AUXILIARY RESERVOIRS FOR IRRIGATION IN THE PUNJAB.

Being a sketch of their uses, the problems involved and suggestions for their solution, with special reference to the geology of the Sub-Himalayan Tertiary formations.

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Synopsis.—Introductory—Alternative sources of additional *rabi* supply—Demand for extensions on existing canal systems—Effect of impoundment on monsoon run off of the Indus drainage system—Influence of reservoirs on waterlogging—Mr. Ashford's tube well—Hydro-electrically driven pumps—Electric power generation at reservoir versus generation at canal falls—Combined function of the reservoirs—Problems to be solved—Geology of the Terrain—Sub-Himalayan Tertiaries the most convenient areas for sites—Disposition of the dam on the strata—Method of adapting dam foundation to the strata—Occurrence of suitable sites-Shoaling and scouring of reservoirs. Outline of design of dam suitable for scouring and spilling up to maximum floods and developing minimum foundation pressures—Conclusion.

Introductory.

The problem of the possibility of constructing large reservoirs for impounding the flood waters of the Punjab rivers for irrigation is one which has begun, during the past few years, to seriously engage the attention of the irrigation engineers of this province.

Irrigation developement in the Punjab is now reaching a transition stage. We are confronted on the one hand by the prospect of an increasing demand for extensions of irrigation from our existing canal systems, which under present conditions cannot be met because, with the opening of the Triple Canal Project, the *rabi* supplies of the rivers which feed those systems will have been entirely tapped, and indeed, on the existing canals, they are found to be insufficient to entirely meet the requirements of the present irrigated areas.

On the other hand, extensions of irrigation on parts of the older canals where there is waterlogging do not appear to be justifiable until a remedy for the evil is found, especially as water-logged areas tend to increase and multiply on account of the continuous filling up of the subsoil and spread of its elevated water table.

It is the object of this paper to put forward the advantages which, so far as investigations to date indicate, are likely to accrue

to the institution of impounding reservoirs as the *solution of both difficulties.*

(11) The only remaining rivers available for giving an additional *rabi* supply, are the Indus, Beas and Ganges.

Before considering their application it is necessary to appreciate the grouping of the existing canal systems in their capacity for providing facilities for reinforcement from those rivers. They divide themselves into three groups, *viz.* :—

Group 1.—Canals under Triple Project, *i.e.*, the Upper Jhelum, Upper Chenab, and Lower Bari Doab, all of which are directly connected.

Also the Lower Jhelum, Lower Chenab and Upper Bari Doab Canals which, for purposes of additional supply, are interlinked with those of the Triple Project since additional water given to one would, within limits, set free an equivalent volume for the others for use anywhere within the group.

It would seem that this group might receive reinforcement from the Indus by means of a feeder delivering across the Jhelum into the Lower Jhelum Canal, the feasibility of the idea will be considered later.

Group 2.—The Sirhind Canal ; which might be reinforced from the Beas.

Group 3.—The Western Jumna Canal ; which might be reinforced from the Ganges system.

Before considering the only other alternative, *viz.*, reinforcement from impounding reservoirs, a brief reference to the possibilities of each of the foregoing modes is necessary, *vide* accompanying Plates I A and I B.

Firstly reinforcement of group No. 1 from the Indus.—The Indus is at present untapped by any perennial canal system. Only one possible line of effective reinforcement from it to the group exists, *viz.*, by means of a feeder taking out near Kalabagh-Mari, running roughly along the railway to Khushab and thence across the Jhelum to the bifurcation of the Northern and Sulki branches of the Lower Jhelum Canal which it would feed. Their combined *rabi* discharge is about 630 cusecs, so that, were it possible to supply them, this volume of water would be divertable from the Jhelum river for the remainder of the group by way of the Upper Jhelum Canals. This would be the utmost reinforcement possible. Some ten years ago a survey of the Indus Jhelum-*cum*-Chenab doab, down to the

confluence in Muzaffargarh was made with a view to a project for irrigating the "Tal" areas from a canal taking out of the Indus near Kalabagh-Mari. The levels show that the falls would be sufficient to run an irrigating feeder along the above alignment, to the bifurcation of the Northern and Sulki Branches. The available average fall would be about $\frac{1}{7000}$. Such a feeder would involve great expense in crossing the Jhelum river where it would have to run over the greater part of the river depression in high embankment for some 20 miles at least, and the actual crossing would have to be by superpassage or syphon since the river there is too low for a level crossing to be effective. Such an arrangement with its attendant river training works plus a barrage at Kalabagh, which would probably be needed, would certainly be excessively costly and financially impossible. In the event of the Sind Sagar Canal being undertaken the cost of the barrage could be eliminated but that of the Jhelum crossing would still be chargeable to the feeder. The only possibility of its being financially feasible would seem to be the undertaking of an aqueduct in conjunction with a railway crossing to link up Shahpur with Khushab, the Railway and Irrigation Branches sharing the cost. Failing this, this method of reinforcement would appear to be impossible. The only alternative *rabi* reinforcement for Group 1, would therefore be from a reservoir on one of its direct feeder rivers. The need for reinforcement, to the extent that it is known to the writer, is detailed in Appendix 1.

Group 2.—For reinforcing the Sirhind Canal from the Beas river a scheme is at present under investigation by which one or more left bank canals taking out below the confluence of the Beas and Sutlej rivers would irrigate in British and Bikaner territory and set free therefrom a portion of the present *rabi* supply, which is drawn from the Sutlej, for the famine stricken tracts in Hissar and for supplementing the tight supplies on the present irrigated area. On account of the heavy cost of the main channels, a reservoir on the Sutlej, such as the Neila site, might prove cheaper. Sir John Benton, late Inspector-General of Irrigation, has expressed himself in favour of this view.

Group 3.—Reinforcement of the Western Jumna Canal from the Ganges river system. This canal falls within the natural grouping of the Ganges fed canals of the United Provinces. The *rabi* supply at present available for it from the Jumna river is insufficient for requirements. The Agra canal which takes off below it comes off badly.

By the proposed Sada-Ganges project, which is now under the consideration of Government, the river Sada would be linked up with the Ganges and the latter with the Jumna, all the canals served by those rivers thus being interlinked and benefited by the additional supply from the Sada river. The additional cold weather supply thus made available for the Western Jumna Canal would be 850 cusecs.

The scheme as a whole would be a profitable one, but there are certain administrative difficulties affecting it which are best explained by the following quotation from the recent speech of the Insepctor-General of Irrigation made before the Karachi Chamber of Commerce. " Estimates had been prepared to show that the scheme would pay very well, but if the United Province part of the scheme were considered separately the return on that would appear still higher ; whereas if the Punjab part were considered separately the return on that would be a good deal less. The Punjab Government wished to have the two parts taken together as an indivisable whole, but the United Provinces preferred a provincial separation of the two parts."

In the event of the United Provinces not conceding to the views of the Punjab Government, the latter might find it more profitable to impound water on the Jumna which would relieve the project of its less profitable portion and allow the water to be used more profitably nearer its source of supply. Hence the Jumna Dam Project becomes worthy of serious consideration.

Preliminary investigations have already been undertaken for dams at Thain on the Ravi, Neila on the Sutlej, and at Kooch on the Jumna by which respectively each of the above groups would be served.

Effect of impoundment on the monsoon run off of the Indus drainage system.

It may be urged that extensive impoundment of the Punjab rivers, which, with the exception of the Jumna, are all tributaries of the Indus, would be prejudicial to irrigation from the Indus itself, it is therefore of interest to know the proportion of the total flood run off of the Indus system which would be impounded by the reservoirs already proposed for the Ravi and Sutlej.

The maximum flood discharges of all the Punjab rivers, except the Indus, are shown in Appendix 2. By the method of reasoning given in Appendix 2A a value is found for the Indus which should be sufficiently true for our purpose. It is about 1½ million cusecs.

Adding this to the monsoon discharge units given in column 10, we have :—

(*i.*)	Indus ...	...	7·5
(*ii.*)	Jhelum ...	...	2·9
(*iii.*)	Chenab ...	...	2·5
(*iv.*)	*Ravi* ...	...	1·0
(*v.*)	Beas ...	...	1·6
(*vi.*)	*Sutlej* ...	...	1·9
	Total	...	17·4 units

According to the schemes proposed for (*iv.*) and (*vi.*) the flood discharge units impounded would not exceed—

(*iv.*)	Ravi ...	...	$1·0 \times \frac{1}{3} = 0·3$
(*iv.*)	Sutlej ...	...	$1·9 \times \frac{1}{5} = 0·4$
	Total	...	0·7

viz., only $\frac{0·7}{17·4} \times 100 = 4$ per cent. the whole monsoon discharge of the Indus system, but it would all be impounded at the end of the monsoon.

As it is probable that not more than these schemes would be considered for some years, and that by the time others are taken up, the Sukkur barrage will probably be well on towards completion and subsequent Sind irrigation possibly be co-ordinated with that of the Punjab, the objection to the impoundment of so small a proportion of the floods seems slight indeed.

Influence of reservoirs on water-logging.

During the past decade perplexities attending the rise of the subsoil water levels on the older canals, leading to the water-logging of certain areas, have been becoming more and more keenly felt and engineers have been sceptical, for sanitary reasons, as to the wisdom of extending the existing irrigation upon those canals until a solution of water-logging difficulties has been found.

The advent of the Ashford tube well, however, would seem to entirely alter the outlook in this respect. Mr. Ashford, as is by now generally known, has been successful in pumping 2·3 cusecs of water from a special wire wound 10-inch diameter strainer tube against a total lift of 17 ft. with an expenditure of 12·4HP. at a pump efficiency of 70 per cent. *viz.*, 5·4HP. per cusec. This means that we shall be able to obtain a sufficient supply per tube for the usual sized irrigation water-course, and that the power used has been brought down sufficiently low to give a fair commercial profit.

The careful development of a system of pumping from those tubes on a water-logged area, so controlled as to lower the spring level sufficiently for sanitary purposes without, at the same time, unduly increasing the lift and consequently the power used so as to impair their commercial value, appears to be the true solution of the water-logging problem.

Hydro-elctrically driven pumps.

Hydro-electric power generated at the dam of a reservoir would be of great value for driving these pumps on account of the ease and cheapness with which great volumes of electric power can nowadays be generated from high water heads, and transmitted and distributed over long distances.

(*a*)—Providing the distance of transmission is not too great, it has been found that it is cheaper to thus generate power in bulk than to generate in comparatively small volumes on the low heads available on the falls or rapids of a running canal, which is the other general alternative. The greater factor of cost which militates against the latter method is that of altering the existing canal works (*vide* Abstract B, Appendix 3). Also

(*b*)—To develop a given power the machinery at a high head is less costly than at a low one.

(*c*)—Power from a dam is available perennially, whereas that generated on a running canal is intermittent and subject to every closure of the channel. This is an appreciable factor since, as Mr. Kennedy has shown (*vide* Buckley's Irrigation Pocket Book, page 244), watercourses are more efficient with a constant than with an intermittent supply, and hence a better "duty" can be obtained by pumps run by power generated at a dam than by power generated on the canal.

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(*a*)—A most important advantage of generating at a dam is that the source of power is at one site under one control and capable of infinite expansion, for pumping purposes, as one system, whereas generation at canal falls is of necessity very limited and inelastic for purposes of expansion. The latter system would lead to multiplication of generating stations and consequent confusion of distribution as the pumped area increased. This is demonstrated by present requirements on the Upper Bari Doab Canal in the event of pumping on the whole water-logged zone around Amritsar being attempted.

The canal supplies now serving the zone are:—

Kharif 274 cusecs, average,

Rabi 135 cusecs, average,

which, if displaced by pumped water, would require about 1164HP. gross at 6HP. per cusec at the pumps (allowing for enhanced duty from a constant supply the volume of which would be fixed by the present Kharif irrigable area) as against a maximum available power of 530HP. generated on the canal by converting two rapids into one so as to give a 9ft. fall. The supply available for this would be about 1,050 cusecs for 240 *days only in the year.*

Power generated at Thain dam, 95 miles from Amritsar, *would be available throughout the year*, and about 10,000HP. could be obtained from the turbines without modifying the reservoir works as fundamentally needed for irrigation purposes. A very slight modification at small cost would double this, and 35,000HP. can be obtained without seriously impairing the reservoir efficiency for irrigation or adding appreciably to its cost.

In Appendix III are exhibited abstracts of estimated cost of pumping on the Upper Bari Doab Canal with hydro-electric power generated:—

(A) At Thain dam, with due allowance for partial duplication of plant on account of varying reservoir water level.

(B) At Tarn Taran rapid on the Upper Bari Doab Canal about three miles from Amritsar.

Thus by generating at a dam, *e.g.*, at Thain, the great powers, perennially available, could be increasingly drawn upon from time to time as necessity arose to meet extended water-logging caused by the spread of the elevated water

table. Moreover, the installation might serve as a nucleus for the supply of power to the industrial market, indeed, the mere fact that such a source of supply existed would be certain to give an impetus to the development of industrial enterprise.

The case for generation of hydro-electric power at a reservoir dam, situated sufficiently near to the water-logged areas, thus seems to be fairly clear.

Combined function of the reservoirs.

The combined function of power generation, plus flood storage for extension of irrigation, gives to such reservoirs an increased value over any designed to meet the latter function alone, and increases their profitableness as is exemplified by the abstract from financial statement for the proposed Thain Reservoir exhibited as Appendix IV.

Problems to be solved.

The above being the factors of utility of such reservoirs, and since they have been shown to be likely to pay a profitable return, it is thought that a survey of the principal problems requiring to be solved, in order to successfully execute them, may be of interest. They are considerable and present a combination of complexities which are probably greater than any that have as yet been faced in any country.

Summarised they are:—

(*i.*) The sites selected must be accessible for construction, and at a minimum distance from the canal systems they would serve, both for purposes of power transmission and for minimum absorption loss between the dams and the headworks.

The valleys selected for the reservoirs will have to be very extensive and must be closed by a gorge at their downstream end so as to reduce the length of the dam to a minimum. The wider and flatter the valley and the narrower the gorge the more paying will the project be.

(*ii.*) The three schemes investigated to date show that, in order to impound sufficient water for requirements and to be profitable without encroaching on existing canal revenues,

the dams will have to be some 200ft. high from river bed. The foundation pressures of these will be considerable and care must be taken to select suitable strata on which to found.

(*iii.*) All the Punjab rivers annually bring down large volumes of detritus to their debouchures ranging from mud to large shingle and boulders. This would deposit in, and speedily shoal up, any reservoir unless its bed were capable of being effectually scoured, and for this reason a reservoir must remain empty during part of the monsoon when all floods would have to be passed without filling the reservoir or appreciably ponding behind the dam. Our knowledge as to the extent to which scouring with a given proportion of flood run-off would be effective is small. The teaching of existing data will be considered later.

(*iv.*) The maximum flood discharges of all Himalayan rivers are enormous (*vide* Appendix II.) but provision must be made for their passage :—

(*a*)--when the reservoir has already been filled ; for the safety of the dam, etc ;

(*b*)—when the reservoir is empty for scouring purposes.

Form of dam.

(*v.*) The most suitable form of dam to meet the foregoing conditions.

Geology of the Terrain.

Suggestions for combating the above problems will be given below, and, since they are all in greater or less degree related to the geology and physiography of the Terrain, a brief description of this is first necessary :

The Terrain may be divided geologically into three broad zones (*vide* accompanying maps)—

(*a*). The mountain ranges of the Himalaya proper consist of pre-tertiary sedimentary rocks and of crystalline rocks of igneous origin.

(*b*). The sub-Himalayan Tertiary formations consist of a great thickness of deposits which have been denuded from the Himalaya by subaireal agency, contemporaneously and subsequently to their elevation, and have been deposited at their base. These deposits have shared in the crumpling up, tilting and folding movements of the earth's crust which have formed

the Himalayan ranges, and thus form a line of hills and valleys or "doons" fringing the base of the Himalaya, and having the axes of their ranges, *e.g.*, the Siwaliks, parallel with those of the Himalaya.

These formations are of the greatest importance to the present discussion since upon them probably all reservoirs would have to be constructed. Their classification and stratigraphic characteristics, in sequence from top to bottom, are as follows :—

I.	Upper Tertiary or Siwalik series.	A. Upper Siwalik group : Course conglomerates. B. Middle Siwalik Group : Conglomerates and sand rock interbedded. C. Lower Siwalik Group : or Nahan Sandstone. Alternate beds of sandstone and shale.
II.	Lower Tertiary or Sirmur series.	A. Kasauli Group : As in I. C. B. Dagshai Group : As in I. C. C. Sabathu Group : Gipseous shales, impure limestone, and sandstone.

The Nahan sandstones appear to be generally the hardest, least jointed and best situated and therefore the most suitable among the Tertiary rocks for dam foundations. They occur at the proposed sites on the Ravi and Sutlej. Specimens were taken from the latter, *viz.*, three inch cubes, and were tested in compression at Roorkee ; giving an average resistance of about 300 tons per square foot, which would appear to give a fair factor of safety, especially seeing that they were taken from six inches below the weathered rock surface and were therefore themselves probably partially weathered.

(*c*). Post Tertiary Alluvium of the Indo-Gangetic plain covering an area of 300,000 square miles, and on which the plains of the Punjab, United Provinces, Sind, etc., are situated. The deposition of this appears to have been by fresh water agency. It is of great thickness, has been subjected to isostatic subsidence with superdeposition. The deepest boring through it is at Lucknow, 1,336 feet deep, or nearly 1,000 feet below sea level, and failed to reach the underlying older strata.

For a complete summary of the geology of the Tertiaries and of the Indo-Gangetic alluvium, *vide* Oldham's "Manual of the Geology of India," 2nd edition, chapters XIV, XVII, XVIII.

The Punjab rivers flow for some distance from their sources between and parallel with the snow ranges in directions roughly south-east and north-west. In several instances the valleys in these regions are fairly open with comparatively flat gradients. Every river after flowing thus from its source suddenly turns southward, breaking through the hard mountain cores through deep ravines and at high gradients at right angles to the ranges, until it emerges on to the plains through the Tertiary hills and "doons" at the base. Through the "doons" the valleys are generally wide and the gradients flat ; from 4 to 40 feet per mile. Where they pass the Tertiary hills, narrow gorges sometimes occur. The Tertiary ranges, on account of the obstruction of their harder cores to the cutting down of the river beds through them as the hills were elevated, sometimes cause the rivers to be deflected and to form loops, *e.g.*, at Neila on the Sutlej and at Thain on the Ravi.

Providing that the strata are found to be sufficiently resisting for high dam foundations, the most promising sites for reservoirs are to be found on the Tertiaries. They would be generally accessible from the plains and are not far removed from the canal systems. They are moreover of flatter gradient and more extensive than the more accessible Himalayan valleys and can therefore impound more water with a given height of dam.

Let us consider the occurrence of the strata of the Nahan and Lower Tertiary Groups which would render them suitable for foundations providing that the sandstones were sufficiently hard, as is shown above, to be the case at Thain, and is the case also at Neila on the Sutlej, where, according to samples, the rocks are harder than at Thain.

The Tertiary rocks are not equal, in hardness, strength and resistance to weathering, to the great masses of granites and quartzites which occur in the Himalaya, nor is there, so far as the writer knows, any occurrence of the latter to be found exposed in the Tertiary area which could be utilized for a dam site.

The hardest rocks available being the sandstones of the Nahan and Sirmour series, they should be sought for when selecting sites for high dams. It will have been observed that even these are interbedded with shales and clays the presence of which, under certain conditions, would not jeopardise the safety of the foundations as will be shown, but, on the other hand, in certain cases, they might prove a fatal source of weakness. Great care must therefore be taken when selecting sites on these formations. This question has so important a bearing on the feasibility of these reservoir schemes that a description of typically good and bad conditions is necessary.

Consider the section of the semi-fold (Plate II, figure 1) consisting of a series of alternate beds of sandstones S and shale C. Assume the strata to have been denuded down to A. A., which may be considered to be the river bed.

A high dam built on such strata should be placed with its length along the "strike" or outcrop, *viz.*, at right angles to our section, and not across the strike, for it is plain that with strata of such diverse characteristics there would be danger of "blowing" by water pressure along the line of bedding. Again a dam built along the strike in position X or Y is not likely to be so satisfactory as one at Z because, again, the water may find its way along the lines of bedding under the dam and "blow" downstream. At Z it is less likely to do so. Again the sandstone beneath X and Y must be sufficiently thick to resist the superimposed foundation pressures tending to cause it to crush down into the underlying clay strata which have little resistance. In this respect the position at Z is much more satisfactory, the sandstones form continuous lines of support throughout the length of the foundations, and may be likened to sheet piling containing the shales between. The latter will tend to act as puddle staunching any flow beneath the dam through joints in the sandstone which occur at right angles to the lines of bedding, and to percolation through the sandstones. The resistance of clay to crushing being small, compared with the foundation pressures which would be developed, it would probably be neglected and all pressure would be assumed to be carried by the sandstone, the latter therefore must be sufficiently thick and close together to carry the load.

A further advantage of such a situation as Z is that the strata there would probably have been subjected to lateral thrust due to earth crust shrinkage, as indicated by the arrow,

PLATE. II

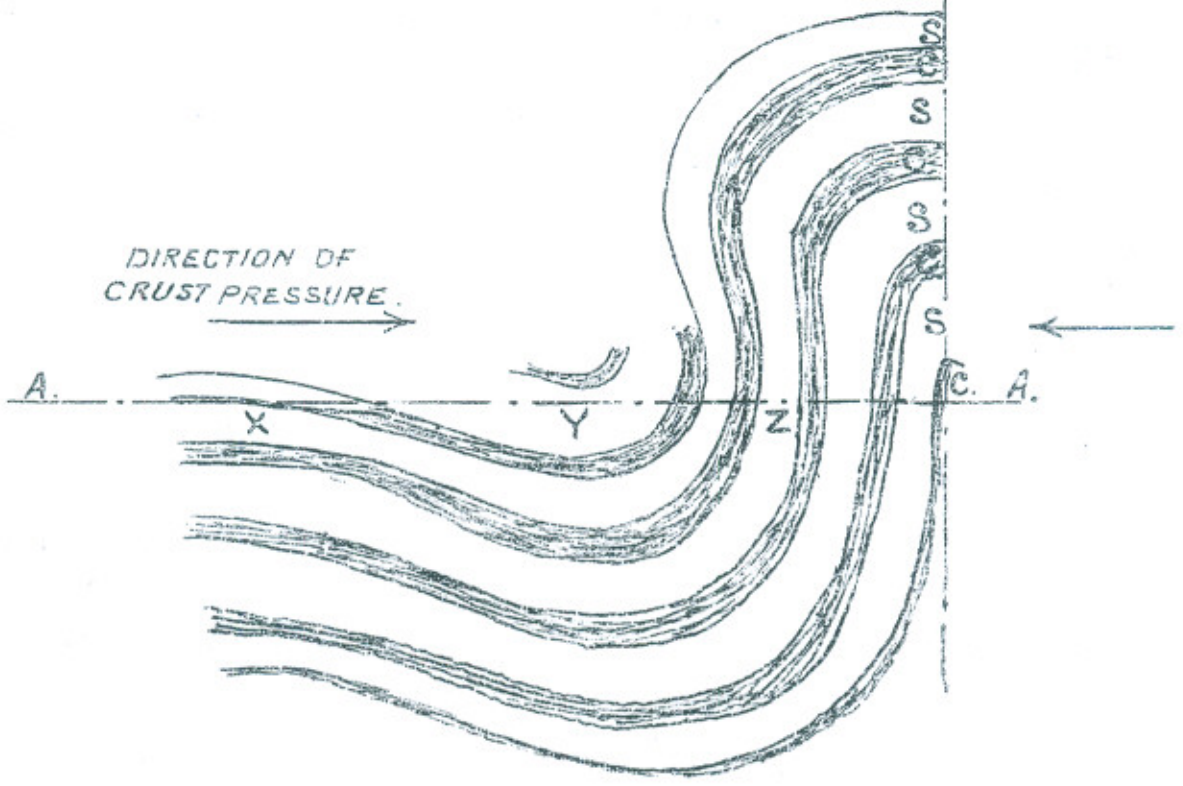


FIG: I.

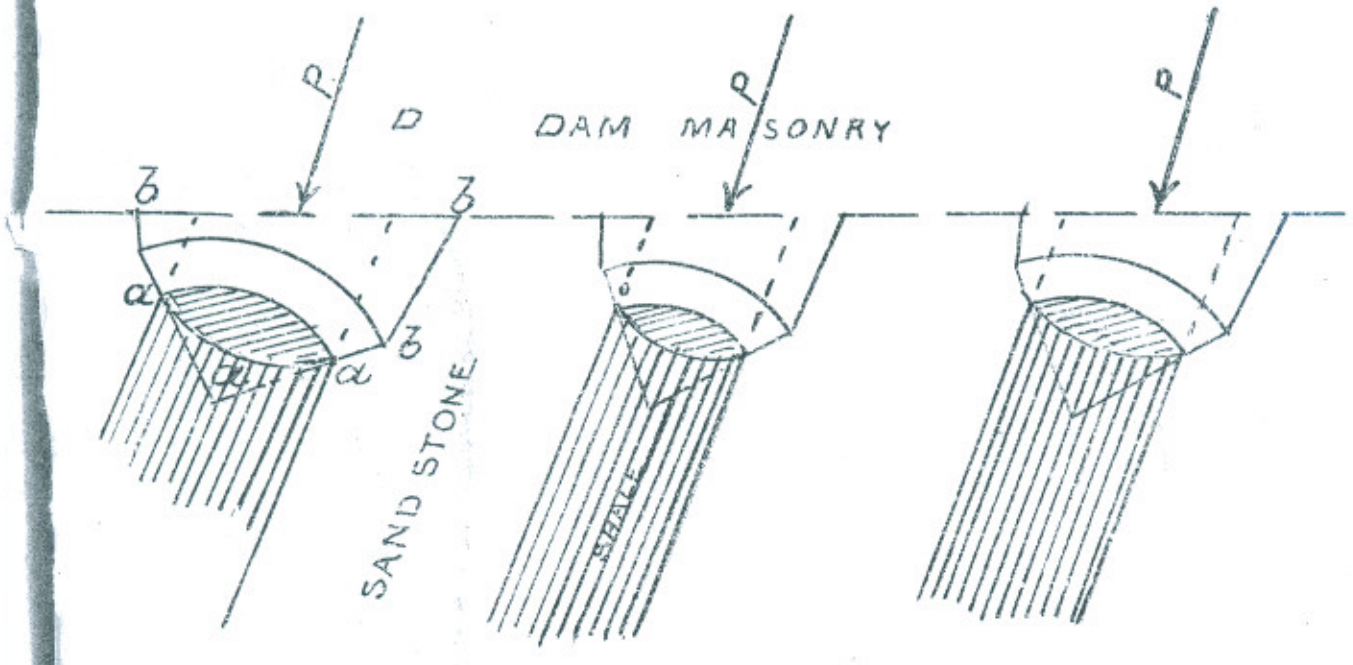


FIG: 2.

which tends to consolidate them and add to their durability. It is clear that the strata at the extremities of a fold are not so consolidated but rather that they have moved over each other to a greater extent and have tended to separate. The position Z is therefore superior in every way to the others and, for these strata, is ideal if they dip steeply away from the dam.

In order to distribute the foundation pressure on such a conformation without fear of splitting the strata along their lines of bedding or shearing them or the masonry, and to give additional stability against sliding of the dam on its foundations, the author suggests the method of bonding the dam to the sandstones shown in Plate II, figure 2. The clay would be removed between the sandstones along the line a. a. a. and the sandstones dressed back at a suitable inclination as a. b. b. A comparatively lean concrete could be filled in, as shown by the hatched areas, its upper face forming the intrados of an arch ring which would be the chief medium for transmitting the foundation pressures P, above the clay, onto the sandstones. The masonry of the dam would be carried down onto the extrados of the arch and over the sandstone surfaces alike. The portion b. b. a. a. would act together as a wedge tightening up the sandstone bedding planes and reducing any tendency to split along them under the component of pressure along their direction. At the same time by making the surface a. a. a. in concave form, the saturated softer clay would be consolidated in the most effective manner, the whole foundation being thus tightened up under pressure. The total thickness of the sandstones underlying the dam, and keyed into it by the above method, must, of course, be capable of resisting in shear the component of P normal to the dip of the strata. The same applies to the masonry.

As regards the possibility of finding sites as suitable as the above, it is of interest to note that, since strata having the above characteristics are the hardest in sub-mountain tertiary regions, the logical sequence is that they should form the cores of the hills in which the narrower gorges occur, and the rivers may form loops about them as explained, the latter are found to offer facilities for dam construction, and maintenance, and for power generation.

The succession of the Nahan sandstones actually occurring at the proposed site of the Thain dam, and which is typical of ideal conditions is shown in section, Plate 2.

Shoaling up and scouring of reservoirs.

Precise data are very scanty and difficult to obtain for accurately estimating the rate at which a reservoir would shoal and scour. The following is an attempt to arrive roughly at the actual conditions we should have to face.

All the solids brought down by the river above the reservoir would deposit therein from the date of closing until the reservoir would again be empty, since while the reservoir is full the draw off and over spill would be from top water only at the dam whereas the majority of the shoaling would be towards the head of the reservoir with a tendency to move towards the dam as the reservoir level subsided.

The fundamental principle of silt transport is that the maximum volume of solids which can be transported by a given discharge varies as its flow energy, *viz.*, as its square and, within limits, investely at its depths. If the mesh ratios of the particles vary, the volume transported varies inversely as the magnitude of the particles, with particles of a given specific gravity. The application of Mathematical laws of this nature is, however, upset by practical conditions, for, on an extensive mountain watershed, the rock formations vary from place to place in character and in their resistance to erosion, so that both the mesh ratio and consequently the volume of the solids vary for a given run off from different parts of the watershed. This fact has an important bearing on this discussion since in the Himalayan catchments, storms will not always break in the same relative intensity over all portions of the catchment.

So much for complications attending silt estimation from floods. The problem is further complicated by the fact that rain water run off is only a portion of the whole run off during the period considered, a large portion is glacial and spring water fed, and supplies derived from these initially carry less silt.

Shoals deposited in the river by the subsiding floods at the end of a monsoon are gradually eaten into and carried on by the under silt-charged glacial supplies in the ensuing hot weather, until, in the extreme case they become over silt-charged and again deposit further down.

Now the Punjab rivers, above their debouchures, are still cutting down, which demonstrates that above the plains they are not fully silt charged. On the other hand, below their debouchures they are known to be depositing. A reservoir

therefore, placed above a debouchure, will be more effectually scoured than one below, and its deposits will in fact be the first to be attacked by the comparatively clear water.

As will be shown below, these deposits will, at the beginning of the scouring season, be of considerable depth, but, since they will extend, for some miles, right across the river bed the whole perimeter of the scouring channel will be in contact for cutting, the scouring supply of May and June may therefore be expected to become fully silt charged before leaving the reservoir until, given time, it has cut down to the original bed level. The remaining side deposits would be removed by the ensuing floods, which would also become fully silt charged.

The problem now resolves itself into considerations of the proportion of shoal to be removed compared with the gross discharge available to do so and of the chances that the scouring supply will have a sufficient uncharged margin to take it up. That it is likely to become fully silt charged has already been demonstrated.

In the absence of definite data as to the ratio of volume of silt to discharge at any of the proposed dam sites, the data given in Buckley's Irrigation Pocket Book are instructive, especially those for the Sutlej River at Rupar which are reproduced in Appendix V.

Compare columns 2 and 4 with 3 and 5. The former, judging by dates, are typical of silt charge in the premonsoon hot weather when the glacial supplies are cutting out the shoaling above Rupar, while the latter appear to typify lesser monsoon-flood conditions when flood water, as far as Rupar, has not become fully silt charged. A comparison of the greatest depth ratios (added by the writer) lends colour to this view. For a given energy near the bed, the volume of silt carried there may be expected to be constant at full silt charge, and to vary as the energy ; the figures however show the reverse, hence columns 3 and 5 cannot be fully silt charged either on the bed or in the water super-strata.

Let us, from these data, endeavour to select a ratio from which we can approximately estimate the amount of shoaling in the proposed Neila reservoir, 30 miles above Rupar. The river falls in the middle of October to cold weather conditions when practically no silt is transported. Neglect this period and give a full value for September and early October when silt is transported

in large quantities. Flood values columns 3 and 5 give about $\frac{1}{80}$ mean ratio. High floods, though moving more silt, would probably have a smaller ratio so that $\frac{1}{80}$ is safe. It does not, however, include silt rolling on the bed for which 10 per cent. allowance must be made and gives $\frac{1}{73}$.

Above the debouchure the ratio would be less than this. But as we have decided to neglect cold weather deposits, $\frac{1}{70}$ can be taken.

2·7 is the specific gravity of dry silt. The ratio in terms of volume then becomes $\frac{1}{189}$ dry.

Let us take $\frac{1}{170}$ for safety.

From the records the average gross run off annually of the Sutlej at Rupar between 1st September, the approximate date of closing, and the 15th October, when the river falls to cold weather conditions, was during the 8 years 1900 to 1908, 82,944 million cubic feet.

The total deposit from this would be $82{,}944 \times \frac{1}{170} = 488$ million cubic feet. This if evenly distributed so as to form a flat surface from the dam up streamwards would have a thickness at the dam of about 50 feet.

The reservoir capacity with a 200 feet high dam is estimated to be 26,654 million cubic feet. So that 1·8 per cent. the capacity would be shoaled up and the reservoir would take 56 years to shoal up entirely supposing that there was no scouring and that all solids were deposited.

Actually the reservoir would be emptied, and scouring begun, by May 1st at latest and would continue scouring until September 1st when it would be again closed. The run off between these dates, during the above years, averaged 444,960 million cubic feet, so that, assuming constant scouring to be spread over the whole period, the water would have to carry off the ratio $\frac{488}{444{,}960} = \frac{1}{911}$th by volume, *i.e.*, $= \frac{1}{377}$ by weight.

Now during the scouring period, judging by Appendix V, the average silt charge ratio at the head of the reservoir is not likely to be more than $\frac{1}{150}$, so that $\frac{1}{150} + \frac{1}{370} = \frac{1}{107}$ would be about the average combined silt charge on leaving the reservoir, which, taking full silt charge ratio at $\frac{1}{50}$, which is if anything on the low side, the margin of safety is $\frac{1}{50} \div \frac{1}{107} = 2$ factor of safety.

The ratios selected may themselves be rather wide of the mark, but their relative values are probably not far wrong and on the safe side, so that the factor of safety of 2 so obtained should be sufficiently near the truth to demonstrate that the margin of safety for scouring is probably safe for conditions at the Neila site, and that both at this and at other sites care will have to be taken to secure a sufficiently large scouring discharge if practically all shoaling is to be removed.

A f. s. of 2 on especially observed data would seem to be sufficient margin. In the absence of more complete data it appears from the foregoing that the reservoirs need not of necessity become permanently shoaled, above a certain limit of regimen determined by the altitude and waterway of the scouring sluices. These should, clearly, *be placed as low as possible.*

Poposed form of dam to meet requirements.

The next problem is how to —

(*a*) pass maximum scouring floods so as to give effect to the above, and

(*b*) spill maximum floods when the reservoir is full.

It is clear that neither should be restricted. The matter has been considered in connection with the aforementioned sites, the results show that for a reservoir project to be profitable the dam itself must be pierced at river bed level to the greatest extent possible for passing scouring floods, and supplementary tunnels can only be provided, if necessary, around its flanks or through the neck of the loop, if there is one, upstream of the dam, which would be placed near the apex. The shortest tunnels yet considered are more expensive per cusec passed than a pierced dam of the form evolved, *viz.*, at Thain the tunnels through the loop (sandstone and shale) would be 1,400 feet long, by, say, 27 feet diameter, and the cost per cusec at 20 feet velocity would be about Rs. 66 against about Rs. 50 under the hollow dam, the total cost of the dam complete over the deep river bed being considered.

Spilling is not feasible over any unprotected Tertiary strata which are all to soft too withstand the great erosive action. The cost of adequate surfacing, either with imported ashlar or with cement concrete, together with that of excavating the hill sides, is found to be prohibitive and would certainly render the works unproductive. The only solution is,

therefore, to spill over the dam itself up to the safe limit and to pass the balance only over flanking spill ways. In addition: we have to consider the question of foundation pressures:—It has already been stated that sandstones are found at certain sites giving a resistance to crushing of 300 tons per square foot, but with the Tertiary strata, having the characteristics already described, the pressure over the shales would have to be carried by the sandstones. Assuming the gross thickness of shale to be $\frac{1}{3}$rd that of the total foundations (as at Thain) the load to be carried by the sandstones would be $1\frac{1}{2}$ times their own proportion of the load, so that 300 tons is not a great strength especially when compared with that of granite on which the highest dams have usually been built, so that care must be taken to keep the foundation pressures as low as possible.

A design of dam for meeting all the above problems has been evolved and put forward by the writer (*vide* Plate 3) it can however only be briefly referred to here. The underlying principles are:—

A dam having the section of an isosceles triangle of 55° basal angles would cause the lines of resultant full water thrust and masonry load to pass through the centre of the base thus eliminating shear factor and causing the resulting pressure to be equally distributed throughout the base. Since the quantity of masonry in this section would be much in excess of requirements it is proposed to divide up the length into a series of pyramidal sections or buttresses and to close them upstream with inclined arching. Spaces between the buttress foundations can be spanned by inverting, thus spreading the pressures over the whole foundation. The inverting would be probably benefited by reinforcement.

The inclined arching would be founded on a thickened base, which is convenient for piercing, the water passing from the sluices over the inverting.

The top of the dam can be roofed in between buttresses by a series of vertical arches of sufficient thickness to support the water loads. The rollway, or downstream profile of the dam, so created, would be ogee in form and parabolic at departure, so as to fit the curve of falling of maximum flood and avoid vacuity. This curve might be continued to the safe limit of impact on the masonry at the point of change to the lower curve which would be a pure circular arc of suitable radius to deliver

SECTIONAL ELVATION

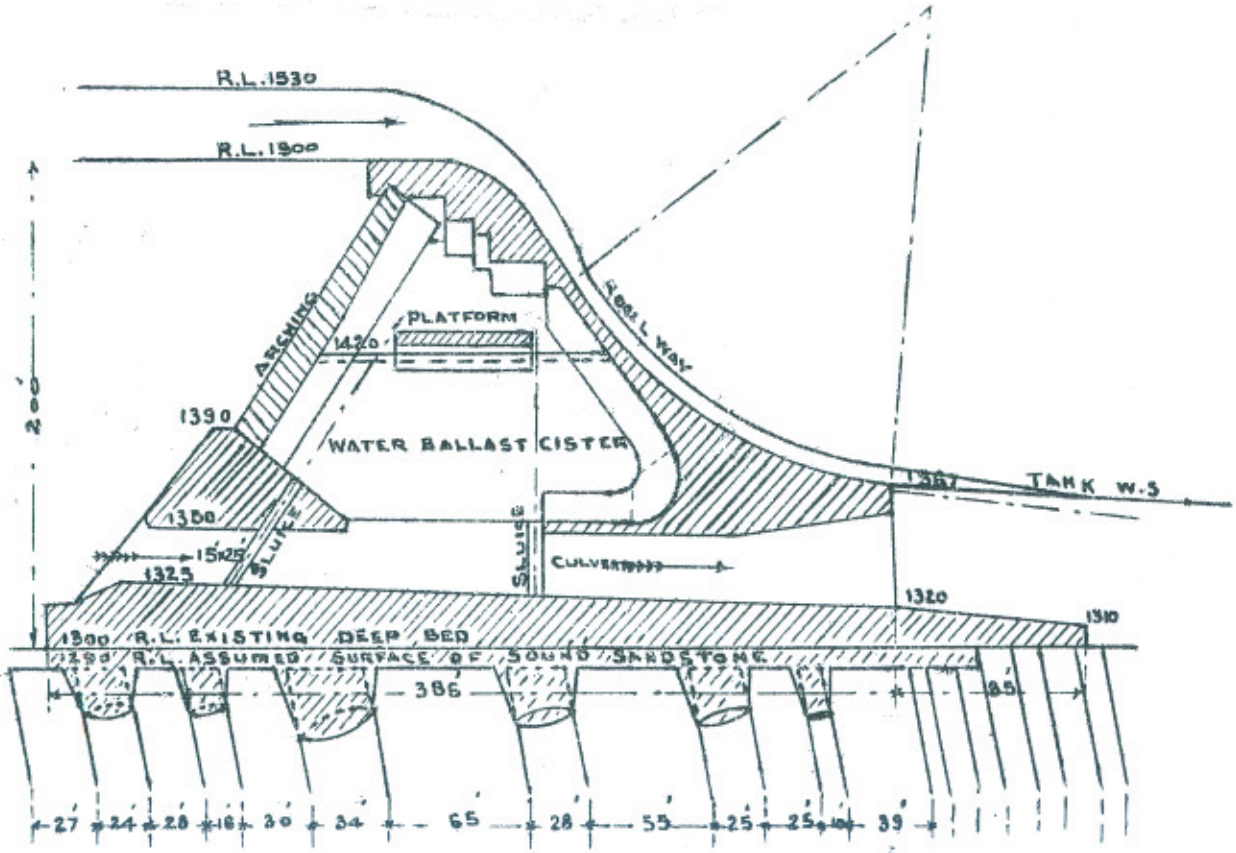
THROUGH CENTRE OF SPAN

OF

CENTRAL THRUST COMPOSITE DAM

AS EVOLVED BY THE AUTHOR FOR THE TERTIARY FORMATIONS

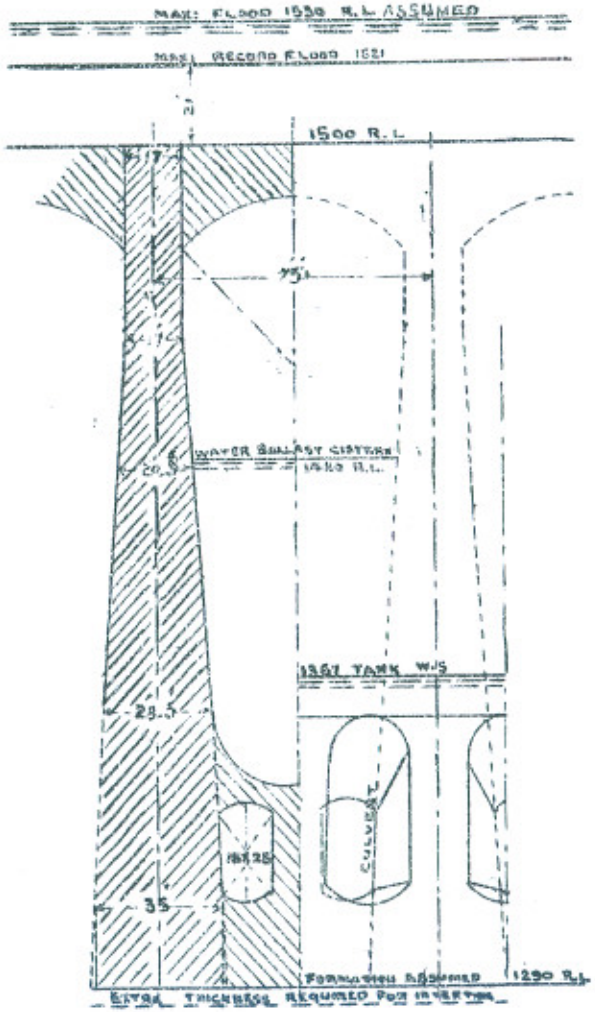
FIG 1



HALF ELEVATION

LOOKING UPSTREAM

FIG 2



SECTION

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the water at the required level and angle and to maintain the centrifugal pressure within safe limits—impact being absent—over its surface.

That such a method of spilling large floods through great descents is possible is demonstrated by actual American experience, but a water cushion must be provided to absorb the great energy developed at the toe.

The loads throughout have been so designed as to keep maximum pressure everywhere in the masonry below 10 tons per square foot, and the minimum quantity of material has been obtained by eliminating shear factor and by balancing the loads about the centre of the buttresses throughout their height.

Such a dam unless of sufficiently massive construction might vibrate under maximum spilling and this would be highly probable if slenderly constructed of reinforced concrete. Vibration or sway action must clearly be avoided, since by it not only might the structure as a whole be weakened, but cracks or displacement might occur in the rollway which would be disastrous. To reduce any such tendency, and at the same time to equalize the stressing in the base of the inclined arching and in the inverting, it is proposed to partially fill the hollow voids with water. This would only add 0·5 ton per square foot to the foundation pressure which, under a total head of 240 feet, from maximum flood to deep foundations, would be slightly under 7 tons per square foot distributed, which is very low for a dam of this height.

There now seems to be a little doubt but that the form of dam which would have to be adopted would be hollow, either of reinforced or solid concrete, on the above lines. As to the choice between these in addition to the above objection to the former, the outstanding considerations are :—

The doubt as to the efficacy of reinforced arches or slabs in the upstream position. The temperature range here will be extreme, for when the reservoir is empty, immediately before it begins filling, the masonry surfaces would be exposed to the heat of the August sun. The high temperatures thus generated would suddenly fall to that of the almost icy cold water as the reservior level rose, and a sudden change of temperature through 80° F. range might occur if the reservoir were filled during flood. Now although the co-efficients of contraction of steel and concrete are identical, steel responds to temperature

change immediately whereas concrete takes hours and days to do so, consequently the movement of the steel within the concrete might have a disrupting tendency on the fabric which would seem to introduce serious risks. This objection would not hold in the case of the inverts which would not be thus exposed. They would always be at low temperature and would probably be largely beneath spring water level.

The thin arching attendant on reinforcement *is not suitable for the roof forming the lower portion of the rollway and the crest must be kept solid*; for such great descents solid masonry must be used for the sake of rigidity. This would necessitate sufficiently substantial buttresses in support. As before stated the pressure in the masonry of these, in the design shown, nowhere exceeds 10 tons, but it is noteworthy that Professor Baker in the 1910 edition of his Treatise on Masonry Construction, states that recent research shows 30 to 40 tons per square foot to be safe pressures in first class 1-2-4 p. c. concrete. These pressures, on his data, give factors of safety of rather over 4 and 3 respectively. Seeing that, in the suggested design, shear factor, with its attendant big stress range and tendency to "fatigue" the masonry, is practically absent, it might be thought feasible to allow pressures approaching 30 tons. The dam as designed does not, in appearance, seem to be excessively solid to successfully withstand the vibration, and possibly sway action, likely to be caused by high spilling floods of 20 feet and over on the crest of the rollway, and with a descent of 150 feet or so, but even supposing further economy in material to be permissible the attendant pressure would certainly fall below 30 tons.

These arguments then seem to show that, apart from the expense of reinforcement at these sites and the cost and difficulty of importing skilled labour to quickly run up so large a reinforced structure, the use of reinforcement in the superstructure would be risky and largely superflous and should not be employed providing there is no dearth of good material for solid concrete.

At all probable sites on the Tertiaries there are practically unlimited supplies of shingle on the river beds, the stones of which consist practically entirely of quartzite and granitic fragments which have only survived the disintegrating forces of the torrents above on account of their great hardness.

The sand is from similar sources. When the shingle has been crushed no better concrete aggregate could be had, hence the plea that concrete be used for the dam masonry rather than the softish sandstones of doubtful weathering quality which alone are to be had locally. It has moreover now been proved that materials for cheap first class Portland Cement are available in abundance in the Punjab, and there is therefore no object in introducing the risks attending the wholesale use of reinforced concrete in these dams on account of a necessity to economise in either a high class aggregate, sand or cement.

Conclusion.

The above review of the principal considerations and problems involved in the construction of these reservoirs seems to show that although the difficulties which would have to be faced in their successful design and execution are considerable, they are all probably capable of solution and that in their double function of meeting extra rabi demand and supplying cheap power for pumping with tube wells on the ever extending water-logged zones the reservoirs would be a paying asset of incalculable moral and indirect value. As regards their ability to supply rabi water alone, it seems doubtful whether in all cases they would be as profitable as the alternative schemes for tapping the Indus, Beas and Ganges, and to settle this further investigation would be necessary. Considered in conjunction with electric power however their great value seems to be obvious, as is demonstrated by the figures given in this paper, from which we see that electrical power can be transmitted very cheaply up to the 100 miles considered and may even be feasible up to 200 miles within which all possible waterlogged areas would come on any canal (*vide* the arcs on the maps. Plates 1A. 1B.)

Canal Group 1 especially would be well served by a reservoir at Thain on the Ravi, since short rabi supplies are likely to be very keenly felt on this group, and, apart from the Indus reinforcement which seems to be of doutbful profitableness, there is no alternative but impoundment on either the Jhelum. Chanab or Ravi rivers, out of which the latter would be more suitable since it would directly supply the two great tail canal systems of the group, *viz.*, the Upper Bari Doab Canal and Lower Bari Doab Canal and compensate the latter for water which could be taken by the remaining canals, and so give elasticity to the group.

Winter freshets would in addition be impounded which would absorb the attendant fluctuations, and steady supplies would be

passed by the reservoir so increasing duties by reason of small absorbtion losses, by the avoidance of spasmodic opening and closing of channels, and by eliminating flushes down the canals.

The site of the proposed Thain Dam is moreover within 100 miles of the waterlogged areas of the Upper Bari Doab Canal.

For Group 2 the advantages of a dam on the Sutlej (as at Neila) do not appear to be so great as far as rabi supply alone is concerned on account of the availability of the big untapped Beas supply, but even here an impounded rabi supply to meet additional requirements of existing Sirhind Canal irrigation with tail extensions into the Hissar desert might be found preferable to the alternative of a long new channel taking out at the Sutlej-Beas confluence,

The proposed supplementary irrigation could be carried out by the Beas supplies.

For Group 3 a dam at Koch on the River Jumna would give an equally large supply to that obtainable from the Sarda Ganges Scheme, but the question of foundations and design of the dam presents greater complexities than the Thain and Neila sites and the desirability of the scheme together with power considerations in preference to the Sarda Ganges would seem to hinge on this point.

A very important field for the additional use of these great reserves of hydro-electric power occurs to the writer:—Reference to the map shows that the greater portion of the Main Line of the North-Western Railway between Lahore and Delhi lies well within the hundred miles radii struck from the three proposed reservoir sites. This length of railway is the main artery of our Punjab communications, it serves the irrigated tracts and has outlets at either end to Karachi from Lahore and to Bombay from Delhi. The traffic upon it is already considerable and will tend to increase in future in consequence of the opening of the Triple Canal Project and the creation of the Delhi Imperial City. This would further be increased by additional exportable grain, etc., raised on the extended areas under the reservoir schemes and from the industries which would be likely to arise were cheap electric power at command. It would appear therefore that it may eventually be found to be worth while to electrify this section of the railway from power to be derived from the reservoirs since the most important desideratum for electrification, *viz.*, continuous traffic giving a

sufficiently continuous load would presumably exist. The railway load moreover would only be a portion of the total load generated and fluctuations could be more economically regulated than where steam is the prime mover. This feature of the combined schemes might be worth the attention of railway engineers. The author estimates from figures already worked out in connection with Thain Project that the cost per British Board of Trade unit, at continuous demand, transmitted 100 miles and transformed, would be about 0·5 anna.

More space has been taken in the writing of this paper than was intended for which the writer must apologize, it appears to him however that in order to make the case for these reservoirs clear, it is not desirable to eliminate or cut down any of the data or arguments all of which seem to him to be indissolubly associated, and which he has endeavoured to express as briefly as he can.

His thanks are due to the Chief Engineer, Irrigation Branch, for kindly placing at his disposal the data in his office bearing on the subject.

APPENDIX I.

Dry tracts which could be irrigated by means of auxiliary reservoirs, and for which the rabi river supplies are now insufficient.

I.—River Ravi.

Total commanded areas are given for the Upper Bari Doab Canal.

(*i*) 240,000 acres between the Sobraon and Kasur Branches of the Upper Bari Doab Canal.

(*ii*) 104,000 acres between the Kiru Nullah and the Ravi, on the Upper Bari Doab Canal.

(*iii*) 65,000 acres between the tail of the Upper Bari Doab Canal and the head of the Lower Bari Doab Canal commanded only from the former.

(*iv*) Supplementary supply of 500 cusecs for the Triple Canal project, *viz.*, by way of the Upper Bari Doab Canal. This would give elasticity to the canals under the Triple project whose rabi supply is expected to be somewhat tight.

(*v*) By this elasticity extensions on the Triple project canals and the Lower Chenab Canal would be possible by a compensating supply to the Lower Bar Doab Canal by the method as in (iv) for those extensions.

(*vi*) In 6 years out of 14 the rabi supply now available for existing irrigation on the Upper Bari Doab Canal is tight and leads at times to excessive "Tatiling" of branches with outcry from the cultivators. 1907-1908 was such a year, the short supply being so keenly felt that the introduction of the enhanced schedule of Occupiers' Rates, then about to be introduced, was indefinitely postponed and work on the Niasbeg Extension stopped. The use of an impounded supply in such years would not only remove the tension but would permit of the enhanced schedule being introduced which would bring the rates on the Upper Bari Doab Canal into line with those levied on the new canals and would increase the average annual net profits of the Upper Bari Doab Canal by 10·34 per cent, *viz.*, by over rupees three lakhs.

II.—Sutlej.

Sirhind Canal. Quotation from a note by Sir John Benton, late Inspector-General of Irrigation, dated 11th April 1910 :—

" The whole of the cold weather supply of the Sutlej is utilized for the Sirhind Canal and it is inadequate to meet—

(*i*) the requirements of the tract in which irrigation is now carried out in British and Native State Territories ;

(*ii*) while in the famine stricken tracts in Hissar district on the South of the tract now irrigated, a large portion of the commanded area received no canal water.

It has been the desire of three Lieutenant-Governors of the Punjab to supply the tract".

APPENDIX II.

Statistics of annual run-off and maximum flood discharges, Punjab Rivers.

	RELATIVE ANNUAL FLOW OFF ACCORDING TO COL. S. G. BURRARD, R. E., F. R. S.					MAXIMUM FLOOD DISCHARGES ACCORDING TO MR. J. S. BERESFORD, LATE CHIEF ENGINEER, IRRIGATION BRANCH.					
	Name of River.	Order of magnitude.	Himalayan area included in the catchment basin. "Square miles."	Total discharge of water in one year. Units (estimated).	Ratio of discharge to area taking that of the Ravi to be unity.	Site of gauging.	Catchment area in square miles.	Maximum flood discharge. Cusecs.	Run-off per square mile. Cusecs.	Maximum flood discharge taking Ravi as unity.	Ratio of discharge to area taking that of Ravi as unity.
	1	2	3	4	5	6	7	8	9	10	11
TRIBUTARIES OF INDUS.	Indus	First ...	103,823	9·0	0·3	...	...	*1,500,000	...	* 7·5	...
	Jhelum	Third ...	13,030	5·5	1·3	Rasul ...	14,300	572,000	40·0	2·9	0·5
	Chenab	Fourth ...	10,588	5·5	1·6	Khanki ...	11,400	500,000	44·0	2·5	0·6
	Ravi	Sixth ...	3,123	1·0	1·0	Madhopur	2,700	200,000	74·0	1·0	1·0
	Beas	Fifth ...	5,663	2·5	1·3	Nowshera ...	5,700	325,000	57·0	1·6	0·8
	Sutlej	Second ...	18,554	3·5	0·6	Rupar ...	7,200	378,000	52·5	1·9	0·7
	Total ...	...	...	27·0							
	Jumna (Tributary of the Ganges)	Fifth ...	4,546	2·0	1·3	Tajewala ...	5,000	300,000	59·5	1·5	0·8

Governing factor.—Glacial and monsoon *vide* "Geography and Geology of the Himalayan Mountains and Tibet," Part III, page 131.

Governing factor.—Monsoon, *viz.*, accessibility full force of the monsoon currents.

* Estimated.

APPENDIX 2 A.

Derivation of monsoon flood discharge unit for the River Indus.

Since the geographical conditions governing the monsoon run-off of a river are identical with those giving its maximum flood discharge we may express, with sufficient accuracy, the former in terms of the latter.

To find flood discharge unit for the Indus.

The monsoon air currents from the Bay of Bengal break in greater force against the outer Himalayan ranges than against those behind which they screen, hence rivers having watersheds exclusively in the former, as typified by the Jumna or Ravi, get a greater run-off per square mile than the latter as typified by the Sutlej and Indus. The Sutlej bears greater resemblance to the Indus than any other Punjab River and is therefore the most suitable for fixing a discharge value for it. Columns 5 and 11 show nearly similar values for the Ravi and Sutlej and column 5 shows 0·3 for the Indus so that 0·3 would similarly be inferred for column 11. Since however column 11 is dependent on monsoon currents and geographical conditions whereas column 5 is in addition dependent on glacial conditions, and since the latter have greater relative value on the Indus than have the former the value of 0·3 must be reduced for column 11. A sufficiently near value seems to be 0·2, which gives maximum flood discharge $103{\cdot}893 \times 74 \times 0{\cdot}2 = 1\frac{1}{2}$ million cusecs nearly, *i.e.*, discharge units as per the foregoing axiom become $\frac{1{\cdot}5 \times 10^6}{200{,}000} = 7{\cdot}5$.

APPENDIX III.

Financial aspect of pumping from tube wells on Amritsar water-logged zone by hydro-electric power at 6 H.P. per cusec at the pumps.

(A) BY POWER GENERATION AT THE PROPOSED THAIN DAM.

Power at pumps 1164 H.P. will meet the requirements of the whole water-logged zone, power being available perennially and capable of infinite expansion.

Transmission taken at 10,000 volts ... ... 3 phase.
Distribution taken at 500 volts ... ... 3 phase.

		Cost per H.P. at pumps. Rs.	Rs.
(*i*).	Generating plant including high pressure conduits, turbines, electric plant, crane, etc.	176	
(*ii*).	Transmission, including transformers and line.	207	
(*iii*).	Distribution line	57	
(*iv*).	Power house and transformer stations ...	60	
(*v*).	Percentage charges at 24½ %	123	623
(*vi*).	Pumps and motors with houses	486	
(*vii*).	New watercourses	161	
(*viii*).	Percentage charges at 24½ %	158	
(*ix*).	Old watercourses, value written off ...	185	990
			1,613
(*x*)	Annual expenditure comprising staff and stores, depreciation and repairs... ...	75	
(*xi*)	Net income after deducting all canal charges *	185	
(*xii*).	Net profit per annum, 185—75	110	
(*xiii*).	Percentage of net profit to Capital Outlay is	6·8 %	

(B) BY POWER GENERATION AT TARN TARAN RAPID ON THE MAIN BRANCH LOWER, UPPER BARI DOAB CANAL.

Power at pumps 530 H.P. being the maximum available from 1050 cusecs which can only be relied on for 240 days per annum.

Distribution : 500 volts. ... ... 3 phase.

		Cost per H.P. at pumps. Rs.	Rs.
(*i*).	Generating plant...	253	
(*ii*).	Modification to canal masonry works ...	259	
(*iii*).	Distribution line	57	
(*iv*).	Power Station, etc.	113	
(*v*).	Percentage charges at 24½ %	167	849
(*vi*)	to (ix) as per (A)	...	990
			1,839
(*x*).	Annual expenditure, etc.	84	
(*xi*).	Net income, etc.	168	
(*xii*).	Net profit per annum 168—84	84	
(*xiii*).	Percentage of net profit to Capital Outlay is	4·5 %	

* Irrigation "duty" was calculated to be 385 acres annual (Mr. A. J. Scratchley, late Chief Engineer estimated that it would be nearer 450 acres per cusec) that for B as 350 acres : being less than for A for the reasons given in the text.

(xiii).	Percentage of net profit to Capital Outlay is	6·8 %	Outlay is	4·5 %

* Irrigation "duty" was calculated to be 385 acres annual (Mr. A. J. Scratchley, late Chief Engineer estimated that it would be nearer 450 acres per cusec) that for B as 350 acres : being less than for A for the reasons given in the text.

APPENDIX IV.

Abstract of Financial Statement of the Preliminary Project for proposed Ravi Reservoir at Thain.

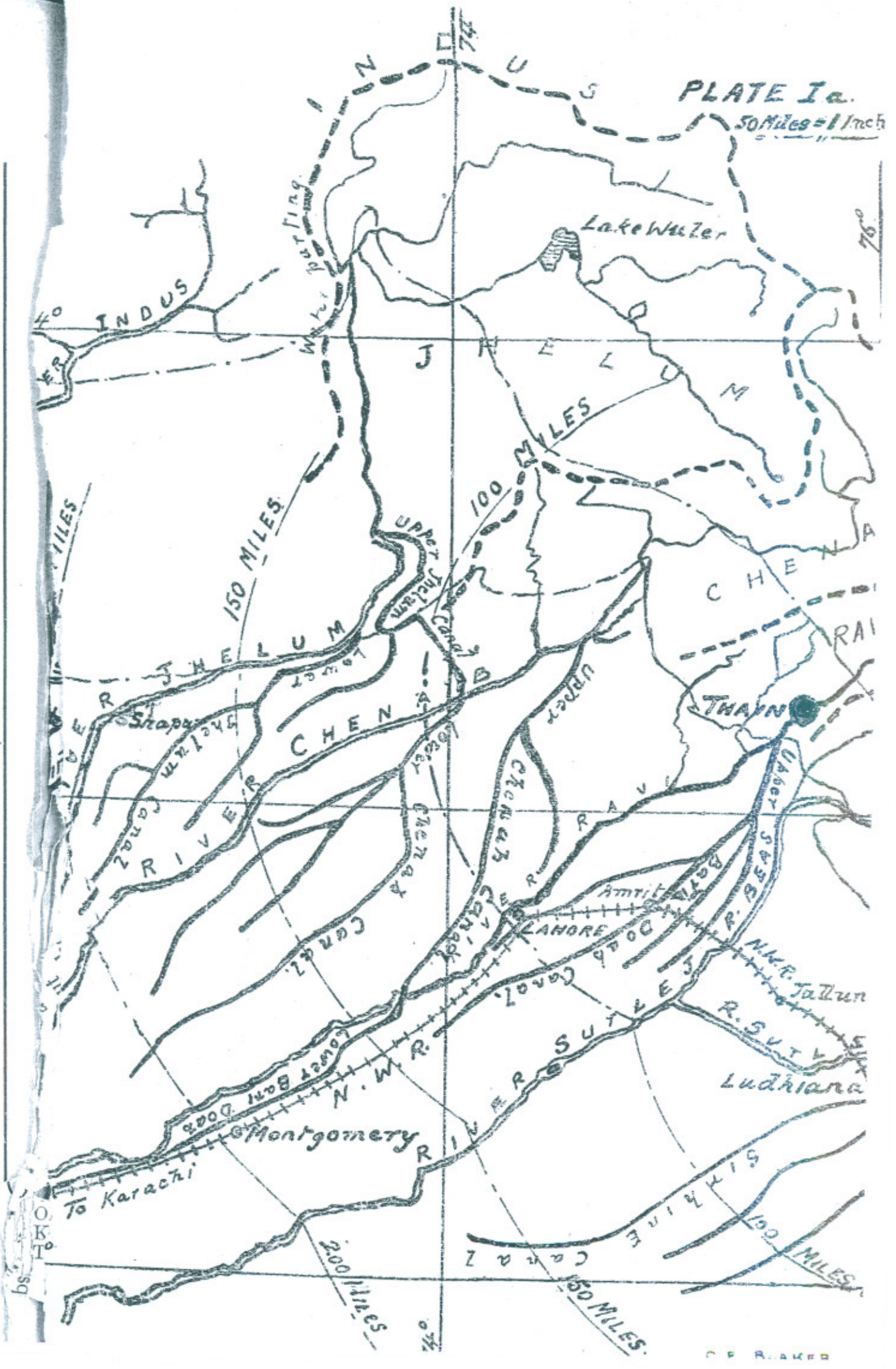
ITEM.	Estimated annual net profits per cent. on capital outlay. Dam constructed by—	
	(a) Hydro-electrically actuated machinery fully used.	*(b)* Manual labour chiefly used.
	Per cent.	Per cent.
(i). From pumping from tube wells on the Amritsar water-logged zone	0·86	0·59
(ii). From extra revenue on canal water divertable on account of pumping	0·08	0·06
(iii). From impounded supply ; direct revenue	3·57	2·50
(iv). From land revenue and malikana on newly irrigated tracts	1·16	0·81
	5·67	3·96
(v). Enhanced value of existing Upper Bari Doab Canal irrigation on introduction of the revised schedule of Occupiers rates, made possible by the scheme ...	2·08	1·46
(vi). Royalty payable to Government on 10·000 H.P. Hydro-electric Power assumed ...	0·65	0·46
	8·40	5·88

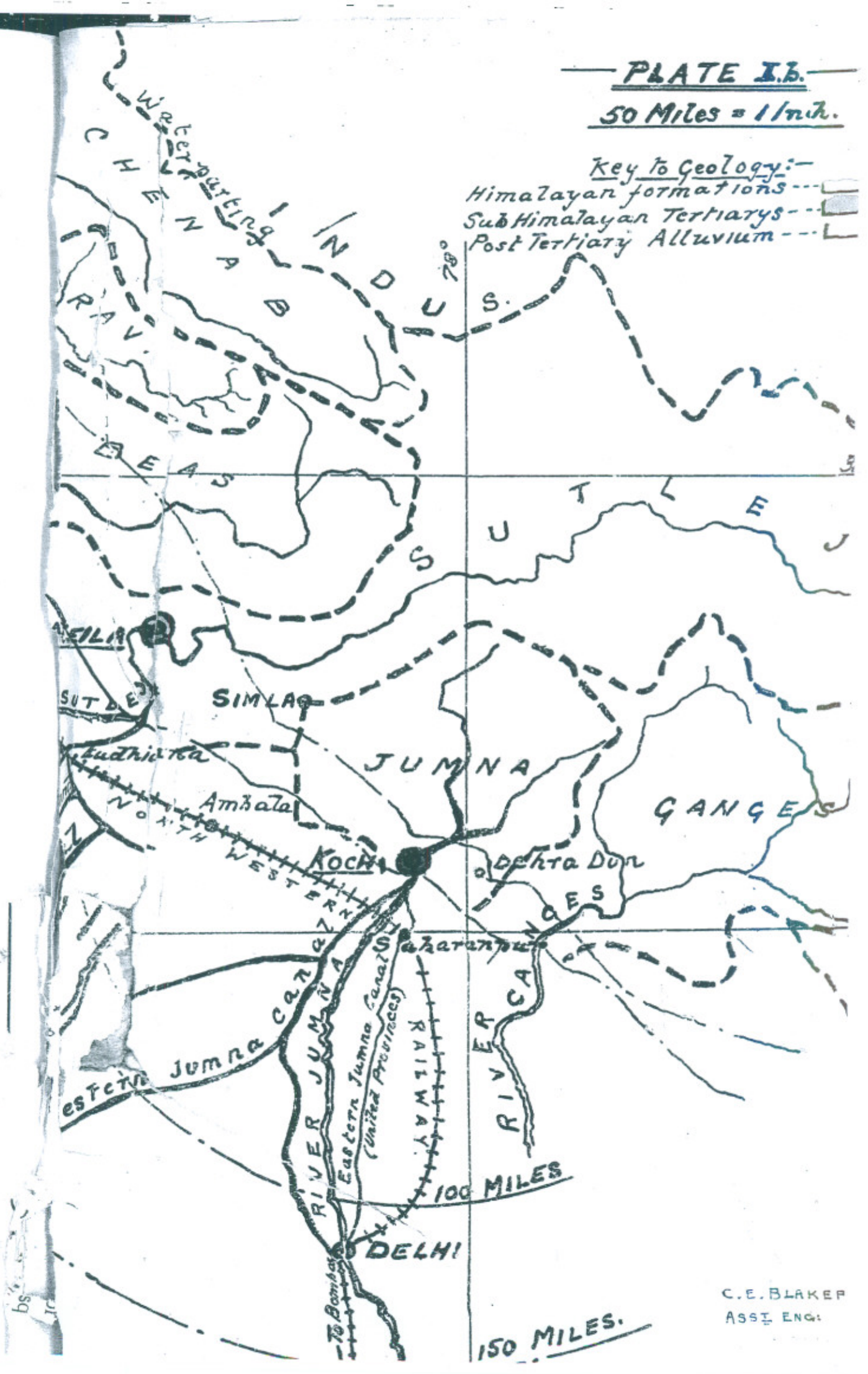
APPENDIX V.

Proportion of silt in the water of the Sutlej River at Rupar.

1	2	3	4	5	6	7
	July 7th, 1894.	July 29th, 1894.	June 13th, 1895.	August 14th, 1895.	July 30th, 1896.	July 6th, 1897.
Velocity of river, feet per second	7·70	10·81	6·33	9·62	4·10	4·30
Proportion of silt to water by weigth at the surface	$\frac{1}{69}$	$\frac{1}{127}$	$\frac{1}{59}$	$\frac{1}{82}$	$\frac{1}{555}$	$\frac{1}{300}$
Weight of silt at surface taken as unity	1·000	1·000	1·000	1·000	1·000	1·000
Weight at depth of 1·5 feet	1·015	1·127	1·217	1·036	1·042	1·067
Do. do. 3·0 „	1·038	1·245	1·260	1·047	1·132	1·145
Do. do. 4·5 „	1·038	1·358	1·329	1·056	1·202	1·152
Do. do. 6·0 „	1·066	1·395	1·427	1·078	1·207	1·254
Do. do. 7·5 „	1·084	1·581	1·496	1·088	1·395	1·383
Do. do. 9·0 „	1·164	1·731	...	1·104	1·689	...
Do. do. 10·5 „	2·024	...	...	1·144	1·932	...
Do. do. 12·0 „	...	...	...	1·154	...	...
Proportion of silt to water by weight at greatest depth	$\frac{1}{34}$	$\frac{1}{74}$	$\frac{1}{40}$	$\frac{1}{71}$	$\frac{1}{289}$	$\frac{1}{2}$

Ex.—Buckley's Irrigation Pocket Book, page 90.


PLATE Ia.
50 Miles = 1 Inch
Lake Wular
INDUS
JHELUM
CHENAB
RAVI
SUTLEJ
Shapur
Jhelum
Upper Jhelum Canal
Lower Jhelum Canal
Upper Chenab Canal
Lower Chenab Canal
Upper Bari Doab Canal
Lower Bari Doab Canal
Upper Sirhind Canal
Lower Sirhind Canal
Upper Sutlej Canal
Lower Sutlej Canal
Thawn
Amritsar
Lahore
Montgomery
To Karachi
Ludhiana
N.W.R.
N.W.R. Jallun
R. Sutlej
150 Miles
100 Miles
200 Miles
150 Miles
100 Miles
74°
75°
30°


PLATE I.b.
50 Miles = 1 Inch.
Key to Geology:-
Himalayan formations
Sub Himalayan Tertiarys
Post Tertiary Alluvium
Western Portion of
INDUS
CHENAB
RAVI
BEAS
SUTLEJ
SIMLA
SUTLEJ
Ludhiana
Ambala
JUMNA
GANGES
NORTH WESTERN
KOCH
Dehra Dun
Saharanpur
Jumna Canal
Eastern Jumna Canal
(United Provinces)
RIVER JUMNA
RAILWAY
RIVER GANGES
100 MILES
DELHI
To Bombay
150 MILES.
C.E. BLAKER
ASST ENGR