No. VI.

MADRAS CIVIL ENGINEERING COLLEGE PAPERS.

NOTES ON CANALS AND RIVERS.

EXPLANATORY OF THE PRINCIPLES

ON WHICH

THE EFFICIENCY OF CANALS

IS DEPENDENT IN INDIA.

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PREFACE.

THE object of the following pages is to explain the principles on which the efficiency of Canals in this country depends.

The reader should be warned that some of the views here enunciated may not be concurred in by many Engineers, whose opinion is entitled to respect; and also, that the Principal of the Civil Engineering College who has kindly consented to issue the pamphlet as one of the College Series, is in no way responsible for the accuracy of its contents.

As these "notes" have been drawn up hastily, it is probable that the reader, if so inclined, will find much to criticize; but though in many cases, there may be a want of clearness in the language, it is hoped that the meaning intended to be conveyed will be tolerably apparent, and that the work will not on the whole be devoid of interest or utility to the younger members of the Department, Public Works.

BEZWADA: *3rd Oct.*, 1862. J. C. A.

NOTES ON CANALS AND RIVERS.

1. IRRIGATION by means of Canals is chiefly applied to tracts of country which have been formed by the gradual deposit of alluvial matter, from rivers in a state of flood. The deposit from the inundation begins to take place at the points where the velocity of the stream is checked; and this being along the margin of the channel, an inundation of the country through which a river passes, will leave behind it a stratum of silt in the form of a wedge, the thick end of which is on the river bank.

2. In the course of time, successive annual inundations ll thus have formed a slope away from the banks, resem- ing the glacis of a fortification. The width of this slope, ll vary according to the nature and size of the river. It y be only 200 or 300 yards, and be perceptible to the eye, it may extend to the distance of many miles.

3. The feature above described is not only to be found along the main channel of a river, but also along its branches. No very extensive tract of country has been formed by the nundation and consequent deposit from a single stream. On the contrary it must have been the work of many.

4. The channels of all rivers, unless when confined by rocks, have been more or less liable to change their course. By referring to a map of any Delta, the reader will observe hat the characteristic of the Delta form, is that a river as it approaches the sea, should split up into two or more branches or arms, which again may be subdivided into smaller ones. Each branch has a tract of country within its influence, and serves to extend the area of alluvial deposit, either by raising its banks, or by extending the Delta seaward.

5. The forms of the mouths of Delta channels will de-

pend in a great measure on the influence of littoral currents but sooner or later, they will encroach on the sea, and turn a portion of it into dry land. As this process is in operation the head of the Delta also undergoes change. Without entering at present into the cause of this, it is nevertheless a fact, that as the Delta extends itself seaward, the branch or branches at the head of the Delta, tend to silt up, and if the process is not checked by artificial means, the complete cutting off of the supply of water, is sooner or later certain to take place. The main channel of the river if left to itself, would gradually absorb the whole supply, and would thus constitute the head of the Delta at some point nearer the sea, where the next bifurcation might happen to have been formed.

6. The fact of such changes having actually occurred will be apparent from a consideration of the physical character of rivers, such as the Indus and Ganges, which, with their branches, have formed by alluvial deposit, the whole of the vast plains which extend from the base of the Himalay to the sea. At some former period, the sea must have washed the foot of the hills, and the Indus, Ganges, and a number of other rivers which now fall into them, must then have fallen separately into the sea, and each would have had its own distinct Delta; and the condition of two such rivers, as for example, the Ganges and Gogra, would have very much resembled that of the Godavery and Kistna, as they are at present. From this analogy, it may be assumed, that there is every probability of the Godavery and Kistna uniting at some future period, when the extension of their Deltas seaward, would admit of their doing so. By the time that happened, the number of branches or arms by which the existing Deltas are intersected, would have disappeared, unless prevented by artificial means; or rather they would not have disappeared, but their form would be changed to such an extent, as to leave room for controversy, as to what they originally were.

7. It is a common occurrence to find dry beds of rivers in alluvial plains, possessing all the characteristics of the existing channels. In some cases channels may be found of such capacity as to show without doubt, that they are deserted beds of the main stream; in others there may be indications of a partial and gradually diminishing supply having reached them; which, by successive annual deposits, has curtailed their section to such an extent as to admit of their being adapted as irrigation channels, or if left entirely in their natural state, such channels may be silted up completely by successive deposits from flood water, and by drifted sand and dust, until they may be no longer perceptible, and all that is left to mark their course is a ridge of high land.

8. It will thus be seen that an alluvial plain (so called) is not made up of an equable deposit of alluvial matter to the right and left of the main channel of a river, but on the contrary by that from a number of channels, some of which may subsequently be obliterated. The fall of the country also, instead of only following the course of the main channel, will be affected equally by all the others. Intermediate between the channels, the ground will be low, and the line formed by the intersection of the two planes sloping away from their respective banks, will evidently indicate the course in which the drainage from those plains will tend to flow. Such lines will be found also on the extreme boundaries of a Delta,—receiving on one side the drainage of a portion of the Delta, and on the other that of the country independent of it.

9. After these remarks it is time to explain that the irrigation of a tract of a country is based on very simple principles. Supposing that a supply of water is required for the land near the bank of a river, which has ceased to overflow it, but which may rise to the lip of the channel, then as the country falls away from the river, it will be readily understood that a cut through the bank will give the means

of irrigating the ground beyond. This may be considered the simplest form of irrigation. Again, if the surface of the river falls so considerably below the lip of the channel, as to be incapable of supplying water to the ground at a distance, by means of a cut carried at right angles to the course of the river, the difficulty may be surmounted by excavating a channel in an oblique direction ; for the course of a river is never straight, and an artificial channel may be formed in a straight line, which will carry the water to a higher level, than that of the surface of the river at any point opposite to it. For every mile of its course, it thus gains something on the surface level of the river, and it becomes a matter of simple calculation to find how far it will have to be carried, before the water issues on the surface. For instance if the fall of the river surface is one foot per mile, but with a tortuous course of one half more than the direct line, an artificial channel with a fall of one foot per mile, running parallel to the general course of the river, that is from point to point of curves, will for every mile of cutting gain six inches on the river. So that if the surface of the water at the head of the cut were five below the lip of the channel, it would gain that amount on the river in ten miles.

10. If the cut were excavated in ground on the same level as that on the margin of the river, the water it carried would then come to the surface and be available for irrigation ; but as the ground falls at right angles to, as well as with, the course of the river, the required level would be attained by a cut less than ten miles in length ; or if the fall along the cut, were less than one foot per mile, say six inches per mile, the water would come to the surface in five miles or less according as the ground might be level, or slope off in the direction of the cut.

11. The water in the river may fall so low at the time during which it may be required for irrigation, as to render the cutting that would be required to bring it to the surface

inordinately expensive; and, to irrigate effectually, it may be necessary to raise the water artificially, by means of a dam or anicut constructed across the channel: but there are other objects to be served by such dams besides simply holding up the water, which, though not so obvious, are of hardly less importance. This will be understood when I have described the condition of the heads of Irrigation channels, which are opened from the river in its natural state.

12. It will be readily understood that the high ridges and the old channels, above described, indicate the most suitable alignment for a series of Irrigation channels. The object would be to conduct the water from the river to the crest of such high lands, and then, for the channels along them, to arrange as far as may be practicable, that the excavation shall be no more than sufficient to furnish the material required for the embankments, which should retain the water at as high a level as possible, consistent with their stability. If the depth of water admitted into the head of the main channel is materially less than what is due to the river at its full height, the depth of the excavation at the head will increase in proportion to the difference; and it will then be an object, in order to make the cutting as inexpensive as possible, to carry the line of the channel through low ground, until the water would flow on the surface. The irrigation limit is then reached, and the channels should be continued along the highest ground, that will allow of the water continuing on the same level with it or above it, as may be found most suitable for the locality. If the ground were level on both sides of the channel it would in many cases be indispensable to have the surface of the water above it; but in the other hand the soil may be ill-adapted for withstanding pressure, or for preventing percolation; and to avoid the occurrence of breaches, it may be desirable to keep the height of the embankments within very moderate limits. The best alignment of channels, under such circumstances, will be explained further on.

ON CHANNELS OPENED FROM A RIVER IN ITS NATURAL STATE.

13. A channel opening direct from a river, and unprovided with a sluice or other regulating work at its head, is subject to the two following disadvantages. It is subject either to have its supply increased to an inordinate extent during high freshes, or to have it cut off altogether. In one case the current of the river may set on the mouth of the canal, or on the bank above it. If the soil is liable to erosion, it will be cut down and washed into the canal. the head of the canal itself would be enlarged; and such destructive action would only be limited by the duration of the fresh. The greater the fall of the canal in this case the greater the evil. Or on the subsidence of the higher freshes, the stream may have moved to the opposite bank of the river, leaving a mass of sand banks between it and the head of the channel, which it would be impossible to cut through in time to replenish the supply. In this case the *less* the fall of the channel the greater the evil. Both the above contingencies must be common in all Irrigation channels, which are opened from a river with a shifting bed. In the latter a temporary bund may in some cases be effectual in replenishing the channel but it has generally to be constructed before the freshes have finally ceased, and is very liable to be destroyed just as it is completed. Though a new head may be formed through the sand banks for the next season, it is next to impossible to cut through them at the close of the rains, with a falling river, and when the water under the surface of the sand bank stands on a higher level than that of the river.

14. The violent action on the mouth of the channel when the river sets against it, may be checked by revetments groynes and such like defences, but they must also have the effect of diverting the action of the stream from its natural course, and thus tend to throw it off towards the opposite bank. Supposing that there were no other difficulties to surmount but the two I have specified, they might be overcome

by the construction of a head sluice, with defences against encroachment, and of a groyne running from the opposite bank, so as to force the stream of the river to pass alongside the head sluice. In many cases however the construction of such a groyne would be impracticable. The river might be too large, suitable material not procurable, and the expense of maintenance of the groyne itself, and the river defences which it would necessitate, would be too great, to be justifiable, unless the channel were of very high importance,—and in that case a dam or anicut across the river would be more efficacious than a groyne.

15. It does not necessarily follow that a dam is required only for the purpose of raising the water, and thereby lessening the excavation of the Irrigation channel. In the rivers in the north of India, the supply when at its minimum is sufficient for the wants of the canals, the size of which is indeed regulated by the minimum supply in the river; and though it may be necessary to raise the water to a certain extent, the principal object to be served by a dam is to *lead* the water to the canal.

16. Some of the rivers in question are several miles wide, and the channel in the dry weather will flow along one bank one year and along the other the next, and the third year perhaps in the middle. The arm leading past the mouth of the canal, which may have been the main channel when the canal was opened, may have become raised at its head, though the bed at the canal mouth may be of the full depth. No dam across the arm of the river would have the desired effect of increasing the supply. Even supposing that below the dam a cut was excavated, so as to increase the fall, and thereby the draught of the channel, it would still be ineffectual; for the velocity thus produced would have to be allowed to go on increasing, until the whole of the river passed over the dam; or it would have to be checked, which implies that the supply be thrown back, and occasion deposit of silt or other matter at the head of the

creek. If the latter is so far up the river, as to be beyond the means of influence, neither then would the dam in the first instance have any power to produce an increased draught of water.

17. It follows therefore that no dam across an arm of a river can be effectual, unless it is designed to be capable of discharging the whole of the river supply. It is therefore apparent that the only means of regulating the supply in a river with a shifting channel, is to dam up the whole of it. This may be accomplished by blocking up various arms, by groynes, revetments and other appliances, and by leaving the channel to be dammed up, of the smallest capacity, consistent with the stability of those works and of the dam itself.

18. Thus, as I have abovementioned, a dam may be used more as a limit to the capricious shiftings of a river than as a means of simply raising the water, though probably in all cases, it would have to be used at times for the latter purpose; for even if the depth of water at the head of the canal were sufficient, the surface fall of the river is generally greater than that of the canal which opens from it, and the water would have to be *forced* into the latter, by closing the dam.

19. At the heads of some of the canals in upper India, the bed of the river is formed of boulders; and permanent dams across the main channel of the river are dispensed with. The above remarks refer particularly to channels with shifting beds, in which the changes produced by a fresh are not capable of being counteracted by temporary expedients; but if by temporary expedients, the full command of *any* stream is not obtainable, then a dam is certainly the only means of acquiring it.

20. While on the subject of river beds, I may allude to the modes which may be adopted to prevent the setting up of the heads of arms of a river—such as those in the Deltas in Eastern India;—which I before remarked is sure to happen, unless prevented by artificial means. Such

arms are, I believe, originally produced by the overflowing of the river banks during a high fresh,—when the water finds a shorter course to the sea, than by the main stream. Up to what point such arms continue to carry the same proportional supply from year to year, and when the equilibrium begins to be disturbed by one channel showing a tendency to abstract by degrees the whole supply, it would be difficult to determine. It is sufficient to know that such a tendency is sure to arise; and that if nature were left to herself, she would assuredly block the heads up completely.

21. The operation was in progress in the Cauvery before Sir A. COTTON checked it by constructing the annicuts, and it is now going on in the Mahanuddy, though measures have been adopted to check it there also, which will probably result in the system which proved so successful in Tanjore, being carried out at Cuttack. The effect of any groynes or other works, designed to deal with one of two Deltaic arms, can only be partial, and in a word unsuccessful. A groyne constructed for the purpose of increasing the supply of one arm, by diminishing that of the other, will doubtless attain that end, but it cannot (I speak of rivers in sandy or alluvial soil) proportion the increase, nor can it, in fact, after once upsetting the equilibrium, prevent the *whole* of the river being carried into the arm, in which there had previously been a deficiency, unless a series of groynes or other regulating works be established on that arm, as well as on the other.

22. The first effect of a groyne, thrown across the mouth of one arm will be to cause a deepening and general enlargement of the head of the other. Suppose this effected by the freshes of a single season. Those of the next season will enlarge the head of the channel still more, and the water that thus enters the channel must find a vent either by enlarging the channel onwards towards the sea, or by finding an escape over the surface of the country, or both. The velocity

in the other arm having been checked by the groyne would lead to an extensive deposit of silt, and its head would soon be completely blocked up and the groyne itself buried in land. A series of counter-groynes would have to be started from the opposite bank of the river; but the supply of the two arms could never be effectually regulated until a masonry work of the nature of an annicut had been constructed across both arms.

ON THE RIVERS IN THE NORTH AND SOUTH OF INDIA.

23. It may be desirable to enter at greater length into a consideration of the causes which render the rivers in the north of India so different in their action from those in the south. The soil in both cases consists of a stratum of alluvial matter over-lying sand, but in the Deltas of the Godavery and Kistna, the thickness of the upper stratum is much greater than it is in the N. W. Provinces, and the sand is of a coarser and heavier quality, and more capable of resisting the action of a stream. The Godavery and Kistna, though liable to undergo considerable changes, do not cut away the land adjacent to the channels, to such an extent as the Sutluj and the Indus, though the fall of country is not so different in the two cases as to account for the comparative permanence of the former. The fall of the country traversed by the Sutluj is 16 inches per mile, and that of the Godavery and Kistna Deltas one foot per mile. The depth of water in high freshes is much less in the Sutluj than it is in these rivers. How comes it then that the channel of the Sutluj has a width of from 2 to 8 miles, and that it is never to be found for two successive seasons in the same place? It is evidently due to the different quality of the soil. The depth of a river will always depend on the nature of the soil by which its channel is lined; and if in any two rivers having an equal fall of surface and discharging equal volumes

of water, the depth varies, it may be assumed that the one with the greater depth passes through soil of greater tenacity than the other. The reduced depth of the one will be made up by an increase of width.

24. In the Sutluj the greatest depth in the cold weather is about 10 feet, and the height of the freshes does not exceed 10 or 12 feet, or at furthest 15 feet, which would give a total depth of from 20 and 25 feet; whereas in the Godavery and Kistna, the freshes rise to a height of between 30 and 40 feet above the summer or minimum level.

25. If, however, we examine the height and duration of the freshes in the two classes of rivers under consideration, we shall find that although the Sub-Himalayan rivers do not attain the same height (at least in the upper Provinces) as those in the south of India, they do not subside so rapidly, and it must be remarked, that, to form a comparison between the two, it is necessary to take into consideration the fact of there being a large body of water in the Himalayan rivers during the dry or cold season. For instance, the Sutluj united with the Beas discharges at its minimum 8,000 cubic feet per second, the Ravee between 2 and 3,000 cubic feet, the Chenab probably more than both together. The Ganges, at the foot of the Himalayas discharges between 6 and 7,000 cubic feet per second; the Sarda in Oude 6,000 feet, the Kowrialee,* the largest of all, though the least known, 13,000 cubic feet per second. The two last when united form the Gogra, which, with the additional supply derived from several smaller affluents, discharges between 22 and 23,000 cubic feet per second. The Ganges near Rahmahal discharges in the month of January, with a mean velocity of 2½ feet per second, 115,000 cubic feet per second —probably more than the minimum discharge of all the other rivers in India (excepting the Burhampooter) put together. Records Bengal Govt., No. XIX, p. 124.

* I have seen boats taking in cargo on this river, within 20 miles of the Himalayas.

26. The depth of the larger rivers, at least after reaching the plains, is 10 or 12 feet, the surface velocity at the deepest part of the stream between 3 and 4 feet a second, or 2 to $2\frac{3}{4}$ miles per hour. An addition of even 5 feet to their minimum depth would enormously increase their volume, and if it be considered that during the three months of July, August and September, it very rarely falls below this, while during the greater portion of that time it retains a height of 9 or 10 feet above the cold weather level, it will be understood that the aggregate action of the rivers in question is far more violent than those in the Deltas of the south of India, in which, though the rivers rise to a great height, they never retain it for above a few days at a time, and afterwards are liable to fall to about 15 or 16 feet below the maximum of the months I have specified.

27. Thus on comparing the Register of the Ganges at Cawnpore for five years (1843 to 1847—see Plate 60, Atlas attached to Sir P. Cautley's Report on Ganges Canal), I find the average height above the cold weather level for the months of July, August and September, amounted to $10\frac{3}{4}$ feet, the greatest height during that period being 13′ 8″, while in the Kistna the average height of the freshes above the crest of the annicut for a similar period (1856—1860) and for the same months was only 6 feet, though the maximum rose to upwards of 17 feet.

28. I proceed to describe the peculiarities of one of the principal rivers of the Punjab with which I happen to be well acquainted; and also the physical features of the country through which it passes, in the hope of enabling those who possess experience of the rivers in the south of India, to form a more just appreciation of the distinctive character of the two, than perhaps they would otherwise have the means of doing.

29. This, however, is not the only object of the following remarks. It will appear as the reader proceeds, that in investigating the conditions of natural streams and dry beds

of rivers, I am endeavoring to gain some insight into the working of streams of whatever kind,—whether in natural or artificial channels.

30. In the country traversed by the Sutluj there are numerous natural channels (now dry), which at one time must have been arms or branches of the Sutluj, or have received the drainage of the higher country towards the Hills. Some of them are intersected by the Sutluj, and this would give color to the supposition that they are deserted beds of arms of that river,—at least as regards several of the larger channels.

31. Their heads are now completely silted up, which would be accounted for on the same principle that explains the silting of artificial channels, or of the secondary branches of a river in a Delta. No river can permanently flow in two channels, unless the bifurcation were in unyielding rock, a contingency of which I question the existence anywhere. The two channels may retain their proportional supply for a number of years, but sooner or later, the whole of the water will be absorbed by one of them.

32. Let us suppose that when the supply of both should have been uniform, a slight alteration should take place in the direction of the stream above the bifurcation, so as to increase the momentum on the head of one of the arms, to something above the standard. The increase of velocity will deepen the bed: a larger supply than ordinary will enter the channel. This must cause either a general enlargement of the channel onwards, or the additional supply of water must find its way over the country. Should this happen, there would seem to be no limit to the increase.

33. The mouth of the channel having been enlarged, would, in the absence of any impediment to the onward flow of the water, continue to be enlarged still further, and there would be no limit to this process, until the whole volume of the river should pass into the arm. The head of the other arm would, in the meanwhile, have lost its supply, in pro-

portion as the other gained it, the velocity would gradually become less, and silt would be deposited until the mouth should become completely blocked up.

34. If, on the other hand, the additional volume of water, poured into the other arm, could not find a vent either by enlarging the channel throughout its course, or, from the land being too high, by increase of inundation, it must of necessity follow, that the velocity would be reduced. The water would, as it were, be heaped up, the slope of the surface be diminished, and the water would be thrown back on the head ;—the initial velocity would be destroyed and the head which had been deepened in the first instance would be again silted up—the current would be deflected on the head of the other arm, where the same process would go on.

35. It would thus appear evident that when a stream sets on the head of a channel with shifting sides and bed, which opens from it, it will either continue to enlarge it without limit, as long as the initial velocity is kept up ; or, if the resistances which are offered to the enlargement of the channel (from the head onwards) are sufficient to check the velocity, the volume of water will be reduced until an equilibrium is established. But if the volume of water is reduced, the current which occasioned the increase by acting on the head of the channel must either be deflected on the head of the other branch (or to the main channel as the case may be), or if it continues in the same direction as before, the velocity can only be kept up by having a diminished section of channel, that is, the head would silt up.

36. Were the banks of a channel incapable of erosion, though the bed might be yielding, if, let us suppose, the banks and head of the channel were revetted, so as to secure them against being washed down, the result would differ somewhat from what I have described above. A current setting on the mouth of such a channel (so as to cause an excess of what we may conceive to be its normal supply), would commence its action by deepening the bed. Were

the deepening to extend along the whole length of the channel, the velocity and volume would go on increasing, and if a vent were afforded for the additional supply as fast as it was delivered, there would be no limit to the ingress of water at the head short of the whole supply of the river. But this is supposing a state of things which could never occur in reality, for no channel could be revetted in such a manner as to render its banks secure against being undermined as the depth of the stream increased ; and further, the material cut out of the bed which we have supposed to be carried on by the stream would accumulate,—could not in fact be carried forward, and would therefore, by raising the bed of the channel further down, diminish the slope of the surface, and thus throw back the stream on the head ; or, if the banks at the head give way, this result would be only the sooner accomplished, as the material composing them would have to be carried on in addition to that of the bed. The resistance would then be increased more rapidly, the stream would be thrown back, as described before, and the velocity at the head could only be sustained by a diminished depth. The head would be wide and shelving down from the mouth. We suppose that the volume of water thrown into the branch or channel is diminished, and of course the difference would pass on to the other branch or the main channel.

37. Let us conceive a case in which the revetments of the mouth and banks of a channel withstand the action of the stream which sets against them. Then, however great the slope of the branch, the resistances which would accumulate along the channel at a distance (unless it be allowed that the supply may go on increasing till the whole river passes into it), would have the effect of diminishing the surface fall, and of diminishing therefore the volume of water. There will then be a limited supply of water, which can be discharged by the channel, while there will be a pressure on the head on any additional rise of the river tending to throw in an increased volume of water. There must be an increased ve-

locity, and if there is no increase of volume, (or say, no proportional increase of volume) in the channel, the depth of the channel must be less in the river in front of the mouth of the channel, than it is in the channel itself. The actual result would be the formation of a sand bank in the form of a crescent, extending in front of the mouth which would constitute, as it were, a natural sluice to regulate the supply of water. The greater the rise in the river, compared with the discharging capacity of the channel, the greater would be the height of this sandbank, and it would disappear only when the channel could carry on the supply thrown into it without any change in the surface fall.

38. The above remarks are evidently applicable to the heads of canals, and they are equally so to the mouths of Tidal rivers, or inlets from the sea.

39. There are many different theories about the formation of bars, and there is, I believe, no branch of Civil Engineering, in which the opinions of professional men will be so conflicting, as in that relating to the improvement of Tidal Rivers. It would be presumption on my part to dogmatize on the subject. I would merely observe that in all the works on Tidal harbours which I happen to have perused, I have found the action and effect of the tide, whether in its natural state or modified by means of artificial works, to be rendered quite intelligible by the simple principles above described.

40. I may be excused a slight digression if I can shew that the formation of bars is due to exactly the same cause as the silting up of the heads of the branches or arms of a river.

41. We may suppose that there are two distinct kinds of tidal action ; one in which the tidal current sets on the mouth of an inlet, that is, in a direction perpendicular to the line of the shore : the other, in which it runs parallel to the shore. The tide may set in a direction intermediate between these two : but it will suffice to consider the action in these cases only.

42. First, then, we have the tide setting on the mouth of an inlet. Let us first suppose the soil to be of a yielding nature, sandy or alluvial. On the tide rising, a certain velocity will be generated ; and, to maintain this velocity, it is necessary that the stream which passes into the inlet should meet with no obstruction. If this condition is preserved,—if during the rise of the tide to the full height, there is no check to the onward flow of the stream, there will be no bar. This, however, is a case that can rarely be found in reality. It assumes that there is a basin or receptacle for the tidal inundation, of such an extent as to admit a continually increasing volume of water, up to the time of high water. But, unless the rise of the tide were very trifling, the velocity would have the effect of enlarging the mouth of the inlet. During the next flood-tide a much larger body of water would have to be provided for, for the same velocity as before would act over an enlarged section, and so on; the receptacle for the inundation, however large, would not be able to receive a supply which would go on increasing without any limit. We must either suppose that the neck of land between the basin and the sea is gradually cut away until the two are incorporated, or we must allow that the material removed by the tidal current from the mouth of the inlet, is heaped up at some point beyond, and that the resistances which would be formed would throw back the tidal current on the mouth. But we have assumed the full velocity due to the tidal rise to act directly on the mouth, while, according to the last supposition, the volume of the water would be reduced. I can see no escape from the conclusion that a complete blocking up of the mouth of the inlet, would ensue. We have supposed the soil to be of a yielding nature. Let us conceive the mouth of the inlet to have been revetted, or to be on rock, what would be the result in this case? It would make all the difference in the world. The tidal basin, if sufficiently large, would allow of the stream flowing into the inlet, the sides of which we have

supposed to be incapable of erosion, with the velocity due to the progressive rise of the tide. The bed, however, would be acted on, and if the materials removed were to be accumulated beyond the terminus of the revetted channel, the tidal current would be thrown back and a bar would be formed in advance of the mouth, like that described above in para. 38. If the bed were permanent, as well as the sides of the channel, it would depend on the depth, whether or not a bar would be formed. If it were sufficiently great to allow the stream to flow in, with the velocity with which the tide approached the mouth of the inlet, there would be no bar whatever. If, on the other hand, it were not sufficiently great to allow this, a crescent-shaped bar would be formed in front of the mouth; or if the whole of the shore were rocky, or incapable of yielding to the action of the current brought to bear on it, the tide would enter in a series of eddies or counter-currents.

43. In a case when the capacity of the tidal basin may be accurately known, as well as the rise of the tide and its velocity from hour to hour during the period of flow, then it would be no more difficult to predict the effect of a channel such as that above described in preventing the formation of a bar, than it would be to predict the effect of revetting an irrigation channel opened from a river, in preventing an accumulation of silt at its head.

44. Any reduction of the capacity of the basin which receives the tidal inundation, must have simply the effect of throwing back the stream, and of increasing the height of the bar.

45. Also an increase in a sea-ward direction, of the length of the tidal inlet, would, by reducing the surface fall of the stream, allow of a smaller body of water to enter; consequently groynes thrown out in the prolongation of the sides of the inlet, and above the high water level, instead of serving to prevent the formation of a bar, would actually produce a higher one than would have existed before. The most advantageous inlet that could be

conceived, is that in which the point of two rocky promontories form the sides.* This, of course, must be apart from any consideration as to the danger which vessels would encounter on entering.

46. The inlet to Kurrachee harbour is something of this nature, but the very limited capacity of the basin prevents a sufficient depth of water being maintained at the entry.

47. In cases where the tidal current runs parallel to the shore, the maintenance of a free inlet is not so difficult as in those in which the current is perpendicular to the line of the shore. The natural condition of an inlet in shifting soil, would then be similar to that of a creek or arm of a river when the stream does not bear directly upon it, that is, it would be shelving. If the tide carries along with it sand or other matter, the mouth of the inlet would, in time, be blocked up as completely as the old beds of rivers above described. But if the head of the inlet were contracted artificially, the deposit of silt might be checked there, at least in a great measure, and though the whole might not return with the ebb tide, a portion of it would, and if the capacity of the basin were sufficient to allow of the tidal current entering without any check, there would be no bar.

48. The principle which, above all others, has to be borne in mind, in dealing with tidal inlets, is, that the formation of a bar is primarily due to the insufficient capacity of the basin which receives the tidal inundation. It would be impossible to give general rules, by which the precise condition of any natural inlet might be determined; but in the cases in which harbours that were naturally good ones, have been injured by artificial works, or those in which harbours that were naturally bad have been improved, it will, to the best of my belief, be found that the tidal inundation was reduced in the one case and increased in the other.

49. I have not alluded to the formation of bars at the

* The harbours of Havanna and Port Philip may be cited as instances of this formation.

mouths of the rivers, but the fact is, a river has nothing to do directly, with the formation of a bar. So far as it impedes the flow of the tide, it will favour the formation of a bar; and as it must do this to a greater extent during freshes than at ordinary times, the bar will be higher at that season in consequence. Of course during ebb tide, the rivers will have more or less effect in reducing the height of the bar.

50. There is a bar at the mouth of the Po, and this may be pointed to as an instance in which the tide could have no effect, as it is generally supposed that the Mediterranean is a tideless sea. The fact is, however, that there is a tide at the mouth of the Po; that it rises between two and three feet and extends for seven or eight miles up the river. But even if there were no tide, it does not follow that littoral and other currents have no effect in producing a bar. The only way to ascertain the part performed by a river, is to observe what is the effect when it empties itself into a lake.

51. But to return to the peculiarities of the rivers of Upper India, as distinguished from those of the South. The existence of various natural channels in the country bordering on the Sutluj (which may be taken as a type of the Sub-Himalayan-rivers, which are most addicted to shift their channels) has been described, and their present condition of being entirely silted at their heads, has been accounted for, on the supposition that they were at one time branches or off-shoots from that river. Had they been independent streams, as at least one of them probably was, which, by the encroachment of the Sutluj, were intersected, and whose supply was thus absorbed, the supply of the lower portions of the trunks, would thus have been cut off from the initial velocity and momentum of the parent stream, and reduced to the condition of an arm of the Sutluj, dependent on a retention of its supply to the contingency of its momentum at the bifurcation, being always in the same proportion to that of the Sutluj.

52. This equilibrium could not possibly hold good for any considerable time. The volume of the water in the

Sutluj, acting as it does sometimes on the extreme right and sometimes on the extreme left of its channel, would either generate an excess of pressure on the head of the branch or the contrary. In the one case, the effect would be what I have above described, (para. 34), in the other, that of a comparative stagnation of the stream at the head of the branch, and the deposit of silt would gradually increase. Whether the branch had a greater or less fall than the Sutluj the result would still be the same, there being no alternative, as I have observed already more than once, between the Sutluj throwing its whole volume into the branch, or of silting its head completely.

53. The natural channels, then, are silted up at their heads, but with that exception they remain in perfect condition and form a remarkable feature in the face of the country, extending as they do, in some cases, to a length of upwards of a hundred miles. They have all the characteristics of inundation channels, that is, their banks are higher than the adjacent country. It is possible that some of them may have been, at a comparatively recent period, lines of drainage (indeed all rivers must have commenced as drainage channels) and from having been used as conduits for the supply of water for Irrigation, have assumed, by means of successive deposits along their margin, the peculiarity due to inundating streams.

54. Some of those channels have evidently also carried a partial supply (whether introduced by artificial means or in the course of nature, I know not) long after the bulk of the volume had been cut off, which has had the effect of reducing their section; and others again have been used as Irrigation channels for many years, the supply being replenished year by year by clearance of the heads. The width of the channels varies from about 50 to 400 feet, and their depth varies from 6 to 15 feet. The most important of them, called the Old Beas, has a width of about 200 feet and greatest depth of about 12 feet. It is exceedingly tortuous, the actual

length of the channel being 425 miles, while the direct distance between the extremities is only 225 miles. On the whole, the fall of the beds of the various channels corresponds very closely, the size not apparently having had much to do with it. It runs from 1 in 8,000 to 1 in 10,000, or from 8 to $6\frac{1}{3}$ inches per mile, and the resulting theoretical velocities without any deduction for bends, would nowhere exceed 3 feet per second, supposing the channel full. In the Beas with a depth of 12 feet of water at the deepest point, it would be $2\frac{1}{2}$ feet per second, and it would be considerably less, if proper allowance were made for the additional resistance occasioned by its extraordinary tortuosity. We should not, I believe, err much in considering the effective fall to be less than 1 in 10,000 or about 6 inches a mile. The same mean velocity $2\frac{1}{2}$ feet per second would be generated in an artificial channel with a side slope of 1 to 1, with a bottom width of 100′ and depth of water of 8·5 feet.

55. The channels, at least those of the size of the Beas or less, show no symptoms of having been subjected to any considerable changes. The deep bed runs along the concave curves of the bends, as a matter of course, and when the channel was full, there was no doubt some degree of erosion. But, on the whole, the channels are of a remarkably compact section, and when they happen to run straight, as they do in some places for a short distance, they are as perfect as if they had been cut artificially. The soil varies a good deal. The general formation, as before mentioned, is a stratum of alluvial soil, which contains a large proportion of clay, and sand beneath. In some places the channel has been coated with deposits of the former, and in others the sand is exposed. In the latter case erosion of the banks would take place to a considerable extent. In some of the other channels, the clayey soil is alone to be seen,* while the

* Supposing the supply of these channels replenished, the action of the stream would be less, than it would be in the case of an artificial channel to the right or left, where the soil is more sandy.

country at a little distance on either side is of the usual formation. I should suppose that this had been occasioned by the supply of the channels having become reduced, so as to cause a contraction by means of alluvial deposit, before it had been finally cut off.

56. I should not omit to mention that the depth I have specified is the depth below the lip of the channel, which again is above the level of the country at a little distance: further, that taking a section of the country in a line perpendicular to the course of the Sutluj, the banks of the channel would be found to occupy the highest points, and to be much on the same level as the banks of the Sutluj itself. The width of this tract of country which may be considered as under the influence of the channels, is in some places as much as 30 miles, but generally it is considerably less (W. of the Sutluj). Further to the westward, there is an abrupt rise which will be described hereafter.

57. I would now beg to draw some conclusions from the information that has been gathered from a consideration of those old channels.

1. It has been seen that their supply was cut off, by the loss of their original head of water, and that the heads became silted in consequence.
2. That with the exception of their heads they are in perfect condition.
3. That the fall is about 6 inches per mile.
4. That the greatest depth of a channel about 200 feet wide, is 12 feet, and that the highest theoretical velocity would be $2\frac{1}{2}$ feet per second.
5. That the uniformity of the section and the absence of any signs of violent action, or change of course, give evidence that the motion of the stream, when the channel was full, was uniform or approaching to uniformity.
6. That the soil is alluvial, but with sand underlying it, and, in some places, predominating.

58. If we return to the Sutluj, we shall find the general

fall of the country in a straight line, to be 16 inches a mile. To this limit, the surface of the water in the floods must approximate. The greatest depth of the water in the dry season is about 10 feet, minimum discharge $1\frac{2}{3}$ millions of cubic yards per hour, highest surface velocity $3\frac{1}{3}$ feet per second. Its course, in the dry weather, is excessively tortuous. Here then we have the river in a condition almost identical with that of the dry channels, and if the dry weather volume of water continued permanent, we may conclude that the Sutluj would assume a form similar to theirs, with the same tortuous channel and the same fall, and that its stream would become *uniform*. This it must approximate to every season, but at the setting in of the freshes the regimen is completely upset.

59. The water then passes over all sandbanks and islands, and the surface fall increases. It would be a mistake, however, to assume that it ever attained a fall (that is, in the direction of the current) equal to that of the country taken in a straight line parallel to its general course, or 16 inches per mile, with the full depth of 10 or 12 feet (the height of the freshes) in excess of the dry weather depth, in all from 20 to 25. A mean depth of 20′ and a surface fall of 16 inches a mile, would generate a velocity of about 7′ a second or nearly 5 miles an hour. Now, as we have seen that the condition of uniform motion is attained when the velocity is little more than a third of that amount, we may therefore conceive that a violent derangement of the bed must ensue.

60. It would be simply impossible that the velocity of 5 miles per hour should be maintained, and I may remark that whenever the velocity of a river is computed in the way I have arrived at this, it should by no means be taken as the actual velocity. If the bed of the river is disturbed after the velocity exceeds say $2\frac{1}{2}$ feet a second, then I would ask what becomes of all the material removed when the velocity rises to double or treble that amount. The water carries a certain proportion of matter in suspension, but it may

take up that, at the very base of the Hills, and unless to make up for the portion deposited during inundation, which however generally withdraws so much water entirely from the rivers, it can carry no more. The sand is displaced, and to a certain extent carried forward, but in the operation a certain portion of the velocity is destroyed. The capacity of the channel however great is not more than sufficient to carry on the volume of the water, and if it is enlarged either by deepening or widening of the bed, the material thus removed will go to contract it at some point lower down.

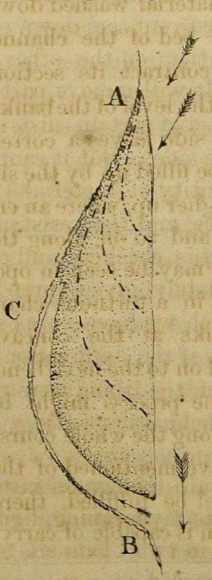
61. It would be impossible to arrive at a complete comprehension of the action of a large river in flood, but a general idea of it may be formed, which may be correct so far as it goes. The Sutluj occupies a channel,—as before explained, from 2 to 6 or even 8 miles wide, a portion of it being occupied by islands, which are only submerged in high floods. Conceive the river as flowing in two Channels, one on the right and the other on the left bank, with such an island between them. If on a sudden rise, the current sets down one of the Channels with greater violence than on the other, it will act more on the bed and banks. It will remove part of the sand and the earth washed down, to a certain distance in advance, and throw part of it on one side. But it cannot carry forward beyond a limited quantity of material. It must therefore be heaped up in advance, and the resistance will thus accumulate until the velocity is checked, and the water held back. This would immediately give a preponderance on the other channel, in which we have supposed the action to be less violent before, or if the bifurcation of the two Channels, that is, if the head of the island were too distant to allow of the water being held back so far, the stream would cut its way through it.

62. The process above described would then go on in the new channel. I have, better to illustrate my meaning, figured the volume of the river as passing in two Channels, one along each bank, but in reality they would be much more

numerous, and if it be conceived that this process of cutting, first one bank and then the other, is carried on in a width on the average of about 4 miles, it may be understood that the *work* thus performed in the course of a season, will be something considerable.

63. I have, by actual measurement in two different places, observed three quarters of a mile in width of high ground,—of old formation, and out of the limits of the channel, and only inundated in the highest freshes,—cut away in the course of a single season, along with villages and large trees, and not a vestige of them left behind.

64. I have been much struck by the fact, that when a concavity of this kind had been formed during the freshes, the river was generally to be found, at the close of the freshes, in its old course, leaving a large sand bank between itself and the concavity ; also, that along the foot of the curve, there was the remains of the deep channel—silted at the head, and gradually deepening to the other extremity. The form would be something in the fashion of the adjoining diagram. The dotted lines shew the progress of encroachment to ACB, the extreme limit. The change I have described as being common after the encroachment, is accounted for on the same principle as that above explained. The stream sets on the bank at A in the first instance, and continues to cut it to the form ACB, but the resistance of the bank would evidently go on increasing until the stream would be held back, and find itself a new course, not perhaps exactly identical with what it had before the freshes, but probably not far from it.



65. I have said the resistance offered by the banks would be considerable, but in fact, the resistance offered by them to simple degradation is trifling. It is more the *removal* of the material which is washed down, that would occupy the force of the stream. The alluvial soil would be melted and carried on to the nearest low ground, where there might be a stagnation in the stream, that is below B, but the sand must, I believe, be carried *across* the stream and form the sand bank on one side. The fact that strong under-currents, and also numerous Eddies are perceptible when the stream is acting on the banks, favor this impression. The banks give way so readily owing to the upper stratum of soil (generally of a hard compact clayey nature) being only from 3 to 6 feet thick. As the river rises the pure fine sand* below is sucked away by the current, and the bank falls by its own weight.

66. Though such extensive degradation of the banks takes place, it does not follow that the material washed down should serve to permanently raise the bed of the channel lower down, and by this means to contract its section. So long as the River in the freshes rises to the level of the banks, any enlargement of the channel on one side leaves a corresponding space on the other, which will be filled up by the silt which is brought down from the reach higher up, where an enlargement may also have been formed; and so on, along the whole course of the river. The process may be seen in operation on any small stream which runs in a tortuous channel, which on washing down the banks at the concave sides of the channel, carries the material on to the next bend, and deposits it on the convex side. The process might be continued on a series of similar bends along the whole course of the stream, and if the condition I have mentioned of the water rising to the brim of the channel be fulfilled, there will be no accession of silt, for the stream is capable of carry-

* So fine as to be utterly unfit to mix with lime.

ing on a certain amount of matter on suspension. If then it has to carry on the material abraded at the first concavity, it must at the same time deposit an equal quantity at the corresponding convexity.

67. In the case of a river cutting down its banks, which may be higher than the flood level, there must of course be an accession of material. It would serve to raise the bed somewhat lower down in the first instance, and permanently so, if the water should not during a portion of the season reach the spot less loaded with silt than it was capable of carrying. The Himalayan Rivers issue from the Hills for several months in the year perfectly clear, but in the alluvial plains they take up silt, and this aid may serve to remove any accumulations that have taken place during the freshes. Not having any of the Reports on the navigation of the Ganges at hand, I am not aware to what extent the "flats" which impede the navigation are due to the washing down of high banks at some distance above them, and to the accumulation of more material than the stream is capable of removing before the subsidence of the freshes. It is at all events sufficient to explain the fact, that in some rivers, for instance the Indus, the higher the freshes, the greater are the impediments to navigation, from shoals.

68. The bed of a river may tend to rise by degrees, and as the mouth advances seaward, it might be anticipated that the bed would rise throughout its course in an alluvial tract of country, and doubtless such a process must take place, and be perceptible in the portion of the river at no great distance from the sea. But this process may go on for ages without affecting the river in its upper regions. In the latter it would be difficult to say whether the continued raising of the adjoining country by means of inundation is due to a rise of the bed, or whether the rise of the bed is not due to the inundation. The fact is, a river has a certain regimen to retain, and will retain it so long as the soil through which it passes remains unchanged. If the bed rises, the banks will

rise in proportion, and if it be asserted that the fall of the stream will be changed by the extension of its Delta, I would point to the form of the channel, and ask if the river has not the power to adjust its fall.

69. The slightest rectification of sinuosities would be sufficient to make up for any raising of the bed, and banks in the lower portion of a river. For instance, I have described the direct fall of country along the Sutluj to be 16 inches per mile while the fall of the channel in the cold season (judging from that of the dry bed of rivers in the adjacent country) is less than half that amount. Supposing at the point where it joins the Chenab, the ground at some future time should be raised 4 feet above its present level, and that the actual length of its course is 480 miles (or double the direct line) from Ferozepoor, it would retain the same fall per mile, but with the surface 4 feet higher at its extremity, by rectifying its course $\frac{4 \times 12}{8} = 6$ miles, or one mile for every 80, or only 22 yards in every mile,—a difference so trifling as to be almost inappreciable.

70. The gradual raising of the land, will not only be the result of inundation from rivers, but must be produced in a similar manner by irrigation, supposing that alluvial matter is thrown on the fields. The process may be so gradual, that it may be unnecessary to make any special provision against it; but it is evident, that sooner or later the loss of fall would have to be made good. On most irrigation wroks on a large scale, there is generally an excess of fall, more than sufficient to make up for any possible raising of the land; but one may easily conceive a case, where there might be none to spare, where by means of a channel of moderate dimensions, the supply of water could only command a very limited area of land, owing to its being on a high level. As this became higher by the gradual deposit of silt in the fields, it would obviously be necessary, in order to keep up the irrigation to the same area, or in other words to supply the same

quantity of water as before, that the channel should be enlarged to make up for the loss of fall, or if there were the means of raising the initial supply, the same result might be accomplished. In the case of a channel from a river, this might be done by either opening a head at some point higher up than the existing head ; or, if local peculiarities prevented this being done, the only alternative would be to raise the water at the channel head, by means of some work on the river, or if such a work already existed, by raising it higher.

ON THE HEADS OF IRRIGATION CHANNELS, OPENED FROM A RIVER IN ITS NATURAL STATE.

71. The selection of sites for the heads of Irrigation Channels must depend so much on local considerations that no general rules can be laid down. If a channel is designed to fill a tank only, by the supply which is thrown [illegible] from time to time by the higher freshes, the management of it must be more simple, than in a case where a channel is used directly for irrigation, and is required to retain a supply for several months continuously.

72. Putting aside the question of expense, which must vary in different localities, it may be asserted that the chief difficulty to be contended against in rendering Channels efficacious, is the precarious condition of the supply of water at the close of the irrigating season. The heads of Channels then will have become more or less silted up, and there is seldom time to clear them, for if they were closed for a fortnight or three weeks, the crops dependent on them would probably be ruined. Some slight improvement might be effected in that time, were there a prospect of a subsequent rise of the river, but the excavation would be carried on under difficulties owing to the percolation of the water which is held in retention by the soil, and if the river were not to rise again, the replenishing of the supply would be hopeless by that means.

73. Bunds are another remedy to be tried occasionally; and while there is a chance of their succeeding, recourse must be had to them. They may answer on some rivers, and be almost sure to fail on others.

74. Cuts on the bed of the river itself, it may be to lead the water into one of the minor Channels or creeks, which feed the Irrigation channel, are also almost certain to be ineffectual. Though the fall of the surface may be great, the infiltration of the water, as the excavation proceeds, renders it impracticable to attain the required depth.

75. All these works refer to replenishing a channel when the supply fails at the close of the season. Of course, the necessary clearance or other excavation may be easily carried on during the dry weather, for the next irrigation season. But as a rule, if the supply fails at the close of the irrigation season, but no temporary expedient can be counted on for restoring it.

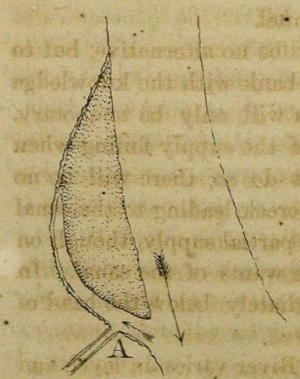
76. It therefore becomes an object of high importance to fix the heads of Channels in positions where they will be least liable to silt up, in order that they may have no greater obstacle to contend with, than what is inevitable,—that is the chance of an insufficient height of the freshes. Unfortunately, unless in a river which flows in a permanent channel, it is impossible to find a site, where the head of an irrigation channel will not be exposed to silting. The advantages of any sites will only be relative: no general rules, either, can be laid down for selecting them; so much must depend on local peculiarities, that what might be sought after on one river, would have to be carefully avoided on another. It will depend on the nature of the soil, fall, &c., and the height of the water, whether it is advantageous or otherwise to expose the head of a channel, to catch the full effect of stream in the River. In some places this might be a desideratum, in others it would simply destroy the channel.

77. I would therefore confine myself to a few observations on particular cases on which I have found Channels to be defective or otherwise.

78. 1: When opened so as to have the stream in the river bearing on the head as much as possible. If the soil is not extremely tenacious, the banks at the head of the channel will be washed down, and the material thus displaced will block up the channel. If the sides of the head are revetted, a great part of the evil may be averted, but it will be found that this will not prevent sand banks accumulating in front of the mouth, and if the stream acts on the bed, a large quantity of material may be carried forward to the lower portions of the channel (para. 38).

79. If a canal is opened from a bank which the river shows a tendency to set against, and cut down at any point above the head, then there must be evident danger of the canal being chocked up by the material which would be washed down.

80. In the case of a river which is liable to occasion mischief of this kind, the most suitable point for opening a channel is where there will always be a sufficient depth of water without any violent stream acting on the banks. Perhaps the most suitable of all conditions would be if the river passed at right angles to the head of the channel, but as there could be no certainty of its continuing in that direction, it would be better to avoid such a site, and to select one where the water would be comparatively stagnant. For instance, if the river flows in the direction shown in the adjoining diagram after receding from a curved channel, which it may have formerly cut for itself by encroachment on the bank, or if A be the tail of creek or arm of the river which leaves the main channel at some point higher up, there will be a backwater there, and, although the stream may pass over the sand bank or island with considerable velocity in the freshes, it will be



less than that of the main stream, and less likely to do mischief. The point A would therefore be a good site for the head of the irrigation channel. It must be observed that the backwater may be of recent formation, and that its mouth may tend to advance down stream, so that care should be taken to have the head of the channel sufficiently low down to guard against the contingency of the channel in front becoming dry, and at the same time not so low as to bring it within the influence of the main stream.

81. It will frequently be found that there is no eligible site for the head of a channel in the bank of the River in an interval of many miles. The River may have receded towards the opposite bank, leaving a mass of sand banks between it and the point where the channel may be required. In such cases, however, there is generally the dry channel of the River or of a branch of it, running along the foot of the bank, and it may be necessary to follow it up to its head, and perhaps to clear it, in order to make use of it as an artificial channel. The head of such a channel, if there is any choice on the matter, should be selected on the same principle as that of an artificial channel, care being taken to hug the bank as much as possible, or at least to remove all the soil excavated, to the side which will be furthest from the action of the stream in freshes, or it would otherwise be washed into the channel.

82. In some cases there may be no alternative, but to cut through the head of a sand bank with the knowledge that the effect of any excavation will only be temporary. There will then be great danger of the supply failing when the River subsides, and should it do so, there will be no remedy, unless it may be that the creek leading to the canal may be large, and may derive a partial supply, though on too low a level to suffice for the wants of the canal. In this case, a bund across it immediately below the head of the latter may be of some service.

83. If the country along the River varies in level, and

the lower portions are subject to inundation while the higher are not, unless perhaps in extreme floods, care should be taken in a case when it may be desirable for the sake of economy to open the canal in low ground, that the line should be carried as nearly as possible adjacent to the higher ground on the down stream side, in order that the channel may not be liable to be taken in reverse by the inundation, and to have its banks washed down.

84. If the canal is to be furnished with a sluice, it should be constructed as near the head as is consistent with its stability. If the bank of the River, and the head of the channel can be rendered secure against injury at a moderate expense, by means of revetments or groynes, the efficiency of the canal would be much promoted by constructing them; but if the River is not tolerably permanent, and there is the likelihood of the Canal head being left at times high and dry, with the necessity of opening a new head at some point higher up or lower down the River, the sluice and works connected with it would be rendered useless. When however there are no such disadvantages to contend against, it would seem highly desirable that every channel should have its head sluice, in order that any excessive supply of water may be prevented from entering. Unless it is built at the head of the channel, this advantage cannot be obtained without the inconvenience of a deposit of silt in the channel between the head and the sluice. The extent of this will of course depend on the height of the water, and the time during which it is held up by the sluice. If the interval between the sluice and the head is considerable, this evil, would be serious; and in many cases, it would be better to construct the sluice at the head, with the chance of its being destroyed. This, however, is a question to be decided separately for each case on its own merits. If a sluice is required to prevent inundation, and if disastrous effects would ensue from its destruction, it might be advisable in such cases to have a second sluice in reserve, at a sufficiently safe distance from the head.

ON THE FALL OF IRRIGATION CHANNELS, VELOCITY, &c.

85. It will not be disputed, I believe, that the higher the velocity of the water in a River or Canal, the heavier will be the amount of matter held in suspension and carried forward by it. While one velocity will take up alluvial matter only, another will take up sand, and if the velocity in the latter case is reduced, the sand will be deposited in proportion.

86. If it be desirable, as it generally is, to convey alluvial matter by means of the Canal water, to the fields which it irrigates, while the introduction of sand must as a rule be noxious; it must evidently be also desirable to moderate the initial velocity as far as possible to prevent the influx of the latter, and also to prevent its being retarded at any point, so as to cause a deposit of alluvial matter.

87. The initial velocity is, however, dependent on the rise of the River, and does not in practice admit of regulation; and the introduction of sand may therefore be considered as a necessary evil, which it may be possible to lessen, though not to remove entirely. As regards the alluvial matter, however, the case is otherwise. The alignment of a Canal might be conceived so perfect, that there should be no change of velocity, excepting at the head along its whole course: that the velocity should thus be kept up to the point of delivery of the water on the fields; and that there should be no accumulation of silt in the bed of the channel, unless in the immediate vicinity of the head, where, in the event of the Canal being furnished with sluices, which do not admit the full height of water due to the level of the River, the supply will enter with a greater velocity, than will be possessed by the stream on the Canal itself, and where a deposit of silt must therefore necessarily take place.

88. It is seldom, however, that Canals are aligned so perfectly in regard to their fall, that no change of velocity is

produced. The fall of country generally becomes less and less, the further the Canal is carried from the head, while the width of Canal has to be reduced in proportion as the water is expended. This would render it necessary, in order that there should be no loss of velocity, that the fall of the channel should constantly increase;—which local peculiarities may render impossible of attainment. Still it should always be borne in mind that a Canal will be more or less perfect, according as the velocity is kept up, or is diminished, throughout its whole course.

89. The fall from the head sluice to the point of delivery indicates the whole effective fall, and if this is one foot per mile, it follows that in order to retain the velocity, the main channel must start with a lower rate, while, if continued in a straight course, it would admit of the channel which actually delivers the water to the fields having a higher rate of fall than 1 foot per mile.

90. If the fall of the country is greater the slopes of all the channels may be increased, up to the limit of the capability of the soil to withstand erosion, but the rate should always, if possible, increase as the Canal progresses.

91. In some cases as in the Canals opened from Rivers at the base of the Hymalayas, this is quite unattainable owing to the extraordinarily high fall of the country near the Hills, but the silting in those Canals may be kept partly under the use of scouring sluices in the cold season, when the water enters the Canal quite pure.

92. It may also be considered necessary on economical grounds, to allow a high fall at the head of the Canal, when the fall of the country is rapid, and when the cutting at the head itself is excessive. As for instance, on the Baree Doab Canal where the depth of cutting at the head is about 60 feet. If the fall were reduced the width of the cutting would have to be increased, and add enormously to the expense.

93. But in a Delta where the fall is tolerably uniform

the slope of the bed of the main channel should be less than that of the branches, which again should be less than that of the minor channels and cuts.

94. Not only for the reasons above stated, it is desirable to give a low proportional fall to the main channel, but it is also of importance that the water should be brought to the surface, and applied to irrigation as quickly as possible. If the cutting up to this point is considerable, the question may arise whether it might not be better to have a higher rate of fall, and thus a smaller width of channel, and consequently a less expensive one, and thus by leading the water to the surface to some point further from the head, to sacrifice a portion of the irrigation. This must be decided by actual calculation in each case.

95. As to the actual fall which should be given to the main trunk of a Canal, apart from the consideration of expense or in fact any considerations, but that of the maintenance of the channel in good working order, I would name 6 inches per mile, in preference to any other, for alluvial soil of moderate tenacity—on the supposition that the depth of water will be from 6 to 10 feet, and the width considerable (say 100')—being nearly the same that I have observed has been adopted by channels in their natural state, in similar soil. I would by no means insist on this being the best fall in all cases.

96. I assume the slope of bed to correspond with the slope of surface, but it may be desirable to cut down the head of the Canal, so as to yield a smaller slope of bed, in order to obtain a supply of water at an earlier date in the season. But the bed always tends to follow the slope of surface, as will be obvious from the consideration, that if the depth is greater towards the head than it is at some point lower down, the velocity (supposing the width to be the same) will be less and silt will consequently be deposited until the velocity throughout becomes uniform. Such a diminished slope at the head must therefore render necessary a considerable annual clearance.

97. On the assumption that a surface fall of 6″ a mile or say 1 in 11,000, is suitable for the main channel at starting, with a width of 100 feet, I proceed to shew the rate at which the fall should be increased as the supply becomes less.

98. Let us suppose that branches are drawn off, taking a certain proportion of the water, and that the width of the main channel is reduced by successive degrees to a width of 80, 60, 40, and 20 feet, and that the depth is reduced successively to 5½, 5, 4½ and 4 feet, but that the velocity throughout is maintained, at what it had at starting with a width of 100 feet, depth 6 feet, surface fall 5·7 inches per mile,—namely, 2·1 feet per second. By means of the hydraulic formula, I find the fall of surface required in the different cases will be 6·4, 7,7·9, 10·3 inches per mile. From the terminus let a channel leave with a depth of 3 feet and width of 10 feet reduced after consumption of a portion of the supply of water, to a width of 6 feet and depth of 2½ feet. The velocity to be the same as before. The fall required for these channels will then be 14·8 and 19·5 inches a mile ; and if we suppose the length of each of the first mentioned channels, or reaches of channel, to be 10 miles, and that of each of the two last to be 5 miles, the whole fall from the head will be somewhat more than 45 feet, and the whole distance being 60 miles, the average would be 9 inches per mile. If the fall of the country did not admit of so high an average, it might be easily reduced by maintaining a greater depth in the channels and diminishing the width. If for instance, in the case above-mentioned the depth for 50 miles had been maintained at 6′, the total fall required would only have been 26 feet, or on the average 6¼ inches per mile.

99. The above will be sufficient to indicate the mode in which the slope of the channel should be regulated in order to prevent accumulations of silt. In practice a Canal is never perfectly aligned on this principle, but unless it can be shown to be defective, as I have no reason to think can be

done, every endeavour should be made to adhere to it, in designing a system of Irrigation works, so far as local peculiarities and other circumstances permit.

100. The accumulation of silt in channels, particularly in the main channel is not only a serious impediment to maintaining a supply of water till the crops are matured, but the clearance may be enormously expensive. Even if the silt cannot be carried on to the fields, as in a perfect Canal, one may conceive possible, one step in advance is gained, if it is prevented from accumulating in the main channel; for the maintenance of the supply in it is the most essential point, and if there are deposits in the branches only, it may be possible to clear them in turn, without cutting off the supply from the river; or if this might not be feasible with the branches, it would be so at all events with the smaller irrigation channels; and it would not only be advantageous to throw on the silt to them, and to clear them in turn, without cutting off the supply of water from the branches, but the clearance would evidently be much less costly from them, than it would be from the larger channels.

101. When the fall of country is so gentle as not to allow of the fall of the channels being gradually increased from 6 inches a mile, it would be necessary to reduce the initial slope somewhat. A very slight reduction, would, as it affects the whole of the channels onwards, in the aggregate, mount up to something considerable.

102. If, on the other hand the fall of country may be too great, the initial slope may be increased, with if necessary a reduction in the depth of water; or if the fall of country is rapid at first and afterwards more gentle, the desired result may be attained by constructing perpendicular drops at intervals.

103. Any change of direction causes a certain loss of velocity, and the water thrown into branches and minor channels would loose velocity, in passing through the head-sluices, unless they possessed the full water way of the

channel. Due allowance would have to be made for this, by adding somewhat to the slope at the heads of the branches and channels.

104. It should be observed that by diminishing the fall of large channels, there is a gain to the minor channels not only of actual fall but of relative fall. Thus, if the fall of country is one foot per mile, I may assign that to both the main channel and the branch, but if I reduce the fall of the former to 8 inches a mile—before the branch leaves it, I gain for the branch, not only the velocity due to a one-third greater fall, but, for the number of miles of the main channel for which the slope has been reduced 4 inches per mile, I may add it on to that of the branch and make it 16 inches per mile.

105. The principle above described of the necessity of keeping up the velocity to the point of the delivery of the water, is so obvious that it must have occurred to every one, who has had much to do with Irrigation works; and I should not have thought it necessary to dwell upon it, at such length, had I not reason to believe that it is very much lost sight of in practice.

ON SILTING.

106. Any one who bears in mind the fact that a change from a greater to a less velocity must occasion a deposit of silt, would have no difficulty in foreseeing the effects in which any hap-hazard alignment of a series of channels would result:—still to make the subject as clear as possible, I would propose to enter into a consideration of the cases of defective arrangement of fall, which seem to me to be most likely to occur in practice.

107. A channel starting from the lower floor of a masonry drop, has a fall say of one foot per mile for 5 miles, and afterwards proceeds with the reduced fall of 6 inches a mile for another 5 miles, the width of the channel being designed so as to retain the same depth of water in both reaches say

6′ and the levels at the terminus being supposed permanent. In this case as the velocity in the lower reach is less than that in the upper; a portion of the silt brought in by the water must be deposited in the former—and it is evident that as the bed at the commencement of the lower reach became raised, the depth of water towards the terminus of the first reach would be greater than the normal depth of 6 feet; and as the surface fall, and therefore the velocity would be less than that at the entry, deposit would take place there also; and the process would continue until a uniform slope of 9 inches per mile was established along the whole distance of 10 miles.

108. Again the velocity and depth can only be maintained by having a uniform width throughout the whole distance. If it were allowed to increase the depth of water until a surface fall of 9 inches per mile generated the same velocity as a fall of 12 inches with depth of 6 feet (that is to increase it to about 8′) the deposit of silt would then be entirely prevented and the channel would present a uniform section, and slope of bed from the head to terminus of the reach; but if the surface of the water at the head could not be raised sufficiently to admit of this, the discharge of the channel would be reduced.

109. In the case of a channel of the same section changing from a less to a greater fall. The permanence of the bed in this condition, would depend on whether the velocity generated by the higher fall sufficed to tear it up. If it could not do so, the depth in the lower portion of the channel, would of course be less than in the upper; and the surface slope of the latter would thereby be increased. The velocity would diminish as the depth increased towards the head, and deposit of silt would therefore take place—gradually, increasing in quantity up to the head, which would assimilate the slope of the bed in the first reach of the channel to that of the lower.

110. If a channel of a certain section passes into one of

smaller section with the same fall. The water in the lower part of the channel must obviously be deeper than in the upper. The surplus slope would therefore be decreased in the upper portion and silting would ensue—by a diminution of the width where the depth was in excess, that is near the change of section, but as the section of the upper channel is diminished by silting, an additional height of water must be required to maintain the supply up to the original quantity, or to what is supposed to be flowing in the lower channel. This would result in the surface slope being equalized to that of the bed and the depth of the upper portion of the channel the same as that of the lower, and the width also, the section of the former having been gradually contracted by silt deposits, until it corresponded with that of the smaller channel.

111. A channel having a width of 50 feet, length 10 miles, fall of 6 inches a mile, passes into another of equal length, with a diminished width of 30, and fall sufficient to maintain the same depth as that of the upper channel, say 6 feet. If the velocity in the 2nd channel were sufficient to act in the soil, it would gradually deepen the bed until it assumed a uniform slope throughout. If the width of second channel remained unchanged at 30 feet, the other channel would assume the same width and in order to maintain the same supply as before the depth of water would have to be increased, or if the action of the stream in the lower channel served to widen as well as deepen it, the section of both channels would be rendered alike, the latter being enlarged, the upper contracted, sufficiently to allow the stream to uniform depth throughout of 6 feet.

112. I have supposed that the material which is washed down is carried on beyond the terminus, but should the channel at any point further down, have a less fall than the rectified bed above described, the material would be deposited there. There would then be a decrease in the effective all of the whole channel, and the bed would assume a more

gentle slope than that above described, while, in order to maintain the same supply as before, the depth would have to be increased.

113. If we suppose that the bed of the lower channel is permanent, or that a masonry work, as for example, a bridge with a flooring, is constructed across the channel where the fall changes from 6 inches a mile, to a greater, then as the surface slope cannot change suddenly, and as the depth is supposed to be 6 feet, it follows that the greater slope (that is of the lower channel) would be continued for a certain distance in the upper channel. But this would increase the depth, and therefore diminish the slope of the surface from the head. To maintain the supply the same as before, the depth at the head would have to be increased. But as the supply would then pass through a larger section, its velocity would be less, and silting would ensue.

114. If the fall of a channel is so great as to cause erosion of the bed, the material removed will serve to raise the bed at some point lower down, and this process if left to itself would continue until the slope should become uniform, and the velocity be so reduced, as to no longer act on the bed. Or if the stream is not prevented from acting on the sides of the channel it will cut for itself a series of sinuosities, until an equilibrium is established. In the latter case, it would not follow that the surface and bed of the stream should be changed with reference to the level of the country, as would have been the case, if the straight channel had been preserved, although, of course, the material that would be washed down, would serve to raise the bed of the channel, unless removed by artificial means.

115. Thus if the direct fall of the channel were 18 inches a mile, when that required to prevent erosion, should be 12 inches a mile, the channel might assume a serpentine form, so that the length of its course should be one and a half mile, for every mile in a straight line. The level of the bed at each point where the new course intersected the old,

would, in every case in which the above proportion of the lengths held good, remain the same as before. Were it however considered necessary, as it generally would be to maintain the Canal in a straight course, the process of cutting in the upper portion, and raising in the lower, would have to be checked by the construction of masonry drops or falls, by which the excess of velocity might be neutralized; and if we suppose, for the sake of illustration, that they are constructed at equal intervals apart, then by building half the height above the level of the original bed, and half below, and allowing the proper difference of level from one to the other, the action of the stream, by cutting away the soil from the bed in the upper half of the reach and depositing it in the lower, would adjust it to the required slope; but of course, the reduction of the slope of bed, would render it necessary, in order to maintain the supply the same as before, that either the width of the channel or the depth of water should be increased.

116. In the case of an aqueduct or bridge constructed with a diminished waterway in a channel, of which the fall above and below is the same, but with an additional fall along the masonry work in order to pass the water with the same depth, but with a higher velocity, let us suppose the work to be an aqueduct of considerable length, and that the supply is constant. Then the depth along the aqueduct must be constant, or the slope of the channel above or below must be changed. But it is impossible that there should be a sudden change from one velocity to another. However gradual, the contraction at the mouth of the aqueduct might be, the fall of the surface in front would be greater than that of the bed of the Canal, as at first assigned, the surface in fact would be higher than that due to the slope of the channel; the fall of surface from the head of the channel would therefore be less than that assigned to keep up a uniform discharge. To rectify this, the depth of water at the head would have to be increased. Also at the lower extremity

of the aqueduct, there would be a loss of motion in communicating the greater velocity of the water from the aqueduct, to the less velocity of that on the channel beyond. The water would not pass off so freely as it would have done, had the lower portion of the channel been a simple prolongation of the upper; and the retardation of motion thus produced, would have to be made good by an increase of depths, in order to pass off the given supply.

117. In the channel above the aqueduct the increase of depth, would cause the bed to silt up until the capacity became the same as at first, also the width of the channel near the aqueduct would be contracted by deposits, until the sides assumed a curved form, the width between them being inversely as the velocity of the stream at different points, the depth being supposed to continue uniform.

118. In the case of aqueducts, bridges or other constructions, in which the waterway is less than that of the channel, not having any excess of fall over that of the channel, the stream would still assume the same surface fall as that above described.

119. I must own that I can see no objection to a moderate contraction of the waterway of bridges and aqueducts; especially of the latter, where the saving of expense may more than counterbalance the loss of fall and other defects, such as the silting above described, and the action of the stream on the bed of the channel at the lower extremity of the work. In most cases the loss of fall would be of no importance, but were an aqueduct or bridge to be constructed near the head of a Canal in a Delta, a difference of two or three inches might materially affect the supply. It has been explained that a contraction must hold up the water on the channel above it, and that in order to maintain the supply which the channel would have carried, had there been no contraction, the water at the head must stand at a higher level than would otherwise have been required. But if the surface of the river cannot be raised to this level, the supply must be reduced,

or if the width of the channel is increased, the deposit of silt will also increase. If there is a head of water in the River to spare, the contraction of the head sluices of a Canal would not be objectionable, but if, as is often the case, the River falls below the height required to maintain the supply, any loss of head occasioned by the contraction, would still further reduce it, and perhaps be the cause of serious loss of crops. If we suppose a case in which the head sluice of a channel opened from a river when an Annicut has been constructed, and assume that the contraction of the waterway induces a loss of head of 6 inches, when the River is at its lowest during the irrigation season; then the Annicut is 6 inches higher than it need have been—that is, had the waterway of the head sluice been the same as that of the channel, the same supply of water would have been thrown into it, with the reduced height of Annicut. In practice, in cases where the level of the River is subject to great fluctuations as in those in the Madras presidency, it is difficult to arrange the head sluices of Canals, so that inconvenience either from excess or defect of head of water, may not at times be experienced.

120. In aqueducts across drainage or other channels, in which the water may rise to the surface of the ground or above it, the surface of the water in the Canal will probably be many feet above the level of the ground,—as for example, at the Roorkhee aqueduct on the Ganges Canal. If the velocity occasioned by a contraction of the waterway were so high as to endanger the embankments at either extremity, or to tear up the bed of the Canal at the lower end, the propriety of contracting the aqueduct would then be very questionable.

121. In falls, when it may be desirable to distribute the momentum of a large body of water, over as large a surface as possible, it may be necessary to allow a width of waterway equal to that of the channel, like the falls in the Ganges Canal, but in Canals where there may be no reason to apprehend any dangerous effects from the more concentrated action of the stream, I see no reason for building works of the kind on so

expensive a scale. It must generally be desirable to maintain the full depth of water above the fall, and to do this the section must be contracted by degrees until the width of the waterway should be capable of discharging the water, with a velocity due to the height of the surface of the water, when the Canal is at its full width, above the crest of the fall, plus the height due to the actual velocity of the stream at the full width. In the vertical falls on the Baree Doab Canal, an ingenious arrangement has been contrived by Captain J. H. Dyas, Director of Canals in the Punjab, by which the velocity of the water in its approach to the falls, is not at all accelerated, and any risk of accidents to boats is thus removed. The water is made to fall vertically through a grating, laid at a slope of about 1 in 3, and formed of wooden bars tapering off on the down stream side. The action of the water may by this means be spread over as large a surface as may be wished.

122. But to proceed with our illustrations of silt deposits. A channel after proceeding a certain distance with a considerable fall, passes into one with nearly still water (suppose for navigation) while the surplus water is carried off by a branch or escape, at the junction. The head of the navigation channel will be silted up, and should the water running past it into the escape have a considerable velocity, and carry a large proportion of silt in suspension, the head would be soon completely blocked up. Suppose the depth to be limited. It may be said that the navigation channel, once filled could hold no more, and as the water in it would be stagnant, there could be no introduction of silt. On the same principle it might be said, that a channel which passes through the bed of a tank, and the water from which would extend up to the tank banks at a considerable distance from the line of the channel, would not silt up the bed on either side, yet every one who has seen an instance of this, or of a similar enlargement of the channel, could not fail to have observed, that the silt was deposited to the right and left, and that it was

evidently only a question of time, whether the raising of the bed of the tank, should extend, if not over the whole surface, at least along the margins of the channel, up to the level of the water in the latter, from which it would slope away in the form of a glacis. But though the condition I have described can be thus readily observed, it admits of being explained by the known principles of the motion of water, and it is more satisfactory to take them for the foundation of an argument, than to point to isolated facts. It will surely be acknowledged that it is impossible that the water which passes into the branch or escape above described, should communicate with the water, in the navigable channel, without impressing some movement upon it. It is a well known law of running water that a stream could not be in communication with still water, without imparting motion to it, in the same direction as its own. The particles of the still water would be drawn on with those of the stream; but as the surface would thus be lowered, motion in another direction would be communicated, which would thus keep up the supply of water to an uniform height; or in other words it would communicate a rotatory motion, that is, form an eddy—carrying silt with it, and depositing it wherever the velocity should be retarded. The process would go on, till the head of the navigation channel should be completely choked up; and if we suppose that instead of being on a dead level, it has a slight fall, the silting will not only take place at the head, but extend further, in proportion as the quantity of water admitted into it, is increased. For as all the water that passes into the navigable channel, is supposed to have a lower velocity, than the supplying stream, every cubic yard of water must deposit a certain proportion of silt, and the capacity of the channel would thus be gradually reduced, until if not cleared out, by manual labor or other means, it would be shoaled up, not completely, but in a slope, commencing at the head of the channel and fading gradually off to the terminus. In a still water Canal, on the contrary, the head only would be blocked

up, though if the water rose at any time above the normal height, it would generate a fall of surface, and the fresh supply of water that would be thrown in, would serve to extend the silting further.

123. As instances of the results above described, I would point to the heads of locks, which are opened from a River, or to sluices at the heads of irrigation channels, which may be situated at some distance from the River. Every one who has had charge of such works must have observed, that they become blocked up in a wonderfully short time, if the River from which they are opened carries a large amount of silt in suspension; and as regards the silting of open channels, with a less slope or velocity than that of the River which supplies them, the above remarks, I may say, are applicable to all such Canals whatever. It is a question of time only, whether their heads become completely silted up or not, and if the velocity of their stream, though great, is still less than that of the River, the silting would only extend to a greater distance from the head, or in other words, the greater the quantity of water that is carried into the canals, with a less velocity than that of the River, the greater the quantity of silt that must be deposited.

124. There is no remedy for the latter process, but in the case of the navigable channel which I have taken as an example, and in that of the lock or sluice at some distance from the River, in which the water is supposed to be stagnant in the interval, the remedy evidently lies in preventing the contact of the stream with the stagnant water. If, for example, a lock were constructed on the navigable channel, immediately below the point, where the stream was supposed to pass in another direction, no silt could enter the channel, except what would be due to the quantity of water let in by a sluice or through the lock valves or culverts to make good wastage. There would be an abundant deposit of silt in the front chamber of the lock, but this must be considered an inevitable evil, for which there is no remedy, unless by actual

removal of the silt, or it might be possible in some cases to establish a culvert in front of the lock gates, which should communicate with a channel, having sufficient fall to allow of the silt or a portion of it being periodically scoured out.

125. In the case of a channel, which is provided with a head sluice, the only way to prevent unnecessary silting, that is silting when the sluice is closed, is to have no reach of stagnant water between it and the River. As I have remarked in a former page, it would be desirable to have a second sluice, even with the chance of its being destroyed, in the immediate proximity of the River, which would give the power of shutting out the high freshes, as required. In many cases, however, this would be impracticable.

126. With regard to the entrances to locks, I may explain that there is a choice of two evils—silting or a dangerously high current: it is impossible in Indian Rivers to escape entirely from both. Danger to boats when actually entering a lock may be entirely prevented, if an eddy is formed in front. This may be produced either by a groyne run into the stream to the height of the surface of the water, at a short distance above the lock, or by a hill (as at Bezwada) or other natural projection, against which the stream impinges, and then strikes off clear of the lock channel. The counter-current which will thus be formed may yield a perfectly safe anchorage, and allow of boats entering or leaving the lock without inconvenience, but in proceeding up or down stream past the natural or artificial projection above mentioned, they must be subjected to a more than ordinary current, that is, a stronger one than they would have had to encounter, had the projection not existed. But notwithstanding this disadvantage, I believe that the condition I have described is the best that can be obtained in a River like the Godavery and Kistna, from which lock channels may be opened in the proximity of an Annicut where there is a current of from 6 to 10 miles an hour. It will be observed, that in this case, the lock may be close to the

eddy, whereas if the channel is opened from the *stream*, there will have to be a kind of basin to facilitate the movement of boats, which will be constantly silting up and blocking the gates.

127. In the case of a lock which may have been constructed at some distance from the stream or from an eddy such as I have described, the channel in the interval will be silted to a great extent. This will be produced chiefly by the high freshes, and as navigation, at least up stream, would be slack at that time, it may be worthy of consideration whether a sluice might be established at the head of the channel, immediately adjoining the stream or eddy and furnished with shutters or baulks working in grooves, and fitting one on the other, so that the higher freshes might be shut out entirely, or if it were required to pass boats, only a sufficient number of the shutters or baulks should be removed, as would give them the necessary depth of water.

128. The remarks I have made as to the necessity of having a masonry work at the head of a navigable channel, such as is above described (p. 124), apply with equal force to channels from which branches or escapes are opened, with a higher fall, or with a fall sufficient to produce a higher velocity, than that of the main stream below the head of the branch. I could point to an instance of a temporary head being opened for a branch channel of which the fall was much greater than that of the main stream—at the distance of about three quarters of a mile above a lock; and very heavy silting being the consequence.

129. The effect of passing the stream into the branch, was to stagnate the water between it and the lock, and to produce a deposit of silt along the bed to a depth of from one to two yards every season. Had the head of the branch been at the lock, it is evident that nearly all the silt might have been thrown into the branch, where it would probably have been less productive of inconvenience.

130. As another instance of rapid silting on Canals, I

may mention a case, in which a bend in an irrigation channel was cut off. The length of the bend, from which the stream was diverted was upwards of half a mile, its width about 50 feet, and depth from 6 to 8 feet; yet in the course of two or three months, it became so completely silted up,—no bunds having been constructed—as to leave hardly any signs of a channel at all.

181. It may occur to the reader that much of the silt which is deposited in the beds of channels might be removed by means of scouring sluices or escapes, but he must bear in mind that unless the velocity of the water at the head of the channel be equal to that of the River from which it is opened, there must be a deposit there, and although a scouring sluice may have considerable effect on the bed for some distance from it, it cannot clear the bed at the head, unless it generates a velocity along the Canal equal to, or perhaps exceeding that of the River, as far as the head sluice. This can rarely be practicable; and even if it were, the scouring sluice could only be used at times when the water it throws off can be spared. But in this case, it would generally if not always be desirable to cut short the supply at the head, and to allow of only so much entering as should be required for actual consumption. This unfortunately is not always practicable. Brush wood may become entangled in the vents of the head sluices,* and prevent their being closed; and besides it would be impossible to regulate the supply to a system of channels to prevent their ever being an excess, unless there were means of communicating along them by a series of Telegraphs. It is therefore, necessary, to provide

* It would seem to be very desirable, that there should be a double set of shutters for the head sluices—one in front, the other in rear of the vents—to obviate this inconvenience, which is a very serious one. It would save an immense amount of silting if the water from the River were cut off when it was not wanted, and may avert accidents. One of the shutters of the Vegaishwuram head sluice, Godavery, was blown in last year by an extraordinary high flood. A set of shutters in reserve would be very valuable in cases of the kind. They would be placed in position before the River should rise to a dangerous height.

means of disposing of surplus water, of which no specific description is called for. I would only repeat, that it is highly desirable that the heads of escape channels should be opened in the immediate proximity of a masonry work across the main channel, in order that there may be no still water between it and the escape. I may add that the vents of the escape should be on as low a level as possible in order that the water, and with it the silt may pass with a high velocity. A calingula, such as is generally constructed in a Tank, is a convenient form of escape in so far as it requires no establishment, or at most a very small one, to look after it. But it is unsuitable for channels in which silt accumulates and the greater the number of openings that are pierced in it, that is the more it approximates to the form of a sluice, the more efficacious it will be.

132. The remarks I have made regarding the comparative inutility of escapes, for removing deposits when the water is entering the Canal charged with silt, are not applicable to them in the dry season, when the water in the River is clear. Any water that can then be spared, may be turned to good account in scouring out the bed of the Canal. But I need hardly remark that water is generally too valuable at that season, to be used frequently for such a purpose. In the rains too, if drainage water in a comparatively clear state is passed into a Canal, an escape may be able to discharge an equal quantity of water, with silt in addition; but it would come to much the same thing, if the initial supply of the Canal were reduced by a quantity equal to that of the drainage water which passed into it.

133. The rapidity with which silt will accumulate must of course depend on the character of the River from which the channels are derived, and will vary greatly in different parts of the country: and the reader whose experience may not have extended to the two Rivers, with which I am most conversant, namely, the Sutluj and Kistna, may think that I attach an exaggerated degree of importance to the subject.

Still if the principles which I have advanced are sound, I trust the illustrations I have given of them, may not be entirely useless to such of my younger brother officers, as may have to contend with the difficulty on a minor scale.

134. That I have not exaggerated the silting in the channels derived from the Kistna may be proved by a reference to actual observation. I found by careful measurements that when there was a depth of from 11 to 13 feet of water on the crest in the Annicut, the quantity carried in suspension by the water that entered the Bezwada main channel, was when dry 1-200 part of the volume of water. When in a state of slime, the silt occupied nearly twice the bulk that it did when dry, and when in a condition resembling putty it was about one-half more than when dry. When dry, it was condensed to the consistence of pottery; and as the silt would not have attained this consistence, when removed by manual labor, the actual quantity, by which the cost of clearance should be calculated, would considerably exceed the proportion above mentioned—of 1-200 part of the volume of water.

135. I find that the River was at the height of 11 feet and upwards on the crest of the Annicut for 28 days during last rainy season. The proportion of silt above mentioned was the largest I observed, excepting in one instance when with 11 feet in the Annicut it rose to 0·6 per cent. of the volume of water. On one occasion it was much less, 0·2 per cent., although the height of the River was greater, ($13\frac{1}{4}$ feet above the Annicut.)

136. The observations were not sufficiently numerous to enable me to draw up a scale, by which the actual quantity of silt thrown into the channel might be known at the different stages of the River's rise and fall. I would not therefore pretend to determine at all accurately the whole quantity of silt, which may be thrown in during a season. But on the supposition that 1-200 part of the volume of water passed through the head sluices for a period of 28

days, let us see what the bulk would amount to. We may suppose that 3 cubic yards per hour per acre were let into the head sluices for that period; and as the acreage of wet cultivation in the Kistna Delta is about 130,000 acres, the quantity of silt would therefore be 13,10,400 cubic yards, or about 10 cubic yards per acre. So much of this as might be deposited in the main channels, would be removed at a cost of from one to two annas per cubic yard.

137. Without asking the reader to put implicit faith in the above calculation, I would yet have him allow that it carries some weight. Of course, the best method of determining the amount of silting in channels, is by examining the annual clearance estimates; but it is unnecessary to enter upon them here, though it is not likely that I should have lost sight of that test myself.

ON NATURAL CHANNELS; THEIR ADVANTAGES, COMPARED WITH ARTIFICIAL CHANNELS.

138. In a former page I have entered into a description of various natural channels which exist in the low country to the west of the Sutluj; and I pointed out that they possess (para. 53) the characteristic of Rivers which have formed the country through which they pass by the deposit of alluvial matter during inundation—by having their banks on a higher level than that of the adjacent ground. I have reason to believe that channels of a similar nature are to be found in the deltas and valleys of other Rivers, and I would therefore propose to enter into a consideration of their qualifications to act as irrigation channels.

139. The principal channel which I described has a length measured along its actual course of upwards of 400 miles, a width of about 200 feet, a maximum depth of 12 feet, and a fall of about 7 inches a mile. The volume of water it is capable of discharging is about 3,500 cubic feet per second. The mean velocity, calculated from a number

of careful measurements of the dry channel, would have been 2½ feet per second when the channel was in full flow. The discharge and velocity would be nearly the same from an artificial channel 165 feet wide, 8 feet deep, and with a fall of 6 inches per mile.

140. The volume of water to be disposed of would be about half that calculated for the supply of the Ganges Canal, and no one will suppose that it would be either difficult to deal with, or to dispose of on a strip of country more than 200 miles in length, and in some places nearly 30 miles broad. There would therefore be no objection on the score of the capacity of the channel, unless that it was not large enough; though as there are other natural channels of exactly similar kind in the same tract of country, this need not be considered as a defect.

141. But as the channel continues of nearly equal section throughout its whole course, the gradual abstraction of the water for irrigation, would render it necessary that some provision should be made for keeping up the velocity to the point where the irrigation should cease, and at the same time for retaining the water on a sufficiently high level. This could only be done by causing the natural channel to assume a gradually diminished section,* and by increasing the rate of fall. The channel would in fact have to assume a tapering form like that of an artificial channel, but with this difference, that it would retain its tortuousness in a great measure unchanged.

142. The required alterations could be accomplished in the easiest manner possible. Even if no artificial aid was applied, the gradual withdrawal of the water for irrigation would cause the channel to rapidly contract its dimensions by silting. For it is evident that if a smaller body of water were to pass through any portion of the channel in which the capacity was undiminished, the velocity would be re-

* In the case under consideration both as regards width and depth.

duced, and silt would accumulate, until the velocity attained the same limit as that of the channel higher up. But the process might be aided and directed by artificial means.

143. It would be no more difficult to determine along a line of natural channel, what the demand for water at different points would be, than it would in the case of an artificial channel. After assigning the probable consumption of water to different localities, it would be known, what section and fall the channel should have at different points, in order to retain its initial velocity unimpaired. It has been observed in a former page (para. 98) that if it be decided to retain the initial *depth* of water, the rate of fall will have to be increased very slightly as the width is diminished, but a depth equal to that at the head could not in practice be maintained to the very extremity of the channel, and a gradual reduction would have to be allowed for. It would thus be necessary to increase the fall by degrees. This would be accomplished by simply cutting off a bend here and there. The actual course of the channel being upwards of twice the length of the direct line, gives the means of adjusting the fall at pleasure. It would be unnecessary to make many alterations of the kind; probably two or three cuts each half a mile in length, which in each case might be made to shorten the course by several miles, would be all that would be needed to gain the required additional fall; and it must not be supposed that any approximation would be made to a straight line.

144. There would thus be no difficulty in regulating the surface fall of the channel. When the correct level at different points had been ascertained, the next step would be to adapt the slope of the bed to that of the surface of the water, as computed; which could be accomplished by constructing masonry works at intervals,—say, at the points from which the minor channels would be opened. Bridges would, in any case, be required, at intervals probably not exceeding 15 miles. By adjusting the floor of the Bridges,

to the level of the bed as rectified, and furnishing them with the waterway suited to pass the supply with the required velocity, the channel would have everything done for it, that would be needed. At those points, at least, the level of the surface water and of the bed, the depth and the width of waterway, would have been assigned as accurately as could have been done in an artificial channel, and the rest would be left to nature, which would rapidly (by silting) form the channel throughout to the required section.

145. There would be a considerable waste of water, from evaporation and absorption in the first instance, but as the demand for irrigation would arise only by degrees, this would be an advantage rather than otherwise.

146. After the stream had formed the channel to the section finally required, there would be no further silting to any considerable extent. If the consumption of water had been accurately computed, the initial velocity would be kept up uniformly throughout. It would not then differ from a well designed artificial channel, except its being tortuous instead of straight.

147. The simple fact of their being tortuous may be urged as a drawback to the natural channels, but except that they may not be so pleasing to the eye, or unless their navigable properties be taken into consideration, I would maintain that the tortuousness gives them a great superiority in practice over most artificial channels.

148. There must be more or less silting on all Irrigation channels, but in the natural channels now under consideration, when once the regimen is established, that is when the velocity is reduced to uniformity throughout, there would I believe be less silting, than in most artificial channels. For in the former the water would be on the level of the lip of the channel, and as has been already explained (para. 66), any cutting away at the concavities of the bends, would give space for a deposit of like extent at the convexities; whereas in an artificial channel of any considerable length,

the surface of the water must in various places, be considerably below the surface of the ground, and any erosion of the banks, at such places, would produce a clear accession of silt, to the extent of the soil above the water line, that might fall into the channel.

149. The natural channel runs along a ridge throughout its whole course, no drainage would therefore be crossed. The drainage of the country on either side might be defective, but this must depend very much on the locality. In the lower part of the Punjab, the fall of rain does not exceed 5 or 6 inches in the course of the year, and there could be no difficulty then on this account. In any case it would stand in precisely the same circumstances, as an artificial channel; excepting that in the latter it would be almost impossible to avoid crossing drainages.

150. If an artificial channel were carried through the country which is traversed by the old Beas, it could not be run along a line of uninterrupted high ground. It would, at one place, be on high, and at another in low ground. If it were allowed the same fall as that of the country, or 16 inches per mile, then as there would be no fall to the right or left,—the country being remarkably level in lines taken at right angles to the Sutluj, excepting where they cross the natural channels, it follows that to irrigate effectually, the water in the channel would have to be on a high level, that is it would have to be carried within embankments; or if it were considered preferable to reduce the slope of the channel to less than 16 inches a mile, a series of masonry falls, would have to be constructed.

151. Now the natural channel has all the advantages which would be afforded to the artificial channel by its embankments, without the disadvantages. The water, standing on a level with the lip of the channel would be available for irrigation of the lower land beyond the bank, by a cutting of a few yards in length. If Bridges were built, as supposed above, at intervals of about 15 miles, minor

channels could be opened from those points to run nearly tangentially to the curves of the main channel, and to tail one into another in succession, or in any other direction, that might be desired, with whatever slope up to the maximum of 16 inches a mile that might be required to maintain the same velocity as that of the main channel. The greater the tortuousness, the greater must be the fall of country compared with that of the channel, and the less the expense, of conveying the water to any point. On the whole I consider the greatest advantage possessed by natural channels, to consist in this—that every minor channel can be aligned with a greater fall, than that of the main channel, and thus be free from the inconvenience of silting,—at all events at their heads. It would be almost impossible to attain this with all the minor channels opened from an artificial canal.

152. Let the reader compare the conditions under which the irrigation would be carried on from the natural channels I have described, with those under which the Ganges' Canal has been excavated, and he may then judge whether I have exaggerated the advantage afforded by the raised margins of the former. The following is an extract from Sir P. Cautley's Report on the Ganges canal. Vol. 2, page 541. "The depth of the water or that to which the high water mark is limited was a point very prominently insisted on by the Committee in the report (Vol. 3 p. 49) to which I have drawn attention in the early part of this paper. It is one moreover of which I highly approve, and to which in fact as much attention as possible was given in my original project. By restricting the high water mark to a limit below the terre-plein of the country, it is evident that all the dangers to which an embanked channel are open, are avoided. This is a fact which directly attaches itself to the Engineer not only in his estimate of cost, but of probabilities of accident. On the other hand, leakage, and the proximity of hollows are the invariable attendants on raised embank-

ments." The above remarks can apply to the main channels only : and embodying as they do, the matured opinion of Sir P. Cautley, may be relied on implicity—so far as the locality spoken of is concerned. Those who are sceptical on the subject, would not find it difficult to obtain evidence from other sources, of the noxious effects occasioned "by leakage and the proximity of hollows," when from peculiarities of the locality embankments could not be avoided. It is to be taken for granted that the principal objection to embankments is the danger they give rise to of swamping a tract of country : though the deterioration of soil (and also I believe malaria) occasioned by leakage, may in itself be a considerable inconvenience—to use no stronger word. Of course, on minor channels, embankments must be resorted to, or the irrigation would all have to be carried on by means of manual labour or machinery. In the Madras Presidency, embankments, if I am not much mistaken, are universally regarded as a desideratum, not only from their furnishing the most economical means of conveying water, but from the facilities they afford for distributing it. Of course, if they are carried to such a height as to endanger their stability, they might prove a source of mischief; and leakage, if the water percolates any saline matter, may have an injurious effect on the soil, for a time : but on the whole, the advantages must be considered to preponderate so strongly as to leave room for a charge of extravagance against an Engineer, who should excavate a channel wholly within soil; unless local peculiarities forced him to do it. Still, no one will deny that the high margin of a natural channel must be superior to an artificial embankment, however favorably circumstanced the latter may be.

153. As regards navigation, the natural channels are of course defective; but the saving of locks, and their establishments, would go some way to counter-balance the inconvenience and delay occasioned by the windings of the channel.

154. I assume that proper means of regulating the supply at the head of the channel would be adopted. Whether it had at one time been an off-shoot from the River, or whether it had been an independent stream which had been intersected by the encroachment of the River, there would be but one way of restoring the lost momentum. It would be useless attempting to re-open the channel by simply clearing out the head. The river would destroy it more or less every season, and the crops under it would be in danger of being ruined. It answers on small Canals, to open them in this way from the River, but even they require a great annual expenditure to maintain them in working order. In a large channel, such as the old Beas, it would be simply impossible to collect the laborers that would be required to execute the annual clearance, and to open out the new heads that would every now and then be required. Besides, this method of dealing with the channel would reduce it to the condition of a mere inundation Canal, to retain a supply for only six months in the year.

155. So long as the River carries water waste to the sea, when it could be utilized for irrigation, the replenishing of a large channel like the Beas could not be thought of, unless the supply were perennial. There is but one way of accomplishing this. It would be necessary to establish a control over the River, to check its vagaries, by contracting its channel, at the site selected for the head, to moderate dimensions, and to gain the power of supplying the required quantity of water to the irrigation channel, by means of an Annicut or Dam.

156. In making the above remarks I have chiefly kept in view the old bed of the Beas, but they may be considered applicable to channels in other parts of the country. In the Kistna district, for example, the old Pullairoo is precisely similar, not to the old Beas itself, but to other channels in the valley of the Sutluj, connected with it; and I conclude that many of the channels in Tanjore that are

used as irrigation ducts, have much the same character. It must therefore be of much importance to determine what relative advantages or disadvantages such channels possess, when compared with artificial works; and on what principle, changes may be introduced, with improvement of their efficiency. It would seem almost superfluous to remark that carefully drawn up plans—showing all the sinuosities—and sections, both longitudinal and transverse, would be necessary in the first instance. It is surprising how much has been written on the subject of River improvements, without any reference to actual measurements. I have read a dissertation, in which it was attempted to prove that the natural course of a particular River, was not from south to north, but from north to south. One would think that a few measurements would have settled the question.

157. It must be almost unnecessary to point out that while *inundation* channels furnish the best lines for irrigation, natural *drainage* channels are the worst that could be selected.

158. Unfortunately many of the native works—on which various modern projects have been based, have been executed at a sacrifice of all considerations, but that of economy in the first instance. Once a system of irrigation is established, it is infinitely more difficult to improve it, than to carry out an entirely new project. In the latter, channels would be aligned with reference to the levels of the ground, on the supposition that irrigation will gradually be adopted wherever water is provided; but in remodelling an existing system, it is impossible to disregard existing interests; and there must in consequence be more or less sacrifice of efficiency.

159. If a drainage course is used as an irrigation channel, it can serve neither purpose properly, and will sooner or later do mischief. It is no doubt very tempting to have the means of carrying water to a distance, ready made; but unless there are facilities for diverting the drainage water

in some other direction, it would prove best in the long run, to incur the expense of a new channel. The objection is due more to the interference with the passage of the drainage water, than to the fact of the channel being in low ground, as the margins would be gradually raised by deposits from the River water introduced, and if the channels were tortuous, minor channels might be carried in a straight line, so as to gain higher ground. The system of bunding in order to hold up the water, has generally to be resorted to on such channels. The natives have a particular fondness for bunds: they are almost the only works which they will come forward to execute at their own cost. But their construction involves a great waste of labor, as well as of water; and the object in view would be answered more effectually by Dams—furnished with shutters which might be removed wholly or in part, when there should be any surplus water to dispose of.

ON NAVIGATION COMBINED WITH IRRIGATION.

160. The facility that will exist for adapting a Canal designed primarily to serve the purposes of irrigation, as a navigable Canal, will depend in a great measure on the fall of country and the nature of the soil through which it is carried.

161. The object of an irrigation Canal may be briefly described to consist in the conveyance of a supply of water to certain fixed points at the least possible expense; or in other words with the greatest velocity, the soil is capable of withstanding. If, for example, the fall of country were 2 feet a mile, and the soil were capable of withstanding a velocity of 4 feet a second, the depth of water in a channel 100 feet wide, would be about 6 feet; and if the depth of cutting were arranged so as only to furnish material sufficient to form the embankments, the expense of conducting the water, so far as the earth work is concerned, would be a minimum.

162. But as communications would be intersected by the Canal, it would be necessary to construct Bridges to reconnect them; and their waterway would have to be proportioned, in some degree at least, to the width of the channel. It would therefore be a matter of calculation whether the fall might be reduced artificially by means of masonry drops, so as to enable the Canal to carry a greater depth of water, with the same velocity as before, and therefore with diminished width; and thereby, by reducing the cost of the Bridges, effect on the whole a saving.

163. But if the velocity were reduced, it could only be by increasing the number of masonry falls, and also the width or depth of the channel, and although it might be conceived that a channel of any width might be formed with no greater depth of excavation than would be required to make up for the embankments, and thus render the cost of the earth work of no consideration, yet there must be the additional expense of all the extra masonry falls, and of increased waterway to all the Bridges; and thus the whole expense of the Canal would be much more than would be required for the sole purpose of conducting the water for irrigation.

164. I do not at all believe that the cost of earthwork would not be greater also, for inequalities of ground must exist every where, which would render the expense of forming a wide channel greater than that of a smaller; and at the masonry drops, the embankments above would either have to be in excess of the ordinary section of excavation, or the section of cutting below would be in excess of that required to form the embankments. Still, if the falls were of small depth the extra expense on this account might not be of material consequence.

165. It is taken for granted that the velocity first mentioned, as that capable of being applied to an irrigation duct, would be too high to admit of up stream navigation; and that the reduction of the fall and velocity would be

undertaken with a view to bring the latter within the limits suited for navigation. It has been shewn that both in regard to excavation and masonry works, this could not be effected without additional expense; and, if it be considered that the Bridges, to adapt them for navigation, must be much higher than those required for an irrigation Canal only, it will be understood that on any large Canal, where the Bridges may be counted by the score, the extra cost on this account must amount up to something very heavy.

166. Further, if the water could be conveyed efficiently for the irrigation, without artificially reducing the natural fall of the country by masonry works, no locks would be required. Every reduction of slope, which entailed the construction of a masonry fall, and, with it, of a lock, to adapt the Canal for navigation, would therefore increase the cost of the Canal, by the outlay on those works.

167. Any diminution of velocity below the maximum which the slope of country and the nature of the soil admit, will therefore be a source of additional expense.

168. It will depend on the importance of the traffic which might be created on the Canal, whether this additional expense would be an economical gain in the long run or the contrary. If the cost of locks and other masonry works were the whole expense that would be occasioned by altering the design of a Canal intended for irrigation only, into one suited also for navigation, it would not be difficult to ascertain in each particular case of the kind, whether the saving effected by reducing the cost of transport of an estimated quantity of goods, would counter-balance the extra expenditure; but if the Canal water enters from a River with a large percentage of silt in suspension, any reduction of velocity below that of the River at the head of the Canal, will cause a deposit of the silt to take place, and so far as this reduction of velocity is produced in order to facilitate navigation, the additional outlay required for removing the silt would be chargeable to the navigation.

169. The combination of irrigation and navigation may be of three degrees. The velocity in a Canal designed primarily for irrigation, may render it in that condition unsuitable for navigation altogether, unless for floating rafts or timber down stream. In another case the velocity may be such as to admit of navigation, but under such difficulties, as to render it more or less unprofitable. In a third case the velocity may be so moderate as to admit of navigation being carried on against the stream, not entirely without inconvenience, but with so little as to leave no question as to the superiority of the water communication, over that by land. As instances of each of the different classes, I may specify the heads of the Canals in the North West Provinces, secondly, the Ganges Canal generally, and thirdly, the Canals in the Godavery Delta.

170. If the velocity against which it is considered practicable in an economical point of view to apply a stream for the purpose of navigation, were a fixed quantity, it would be an easy matter to ascertain in the first case above-mentioned, what additional outlay would be required to make the Canal navigable. But there is no such standard, nor can there be, as a velocity which may be easily overcome by steam, and at times by the help of the wind, would be altogether unsuitable for haulage.

171. Until the cost of navigating vessels against a certain force of stream, is determined for each locality, there can therefore be no precise limit fixed of the velocity to which the current in a Canal ought to be reduced to make it serve for navigation. Supposing it fixed with reference to the power of the boats in common use in a particular locality with the ordinary crew, to convey goods at a lower cost than, could be done by land. The saving thus effected on the total produce annually conveyed, compared with the interest of the cost of the additional works constructed for navigation would obviously shew the economical effect; but what might be applicable in one locality might not hold good in another.

172. It would be still more difficult to ascertain to what extent the velocity might be still further reduced, so that the profit derived by the improved facility of transport, might counter-balance the expense of additional masonry works which would be entailed.

173. There is evidently some limit beyond which it would not pay to cut down the slope of irrigation Canals, while there is as evidently a limit within which, in many cases, it would.

174. The highest rate of fall I know of, as existing in an irrigation channel, is at the head of the Baree Doab Canal in the Punjab, in which the actual fall of bed per mile for the first 12 miles is upwards of 4 feet, with 141 feet additional fall, overcome by artificial rapids and masonry falls; in all about 190 feet in 12 miles. The depth of excavation at the head is upwards of 60 feet, which however rapidly works out to the surface, as the fall of country is much greater than that of the bed of the Canal.

175. No one in his senses would propose to reduce the slope and increase the width of this portion of the Canal, to allow of its being used for navigation. Here then, is a case of a Canal, in a portion of which at least, combined irrigation and navigation would be impracticable.

176. We may next refer to the lower portion of the same Canal and of the Ganges Canal, as instances of navigation and irrigation combined, but in which the former is or will be subjected to so high a velocity, as to very materially affect the cost of transit.

177. In the case of the Ganges and Baree Doab Canals irrigation has been considered the primary object, and locks and other works for navigation have been added, but I believe in neither of those Canals has the slope anywhere been assigned with a view to the requirements of navigation. It has on the contrary been made as high, as, whether correctly or not, was supposed compatible with the stability of the bed; and deliberately so, as it was conceived that any

diminution of the slope beyond what was required for the irrigation regimen would be purchased at a higher cost, by the additional outlay required on the masonry works, than would be compensated by the improved means of navigation.

178. An officer in the Bengal Engineers who has been employed on the Canals in the North West Provinces and the Punjab for 16 or 17 years, casually remarked to me not long ago, that he believed the best mode of dealing with the Ganges and Baree Doab Canals, would be to have separate still water Canals for navigation, and I have every reason to think he was right.

179. In the Baree Doab Canal, leaving out of the question the first 80 miles, in which the fall is excessive, I find that the fall of the last 140 miles of the main channel is 200 feet or nearly one and half foot a mile, the velocity from 2 to $2\frac{3}{4}$* feet per second. If the slope were to be reduced one half by means of falls, 12 falls of 8 feet and one of 4 would be required with the same number of locks. For still water navigation, 25 locks and a new channel would be required without falls. The comparative cost of the two would be a matter of calculation by actual measurement; but I believe if the advantages of the still water navigation be taken into account, the separate channel would be found to be far superior to the other.

* The estimated velocity in the Ganges Canal is still greater, $3\frac{1}{2}$ to 4 feet per second, or nearly $2\frac{1}{2}$ to $2\frac{3}{4}$ miles an hour.

180. It should be borne in mind that the supply of the Canals in the North West Provinces is perennial, and that still water navigation and consequently locks* have not to be provided for, as has to be done more or less in the Canals in the south of India, where without such aid the supply of water would be insufficient to allow of the navigation being continued throughout the year. The velocity in the former Canals would therefore be uniform throughout the year, and be, in consequence, a *con-*

* Locks and side navigation channels are constructed only in the vicinity of masonry falls.

stant impediment to up stream navigation. What may be suitable in the Canals in the south of India, may therefore not *necessarily* be applicable to those in the north.

181. It must also be recollected that the Ganges Canal has been excavated on the assumption (see para. 152) that the water should be carried as much as possible within soil, and that embanking is to be avoided. Let us suppose a portion of this Canal to be 50 feet in width, to have a depth of 6 feet of water, and a fall of 15 inches a mile. The velocity would then be nearly $3\frac{1}{4}$ feet per second or upwards of 2 miles an hour. Then if we suppose that to render navigation profitable the velocity should not exceed 2 feet a second or about $1\frac{1}{3}$ miles per hour, a channel of 100 feet in width with $5\frac{1}{4}$ feet depth of water, would be required, in order to discharge the same quantity of water. In short the restriction of the use of embankments, would render any considerable reduction of the velocity so enormously expensive, as to make it practically unattainable.

182. In the deltas in the south of India the fall is more moderate than that above-mentioned, and the navigation has been combined with irrigation with fewer difficulties to contend against. The slope of the channels has not been arranged for the one without reference to the other, but while it has been considered as sufficient to carry the supply for irrigation, it has been retained sufficiently low to admit of the water being held up from one lock to another, and thus to allow of still water navigation being carried on, when the water is not required for irrigation, or when it is so scarce as to leave none available for it.

183. Though navigation and irrigation are thus carried on in the same channel, it is not without considerable drawbacks to the efficiency of both. If once the velocity is determined with which the supply in the channel will carry forward the silt thrown in from the River, (excepting a certain portion which must always be deposited when the velocity of the River at the entrance exceeds that on the channel), it

should undergo no check until it reaches the point of delivery, as has been shown at length in a former page (para. 87).

184. In order to understand the extent to which an irrigation channel, considered only in that capacity, must be modified, if any modification at all is necessary in order to adapt it for the purposes of navigation also, it must be first known, what slope of channel and what velocity is best suited for the proper working of the former, that is for the most advantageous delivery of the water for irrigation, and for the maintenance of the channel in the most economical manner. I have already explained that a slope and velocity cannot be fixed upon, which shall be the best possible for all channels, considered with reference to irrigation; that, on the contrary, it must depend on the general fall of the country, as well as on the nature of the soil. I have however expressed an opinion that a slope of 6 inches (para. 95 and 57), per mile, in a large channel with a depth of about 8 feet, which would generate a velocity of $2\frac{1}{2}$ feet per second or $1\frac{3}{4}$ miles per hour, is suitable for a country with a moderate fall,—such as the deltas of the Godavery and Kistna, and I have given my reasons for adopting it in preference to any other.

185. It may be contended however that the velocity I have assumed is unnecessarily high, and that a velocity produced by a surface fall, say if half what I have allowed, or 3 inches per mile would be preferable;—and that the channels would not be materially more expensive, while the advantage resulting to the navigation would be very great. If the deposit of silt were left out of the question, one could easily understand there being many cases in which this would be true; and there might also be cases in which the fall of country is so gentle, as to necessitate the adoption of a slope of 3″ a mile for the channels, whether they silt or not.

186. But in the case of delta channels in this Presidency, it must be desirable, so far as the irrigation only is con-

cerned, to adopt a higher fall than 3 inches a mile, if, as I believe is everywhere the case, the fall of country would admit of it.

187. At the risk of being charged with repetition, I must enter into a consideration of the conditions, upon which the slope of the surface of the main channels should actually depend.

188. The surface of the water at the head of the channel, will be determined with reference to an Annicut or Dam across the River, or if there be no such work, it must be determined approximately from observations of the River for a series of years; and, in designing a scheme for irrigation, the surface of the water at the head must, whether correctly or not, be taken as the basis of all the calculations; and the channels must be excavated, so that the water when entering at that height will furnish the required supply for irrigation. If the water falls below that level, for say a month in the irrigating season, then if the want of water for that period would prevent the crops coming to maturity, a portion of them would be lost, and it would be no advantage to raise the water at other times higher than the minimum for that period, unless for the purpose of storing it in Tanks, or occasionally, when from want of the ordinary fall of rain, the rate per acre required will be greater than what may be fixed as the standard allowance.

189. In the delta channels in the Northern Districts of the Presidency, the principal irrigation season is from June to November and the standard level of the water at the heads, will be the highest obtainable in the months of October or November. If it were less, the area to be irrigated would have to be reduced; if it were greater, a deficiency would exist in those months and nothing would be gained.

190. As the River during the freshes from June to October, is much higher than the standard level; it must throw the water into the channels with a velocity due to the head of water, that is to the difference between the levels

of the surface of the River and the channel. If the channels have a fall sufficient to produce a velocity equal to that of the River at the entry, they would carry forward all the silt, for every cubic yard of water thrown into the channel must then carry with it the same proportion of silt, as is carried by an equal quantity in the stream which runs past the mouth of the Canal.

191. But otherwise, the velocity in the channel will be insufficient to carry forward the silt, and the lower the velocity of the water compared with that in the River the greater will be the accumulation of silt; and it may be readily conceived, that if the loss of velocity is considerable the deposit may take place to a very great extent.

192. It has already been observed that an irrigation channel should possess the greatest fall compatible with the delivery of the water at given points, without loss of velocity, and with the stability of the soil exposed to the action of the stream. But on the other hand, the length of country to be irrigated may not be great, and it may be desirable to commence the irrigation as near the head of the channel as possible; and to do this, the fall of the surface of the channel would have to be reduced.

193. There is therefore only one object for reducing the slope of a channel below the maximum above-mentioned, as far as the interests of irrigation are concerned. The question then is, will the advantage thus gained in the shape of additional irrigable area and in improved means of navigation, counter-balance the loss occasioned by the accumulation of silt,—also will the cost of a channel with a small slope differ materially from that of a greater?

194. One may easily conceive a case in which the advantage gained in the command of a larger area of ground may be so great as to render it most desirable to have a low rate of fall, and to more than make amends for the silting; and of which the cost should not be greater, but actually much less. We might, on the other hand, see at a glance

that in a country like that at the head of the Baree Doab Canal, described before, a low rate of fall would be out of the question.

195. There can therefore be no general rule laid down, which will be suitable for all localities, and the only proper way of proceeding, is to judge each case on its own merits.

196. Let me for the sake of illustration suppose, that a channel is to be opened at the head of a Delta, the fall of the ground from the River along the line of the channel to be 18 inches a mile,—the surface of the water at the head to be 12 feet below the surface of the ground, and the depth of water to be 8 feet. Let us see what would be the different effects of different rates of fall, from 3″ to 12″ per mile—the limits within which it may be assumed that combined navigation and irrigation may be more or less effectually carried on.

197. First, to ascertain the distance from the head at which the water will be available for irrigation, that is, will reach the surface,—with the fall of 3″ per mile, 18 N. (N. the number of miles) $= 12 \times 12 + 3$ N ; from which it will be found that N = 9·6 miles. Similarly with a fall of 6,″ 9,″ and 12″ per mile, the distances will be respectively 12 miles, 16 miles, and 24 miles : so that by adopting a 3″ fall instead of 6,″ a strip of land 2·4 miles wide would be gained for irrigation: instead of 9,″ 6·4 miles; and instead of 12,″ 14·4 miles.

198. It would depend very much on the scale of the channels, whether the area thus gained would be of much importance, and whether there would be more land available with the greater fall, than the supply of water at command would be competent to irrigate.

199. In a Delta such as those of the Godavery and Kistna, it would be readily acknowledged that a sacrifice of 14½ miles could not be thought of, but as regards the other cases it would be a matter of calculation, the cost of original excavation and of maintenance in each case being compared,

and the value of extra cultivation being set off against the additional expense of the channel with the smaller fall.

200. We have next to ascertain what would be the actual cost of the different channels in the cases supposed. We may take the width of bed of the 3″ fall channel at 100 feet, and ascertain what sized channels the other falls will require to yield the same discharge,—the depth of all being 8′; and to facilitate the calculation, I may take 5,000 feet to represent a mile, and the side slopes at 1 in 1.

201. It will be found that the widths of bed required to yield the same discharge will be 70′ for a 6″ fall, 55′ for a 9,″ and 48′ for a 12 inch fall; and as the depth of cutting at the head will be 20′ in each case, and 8′ at the other extremity, the cubical contents will be easily ascertained.

202. If we suppose that the channel with the lowest rate of fall would cost 3 lacs of Rupees, the cost of the others with a fall of 6,″ 9,″ and 12,″ would cost respectively $2\frac{3}{4}$ lacs, 3 lacs, and 4 lacs,—the same rate per cubic yard being allowed to all, as any saving in the channels with less width may be supposed to be balanced by extra bridges, &c., due to their increased length. Omitting the last, we may thus sum up the comparative advantages of the different channels.

203. The channel with a fall of 6″ per mile would cost 25,000 Rupees less than one with a fall of 3 inches. It would have a velocity of $2\frac{1}{2}$ feet per second or $1\frac{3}{4}$ miles per hour, or somewhat less, while the other would have a velocity of only $1\frac{3}{4}$ foot per second or less than $1\frac{1}{4}$ miles per hour. It would therefore carry on a larger proportion of the silt brought in from the River; while, on the other hand, the channel with 3″ per mile of fall would gain the command of a width of $2\frac{1}{2}$ miles additional for cultivation, and would be more advantageous for navigation.

204. The cost of the channel with 9″ fall would be the same as that of one with 3″ fall, while it would render
of $6\frac{1}{2}$ miles incapable of being irrigated, and

a width
still further re-

tard the navigation,—the velocity being about 3 feet per second, or about 2 miles an hour.

205. The value of the land which would be lost for irrigation would depend on the width of the Delta, but unless the irrigation were extended, or there was a prospect of its being extended, over the whole of the Delta, within the command of the water in the channels, the loss of a width of 2½ miles would not I believe be a serious consideration.

206. Here then we have, at least in the case under consideration, the question reduced to narrow limits. A channel with a fall of 3″ per mile costs more than one with a fall of 6.″ It would command more land, but not much more (probably) than would compensate for the additional cost, while it would leave a deposit of a much larger body of silt behind.

207. Cutting out the consideration of the prime cost, we fall back on the old subject of silt. If the irrigation only is concerned, the question is decided in favor of the 6″ fall. It therefore remains to be determined whether the navigation is of such importance as to justify the additional outlay required to maintain in proper order the channel with the reduced fall of 3.″

208. This might admit of calculation and may show in favor of the latter fall, in instances in which the traffic is o great importance, but it cannot be laid down as a rule to be adopted in all cases.

209. If the area to be irrigated is of very great extent, say several hundred thousand acres, the cost of excavating a channel on the supposition that the stream thrown into it would have a surface slope of 3 inches per mile, would be so great in most, if not all cases, as to render it difficult of being carried out at all. If however, the supply of water in the River admits of the surface slope being increased to 6 inches per mile, while the bed has a less slope during the irrigation season, the required supply of water will be thus obtained; and the practical result would be much the same, as in the case of the bed being dug to a slope of 6 inches per mile,

excepting that the same quantity of water might have been obtained from a lower surface level of the River by forming the slope of bed from the level of the head sluice floor in the first instance at 6″ per mile. Moreover, if the depth of water at the head of the Canal is greater than it is at any point lower down, the velocity will be less in an inverse ratio, and silt will be deposited, until the bed assumes the same fall as the surface of the stream.

210. I do not mean to say that the above arrangement is a defect; whether it is or not, will depend on various considerations, in which it is unnecessary to enter; I merely wish to show how a channel with a slope of bed of less than 6 inches a mile, may during the irrigation season have a surface slope of 6 inches. In channels where the surface slope during that period does not exceed the slope of bed, the remarks I have already made will suffice to show the condition of its action.

211. But if the surface slope is raised to 6 inches for the benefit of the irrigation it must render the navigation the more difficult. Suppose that it had been highly *desirable* to have kept the slope at 3″ per mile, but that the great outlay it would have entailed may have rendered it impracticable. But after being carried a certain distance, say up to the first regulator or lock, the water comes to the surface. A channel with a fall of 3″ per mile, sufficient to carry the full supply for irrigation, may be excavated from that point onwards, at a comparatively trifling cost in excess of one with a 6″ fall, not by increasing the depth of water so as to obtain the same velocity, as would be furnished by the latter, but by increasing the width, and thus passing the supply with a reduced velocity.

212. The actual velocity in the first portion of the Canal would be that due to a surface fall of 6 inches, and the minimum depth of the channel, say 6 feet. This with a channel 100′ wide would be $2\frac{1}{4}$ feet per second nearly, or above $1\frac{1}{2}$ miles an hour.

213. If in the second reach of the Canal the width and depth were the same and the surface slope of 3″ per mile, the velocity would be 1½ feet per second or upwards of 1 mile an hour. Then for every cubic yard of water thrown into this channel, it would leave behind it, a certain portion of silt, whatever might be due to the difference of the velocities 2¼ and 1½ feet per second.

214. There is no escaping from this conclusion. It must be obvious to every one, and it is only a repetition in other words of what I have advanced before; but I trust the illustration I have given will not be considered altogether superfluous. If the reader's patience is not exhausted, I must ask him to follow me a little further still on the same subject, before I have done with it.

215. We have supposed the stream in the second reach of a Canal to be flowing with a velocity of 1 mile an hour, the width of the channel 100 feet, the depth 6 feet, the slope of bed and of surface 3″ a mile. If the whole of the water which to comply with these conditions would have to be thrown into the Canal, were required for irrigation, either by means of channels at the extremity of the reach, or from the next reach, the depth and velocity would be uniform.

216. Suppose that the actual quantity of water required for irrigation, or for consumption in the lower reaches were less than the full supply due to the depth of 6′ and fall of 3″, the quantity in that case thrown into the second reach would have to be less; and if the depth were thereby reduced so much as to impede the navigation, with the fall of 3″ per mile, then to increase the depth the fall would have to be reduced (by holding up the water at the lock) in proportion as the quantity of water were less than the *full* supply.

217. If the excess in the capacity of the channel over what might be required for the irrigation, were permanent, it would be a dead loss, so far as the irrigation would be concerned, not only in any additional outlay which the extra width may have entailed, but also by that, which the silting

occasioned by the continued reduction of slope would give rise to.

218. To make a practical application of the foregoing remarks, I would ask the question, whether the velocity of $2\frac{1}{2}$ feet per second or $1\frac{3}{4}$ miles an hour, namely that due to a channel with a width of 100 feet, depth 8 feet, and surface fall of 6 inches a mile, can be attained at the head of the channel, designed to irrigate a particular locality, and whether that velocity can be maintained up to the point of delivery to the fields. Then, if that velocity is the measure of the stability of the soil against the current, it is the one which ought to be adopted for a merely irrigation channel.

219. If again it is required to reduce the surface fall to 3″ a mile, to facilitate navigation the following effects will be produced. The original cost will be greater. If the bed of the channel near the head is to have a fall of 3 inches a mile, the additional outlay would in most cases, be so great as to render it impracticable,—but if it is actually carried out to that slope, the additional silting will be that due to the loss of velocity. If the bed is excavated to a slope of 3″ which a surface slope of 6″ is generated, along the first reach, its silting will be greater than would be produced for the same quantity of water by the same slope of bed and surface, owing to the velocity being inversely as the depth, which would be greatest at the head and be gradually diminished to the end of the reach. If the water at the end of the first reach is thrown with a velocity due to a fall of 6″ a mile, into the second reach, with a slope of bed and surface of 3″ per mile, the silting in the second reach will be, for every cubic yard delivered equal to that due to the difference of velocity in the two cases. If the supply of water thrown into the 2nd reach is less than that required for irrigation, the width of channel is unnecessarily great. If the supply as above is so much less than that required for irrigation, as to leave insufficient depth of water for navigation, and the surface fall has in consequence to be reduced by holding up the water at a

lock at the end of the reach, the velocity will be reduced, and a further deposit of silt will take place.

220. What the whole amount of silt thus deposited in the main channel by the operations above described would amount to, could not readily be foreseen. But it would be open to actual observation and measurement on any channel which had been executed. That is a test which can be objected to by no one; the only question is, whether it would be allowed that the silt found in the bed of a channel is occasioned by the navigation.

221. I would therefore repeat the assertion which I made in a former page (para. 87) that with the exception of the silting at the head of a Canal due to any deficiency which may exist between the velocity of the stream and that of the River, there should, in the irrigation Canal which is properly aligned, be no silting whatever.

222. There may be slight accumulations at masonry works; and peculiarities of ground may render it necessary to sacrifice velocity to a certain extent. I believe, that in most cases a very high degree of perfection is attainable—at all events, it will be acknowledged that the principle, should be kept clearly in view, and that if there is any deviation from it, it should only be where there is really good ground for it. If we cannot attain to perfection, there is no reason why we should give up the search for it.

223. I have said unless there is good cause: circumstances may render it necessary to carry out a channel which it may be foreseen will silt up enormously, but the advantages derived from the irrigation would more than counter-balance the loss. It might have been possible to have carried a channel in another line, which would not have silted, but the original cost may have been more than sufficient to outweigh the expense of maintaining the other. No one therefore would dispute the propriety of adopting the most economical channel. I would merely insist on the propriety of avoiding *needless* expenditure.

224. But it will perhaps be said that I have thrown the whole onus of the silting produced in main channels, by a reduction of the surface fall below what I take to be the proper standard for irrigation, on the navigation; supposing the reduction to have been effected on purpose to render the channels navigable.

225. I do not deny this; on the contrary I would distinctly assert that it is the case; but I am far from assuming that the advantages gained by facilitating or creating navigation, are not sufficient to counter-balance the inconvenience and expense occasioned by the silt.

226. The latter will vary on different Canals to a very great extent; the traffic on one system of Canals may be enormous, while the silting may be less than exists on another set of Canals, in which the traffic may not be one-tenth so important. Surely there can be a fixed rule, either that combined navigation and irrigation are an unqualified advantage or the contrary. What would hold good for channels with a small quantity of silt, would be utterly inapplicable to those in which the quantity is great; but the question may be considered as resolved into very narrow limits, if viewed with reference to the amount of silt.

227. And it would not be difficult in many cases to answer the question. Let the quantity of silt annually deposited in a series of channels which are supposed to be well designed, be determined, and let the annual cost of removing it, excepting the portion at the heads due to the loss of the velocity at the entrance, be computed. Let this, added to the cost of purely navigation works, and establishments, be compared with the saving effected on the transport of the whole of the goods conveyed annually by those channels, and I should say that a very fair approximation of the net saving would be arrived at. If the silting were nil, a very moderate amount of traffic would suffice to balance the cost of the navigation works, locks, &c., and establishments, and even in cases where the silting must be considerable, as in the Goda-

very channels, one can conceive that after due allowance for all drawbacks on this account, the aggregate saving may be enormous; but it would be as easy to conceive a case, if not to exhibit a practical example, in which the balance might be all the other way.

228. As regards the Godavery channels no one could cavil, with any show of justice, at the arrangement of combined irrigation and navigation which is in force there. The repairs of irrigation works for last year cost only 4 per cent. on the revenue, and united with the repairs that are charged solely to works of navigation, cost altogether but two lacs of Rupees, while the land revenue has risen to nearly 34 lacs of Rupees, or double the amount which was collected previous to the construction of the Annicut; and the traffic has arisen to a surprising height. The total value of the produce that passed through the locks at the heads of the main channels, during last official year, amounted to no less than 58⅔ lacs of Rupees. The number of boats nearly 34,000, and of rafts 5,770. (Chief Engineer's Administration Report for 1860-61).

229. These facts cannot be controverted, and the design which has produced such splendid results can hardly fail to elicit the cordial admiration of every one who takes an interest in the improvement of the country.

230. But the very fact of this success may be productive of mischief in other places, if the system on the Godavery is blindly copied, without proper attention to the peculiarities which may cause them to differ in a marked manner from the Godavery. The chief lesson to be learnt from the rapid improvement in the condition of that district, is not that irrigation and navigation to be successful must be carried out in the same channels, but that neither the one nor the other should be neglected.

231. It is quite possible, and highly probable, that navigation may in most cases be indispensable, to give proper effect to extended irrigation; but there may be other cases

in which the conveyance of the produce raised by means of the irrigation channels, or of other goods in return, may be of quite secondary consideration. What would the transport of cotton from Berar to Cocanada, and of salt from Cocanada to Berar have to do with the Agricultural produce of the Godavery district, or what would the conveyance of troops or military stores, beer, gunpowder, &c., have to do with it? Evidently very little; and may there not be cases in which such traffic may far exceed that due to the simple extension of irrigation and in which the channels which would have to run on the shortest and most suitable lines of communication may not be at all suited for extending the irrigation? There would surely be many cases, in which if a channel were forced to answer both purposes, it would answer neither in a proper manner, and in which it would be far preferable to retain the channel exclusively for navigation, and to excavate a separate channel, probably in another direction for irrigation.

232. Further than suggesting that the peculiarities of every district should be studied attentively before any judgment as to the superiority of combined navigation and irrigation over a system of separate channels, is formed, I have no intention of pursuing the subject of the comparative advantages of still water navigation.

233. I would simply remind the reader that the solution of this question will have to be worked out separately for every locality, in which it may be raised. I have already called his attention to the importance of preventing any check to the velocity of the stream, which may be productive of accumulations of silt, and have shown that except at the head of a channel, no such accumulations should take place, if it is properly aligned for irrigation. The channel may be designed for navigation also, and the silting which this would occasion may be accepted deliberately, as a necessary inconvenience which will be more than counter-balanced by the increased facilities of transport that

would be furnished. It will be only one step further to ascertain, whether it would be preferable to retain the channels in which the principal traffic is carried on, for navigation only, at least in their lower reaches, and to irrigate by means of side channels, or others, as the levels of the country may indicate; the additional cost of the navigation channel being, it would be supposed, counter-balanced by the saving effected in transport by still water navigation.

234. It should be observed, that still water navigation may in some instances be very objectionable, owing to the growth of weeds. In some of the channels near the foot of the Himalayas, a very strong current is required to keep the weeds down, and I should therefore consider it doubtful as yet, how far still water navigation may be suitable in that part of India (see Sir P. T. Cautley's notes on Doab Canal page 175).

ON THE IRRIGATION WORKS IN THE NORTH AND SOUTH OF INDIA.

235. That there must be some radical difference in the conditions under which Canals in the north and those in the south of India have to be carried out, cannot have escaped the notice of any one who has paid the slightest attention to the subject. It must have struck the most casual observer, that the Canals in the south of India have proved remunerative almost as soon as they were opened, while those in the north have to linger on for many years before they return sufficient to cover the interest of the capital expended.

236. This is at once partially explained by the simple consideration that the Canals in Madras are opened out by degrees, while the Ganges, and other, Canals are nearly completed before any water is thrown into them. In the one case, after an Annicut has been completed, and a command over the water in the River thus obtained, the water can be turned to use by the simple excavation of channels in dif-

ferent directions. The depth of excavation at the heads of the main channel may be considerable, but it is generally practicable to excavate them to the capacity required to deliver a supply of water sufficient for the immediate wants of the district, during the period occupied by the construction of the Annicut, which will probably not exceed 3 years. Sluices and other masonry works will be required also, but on some if not all of the projected lines of channel, their progress will keep pace with that of the Annicut; and there are generally existing channels,—natural or artificial, which may be used temporarily if not permanently, to distribute the water in different directions.

237. Further in every part of the Madras Presidency, there are a number of rain-fed Tanks, the revenue derived from which may be liable to undergo extraordinary fluctuations, owing to the uncertainty and insufficiency of the supply. The cultivation then becomes a lottery; it may be profitable or it may not; but the cultivators, though they may be ready to run the risk of losing a portion of their crops, will be obliged to refrain from cultivating all the land under their Tanks, though if they could secure a good season, they would be only too glad to do it. The addition of the water supplied by means of the Annicut channels to such Tanks, would have the immediate effect of securing the revenue and of giving confidence to the people. In looking over a list of Tanks in a single Taluq in the Kistna district, I find that on one the revenue had fallen in one year to 365 Rupees, while it has now risen to 10,000 Rupees, in another in one year no revenue had been collected, while the maximum since the construction of the Annicut has been 4,000 Rupees. Similarly in two others of which the revenue had fallen in one year to 123 Rupees and 323 Rupees, about 10,000 Rupees are now derived,—and I have no doubt that much more striking instances might be brought forward from other districts.

238. Even with an expenditure of 20 lacs of Rupees

which is more than would be required to bring an Annicut and channels on a large scale, into operation, it will be readily understood, that an increase of revenue sufficient to constitute them remunerative works, or a return of 5 per cent., might be realized almost in the very first year, during which a supply of water is provided. Direct irrigation by means of small channels would be carried forward at the same time; and as the demand for water increases, there is comparatively little to be done, beyond increasing the capacity of the main channels for a few miles from the Heads.

239. A large quantity of silt is thrown into the Tanks along with the River water, and eventually their capacity will be so much reduced as to render them unserviceable, but this operation will be a gradual one, and it can hardly be considered an evil, if there is sufficient water in the River to extend the irrigation to the beds, and if the capacity of the channels is made sufficiently large to carry the supply required for the purpose, as well as to provide direct irrigation by means of small channels to the land under the Tanks. Whatever may be done with the Tanks eventually, it cannot be denied that they are invaluable subsidiaries to the Annicut channels in the first instance, and in computing the expense of irrigation in different parts of India, it is but fair that they, or any other existing works which may be used to distribute the new supply of water, should be taken into account.

240. It is not to be implied that the channel irrigation alone would not rapidly become remunerative, but unless a plentiful supply of labor is available, the channels cannot be excavated so fast, as the demand for water arises. Even with the Tanks, which, it may be said, make the water go much further than it would do otherwise,—the demand is always in advance of the supply, and will continue in advance of it, so long as there is a good market for the produce; and there is land remaining to be irrigated.

241. Thus the Delta projects in the Madras Presidency

provide in the first instance for the supply of water sufficient to place existing cultivation in a state of security, and for a moderate extension of irrigation to new land; but they admit of expansion, until they comprehend the whole of the country which can be brought within command of the water. This system must be considered to be practically a very perfect one. It may necessitate the enlargement of masonry works and alterations which by proper foresight might have been avoided; but it does not follow that it is more economical to construct a masonry work, for instance a sluice, so that it should be capable of meeting the wants of a channel ten or twenty years after its construction, than it would be to allow a waterway sufficient for its wants in the first instance, and to enlarge it afterwards as the capacity of the channel should be increased. There must evidently be a proper medium to be observed in such matters.

242. If we turn to the Ganges Canal, or to the other Canals in the North West Provinces, we shall find that the procedure is the reverse of what I have described. I trust that it will not be supposed that I am instituting a comparison between the works in the two Presidencies, for the sake of holding up the system on the Madras side to admiration at the expense of the other. Let it be understood that I attribute the difference to the physical peculiarities of country in the two cases. Any one who institutes a comparison between the two systems, without taking those peculiarities into consideration, will doubtless arrive at the conclusion that irrigation in Madras is more profitable than it is in the North West Provinces; but if, from that conclusion, he takes it for granted that the scale of expenditure depends entirely on the different management of the Canal Officers in the two Presidencies, he can have but a very imperfect knowledge of the obstacles which have to be contended against, in drawing a supply of water from the sub-Hymalayan Rivers.

243. The numerous reports which have been published

on the subject, and particularly the voluminous report of Sir P. Cautley on the Ganges Canal, furnish nearly all the information that could be desired. Still nearly all official reports are addressed by officers to their immediate superiors in their own department, and it is taken for granted that the latter understand the general features of the locality, which may be brought under consideration. Terms are used, which may be unintelligible to those, whose experience may not have extended to that locality, and may even mislead the reader, for the same word may have different significations in different parts of India.

244. I am sanguine that the reader who is interested in Canal works, will thank me, if I can help him to gain a clear idea of what the difficulties which have to be encountered in the North West Provinces, really consist.

245. It has already been explained (para. 56) that there is a strip of low land to the westward of the Sutluj, which is capable of being irrigated from that River. If a line of level were carried at right angles to the general course of the Sutluj, the banks of that River would be found to be higher than any other point in the line. If the freshes in the Sutluj rise to the level of the banks, and in extraordinary floods, rise above it, more or less of the land in question would be inundated. It may therefore be considered as within the limits of inundation, and any channels which are excavated for the purposes of irrigation, and which merely carry a supply during the rainy season, may be termed inundation Canals. The tract of low land I have described is called the "Khadir." In the valley of the Sutluj, it extends, as I remarked before, to a maximum width of 30 miles. Beyond, there is a sudden rise it may be of 30 feet, or it may be 50 feet or even 80 feet, and if we continue to proceed at right angles to the general course of the Sutluj we shall find a table land on the higher level, of variable width, till we approach the valley of the Ravee, when there will be an abrupt descent, to nearly the same level as the

"Khadir" of the Sutluj. The high land is called the "Bangur," and it may be considered the feature, which more than any other, distinguishes the alluvial country in the north of India, from the delta formations in the Madras Presidency.

246. It is to be found on all the Himalayan Rivers (I believe without exception), and indeed may be considered as a characteristic of all large Rivers, which traverse extensive alluvial formations.

247. The "Bangur" does not differ materially from the "Khadir" in regard to soil. In some places it is more sandy, and in others the alluvial stratum is thicker, and of a more compact quality, but the formation is as much an alluvial one as the Khadir. The surface is more irregular, owing to the drainage water which has to traverse it, having a greater fall into the Khadir, than any drainage course originating as the latter could have. Deep nullas are thus formed, and the surface of the country may occasionally be cut up into a net-work of ravines (see pl. V and VIII, Atlas to Sir P. Cautley's report on the Ganges Canal), which would have to be carefully avoided in aligning a Canal. The soil, consisting of a stratum of tenacious clayey alluvium (generally) overlying pure sand is an excellent material to deal with so long as the upper crust is not passed through; but below this it would yield more readily to the action of water than perhaps any other formation that could be found.

248. The comparative widths of the "Bangur" and "Khadir" will vary in different Doabs. Between the Ganges and the Jumna, the latter is not of great extent, and the "Bangur" in many places touches the Rivers. In Oude the same is the case with the Gagra, though for a considerable distance, the "Khadir" has a width of from 3 to 6 miles.

249. On the left bank of the Sutluj, the Khadir is generally from 5 to 10 miles wide, the Bangur receding from the River at Loodiana and never rejoining it. It can be

traced through the Bhawulpoor territory into Scinde, the Narra apparently running at its base, and the "Bangur" itself constituting the great Scinde desert. On the right bank of the Sutluj, the "Bangur" touches it at only one point some miles above Ferozepoor, and then gradually recedes from the River. At Loodiana it is about 70 or 80 feet high, above Ferozepoor about 50 feet. To the southward the height is gradually diminished, until in the latitude of Moultan, it fades into the general level of the "Khadir."

250. On the Ganges the "Bangur" is about 80 feet above the surface of the River opposite Roorkhee, and about 50 feet at Cawnpoor. In Oude it is about 60 feet above the level of the Gagra, at the distance of 25 miles from the base of the Hills, and above 40 feet in the latitude of Lucknow.

251. The origin of the "Bangur" I do not pretend to account for. It may be due to a gradual elevation of the land, such as we know is going on in different parts of the globe, or to the lowering of the beds of the Rivers, at the base of the Himalayas, or it may be to both causes.

252. If we now consider the means of irrigating the country above described, we should observe that the Khadir of the Sutluj is alone of sufficient width to afford room for a large channel. In Scinde there is also a tract of land suitable for irrigation (and actually irrigated) by cuts from the Indus, but in by far the greater and most important part of the North West Provinces, it is to the "Bangur" for which irrigation is most required. The crops are dependent on the direct fall of rain, and more or less on wells and small Tanks, from which the water is raised to the fields. The degree to which cultivation can be profitably carried on will vary greatly in different provinces, and even in different parts of the same province. In Oude and the country to the eastward, drought is seldom experienced, though owing to wells and Tanks having to be used to supplement

the rain supply, the cultivation will there be more expensive, than would be the case, if Canals were introduced. In the Doab between the Ganges and Jumna, the water in the wells ranges from 13 to 105 feet below the surface of the ground. (Sir P. Cautley's report, vol. 1, p. 340). In the southern parts of the Punjab and in the extensive tract of country between the Sutluj and Jumna, wells are not only 60 feet deep and upwards, but the water is brackish. The fall of rain is insufficient to mature a crop, and the consequence is that the tracts of country in question, are for the most part desert, though the soil is in no way inferior to that of the "Khadir," of the Rivers, where the crops are as luxuriant as could be wished.

253. Having explained that it is the "Bangur" land for which irrigation is in the main required, I proceed to show where the Heads of the Canals may be most suitably opened.

254. If we proceed along one of the Himalayan Rivers, for instance the Ganges, in the direction of the Hills, we shall find, at every point which we may examine, the "Bangur" land running parallel to us;—until we arrive within 10 or 20 miles from the Hills, there is no interruption of any kind, unless it may be where a stream has cut through it. If, with a view to save the masonry works which would have to be constructed if we opened the Head at the debouchure from the Hills, we should look for a site below the point where the Hill torrents join the River, we should find that there would be no escape from the alternative of entering the "Bangur" land in a cutting of from 50 to 80 feet deep. (Ganges Canal report, vol. 1, page 19-20).

255. The surface fall of the "Bangur" from Roorkhee to the southward for a distance of 20 miles is less than 2½ feet a mile (Ganges Canal report, vol. 1, page 202-206), the soil is sandy throughout, even on the surface. The velocity of the water in a Canal carried through this soil should certainly not exceed 2½ feet per second; and with a depth of 10 feet, and a supply of 6,500 cubic feet per second, the width of the bed would have to be 250 feet. The fall of the bed would

only be about 5 inches a mile, and before the water reached the surface, the Canal would have to be carried a distance of upwards of 30 miles, and would cost for that distance only not much short of a crore of Rupees.

256. If any point lower down the River were tried, it would be found that nothing would be gained, for although the height of the Bangur land might be less, the surface fall would be less also, and the Canal would therefore have to be carried in a deep cutting to a greater length.

257. The above explanation must be superfluous to any one who has examined the surveys of the country between the Ganges and Jumna, but the relative levels of the "Bangur" and "Khadir" might not strike one, who had merely glanced at the plans, particularly as no crop sections of the Doab are drawn out. The fact is, that once it is decided that the Canal must be opened at some point near the Hills, the level of the country with reference to the River at other places to the southward is a matter of no interest, excepting at the positions selected for the termini of the Canal and branches.

258. It must be evident from the above description that it is only by selecting some point near the Hills, where the fall of the country is rapid, and where it exists both *along* the course of the River, and *towards* it in the direction of the Hill drainage, that the Bangur land can be entered with a moderate amount of excavation. The attainment of this object might not however carry the Head sufficiently far up to secure it against injury from the capricious changes of the River. It would cost much less and be more satisfactory in every respect to have the Head of the Canal at the point, or at a short distance below it, where the River debouches from the Hills, where the bed is formed of large boulders, and where there will be facilities for gaining a control over the supply, such as do not exist at any point lower down throughout the whole course of the River to the Sea.

259. These advantages are somewhat dearly purchased it

must be allowed. A great surplus fall has to be disposed of, and torrents of the most formidable kind are intersected, which can only be surmounted by means of works of extraordinary massiveness, and extremely expensive.

260. It would thus appear that the masonry dams, falls, and other costly works which have been constructed near the Heads of the Canals in the North West Provinces have been forced upon the Officers who designed them. The estimated expenditure per mile for the first 24 miles of the Ganges Canal was about 2,40,000 Rupees, or in all to nearly 57½ lacs of Rupees, while that of 523 miles of main channel beyond the 24th mile, was only at the rate of about 14,000 Rupees a mile, an amount which cannot be considered immoderate, if it be noted that it provides for the construction of Bridges at intervals of every 3 miles, and of numerous locks, falls, and other masonry works. It may be said that the first 24 miles of the Ganges and Baree Doab Canals, cost nearly one-third of the whole outlay,—or in round numbers from 60 to 40 lacs of Rupees. In the latter Canal there is the disadvantage arising from high rates of labour* and materials to contend against, in addition to that occasioned by the extraordinary fall of the country for some distance from the Head.

* At least half as high again, on the average as the rates in the North West Provinces.

Bricks owing to the great scarcity of fuel cost 14 or 15 Rs. per 1000.

Saul 2½ Rs. a cubic foot.

Bricklayers 15 Rs. a month.

The cost of earthwork again is moderate enough.

261. Moreover, the Head works must be completed entirely before the water can be let into the Canal. At the lowest computation a period of ten years will be occupied in the operation, and as the remainder of the works would be carried forward during the same period, it may be computed that on each of the Canals above-mentioned, nearly a crore of Rupees *must* be expended, before the irrigation can be commenced.

262. Those Canals thus labor under a great financial disadvantage at starting; and the number of masonry falls, dams,

&c., with which they are furnished necessitate the employment of expensive establishments, which must be kept up to much the same standard, when the irrigation first commences, as it will amount to, when the whole of the water is utilized.

263. A limit has to be fixed for the quantity of land to be brought under irrigation. Any increase in the supply of water above what the capacity of the channel provides for in the first instance, would necessitate an additional outlay on the masonry works, as well as on the channel, and although any quantity of water could be obtained from the River during six months in the year,—April till October,—it must depend on the demand for the produce of that season, whether the additional supply of water would be taken up by the cultivators or not.

264. In the North West Provinces the largest crop irrigated is wheat, which is sown in October and ripens in March, and the capacity of the Canals is made sufficient to appropriate the whole of the water in the River, that can be utilized in that period. The actual area of wheat under irrigation on the Canals to the east and west of the Jumna, exceeds that of all the rain or "Khurreef" crops put together. Of course, therefore, any enlargement of the channels, designed to improve the latter crop only would be comparatively unremunerative. This is the reverse of the condition of the Canals in the deltas in Madras, on which the irrigation is applied principally to rice, during the rainy season (June to December), for which period, the supply of water in the Rivers is generally, and in some cases far more than, sufficient to irrigate the whole area of the deltas.

265. When on the subject of the Canals in the North West Provinces I may refer to the extraordinary difference that prevails in the mode of dealing with the foundations of masonry works constructed on them, from that adopted in the Madras Presidency. To a Madras Engineer the foundations allowed to the masonry falls, dams, and various other works on the Ganges Canal, must appear excessive when he

is accustomed to see Anicuts constructed in the sandy beds of Rivers on wells not exceeding 6 or 8 feet in depth. If the reader refers to the Atlas attached to Sir P. Cautley's report on the Ganges Canal, he will observe, however, that it is not on all masonry works that deep foundations are used; those of bridges and locks, are as moderate as would be employed in similar situations in Madras. The foundations of falls, dams, aqueducts, or works of whatever kind when a stream with a very high velocity is expected to act on them, are alone such as to give any cause for astonishment. But it should be taken for granted by those who have no experience of the Himalayan torrents, that an Engineer who designs bridges, or locks, on much the same pattern, at least so far as the foundations are concerned, as those erected on other parts of India, will not adopt foundations of extraordinary massiveness on other works without some good reason; and although the reason may not be apparent, some faith should be placed in designs which have been adopted after the most careful observation of similar works during a long series of years.

266. The magnificent works on the Ganges Canal have been built on the model,—though on a much larger scale,—of those on the eastern and western Jumna Canals. The former is in the same Doab as the Ganges Canal, and the nature of the soil and of the obstacles to be overcome, may be considered as precisely similar in the two cases. The Ganges Canal was designed by Sir P. Cautley after twenty years' experience on the other, and during that period he planned and carried out nearly all the falls and other works, which were required for regulating the fall of bed, and for disposing of cross drainage. Experience was gathered in that time by failures as well as by successes. For instance, a dam which was constructed across the Nogong River, where it crossed the Canal was destroyed. A section of the work is given at page 857, vol. 1, of Sir P. Cautley's report on the Ganges Canal. No one looking at it would

suppose that the foundations were not sufficiently strong; indeed, but for the result, they might be considered extravagant. Again, on one of the masonry falls with two descents of 7½ feet each, Sir P. Cautley reports* that "when the water was first admitted over the falls, there was a good deal of slack water in the lower chambers, which relieved the floorings in a great measure, from the action of such a body of water falling upon them. South of the falls however, and between them and the Muskurra works, there was still a descent of 12 or 13 feet, on a line of about 3 miles in length, somewhat tortuous certainly, but over a sandy bed. In August 1837, after we had done all in our power to oppose the retrogression of levels upon the tail of these falls, and at a time when it was considered that this had been done effectually, at least sufficiently so, until another set of falls could be built south, the lower chambers sank, owing in all probability, to the sub-soil having been carried away by percolation, arising from the Head water acting under the foundations upon soil not sufficiently protected by the tail foundation wall, which wall had been laid bare by the retrogression of levels."

* Report on Doab Canal Roorkhee, 1853.

267. The dam across the Muskurra River on the same Canal, was founded on three lines of wells,—the first and rear lines being carried to a depth of 12 feet,—but was breached in 1829, to a width of 200 feet, besides 150 feet of revetment. In rebuilding it one bay of 85 feet clear waterway was left—to be filled in with earth to a height of 6 feet, that it might give way to a moderate flood. The apron consisted of River stone to a width of 20 feet covered with a timber platform. A flood in 1835, destroyed a great portion of the latter, and above 100 feet of the body of the dam. Again, it was repaired to an extra degree of strength. The apron was built of boulders in cement to as great a depth as spring water would admit of, and covered with a paving of brick on edge to a width to 20 feet; and

for an additional width of 40 feet, boxes filled with River stone were laid, and retained in position by lines of piles driven parallel to the body of the work. The front apron was also built of boulders in cement. But even these additions proved insufficient to withstand the floods. In 1842, a portion of the apron was destroyed, the foundations were exposed to a depth of 10 feet, and some of the wells had fallen in.

268. Similar accidents occurred to other works, and it may be said that the position of the officers on that Canal was one of the greatest anxiety for many years. It is only very lately that the "great difficulties experienced in controlling the mountain torrents which intersect the channel of this Canal in the first ten miles of its course have been overcome, and that the principal dams and regulators on this part, have been placed, and are maintained by vigilance and timely reparation, in the most efficient order." (Report on the Canals North West Provinces, 1859-60.)

269. I have already remarked that the supply of the Canals in the North West Provinces is perennial, and as they are never closed except for a few days at a time, or on extraordinary occasions when a crop must be sacrificed, it must be exceedingly difficult to repair any of the works near the Head, where spring water comes to the surface, and it would therefore be the most economical and advantageous plan in every respect, to make the works sufficiently strong in the first instance.

270. As regards the use of deep foundations to Bridges across natural channels, instead of a flooring with front and rear curtain walls, it must depend very much on the locality, which is the preferable mode of proceeding. A flooring will not prevent a severe action on the bed beyond, and it is only in localities where stone can be procured to form a rough apron, that the action can be softened off by degrees. In many parts of the North West Provinces, one may traverse a hundred miles of country without meeting a stone

or piece of lime kunkur as large as a walnut, and where brick will therefore be the only material available. In many cases spring water will be found in the bed of the stream, and the curtain walls of the flooring would have to be formed of wells; and the only material to be found, for forming the apron, would be brick cubes, which I should say, are the most expensive things that could be used for strengthening a work. They may have to be used at times, for want of any other material, but as their effective weight in water is from one-half to one-third* that of stone, they must be altogether unsuitable for a work exposed to the action of a violent stream; and in any case, it may be questioned whether it would not be much better to carry the foundations to a depth in the first instance, sufficient to secure them against the action and have done with them, instead of subjecting the work to constant supervision and repair.

* A cubic foot of old brick work in the Kistna district, has been found to weigh almost exactly 100 lbs. and a cubic foot of soft gneiss 171 lbs. In water the stone would weigh nearly three times as much as the brick.
One of the cut stones which was ripped off the front wall of the Annicut at Bezwada by the freshes of 1861, and was carried to a distance of upwards of 80 feet contained 31⅝ cubic feet. Its weight would be nearly 2½ tons.

271. In the case of a suspension Bridge, or others in which the distance between the piers is considerable, there can be little doubt, of the superiority as regards economy of the deep foundations, over a flooring and curtain walls; though of course, unless the stream is to be violent, it does not follow that either are necessary.

272. In the Bridges on Canals in the North West Provinces, floors and curtain walls are generally adopted, not only for the purpose of rendering the foundations more secure, but also to serve, to a certain extent as dams, to check the action of the stream on the bed, when there is reason to apprehend that the slope and velocity allowed may be in excess of that which the soil would stand. But in Rivers, the surface of the stream even in the dry weather, may stand at so high a level, as to render it difficult to construct

a flooring at all ; and in such a case, the method pursued in the North West Provinces of sinking blocks for the foundations of the abutments and piers would seem to be the very best that could be adopted.

273. The above explanation of the physical features of the country in the north of India, will have rendered it evident to the reader that the system pursued in the Madras Presidency of constructing Annicuts across a River, and of raising the water by means of them, in order to reduce the depth of the excavation at the Heads of the channels cannot be applied then as a general rule.

274. To make the conditions, in the two cases at all similar, it will be necessary to confine ourselves to the "Khadir" lands or in other words to the tract of country along each of the Rivers in the North West Provinces, which is within the inundation limit. But I have explained that the "Khadir" land is generally of insufficient width to furnish room for a first class Canal : and moreover the fact of the width being inconsiderable implies that the water in the wells is influenced by the proximity of the River ; and as the cold weather level of the latter is not above 15 feet below the lip of the channel, and is less than that below the level of the ground at a little distance from it, the cultivator could never be in any straits for want of water. As a rule a great part of "Khadir" land is inundated during the floods, and the wheat which is sown on the saturated ground on the subsidence of the inundation, requires no further supply of water to bring it to maturity. There are generally some slight showers of rain in the winter, but at the worst, if this aid fails, the people can have as much water as they like at the depth of 10 or 15 feet below the surface of the ground. I may add, that the upper stratum of alluvial soil being only 3 to 6 feet deep, the water permeates the sand underneath it, and will stand at a higher level when the River is in flood than in the dry season, but the change in surface of the water in the wells

must be the work of time, and though the River may subside somewhat suddenly in September or October, the water in the wells will not be affected immediately, but will retain a comparatively high level to a much later date.

275. Of course the further the "Khadir" land recedes from the River, the more will the advantages above described be absent. The land will not be inundated and the depth of the wells will gradually increase with the distance from the River. It would be difficult to define the limit at which irrigation from wells becomes unremunerative. Much must depend on the rent to be paid, but still more on the aid derived from rain. In the lower parts of the Punjab, the fall of rain is very precarious; still there are always a few showers during the year: and in the winter there are heavy dews which must supply its place in a measure. But taking things as they are, I should say that cultivation languished when the depth of the water in the wells below the surface of the ground exceeded 25 feet. This depth is attained at the distance of 5 or 6 miles from the River and at the distance of 25 or 30 miles from the River, that is on the extreme limit of the western Khadir of the Sutluj, the depth is 50 or 60 feet and in some places even more.

276. Here then we have at least one tract of Khadir land, which would admit of irrigation on an extended scale, and a similar strip of country exists on both sides of the Indus, both in Scinde, and in the provinces to the north of it. I am not aware of there being any other tracts of country along any of the Himalayan Rivers, at all events of equal importance in which the same want of artificial irrigation is experienced.

277. But in the Punjab and in Scinde irrigation is already extensively applied to the Khadir lands. Moultan, the tongue of land between the Chenab and Indus, Bhawulpoor, the Derajat, and the low lands in Scinde are watered by hundreds of channels, many of them of great length. I

conclude that the system of irrigation that is now in force in these provinces was introduced by the Arabs, in the first Mahomedan invasion of India. It seems to be identical with that pursued in Egypt; and the prevalence of the date tree and the universal use of the Persian wheel for lifting water, as well as the style of building, in the valley of the Indus, gives it an extraordinarily close resemblance to that of the Nile.

278. The "inundation Canals" in Scinde and the Punjab, though they prevent the country from being entirely desert, excepting a strip 3 or 4 miles in width along the margins of Rivers, are yet very imperfect. They might be much improved and extended even on the existing system. The people have been subject to oppression and the country to anarchy for ages, and the chief obstacle to improvement is now the want of population. They are much more efficacious than similar channels (considered without reference to Tanks and without Annicuts) from the rain-fed Rivers of Madras, which draw off a supply from the River only during high freshes. They are secure of sufficient supply for indigo, which requires water from April till August. But there is very liable to be a failure in October and November, when the rice crop is coming to maturity, and when the lands for the wheat and other rubbee crops require to be inundated before ploughing. The supply fails not from any want of water in the Rivers but from the changes which it undergoes during the floods, (as described above, 64-65). The maintenance also is expensive, new Heads being very frequently required, and the clearance for some miles from the Heads being often so heavy as to be almost equivalent to cutting new channels. Further, they have to be carried for a considerable distance before the water can be applied to surface irrigation (inundation). Captain Fife, Bombay Engineers, thus summarizes the defects of the existing channels in a report on the Narra, 1861, (Bombay records LX. New series, page 19). "The precarious nature of the revenue on the

common inundation Canals, arising from the uncertainty of the inundations; the heavy expense and difficulties, the cultivators have to contend with in forming and maintaining their deep and imperfect kurrias (minor branches) and raising the water from them with the aid of machinery to the level of the ground: the waste of time, waste of labor and waste of wealth from obtaining only imperfect crops: these were some of the overwhelming disadvantages, but very imperfectly understood ten years back, and under which Scinde still labors. This subject is now however, I believe fully comprehended by all who have a sound knowledge of the country. And I can only conclude this report by expressing a hope that no obstacle may be permitted to stand in the way of works like the Nutrow permanent Canal, which will, more than any others, add to the annual revenue of the province, and improve the condition of the people." A great part of the crops jhoar (cholum) Bajra,* Cotton, Indian corn, &c., are irrigated by Persian wheels. On some of the larger Canals there will be upwards of a thousand of these machines,—not always at work certainly, but used more or less to make up for the want of flooding. The area of land irrigated by each will depend on the nature of the soil, depth of water and number of bullocks employed, and of course will vary greatly, but 10 acres will not be far from the correct average I believe.

* NOTE.—On one of the Scinde Canals (Bombay Selections LIII. p. 106) the following is the account of the different kinds of irrigation:

Beegas.		Revenue.
9365	Churka or wheel.....	Rs. 12,861
1762	Natural but uncertain flow.....	„ 1,540
7209	Rice.....	„ 20,979
2000	Rubbee(that is wheat, &c.)	„ 2,000
20,336		37,380

a Beega is about ⅔ of an acre, but varies in different provinces.

279. I may incidentally remark that the provinces in question have one natural advantage over the deltas in the Madras Presidency, the value of which can hardly be overestimated,—that throughout the Khadir lands there is good spring water to be found. It may indeed be at a considerable depth below the surface, but it is still every where

attainable, (unless in parts of Scinde) and once a man becomes the owner of a well, he may look upon part of his crop, at all events, as secure. It is the absence of sweet water in the Godavery and Kistna districts and elsewhere, that renders the formation and maintenance of Tanks and channels or neglect of them in the Madras Presidency a matter of life or death to the people.

280. The maintenance of the inundation Canals in the Punjab and Scinde is I have said expensive, and the irrigation is partial, and dependent on mechanical aid. It would seem desirable to ascertain if there is the means of making the supply perennial and of constituting existing Canals into branches of larger channels which might be opened at some favorable point higher up the River, and run nearly parallel to it, with the water on as high a level as might be wished.

281. Doubtless, this would be a most desirable consummation, but the question is, how far it is practicable. There are two Rivers to be considered, the Sutluj and the Indus. The first at Ferozepoor—or where the Bangur land touches it, about 20 miles above it,—commands the Khadir land to the westward, comprehending an area of upwards of 5,000 square miles, and that to the eastward, a strip of country about 10 miles wide and several hundred miles long, but mostly belonging to the Nawab of Bhawulpoor. The Indus at the junction of the Chenab, commands the whole of the country onwards to the sea, including the whole of Scinde, part of the Bhawulpoor Territory, and adjoining it, that ceded to Meer Ali Morad.

282. To say nothing of navigation what would Canals be worth which should prevent the supply in the Sutluj and Indus running waste to the sea for six months in the year, November to April. The minimum discharge of the former is about 8,000 cubic feet per second; that of the Indus, I have no means of ascertaining, but it is probably between 30 and 40,000 cubic feet per second.

283. The only means of securing a perennial supply to Canals opened from those Rivers, would be by gaining a complete control of the latter, which could only be accomplished by the construction of masonry works across the channels, and by extensive flank defences to prevent their being turned. The Madras Annicuts have been so successful in positions, where, not many years ago, most Engineers would have anticipated nothing but failure, that one would naturally turn to them as the model to be followed on the Rivers under consideration.

284. The chief difficulty would be, not to give a work sufficient strength to withstand the floods, or to protect it against a flank movement of the River, but to construct it at all. The Godavery Annicut was closed when there was a considerable body of water in the River, though not without great difficulty:* but there were stone quarries at no great distance from the work; and the only practical difficulty was to have a sufficiency of boats, wagons, and coolies to bring the stone to the spot. But had there been no quarries, how many brick cubes would have served to make up for the want of them?

* See Lieut. Col. C. Orr's reports—vol. 4, Professional Papers. Madras Engineers, page 44, para 8.

285. I do not think it likely that a project to throw a dam across the Indus would meet with serious consideration at present. If any improvement in the existing system is thought desirable, it would probably not be extended beyond the opening of main channels at Sukkur, where the River is confined by rocks. One channel has already been carried out from that point, by Captain Fife, and the experience gained from that work, would make him the most competent person to judge of the possibility of feeding the various inundation channels to the southward, by main channels from the same site, with the beds on a level sufficiently low, to admit a supply during the cold season. The

channel already excavated provides for a depth of only 1½ foot of water, when the River is at its lowest. Captain W. Baker suggested the cut originally, and proposed a depth sufficient to allow 5 feet of water in the dry season. The change is probably due to the necessity of limiting the expense of the work, and to the anticipation of inordinate silting of the Head during the floods, which would necessitate the closing of the channel for several months in the year. Information on this point: the quantity of silt, compared with the supply of water, would be valuable and interesting.

286. I may remark, that unless the channel is confined within a rocky gorge, so that the width of the stream, in the dry weather is not materially less than in the rains, the simple contraction of the waterway will not be sufficient to ensure a supply to channels on either side. Many of the Indian Rivers could not be contracted by artificial works—at places where they pass through alluvial soil or sand, to much under the width of a mile, while in the dry season, the width of the stream might not exceed one quarter of a mile. On the subsidence of the River, the Heads of the Canals, on one side or the other, would be liable to have a sand or mud-bank, three quarters of a mile in width between them and the River; which, in all probability, it would be physically impossible to cut through in time to prevent the destruction of the crops.

287. It might be possible by a system of groynes, to obviate the occurrence of the serious inconvenience I have described; but they would be, at best, a very imperfect substitute for a dam, and could do nothing to raise the water, when it might have fallen to an extraordinarily low level.

288. The Sutluj though a formidable River, is far inferior in size to the Indus, and I am not aware of any River in India, that affords a finer field for irrigation. The country under its command, from the junction of the Beas,

to the southward, is some thousands of square miles in extent; and as channels opened from it at that point, would not be subjected to the draw backs* of those opened nearer the Hills, so far as drainages and masonry works to cross them are concerned, the supply of water need not be limited by that afforded by the River in the dry season. In fact the principal expense would be in constructing a dam across the River; and as in the case of the Annicuts in Madras, the larger the channels, the higher would be the returns in proportion to the outlay. If for instance, the expense of a dam and Head-works were to amount to 50 lacs of Rupees, and that of the channels and other subsidiary works to as much more, and that water for 10 lacs of acres (which is a low estimate) were supplied; the returns at 1 Rupee per acre would be 10 per cent. on the outlay; and if by the expenditure of another 50 lacs, in enlarging and extending the channels, so as to double the supply of water, an additional return of 10 lacs were realized, the whole returns, on 150 lacs, would be 20 lacs or 13⅓ per cent: which would be no exaggeration, for by doubling the expenditure in the channels, the supply of water would be more than doubled.

* As regards silting they would be immensely inferior to the Hill Canals. But they might be closed for three months in the year without injury to the irrigation. It would be near the Heads of the main channels where the heaviest silting would take place; and it might be worth while to have a double set of main channels for the first 5 or 6 miles from the Head, and to use them alternately.

289. It would serve no purpose to enter into the details of a project for the irrigation of the "Khadir" land under the Sutluj. I would only beg to remark that a dam across that River must of necessity be a very expensive work. No material but brick would be procurable, unless for coping, grooves, and other work in which stone might be considered essential, and every cubic foot of it would cost about a Rupee. Even bricks would cost 14 or 15 Rupees a thousand, if not more; and for the enormous quantity that would be required, it would be difficult to get sufficient fuel, at any price.

290. In conclusion, I would beg to point out that it is customary in the North West Provinces as well as in the Punjab and in Scinde, for the cultivators who draw off a supply of water from the Canals to excavate and repair the minor channels themselves. The minor branches or Rajbabas from the Canals in the North West Provinces are excavated under the superintendence of the Canal officers, though the outlay is charged to those to make use of them. But their time and attention is not taken up with making or repairing wells or in excavating and repairing channels, which may do nothing more than water a man's garden.

291. In the Madras Presidency, on the other hand, all works however small, and all repairs of irrigation works estimated to cost over 25 Rupees are carried out under the supervision of the officers of the department of public works. How this system came originally into operation, I would not attempt to explain. It will be allowed, I imagine by all parties, that it has great drawbacks. The question is not whether the work can be done best by the revenue authorities or by the department of public works, but whether it could not be done by the ryots themselves. There can be no doubt that it is not any difficulty of construction, that would stand in their way; but the difficulty of doing any thing whatever contrary to "Mamool." But when so much is said and written about educating and improving the natives, one would think that any efforts of the kind would not be of much good, if they did not teach the natives first of all to help themselves. If there is one thing more than another in which they have an interest, it is the maintenance of their irrigation works, without which their land is useless.

292. If the thousands of petty Tanks and channels in the Presidency were repaired by the ryots, both they and the Government would be gainers. The latter could well afford to reduce the revenue by the average cost of the annual repairs, less the charge for superintendence, while the ryots could of course execute the work cheaper than

could be done by the department, to say nothing of the benefit they would derive by learning to exert themselves.

293. It would doubtless be very difficult to introduce this change. It would probably be answered by those best capable of judging, that the people would simply neglect to do the work—so improvident are they and so religiously tenacious of established customs. I dare say the subject has been well considered already: and it would not have been becoming in me to have alluded to it, had I not been naturally led to it, in describing the peculiarities of the Canal system in the north of India.

294. Though it may be impossible to induce the ryots to repair existing Tanks and channels, it would be well worthy of consideration whether some improvement on the established system may not be feasible, in any extensive new projects, which may be carried out in future. I believe nearly every officer who has charge of irrigation works, could point out to instances when from want of water or other cause, he may not have supported a channel which a ryot was anxious to have excavated, and when the ryot has then volunteered to do the work himself; and as for bunds, the difficulty is to *prevent* the ryots from constructing them. The extension of irrigation from a new Canal would doubtless be slower, were the water withheld until the ryots should dig the small channels to their fields; and any such delay might be vexatious to the officer who may have designed or carried out the Canal, particularly if he is the only person who is very sanguine of its success, but if he were supported by the Government, I do not think he would fail in the long run.

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