than anticipated and areas are rapidly coming up to those obtained on Canals.

The total discharge obtained from wells in Kharif 1938 was 595 cusecs, in Rabi 1938-'39—605 cusecs and in Kharif 1939—611 cusecs. Duty worked out to :—

1938-39—

Kharif	153
Rabi	260

1939—

Kharif	162
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More volume has also been applied to fields in either fasl than was hoped for.

8. *Consumption of water and stability of water-table.*—In working out the probable areas and allowing for percolation losses in the distribution channels, 88,000 gallons per acre-watering for wheat and 110,000 for sugarcane corresponding roughly to depths of 4 and 5 inches respectively were taken as the crop requirements.

In a year of normal rainfall, the wells were expected to run 3,000 hours but in actual practice they have run far more. This was due to the preceding two years of partial drought but anyway pumping from the subsoil has been more than hoped for and the replenishment of the subsoil water-table as a result of the seasonal rainfall has been less. The wells in 1938-39 ran 4,755 hours average and have already run 1,950 hours during Kharif 1939. This would show that the estimate of 3,000 hours running was on the low side for the areas on this side of the Ganges and it would be useful to investigate the

effect of this increased pumping on the under-ground reservoir. The statistics maintained of spring-levels in Tube-well areas show that the water-surface went down by 2·5 to 4 feet between September 1936 and September 1939. As, however, the year 1938-39 had scanty rainfall of 13·23 inches against 28" to 30" average, these drops cannot be accepted as an evidence of the water-table depressing due to the extra pumping on Tube-wells. These observations would require to be taken from season to season for a period extending to 7 years at least to determine with any degree of accuracy the effect on spring-levels. Dr. Mackenzie Taylor examined this problem in detail in 1935 and after examining the relations between recorded rainfall and observed spring-level, his conclusions were that the average depth of the water-table over the area is practically constant as taken over a number of years, indicating stability. In two years out of three, the range of movement of the table about the mean is to the extent of 1·5 feet.

In view of the two dry years, therefore, the fluctuations in the water-table responding to scanty rainfall, though insignificant should not by any means be taken as alarming.

9. *Pumping sets*.—Centrifugal pumps directly coupled to induction motors have been usually employed and are of three types :—

- (a) Horizontal shaft centrifugal pump coupled to 10 and 12·5 H. P. motors.
- (b) Vertical spindle pumps.
- (c) Borehole deepwell turbine centrifugal.

The adoption of these types has been governed by conditions of spring-level. Where the latter ranged between 12 to 30 feet, horizontal pumpsets have been installed in the sumps 2·5 feet above the normal October spring-level. This type has proved most popular in as much as it admits of easy erection, dismantling and inspection of parts. Its possible demerit is the liability to hunt when suction goes beyond 25 feet or so. This occurs when flow becomes irregular due to water flowing in sections. As with 1·5 cusec wells suctions are limited to 20 or 22 feet, this disadvantage does not arise.

In areas where the spring-levels are subject to sudden and high rise with rainfall and there is the danger of motor drowning in the sump due to a leaking sump or cement plug, the vertical spindle pumpsets have been tried successfully. The details of their construction are the same as of horizontals except that the spindle is vertical and coupled to a vertically-driven motor properly levelled and supported on girders some distance above the pump. This installation above the sump plug protects the motor against dampness and getting burnt in case the sump is flooded.

The third type *i.e.* Borehole deepwell turbine pumps have been installed, as their appellation indicates, where spring-level is below 35 feet and the construction or sinking of sumps so low below ground offers practical difficulties and would be expensive. On such wells 10" or 12" diameter wrought iron casing pipe is sunk to a depth of 45 to 55 feet below spring-level and the annular space between the tube-well suction pipe and the casing is sealed with a cement plug. The vertical motor is fixed in a kiosk at ground level and the pump, usually 5-staged goes below the water. 62 such wells have been sunk in this Division in the Trans-Hindan tract where spring-level varies between 40 and 45 feet below ground. The motors are of 17 to 21 H. P. and the pumpsets are of Harlands, Byron-Jackson, and Cook's manufacture.

The other pumpsets used have been manufactured by Messrs. Worthington-Simpson, Ltd., Mather and Platt, The Harland Engineering Co., Cook's, Byron Jackson, A.C.E.C., and Ruston.

10. *Draw-downs and efficiencies of pumpsets*.—It had been originally intended that the depressions in water-level should be limited to between 18 and 20 feet in all cases to pump 1·5 cusec discharge from a 6" Tube-well. This limit has been adhered to except in Bulandshahr and Aligarh districts where strata encountered to locate strainers were not as good as in other districts in their water-bearing properties and in order to obtain even 25,000 G. P. H., depressions have had to be increased to 22 feet. This increase in the draw-down has not much affected the normal course of recuperation during closure or cessation of pumping, as observations of spring-level show that the water surface returned very near its previous depth in the usual course.

The overall efficiency of the pumpsets has varied with different makes, local conditions of spring level and depressions as also with the amount of care bestowed by the mechanical staff. The makers stipulated that the horizontal shaft centrifugals will give an overall efficiency of 68 to 70 per cent. and as a result of the last 3 years' working the average overall efficiency has been 60 per cent. This is not surprising in view of the partial drought and the consequent large number of pumping hours practically on all wells.

With the deepwell borehole sets, the makers specified it at 70 per cent. and actuals have varied between 61 and 65 per cent. This is considered quite satisfactory under the exceptional circumstances. The slight lowering of efficiencies has been due more to the

drop in spring-level and it is hoped still that with a season of normal rainfall, the underground supplies will recuperate and the pumpsets may work to their normal characteristics.

11. *Lined channels.*—The Tube-wells on this side have been provided with an average $2\frac{1}{2}$ miles length of channels, of which 6 furlongs to 1 mile has been lined with masonry in a trapezoidal section and the unlined portions after construction have been left to the care of the cultivators for maintenance. For the lining work, ordinary 3" thick bricks have been largely used in 1 : 4 cement mortar and the work has been done after running the kacha channels for two seasons to give time for earthwork to consolidate. The lined lengths have generally stood very well and the cultivators appreciate them greatly. Losses by percolation have been considerably reduced and the cultivators obtain their supply far more quickly where the fields adjoin them on either side. The expenditure involved has been Rs. 1,700 per mile length on the average on lining work. They are aligned on watersheds in a way to provide flow irrigation in the whole commanded chak.

12. *Piped supply.*—It is now contemplated to experiment with piped supply on new wells and thus follow the practice obtaining in California. The supply from the Tube-well will in that case be pumped direct into 12" cement concrete pipes embedded 1.0 to 2.0' below ground, and at outlet sites these pipes will have sumps high enough to account for the head. The outlets will be provided in these sumps for irrigation purposes. The 12" pipes will be cast locally at central places and will consist of 1 : 2 : 4 cement concrete without any galvanised wire or rabbit reinforcement. The pipes will be in 3.0' length pieces with collars cast similarly for the joints. The experiments made so far point to the possibility of their substitution and the rate for their mass manufacture is likely to be 0.4-0 per r. ft. The substitution of this system will result in economy in that no land will need to be acquired for the channels; there will be no culverts and no syphons except those on the cultivators' guls and Barhas. The enterprise needs to be given a fair chance. The maintenance costs of the distribution system will be very greatly reduced. Standard designs for sumps and alignments of the pipe-lines are being worked out and it is hoped to try this alternative system on new wells in the course of the next few months.

13. *Revenue procedure.*—Water on Tube-wells is sold on a volumetric basis in terms of electric units consumed in pumping as indicated on the meter. The discharge is varied on a seasonal basis. In Kharif fasl, the sugarcane crop is charged for 50 per cent. more while all others have the same unit rates both in Kharif and Rabi. As the water-depths or pumping head varies between areas and from well to well and it being desirable to standardise the rate per thousand gallons of water pumped, the price of an electric unit needs to be varied according to the different lifts obtaining in the area.

As at present notified, the schedule of rates takes into account the gallons per unit. The higher the unit discharge, the higher is the unit rate in order to obtain the rate per acre-watering as uniform as possible for the cultivator. These rates are :—

	Kharif.		Rabi.
	Sugarcane.	Other Kharif.	
	Rs. A. P.	Rs. A. P.	Rs. A. P.
Over 4,400 gallons	0 2 9	0 1 10	0 1 10
Over 4,000 gallons	0 2 6	0 1 8	0 1 8
Over 3,600 gallons	0 2 3	0 1 6	0 1 6
Over 3,200 gallons	0 2 0	0 1 4	0 1 4
Over 2,800 gallons	0 1 10	0 1 3	0 1 3
Over 2,400 gallons	0 1 8	0 1 2	0 1 2
below 2,400 gallons	0 1 6	0 1 1	0 1 1

The rates on each well are fixed at the beginning of each fasl after carefully observing the discharges on the right-angled 12" V-notch and the consumption on the revolving disc.

IRRIGATION DEVELOPMENT DIVISION (WEST).

Statement showing crop-acre rates—1935 to 1939—for different blocks.

Blocks.	No. of wells.	Sugar cane.				Cotton.				Other Kharif.				Wheat.				Other Rabi.				Remarks.
		1935-36.	1936-37.	1937-38.	1938-39.	1936.	1937.	1938.	1939.	1936.	1937.	1938.	1939.	1935-36.	1936-37.	1937-38.	1938-39.	1935-36.	1936-37.	1937-38.	1938-39.	
		Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.
Roorkee	4	11 0	9 2	5 10	..	..	2 8	3 3	..	8 4	5 14	4 7	..	3 13	1 12	2 5	..	3 9	2 4	2 11	..
Kakra	13	..	8 15	13 15	..	..	2 13	3 0	..	..	1 14	3 0	..	..	..	2 2	..	..	..	2 6	..
North Loi	39	..	7 12	16 14	..	..	2 14	3 11	..	..	3 1	3 12	..	..	..	2 5	..	..	..	3 6	..
South Loi	24	..	13 15	18 0	..	..	3 11	4 5	..	..	3 7	3 2	..	..	1 15	2 11	..	..	2 1	4 9	..
Deha	24	11 0	20 15	25 1	..	2 12	4 5	6 0	..	2 14	4 12	5 2	..	..	3 8	3 13	..	..	4 9	7 2	..
Lohara	24	17 0	18 12	22 2	..	4 4	5 1	8 2	..	3 9	5 11	6 2	..	5 15	3 11	3 11	..	5 12	6 3	6 3	..	
Sardhana	20	11 0	13 15	13 2	..	3 8	4 0	4 0	..	5 0	4 9	4 10	..	3 12	2 15	3 1	..	3 13	4 7	3 6	..	
Meerut	10	..	13 3	17 5	..	..	4 1	4 0	..	..	5 14	5 7	..	..	..	3 5	..	..	..	4 2	..
1938 North Bhatipura	38	10 6	11 1	15 1	..	3 7	4 8	3 12	..	3 14	5 8	5 2	..	3 12	2 12	3 4	..	3 8	2 5	4 6	..	
South Bhatipura	25	..	..	13 13	..	..	..	4 13	..	..	..	5 3	..	..	..	..	..	..	..	..	..
Upehra	17	12 7	20 13	19 0	..	3 14	4 2	5 0	..	3 1	5 7	5 3	..	4 12	3 0	3 15	..	4 0	4 0	5 3	..	
North Hapur	39	14 10	23 15	20 6	..	3 13	5 6	5 4	..	6 0	5 15	5 4	..	4 9	2 11	3 3	..	3 14	4 1	4 13	..	
South Hapur	29	..	..	19 10	..	..	..	5 12	..	..	..	5 4	..	..	..	..	..	..	..	..	..
Ghaziabad	11	..	17 1	19 11	..	..	6 12	7 1	..	..	5 15	6 9	..	..	2 4	3 15	..	..	2 0	4 15	..
East Kutchesar	21	10 8	13 10	16 0	..	3 14	4 1	4 10	..	6 8	4 3	4 12	..	3 4	2 13	3 8	..	3 7	3 9	6 0	..	
West Kutchesar	29	..	..	16 0	..	..	..	5 5	..	..	..	4 7	..	..	..	..	..	..	..	..	..
Jehangirabad	43	10 0	11 8	12 11	..	5 0	4 13	3 4	..	8 12	4 2	3 14	..	3 0	3 2	3 7	..	2 13	2 10	5 0	..	
North Shikarpur	25	10 4	12 6	14 7	..	4 0	4 6	4 6	..	4 4	3 14	3 5	..	2 4	2 12	3 10	..	1 10	3 1	4 14	..	
South Shikarpur	26	..	..	13 7	..	..	..	3 14	..	..	..	3 5	..	..	..	..	..	..	..	..	..
Debai	16	..	7 8	12 14	..	..	4 1	4 6	..	..	4 4	3 9	..	..	3 0	4 14	..	..	3 10	4 11	..
Atrauli	24	..	5 14	9 13	..	..	3 3	3 2	..	..	3 1	2 9	..	..	2 0	4 4	..	..	2 1	4 0	..
..	..	11 13	14 8	16 7	15 3	3 14	4 2	4 5	4 3	5 4	4 10	4 8	4 3	4 0	2 12	3 6	5 15	3 10	3 6	4 8	5 10	
		Rs. 13-0				Rs. 4-3				Rs. 4-10				Rs. 4-0				Rs. 4-5				

14. *Usual irrigation rates.*—Records are maintained on each well showing irrigation by crops as it progresses from day to day and the units consumed in each case. Abstracts are made out for each man in the Jamabandi register giving the details of assessment for each occasion. The average acre rates have been worked out for different crops in each block. As a result of 4 years working, these come to :—

	per acre crop.		
	Rs.	A.	P.
Sugarcane	13	0	0
Cotton	4	10	0
Other Kharif	4	10	0
Wheat	4	0	0
Other Rabi	4	5	0

It will be seen that these rates are fairly reasonable. Only for sugarcane, the rate seems to exceed that on Canals but considering that the waterings are more and the intervals shorter, the rate is fair enough.

The advantage accruing to the cultivator in normal years in volumetric system is considerable. In the event of rainfall occurring after one watering during the wheat season, he is saved from buying a second, whereas in a flat-rate system, he derives no advantage through reduction of demand on account of rains. In dry years, however, the quantitative system involves higher assessment. On the average, in the Rabi season at any rate, the economic advantage lies with the volumetric system and in Kharif when demand is more regular during April to June, both classes of cultivators take as much water as their crops require. During breaks in the monsoon and in a year of early cessation, the volumetric system enables the cultivators to balance savings they may choose to effect in the purchase of water against a possible increased yield in the crop due to extra waterings.

The crop experiments conducted in March-April 1938 by the Agricultural Department in average zones, demonstrated that the yields in Tube-well areas are appreciably more under normal conditions both for sugarcane and wheat.

15. *Conversion Schemes.*—The possibility of developing agriculture in the Southern districts of these provinces, where neither river water is available for pumping for irrigation nor suitable subsoil strata existed, has been studied. In Muttra and Agra districts where Tube-wells cannot be sunk, relief has been given by increasing the available supplies of Ganges Canal water by supplementing the Canal system in the upper districts where Tube-wells have been sunk successfully. This has been done on three channel systems.

(a) The Daurala Distributary with a culturable command of 19,846 acres and head discharge at 99 cusecs has been converted into a Tube-well fed channel. The average Rabi *plus* sugarcane area irrigated (5 years average) prior to its conversion was :—

	acres.
Rabi	6,194
Sugarcane	4,708
Total	10,902

and the channel ran generally to the roster of 4 in 5. The equivalent head discharge was, therefore, 79 cusecs. This system was selected for a change-over as the water thus released was passed down for the Mat Branch extension. 5 batteries consisting of 32 tube-wells and giving a total discharge of 62.5 cusecs constant were constructed to feed the channel in its different stages. These wells were projected after taking into account the culturable areas for each portion. The project was completed early in 1936 and the result of its 3 years' working shows that the average areas irrigated in the old canal command are :—

	acres.
Rabi	4,924
Sugarcane	5,084
R + S	10,008

Besides this 10,008 acres in the old command of 19,846 acres, the conversion took over the protection of 7,154 acres contiguous to the command and R + S in that portion has been 4,010 acres.

Thus 62.5 cusecs constant Tube-well supply has done 10,008 + 4,010 or 14,018 acres R + S, giving a duty of 224.3 against 10,902.79 or 138 prior to conversion. These results are certainly most encouraging but take into account the three exceptionally dry years we have had.

True, there have been serious complaints from the cultivators in the command regarding short supplies, but that was due to their desire to increase the sugarcane area out of all proportion. The increase in cane area means in itself an increased supply to satisfy the Rabi + Sugarcane percentages.

(b) *Meerut Distributary tail system.*—The tail portion below mile 6—Meerut Distributary is now fed by 3 Tube-wells giving an average discharge of 10·7 cusecs. The canal culturable command for this portion was 2,964 acres and 2,445 acres have been added to it bringing the total command to 5,409 acres. Area statistics for this portion are :—

Area.	Culturable area as projected.	R + S before electrification.	R + S after electrification.	R + S in project.
Former	2,964	1,706	1,430	1,706
New	2,445	..	954	1,222
Total	5,409	1,706	2,394	2,928

The discharge previously allowed for 2,964 culturable command was 10 cusecs and irrigation factor for R + S was 170·6.

The system is run in two weeks extending to three when demand is very keen.

Week.	Culturable commanded area.	R + S projected.	Area irrigated.
A	2,868	1,605	1,544
B	2,541	1,323	840
Total	5,409	2,928	2,384

Area done in ' B ' week is 540 acres only. ' A ' week is helped by 4 cusecs from the tail of the unelectrified portion. The average discharge is; therefore, $10\cdot7 + 4/2$ or 12·7 cusecs. Irrigation factor works out to $2384/12\cdot7$ or 188 and is an improvement.

(c) Another method was tried on the Right Akbarpur Distributary that takes off from the Anupshahr Branch of the Ganges Canal. Its lower reach has been put on the volumetric Tube-well supply and the wells have been sited for the command so as to take up individual chaks. 10 wells have been sunk and the released canal water was passed down Anupshahr Branch for the precarious tracts.

16. *Ganges Canal Feeder Wells.*—Another method of succouring the southern districts has been by supplementing the Ganges Canal supply during the period of low river discharge by sinking feeder wells 1 furlong from the Canal and sited at 4 furlongs intervals. 30 such wells have been constructed which pump 85 cusecs in the Canal and are operated for 18 hours of the day during the off-peak load period of the grid and the energy consumed is paid for at $1\frac{1}{2}$ pies per unit during off-peak period.

17. *Behaviour of transmission lines.*—The total length of transmission lines is 4,500 miles and 2,500 substations have been put up so far. The lines have stood very well. Improvements such as substituting the new design of cross-arms and replacement of the sal ballas by iron rails on rural feeders have been in general progress. The losses during transmission come to about 17 per cent. and the drop in voltage at the end of long feeder lines has in some cases been significant. Voltmeters have now been fixed at tail ends to determine these drops and it may be possible to remedy it to some extent.

18. *Industrial loads.*—The main industries connected so far include the Vegetable Ghee Factory at Begumabad, Oil-crushing and Spinning Mills at Aligarh, Steel-rolling Mills near Shahdara and the Card-board factory under construction near Meerut. Besides these, a large number of small connections have been given for brass industry and flour mills. The latter are over 500 and increased so rapidly that it has now been decided not to give any more connections within 4 miles of an established plant.

19. *River pumping.*—The dry weather discharges of Ramganga river in Moradabad district and of Kali Nadi in Bulandshahr and Etah districts were found adequate enough to be utilised for a system of gravity canals on the former and to supplement the supply in the Upper and Lower Ganges Canals. Pumping stations have been constructed on these streams at suitable sites.

The Ramganga.—The dry weather supply available varied from 500 cusecs in November to 200 in April and 200 to 300 cusecs are pumped at two stations for Canal rabi supply.

The Kali Nadi.—The average discharge is 100 to 150 cusecs depending on the intensity of the preceding monsoon and had flowed to waste before. A pumping station was installed at Sumera in 1930. 100 to 150 cusecs are lifted 20 feet into a 6 miles long feeder-channel that tails into the Ganges Canal at Sumera—mile 163. Three horizontal pumps of 40 cusecs each and one vertical have been erected and the maximum peak load from them is 300 kilowatts.

Lower down the same Nadi, another pumping station has been constructed at Nadrai where a fresh supply accumulates in the Nadrai as a result of subsoil seepage and was found to be 50 cusecs minimum during dry weather. This quantity is raised 32 feet into the Canal by a vertical spindle Sulzer pump driven by a 200 kilowatt motor installed on a hollow extension of the aqueduct pier. This 150 to 200 cusecs supply added to the canals has been allotted for protecting additional areas by means of new channels constructed on the Ganges Canal.

20. *Future possibilities.*—Between them, the present wells on the west of the Ganges command and protect 5,40,000 acres or 840 sq. miles and barring 30 wells sunk in Saharanpur and Aligarh districts, all the rest have been allotted to three districts—Muzaffarnagar, Meerut and Bulandshahr. This has been only touching the fringe of the problem so far. There are large tracts of culturable land in another six districts where subsoil and spring-level conditions coupled with the incidence of rainfall offer scope for tube-well construction and consequent development of agriculture. Preliminary reconnaissance has been carried out recently and reveals that a total of 2,400 sq. miles or 1½ million acres additional area is in need of protection and could profitably be prospected for possible extensions.

More areas on the east side are similarly conditioned. If power could be made available for abstracting subsoil water in all such areas, it will open up possibilities for small cottage enterprises as well by making energy available at a large number of rural substations.

There are also several streams whence dry weather flow could be lifted into gravity canals with advantage to the countryside. The data collected so far is inadequate yet for tentative proposals which could be mentioned.

In the discussion that followed Mr. F. H. Hutchinson, I.S.E., Superintending Engineer, Development Circle, United Provinces, said, "I should like to supplement the remarks which have been made by Mr. Sahai.

1. *Charges for water.*—I find that by the present method of charging for water the cost to the cultivator ranges from 23,000 to 28,800 gallons per Re. 1 for Sugarcane and 33,000 to 43,000 gallons per Re. 1 for Rabi and other Kharif. All cultivators are not therefore paying the same price for water. In addition if the rate is reduced by 1 pie per unit on a well running for 5,000 hours the loss of revenue is Rs. 234. The drop in spring level has resulted in lowering the rate per unit in numerous cases, in one case it was as much as 4 pies per unit. I propose to recommend that rates should in future be:—

26,000 gallons per Re. 1 for Sugarcane.

38,000 gallons per Re. 1 for Rabi and other kharif.

Tube Well Operators will be supplied with tables from which they can record the assessment.

2. *Piped distribution.*—The present masonry channels are far from satisfactory and are constantly breaching. In future wells I am proposing to substitute unreinforced concrete pipes 12 inches diameter. This system of distribution is I understand extensively used in California and I am confident that it will be successful on Tube Wells in the United Provinces. I am proposing to lay the pipe in trenches two feet deep. No land need be acquired and no bridges or syphons will be necessary. Outlets will be from sumps and will consist of either three 5" diameter pipes or two 6" diameter ones into which tapered wooden plugs will be driven. It should be possible to convey 1.5 cusecs in a 12" diameter pipe for 4 furlongs with a head of 3'-6", sumps near the well will therefore have to be 4 ft. above G. L. This means pumping against a slightly greater head than we are doing at the existing wells but I anticipate that these pipe lines will not cost more than masonry channels and maintenance charges should be negligible.

3. *Delridge Meters.*—At present there are a few wells at which the discharge exceeds 2.0 cusecs. This discharge is excessive for the present volumetric system and we are charging either on an acreage basis or a rate per acre watering, neither system is

satisfactory as the consumption of water is excessive. In these cases I am proposing to improve matters by subdividing the commanded areas into approximately 500 acres chucks and to provide a Dethridge Meter for each, the volumetric scheme can then be applied. If this method proves successful it might be advisable in future to design a well to give the discharge required for the area commanded instead of adjusting commands to suit the discharge of the well as is done at present. By the present method it is exceedingly difficult to give every cultivator his fair share of underground water supplies.

4. *Duties.*—Mr. Sahai has referred to the duties obtained west of the Ganges, a comparison between these figures and those obtained East of the Ganges is interesting. The figures which are in acres per cusec are :—

Crop.	Duty per cusec.		
	West.	East.	Budaun.
Sugarcane	49	47	21
Other Kharif	106	3.9	6.5
Rabi	259	193	205
All crops	140	242	233

5. *Financial results.*—The following figures will I think interest the Board :—

During 1937-38 Gross Revenue was 12.79 lakhs and working expenses 17.91 lakhs.

There was therefore a loss of Rs. 5.12 lakhs. This was mainly due to idle capital during the construction period. For 1938-39 the final figures have not yet been received from the Accountant General. During the current year I estimate that revenue will be in the neighbourhood of 36.00 lakhs and that working expenses will not exceed 22.00 lakhs. The estimated profit is therefore 14.00 lakhs whereas the forecast for 1939-40 in the original project was a net profit of 7.02 lakhs.

6. *Average hours run.*—The successful results which are being obtained are mainly due to pumps west of the Ganges running for far longer hours than was anticipated in the project. The forecast was based on 3,000 hours per annum the figures actually obtained during 1938-39 were :—

	Hours.
West	7,455
East	1,920
Budaun	2,100

7. *Future Developments.*—A map is hanging on the wall on which I have shown the areas, within reach of the present Hydrel Grid, in which an extension of the Tube Well Scheme appears possible. I estimate that from 1,000 to 1,500 more 1½ cusec wells are possible. Unfortunately we have had 3 poor monsoons in succession and it will not be safe to carry out extensions on a large scale until it has been proved that underground reservoirs will be adequately replenished. I have seen literature concerning tube wells in California. There they appear to think nothing of subjecting a well to a depression of as much as 169 ft. I understand, however, that there are places in California where spring level has dropped by as much as 100 ft. and vast sums are now being spent on new forms of irrigation. In the U. P. it is hoped that by limiting depressions to approximately 20 ft. and extraction to 1 cusec per sq. mile we shall not take more from the sub-soil supplies than will be put back in a year of normal rainfall.

8. *Artificial rain.*—Finally, gentleman, there is one form of irrigation which has not as far as I know been attempted in India so far. You will, I think, all agree that by far the most efficient form of irrigation is rain. The question in which I am greatly interested is whether artificial rain can be produced at a sufficiently low cost to enable it to be used by the Irrigation Department in India. I referred the question to Mr. Edgecombe some time ago and have obtained from him a considerable amount of interesting literature on the subject. Unfortunately however none of these publications give any figures to show that this form of irrigation has proved economical. There is however ample evidence to show that rain making units are by no means new in other parts of the world. For example the California Citrograph for September 1929 describes the irrigation system on Douglas Fairbanks Ranche of 3,000 acres. The article is an interesting one, it describes how 80 acres of valencia oranges, nurseries of 40,000 orange

seedlings and part of 25 acres of alfalfa are under overhead irrigation and 125 acres of oranges are under surface irrigation. The final paragraph of the article does however make me wonder what the financial results have been, it reads as follows :—

“ The water system and supply is owned by the ranch. A lake of 125 acre feet capacity was completed in January, 1927 for storage purposes. Four deep well pumps in San Dieguito valley one mile away keep this filled to capacity. This lake has been stocked with black bass. Booster pumps at the lake supply the small reservoirs for the areas under surface irrigation and a 75 h. p. two stage centrifugal pump supplies the pressure direct for the overhead irrigation system.”

The system appears to be a very extravagant one.

A 75 H. P. pump for an area of about 100 acres could not be contemplated in the U. P. Possibly the main object of the plant is to keep the black bass alive.

There appear to be two methods by which artificial rain can be produced :—

(a) By means of portable laterals from a fixed main.

(b) By means of a system of fixed overhead pipes. In either case revolving sprinklers on nozzles are used, in the latter case the range can be as much as 330 ft.

In the neighbourhood of Hapur and Ghaziabad both of which are within easy reach of the Delhi market, we have large market garden areas where as many as 13 or 14 waterings are taken per fasl. I am hoping that the U. P. Government will be persuaded to find the funds for an experiment in connexion with a rainmaking unit in one of these areas.”

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List of Sub-Committees provided by the Central Board of Irrigation.

Serial No.	Name.	Date.
1	Sub-committee convened to examine the Nayaunggyat Dam Project, Burma	12th December 1927.
2	Sub-committee convened to enquire into the causes of floods in Orissa and possible remedies	22nd August 1928.
3	Sub-committee convened to report on the practicability of the proposal of the Engineer-in-Chief, Cauvery Metur Project to utilize cement concrete in place of cyclopean masonry in surkhi mortar in the construction of the Metur Dam	11th April 1929.
4	Sub-committee convened to examine the causes of failure of the Islam Weir, Sutlej Valley Project, on the 19th September 1929	10th December 1929.
5	Sub-committee convened to report on the organization of the Irrigation Department, Bengal and the practicability of separating the Department and forming a separate Board of Waterways	13th March 1930.
6	Sub-committee convened to enquire into the desirability of remodelling the headworks and canal system of the Son Canals in Bihar and Orissa	16th January 1931.
7	Sub-committee convened by the Government of India to report upon the Quetta Drainage Scheme, Baluchistan	24th February 1934.
8	Sub-committee convened by the Government of India to report on the conversion of the Paharpur Canal (North-West Frontier Province) into a perennial canal	15th September 1934.
9	Sub-committee convened by the Government of India to report on Distribution of the Waters of the Indus and its Tributaries	1934-35.
10	Sub-committee convened to suggest protective measures against damage caused by floods in 1935 to "Anderson Weir" of the Damodar Canal, Bengal	1935-36.
11	Sub-committee convened to examine the Haveli (Punjab) Project, 1935	10th August 1936.
12	Sub-committee convened by the Government of India to examine the Khairpur State Lloyd Barrage Project, 1935-36	13th December 1937.
13	Sub-committee convened by the Government of India to examine the Spin Karez Dam Project in Baluchistan	26th December 1938.

List of Publications issued by the Central Board of Irrigation .

Publication No.	Title.	Date.	Number in stock on 1st January 1940.
1	Digest of Technical Notes 1931 (Reprint) A summary of views of Chief Engineers on the following subjects :— I.—Waterlogging and Reclamation. II.—Effect of deforestation and afforestation on river floods. III.—Design of works on sand foundations. IV.—Fluming of canal works. V.—Regulation at canal headworks. VI.—Design of canal falls.	24th October 1931	17
2	Digest of Technical Notes 1932 A summary of views of Chief Engineers on the following subjects :— I.—Waterlogging. II.—Design of works on sand foundations. III.—Design of canal falls. IV.—Staunching of canals.	15th October 1932	Nil.
3	Catalogue of Books in the Library of the Central Board of Irrigation, Simla First Supplement to the Catalogue of Books Second Supplement to the Catalogue of Books	2nd January 1934 2nd January 1935 2nd January 1936	Nil. Nil. 180
4	Hydraulic Diagrams : Energy-of-Flow, Pressure-plus-Momentum Diagrams for the simple graphic solution of problems involving a change of section in a stream of water	31st July 1934	Nil.
5	Glossary of Technical and Vernacular Terms in connection with Irrigation in India together with Standard Notations	15th October 1934	Nil.
6	Fluming : A series of examples illustrating the use of Hydraulic Diagrams—Central Board of Irrigation Publication No. 4	31st November 1934	Nil.
7	Standing Wave or Hydraulic Jump	1st December 1934	Nil.
8	Observations and Record of Pressures below Works on Permeable Foundations	15th December 1935	Nil.
9	Stabilization of Soils by the use of Bitumen Emulsion	1st February 1935	Nil.
10	Irrigation Canal Falls	15th February 1935	Nil.
11	Annual Report (Technical) of the work of the Central Board of Irrigation, India, 1934-35	1st May 1936	147
12	Design of Weirs on Permeable Foundations	1st September 1936	132
*13	Annual Report (Administrative) of the work of the Central Board of Irrigation, India, 1935-1936	1st October 1936	22
14	Annual Report (Technical) of the work of the Central Board of Irrigation, India, 1935-36	1st April 1937	190
*15	Annual Report (Administrative) of the work of the Central Board of Irrigation India, 1936-1937	15th September 1937	21

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Publication No.	Title.	Date.	Number in stock on 1st January 1940.
16	Annual Report (Technical) of the work of the Board of Irrigation India, 1936-37	1st April 1938	116
17	Notes on Waterlogging and Land Reclamation in the form of a Questionnaire	15th September 1938	220
*18	Annual Report (Administrative) of the Central Board of Irrigation India, 1937-38	15th September 1938	21
19	Annual Report (Technical) of the Central Board of Irrigation India, 1937-38.	1st April 1939	129
20	Regime Flow in Incoherent Alluvium	18th July 1939	In press.
*21	Annual Report (Administrative) of the Central Board of Irrigation, India, 1938-39	15th September 1939	22

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