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THE RELATIVITY OF NAVIGATION AND ENGINEERING SCIENCE.

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The facility and unerring sub-conscious judgment with which the ordinary " mallah " guides his boat through unknown rivers is in reality marvellous, though little noticed. To him the sheet of water reads like a book, the spelling of which has come by the experience and familiarity of years. Were the same knowledge possessed by the engineer he would be able to unravel the laws which underlie the spelling of the " mallah's " vocabulary, while the " mallah " himself can only explain that it is so because it must be so. His knowledge is invaluable but cannot be applied to more than the guiding of his boat. Learning some of the first principles from him, we may expand their application to the science of engineering in a wider field, for a relation between the two holds good.

The first guide to the " mallah " is the ripple on the surface, but the ripple has its foundation in the eddy. If therefore we understand the former, we may know far more of the latter.

But more than this, just as much as the ripple, so do the absence of ripples and other aspects appeal to the " mallah." Dead sheets of water with a glassy white look spell deeps to him, just as other glassy white sheets, alive with ripples, though barely distinguishable, spell shallows. Again, belts of patchy white consisting of a series of eddies swelling up and dispersing on the surface are by no means shallows, but deep flow near a bank, or along the main stream, which is scouring its bed.

It is in contrast with these three different whites that the ripples appear as shades of varying roughness. They are full of meaning to the " mallah," for in them he sees the dividing lines of shoals which map out the bed on the surface. The shoal may not of necessity shelve up to a visible bank, as it just as frequently occurs in deeper water, but in both cases it is the shoal, or change in depth, which gives the surface shade. This is an all important point to remember. Since in navigation it is not so necessary to know the depths of mid-stream as it is to follow the outer boundaries of flow, the " mallah " pays more attention to the marginal ripples.

Moreover, the " mallah " has visible banks of shoal to guide him, and these he takes in at a glance, filling in the wanting details by the help of the ripples, and combining both, he follows the contours of the river, and guides his boat, much as the engineer follows a mass of reduced levels dotted over his paper, and guides his pencil along any one contour. For instance, to the " mallah," that cutting bank, nothing more than a deep heavy line of shadow in the distance, indicates that the deep stream is there. In the other direction, those few stranded objects and jungle show that a shoal is forming there. Nearer by other banks

and shoals are plainly visible. With an eye on all these he traces the shades in his immediate vicinity to connect up the line of flow at a glance. Just then as the " mallah " traces the line of deep flow along which he has to steer, the engineer traces the line along one contour. A law guides both, closing all passages tempting, but barred, and each is able to read consistency in seeing confusion. Only one system runs through the river, as only one runs through the contours of the land, and practice and experience have shown the one to the " mallah," and the other to the engineer.

Again, the " mallah " has a knowledge of effects which greatly assists him. For instance, if he be sailing under an eroding bank, he looks out for the shoal which he knows must be forming lower down on the same side at which the erosion is taking place. Many engineers still dispute this point, and stand in doubt whether the detritus of erosion is laid down on the same side or is carried over to the other. The " mallah " simply knows, and is meanwhile calculating how big the shoal will be, according to the severity of the erosion, or the length of the bank along which it is active. He is therefore prepared to guide his boat away from the bank when erosion slackens, and seeking for the deep flow further out in mid-stream, is soon able to distinguish the ripples which mark its course.

The " mallah " moreover has an uncanny accuracy in telling you approximately what unsounded depths may be, or astonishes you by prophesying that a certain creek which is going strong is doomed to silt up, while another which is just struggling into existence will develop. Without knowing it he is still calculating the effects of the erosion above, and bases his conclusions on it, while the engineer is yet squabbling. His boat is at stake and he cannot afford to argue, but he simply respects where he knows.

Now all this lore which the " mallah " stores is true science, for his success in navigation is undeniable, and is as we have said even marvellous. It is worthy of a book, but as the " mallah " himself will not write it, it falls to the lot of some one, less competent, to do so. These remarks are therefore offered with apologies to the " mallah's " better experience, but where there are imperfections, it is hoped that some one with better judgment will offer the needful corrections.

If then, in the search for science we hope to utilize the " mallahs " lore, we shall first have to interpret the ripple which is his principal guide. In doing so we shall find that we must also interpret the shade on the surface which is the mark of the ripple. Contrasted with the shades are sheets and belts of white, which, while they give other meanings, intensify the shades. The whites will therefore also have to be interpreted. It will be found that they are associated with the ripple in more ways than in the mere constrast of light.

While therefore light and shade give us the two broad aspects by which perfect navigation becomes possible, they also interpret relative effects which are valuable to the engineer.

There is it is true another rough and ready guide by which navigation may be conducted, for the dark central flow marks out the boatman's course, and any one may follow it. Yet this frequently grows indistinct, or in broad reaches of the stream, may entirely disappear. It is then that light and shade give us our bearings. Moreover, navigation must often leave the deeper flow for shallower passages, and must then depend entirely on careful steering. We therefore see that the "mallah's" knowledge is essential.

Confining our attention first to the white aspects, we shall discover that they present themselves under three distinct interpretations. There is that aspect which gives us a dead white surface, and its interpretation is still water, with no ripples whatever. It generally indicates the deeps, such as those of back-waters. Then there is the white which is by no means dead, but is alive with ripples, shimmering on the surface, ripples which are not so intense as to give us any noticeable shades. This white is usually spread out in sheets, and is the white of shallow water with very little velocity. Finally there is the white which swells up in big visible eddies, each rising as a peak, and spreading out in a white patch. The patches, by merging into one another, give us an almost continuous belt of white. This white indicates active deep flow where the bed of the stream is being scoured.

These then are the three distinct aspects by which white presents itself, *viz.*, the dead white of still water pools, the shimmering white of shallows, and the swelling white of deep eddying activity.

Before leaving the white, it may be noticed that as the depth of the shimmering shallows decreases, the surface may take on a blackish or other local colour of silt which shows up from the bed close under the surface. This must not be confused with the shade of deeper water, but it very seldom gives any trouble and will not be mentioned again.

Another more important discrimination will be called for in interpreting differences in the deep swelling white. This white varies in intensity with depth, the eddies becoming whiter with greater depth, and darker with diminishing depth. As the depth diminishes eddies grow more violent, since they break on the surface while their initial strength is yet great.

Now in contrast with the white we have the shades of ripples which are to be the all important guides. As noted, it will be found that they are invariably associated with the whites which are in fact responsible for their being. As the two aspects run side by side, a relation might have been suspected. The clue to this relation will be found when we confine our attention to the stream flowing close to a steep bank. Here we shall notice that a white narrow belt of swelling eddies forms next to, and along the bank, while along its margin another narrow belt of shade appears. If we continue to examine the white more closely we shall see that it swells up visibly to a level higher than the normal stream, and that it is the readjustments arising out of the differences of level which give us the ripples of shade along the margin. This is very important, for it gives

us a cause and alongside the effect, and leads us to a law. We shall find that not only has each bank its line of white and associated line of shade, but each swelling eddy has also its central patch of white and surrounding circle of shade. In fact, however, slight the eddy, these two phenomena of white and shade occur on the surface as cause and effect. Along a steep bank we see a dark narrow line of shade, but along a shelving bank the shade alone is visible as a broad belt. We may with difficulty sometimes distinguish the lines of white separating the shades in the broad belt also, but usually these are lost in the predominating shade. On the other hand, in the sheets of shallow white the shades are lost and only the white appears. Again, in the large individual eddies the white predominates, but in the smaller ones the shades.

We therefore conclude that the two aspects of white and shade are associated as cause and effect, and give us a law. Barring the action of wind, ripples on the surface are not otherwise possible.

From the above we may further conclude that white indicates the absence of eddies, while shades indicate their presence, visible as readjustments on the surface. The still-water pool leads us to this conclusion in the first instance, but the swelling eddy completes the reasoning. Such an eddy forms, as it were, a column from bed to surface, enclosed on itself and opposing the surrounding forces. It is this which gives us the white, since within the circle of the eddy the water is comparatively still. The surrounding forces, however, dance around the central still water column in minor adjustments, which, breaking on the surface, give us visible ripples. What is true of the large swelling eddy is true of the smaller ones, for all are similarly constituted.

So then we may trace the ripple back to the eddy, and as it is the eddy which enters into the science of the engineer, the " mallah's " lore and the engineer's science become closely correlated. Since the " mallah " has been born and reared on the river, and has been taught by a life of hard experience, the engineer need not be ashamed to go to him for learning. The " mallah " certainly makes a success of his art, and by navigating his boat with skill, proves the correctness of his knowledge. A wide field of research is by him therefore opened out.

The remarkable fact is this. Surface impressions interpret the bed correctly and in great detail. They give us as it were a negative photograph of the bed which it is our duty to develop. There is, in other words, an intimate relation between bed and surface, and that relation we have discovered to be supplied by intervening eddies. If so, the conclusion follows that eddies must exist from bed to surface in such a way as to connect the two. So far we have only found the deep swelling eddy to be continuous, but we shall return again to the smaller eddies which are not continuous, and see how they effect the problem. We shall be in a better position to do so after we have grown more familiar with the " mallah's " simpler lore.

It has been noted that the ripples form the mallah's guide. These in contrast to, and in combination with the whites, give him as we have

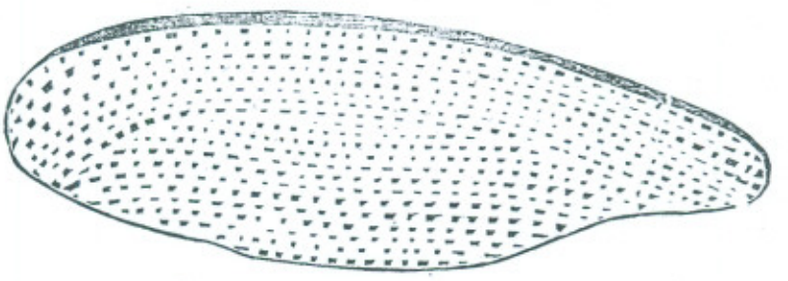
seen, the shades by which he reduces navigation to a fine art. By them not only are the banks and shoals mapped out, but all the changes in depth are known. From the faintest markings to the deep shades he draws his conclusions. Recapitulating briefly, the narrow lines of shade give him a steep bank, and the broad belts a shelving one, while the whites appeal in dead, shimmering, or swelling aspects to read backwaters, shallows, and deeps respectively. These give the finishing touches to his art, but in contrast there is the dark central deep flow tinged with the local colour of silt which is generally of a reddish brown. The " mallah " calls it the "red water."

We shall not often allude to this dark central flow, but may note that it is the turbulent part of the stream, rolling and swelling in eddies. On a large river in flood it appears in a remarkable succession or rolling waves which may be seen from a distance, for the level of the central stream is higher than the surrounding water. The reason will probably be found in the number of deep swelling eddies which appreciably raise the surface. We, however are concerned with the general appearance of the stream so as to be able to recognize and distinguish it. This gives us, as we have said, a rough guide to navigation. Once known we may readily pick it up, but it will lead us through many difficulties, when light and shade will be our only guide.

Having examined some of the causes which underlie the " mallah's " knowledge, it will be necessary to reduce the surface appearances by which he is guided to representations on paper. These at best will be conventional, but it is hoped that they will convey the problems which daily confront the " mallah " correctly to the reader's eye.

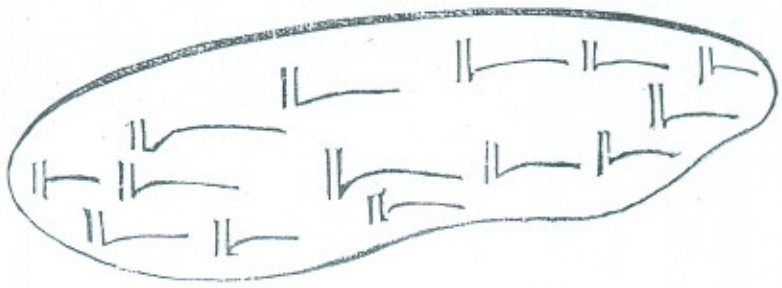
Many of the familiar surveying conventional signs will be retained such as those which represent visible shoals of sand and islands overgrown with river jungle ; but many new ones must be introduced to represent ripples of shade and differences of white.

Thus, the following will represent a shoal :—



The heavy line on the upper side will indicate that the bank is steep and often eroding, while the light lower lines will show that it is low and shelving.

Again, islands, overgrown with river jungle, will be marked thus :—



The jungle will indicate that the island is growing old, and is probably well established, whereas sandy islands, as those of shoals, have been newly laid down, and are usually unstable.

Stranded objects which mark out some of the shallows about to appear as shoals will be shown thus :—



Ripples may conveniently be indicated by a sinuous line, thus :—



which, by being heavy or light, will show severe or slight action respectively. Associated with the ripple but also distinct from it will be the breaker, shown thus :—



Here the ripple breaks over in successive waves, usually across a rapid at a narrow passage.

The shimmering sheets of shallow white may be indicated thus :—



The swelling belts of deep eddying white thus :—



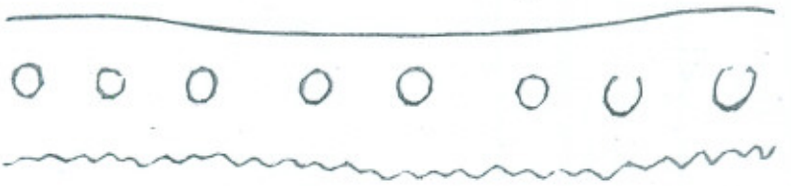
While the still deep-waters will be left blank.

The normal central red water flow, or main stream, will be shown by short arrow heads, thus :—

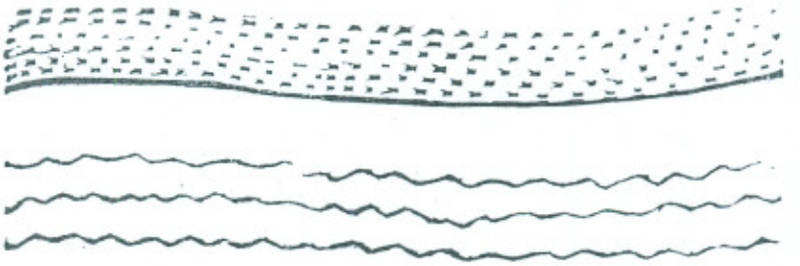


Armed with these conventional signs we may proceed to illustrate some of the simple combinations as they would appeal to the "mallah" as the a. b. c. of his knowledge.

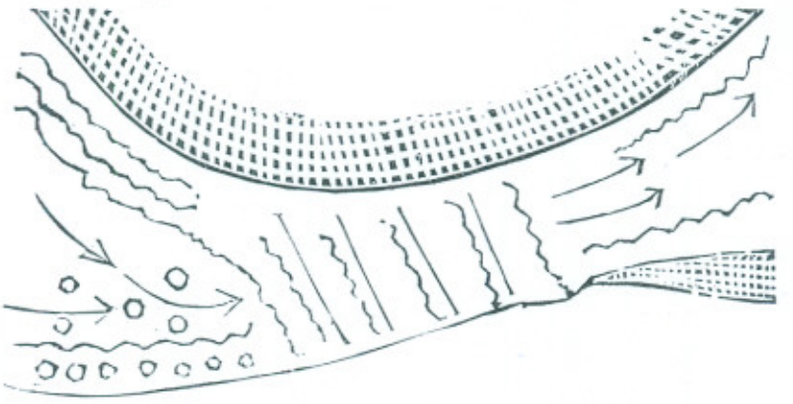
Thus an eddying bank with the stream flowing strong under it would be represented in this way.



While the flow along a shelving bank would be shown thus :—



A narrow passage has much of interest as it



combines and concentrates intense action at one point, and the effects are shown as above.

Here there is heavy erosion round the right bank along which the main stream has set, in eroding attack, while a shoal is pushing out from the left side, helping the narrow passage to maintain itself. The passage is so narrow that it creates marked afflux upstream which is maintained till the water breaks over the narrows as a rapid. These effects are clearly indicated by the surface impressions. The line of shade on the

eroding steep side and the broad belt on the shelving side approach each other, as shown, till they merge just above the narrows. The lines of the shelving side are then carried right across the stream in heavy waves which break across the narrows. Higher upstream, as the main flow approaches the narrows swelling eddies show that it is growing deeper. Below, the indications of light and shade show that a shoal is forming on the right, while the main stream passes over to the other bank. All these are very important effects but we shall allude to them as occasion arises.

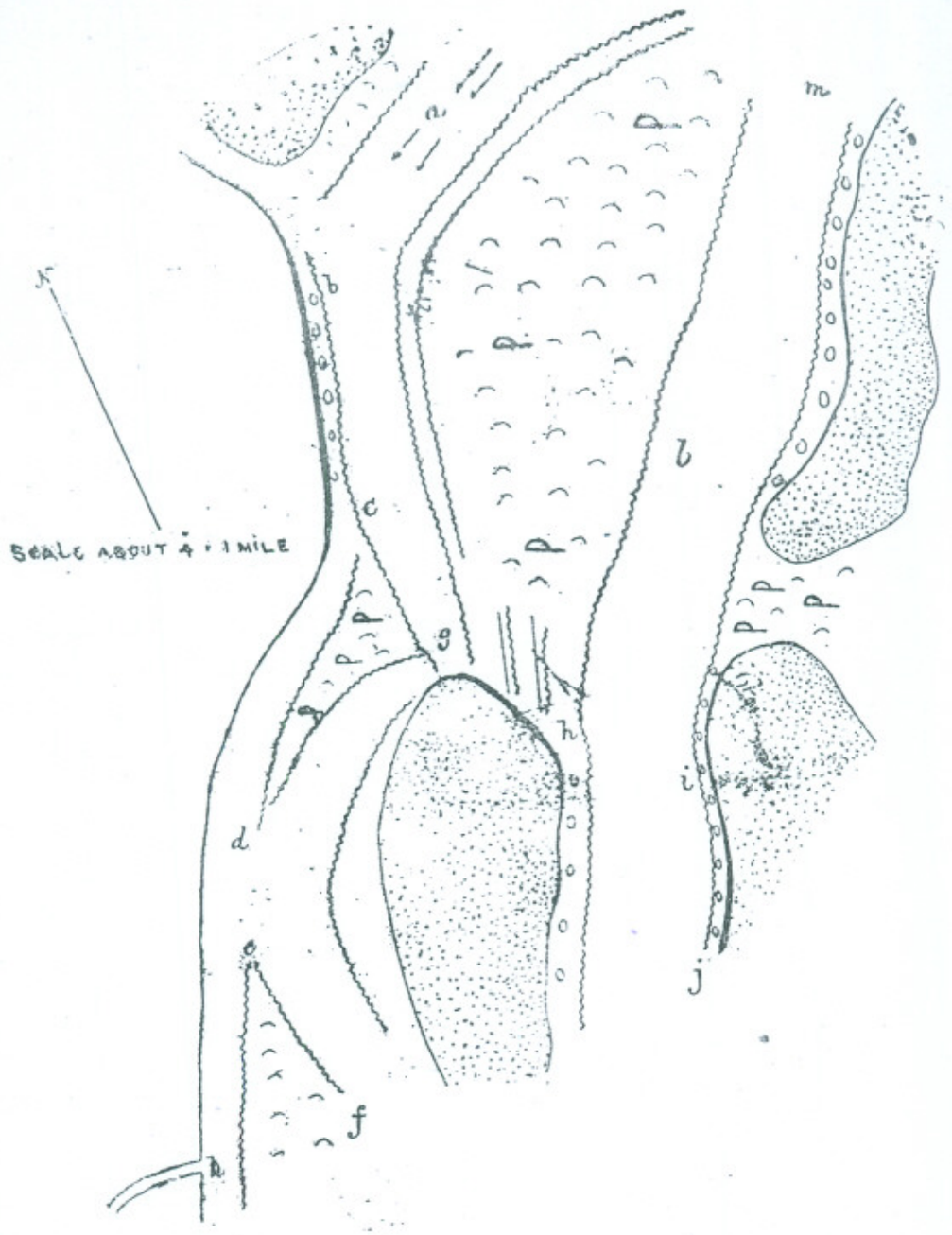
Meanwhile we may pass on to an example on a larger scale shewing a portion of the complete river in a short reach. By it we may see whether we can puzzle through the labyrinth as the " mallah " would. Since it is not possible to present perspective which is the " mallah's " view, we are able to see more of the effects at a glance than he is. On a river also there is motion and relativity which is often very misleading, while the lights are changing, and have different appearances from different angles. All these are heavy handicaps for the " mallah," but he will still find much less difficulty than we do in getting through. If we can find our way successfully at all, we shall do well.

The problem before us then is to steer from a point a, at which our boat has arrived and to follow the course of the mainstream, avoiding the creeks on the way.

To be able to do so we should remember that the " mallah " takes into account all the visible marks, such as eroding banks, shoals and stranded objects. Combined with all these he interprets the ripples and surface shades.

Let then the letters mark points at which we may need to take our bearings. From point a we may see that an eroding bank is before us from b to c. We should therefore steer close along it. At c, a novice would enter the side creek c d, but duly instructed, we are aware that a shoal, the result of the erosion, is forming here, and that the creek is struggling for existence. By surface ripples and perhaps a few stranded objects, the " mallah " would point out that another branch g d is forming, and is bound to increase in preference to c d, so long as erosion from b to c continues. By the breakers ahead from g to h we also note that the mainstream must be passing by that way, and still further on, another eroding bank, i j, shews us where it has gone to. The course therefore which we should follow will be a b c g h i j.

Now, by questioning the " mallah," we may know far more than this. For instance, we can tell off-hand that this is an unnatural course for the main stream to adopt, for why does it not follow the straighter course a b c d e f? His ready answer is that it has been diverted from it by the heavy erosion along b c. Were that erosion to cease, as in the cold weather months, the creek g d e f would develop while it is possible for the minor branch c d e k to form a distinct creek, since the



RIVER DIAGRAM

flow coming round the curve round g d e may erode along g d sufficiently heavily to throw up and complete the shoal forming from d to e. The cold weather river would in fact have two creeks, one c d e k and another g d e f. All this the " mallah " will tell you quite glibly, and what is more, his prediction will also come right.

Now, how does the "mallah " know all this ? He may never have seen the site before, but is just as familiar as if he knew it intimately. All parts of the river are as familiar to him. Indeed he does not rely on his knowledge even of the past week, so much as on what he sees to-day, for the river changes are numerous and frequent. He is not simply going by the ripples, but more than this, he is calculating effects. The erosion from b to c is the clue which is guiding him, and the knowledge that it must have its immediate reaction in carrying down shoals. All the changes in the wedge c g d are the direct effect of the erosion along b c. At c silt is heaviest, and therefore the tendency is to shoal more heavily than at g so the channel g d will develop. All this he calculates, and on the conclusions he will go great lengths. For instance, he will tell you that, although you are floating in 12 feet of water in the main stream from c to g, the depth just beyond the ripple is only 1 foot ; at c it is 3, and at g it is also 3, but at g it will increase to 4 feet as the river falls, whereas at c it will diminish to 2. If he could explain more he would say that not only is the tendency to shoal at c more intense because of heavier silt, but that the backwater entering from the wide channel g d is flattening the surface at d, and is setting against the development of c d, helping to silt it up at c. At d the depth he says will be 5 feet, at e 6 feet close to bank, at f 3 feet, and at k 3 feet, but unless the creek c d e k becomes a separate distinct creek the reach e k will soon dry up.

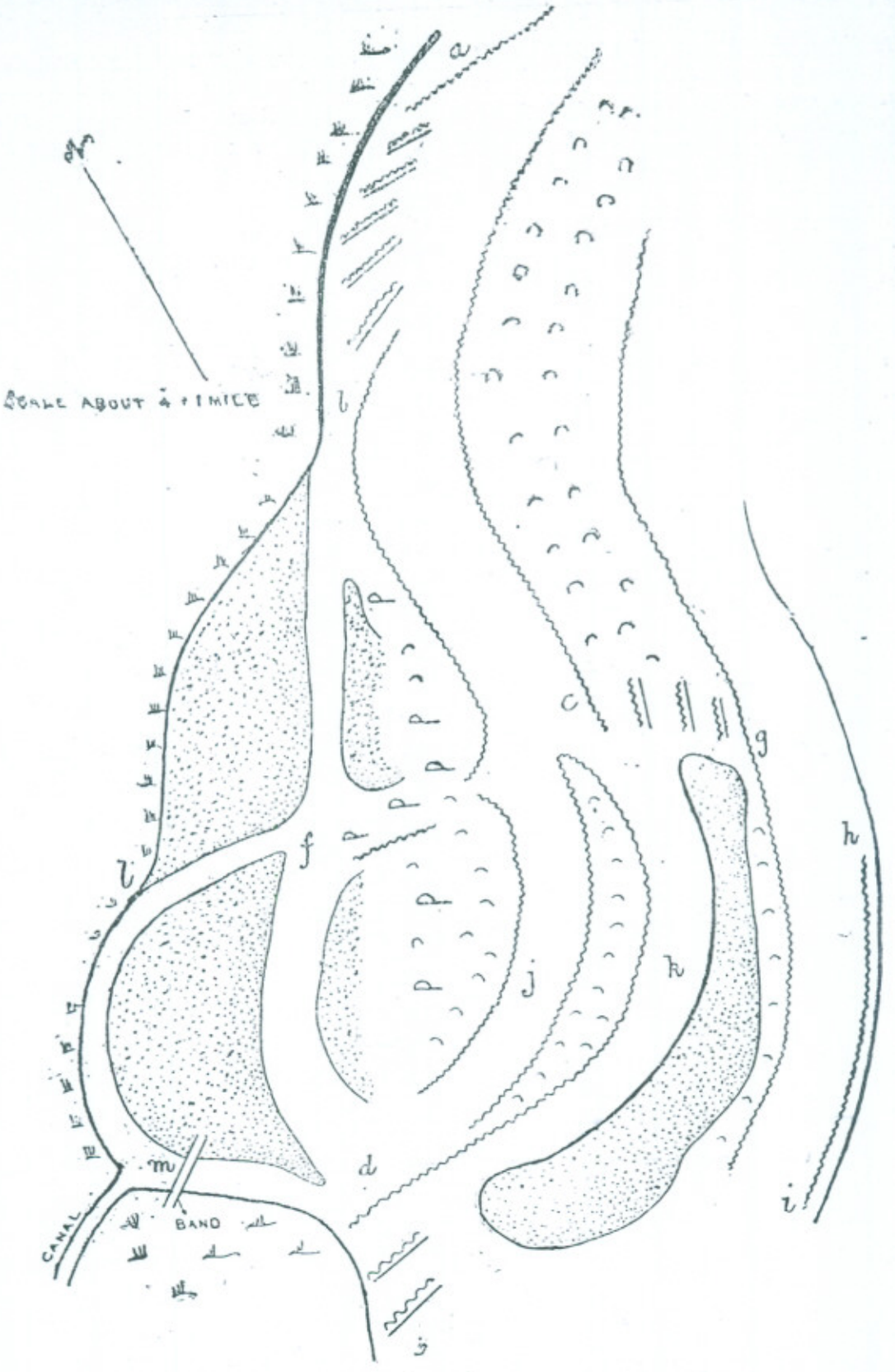
Now, this is a reach which the writer has had occasion to examine very carefully, for a canal head at k. The main stream had been something like m l g d e f the year before, but since it had come round to a b, these were the results. The question arose whether the main stream would not again next year flow along c d e f, a condition very undesirable. The " mallah " was of opinion that it would, should erosion along b c at any time cease, or even slacken. Here again erosion is given as the prime factor. It is in fact an enormous force, or rather the silt torn from the banks is. In this instance it turned the whole main stream from the right bank to the left, deflecting it a mile out of the straight, into a difficult loop. Now again, should it cease, the main stream would come back again to the right bank. The turnover is maintained against tremendous forces commanded by levels, and will remain in the loop so long as erosion above continues. All this will impress the mind and will show us what a mighty factor silt is ; but more than this, the law on which it works is by this example, not only emphasized, but shown to be exact in detail, such as the " mallah " can read. We therefore learn that silt eroded from a bank is an enormous factor to be accounted for,

on the same side, immediately below the erosion. It is not carried over to the other side, as many engineers still believe, for all the evidences are on the side of erosion, and these the " mallah's," and our own observations, show us. We therefore accept the law, and having done so, it is easy to trace the details which lie directly in its path.

Let us now try another reach of the river, also drawn from actual observation. Here we start at heavy erosion from a to b which gives us what would appear to be an enormous still-water lake below, but which consists in reality of extensive shoals in the process of forming. Our only visible clues are one or two fragments of shoals and a few stranded objects, but the surface is alive with ripples. Our immediate object is to steer from a to f, at which point a canal from a subsidiary feeding creek offtakes.

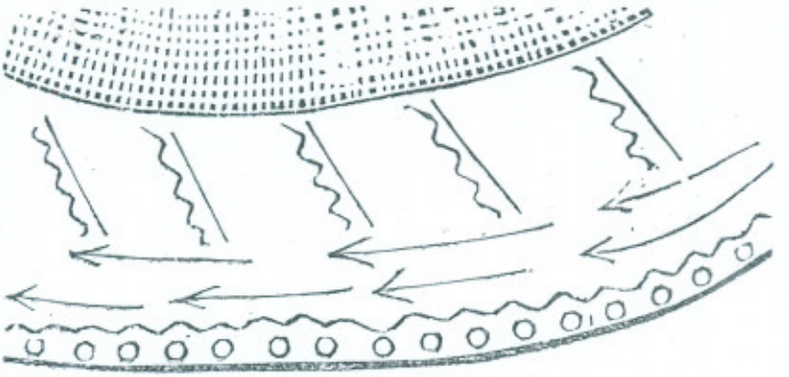
We shall notice that the main stream apparently passes along the line b c g h i, this being the stronger flow, though the stream divides into two nearly equal portions at c. The western branch again subdivides into c j d and c k d, the latter being the stronger creek. We might know this since c j is not entirely free of the shoaling which is coming from erosion along a b. For this reason the short cut c f, as we can see from stranded objects, is fast silting up, and has only from one to two feet of water. Our boat would therefore do wisely to stick to the channel c k d in order to enter the deep back-water d f. Actually, in this reach the steering of the boat was in the hands of an inexperienced man, and he tried to bring it through c j d, and stranded it once or twice before getting through. Further comments are hardly needed, though the passage has very interesting shoals and breakwaters, which would perplex many. The river had evidently at one time eroded a deep bay b l m d, which, with the resultant shoal which must have formed below d, eventually caused an avulsion along c j e. As erosion travelled upstream to a the erosion around a b continued to push the stream further east, till it finally pushed it partly into a side creek g h i.

Now, let us get back to the narrow passage in our first illustration. The question arises why should it remain narrow, so much so, as to cause afflux upstream which, in release, creates a rapid. It is true that the forces of the stream are concentrated and directed towards the narrows, for the flow on the right is being forcibly turned by a resisting bank, while the flow from the left is being directed by a shoal, the result of other erosion on that side above it ; but would these two forces in meeting create afflux so great ? and would they continue to maintain it ? Now that we know the enormous turning powers of a forming shoal we are led to suspect that the shoal on the left is also helping to push the stream into the bank on the right. The intensity of breakers on that side is greater than on the right side indicating that the opposition is also greater. To illustrate this more clearly we may represent a bend not so pronounced, in which the shoal on the left does not approach so near



RIVER DIAGRAM

to the right bank. The figure below will show that we have breakers on



the left, but these do not reach across the narrow passage. They indicate that the shoal here is pushing its way across to the right in opposition to breakers which only occur on that side and are fighting an independent battle. As the shoal is a factor to be counted, it therefore appears that even after its full turning strength has been spent higher up, it still persists as a force from the left, and by continuing to enlarge the shoal finally pushes the stream into the right bank. The noisiest part of the rapid, be it noted, is invariably over this shoal.

Thus we are justified in concluding that the remarkable narrow passages are maintained by both the direct resistance of the eroding bank and the pushing effort of the shoaling one. As we have stated, the afflux above is appreciable, and may be noted by the swelling eddies which grow more frequent and are whiter.

Below the narrows there is the shoal on the right which is the direct result of the erosion above and which now reacts with enormous force to divert the flow to the other side. We have already alluded to this. Much has been said in previous articles and it will not be necessary to enlarge on it. We may however briefly recapitulate what river action in this respect is. Impelled by a probability, flow may as readily set against a bank as run parallel to or away from it. If it sets against it, there is erosion, and this increases all down the eroding bank, till the stream, now also partly deflected, is unable to bear it forward. The eroded material therefore reacts in proportion to the forces of erosion by laying down a shoal which further deflects the stream, and completes the turnover. This is the genesis and development of a shoal. To understand the behaviour of rivers it is essential to note that it forms on the same side as the erosion, and is not carried across. Until we admit, this we are not in a position to even begin to understand a river.

Now, many eminent engineers believe the contrary, and argue that the shoal on the left is the direct result of erosion on the right. They arrive at this strange conclusion by an argument which recognizes a system of cross currents inherent in flow. By their theory there is a lower current setting towards the bank, and an outer current away

from the bank, the circuit being competed by an uprising current at the bank and a reverse downward current on the further side. Thus flow may be said to have not only forward, but rolling motion, and the latter would account for the shoal on the left. Now, the only point of this theory which may seem to be verified is the surface effect close to the bank which pushes outwards. But this is very limited and appears only close along the bank. It can therefore by no possibility reach across a river. The effect along the bank is due not to cross currents, but to the swelling eddies which cause the surface level to rise. It is this which reacts as an outward pushing force, readjusting the levels in a belt of rippling shade a little further out.

We therefore conclude that the bigger visible effects of river changes depend mainly on bank erosions. These bring large excesses of silt into operation, and the resulting shoal becomes a mighty factor to be accounted for. The "mallah" realises this to the full, and apart from the ripples uses it to the utmost. We have seen how much information he can draw from it. Not only does the present lie explained, but the future may be divined. Bank erosion therefore is the law of river changes, and silt is its agent.

We need now to return to the ripple and to re-examine it more closely in its relation to flow. As we have said, an intimate relation between bed and surface is visibly proved to exist by the eddy which correlates the two, but how? presumably through the intervening mass of water which receives impressions at the bed and transmits them in eddies to the surface. Let us examine into this presumption. To do so the writer will briefly have to recapitulate the laws of flows as they have been enunciated by him in a previous article.

Water, when free to move through space, tends to make direct paths for itself, but its filaments do not follow strictly straight lines, but lines which pulsate about the straight in regular rhythm. The moment however that boundaries are applied the rhythm breaks down, and eddies appear, bursting in an instant throughout the mass. If the boundaries themselves be regular the rhythm will again grow regular, but under altered conditions and altered laws. Thus, motion which, before the eddies had appeared, had followed a law by which resistance varied simply as velocity, now follow another law by which resistance is found to vary as the square of the velocity. The exponent is in reality not an exact square, but is varying, having a value in the vicinity of two when the boundary is smooth and unyielding. This then in the manner in which eddies fill the mass of water and communicate effects from bed to surface.

Therefore the presence of eddies implies restraint imposed by boundary, the boundary affecting the mass by lateral stiffness; but there may be, and usually are, great varieties in degree of stiffness, from that of an extremely elastic boundary, as that of air, to that of a comparatively unyielding boundary as that of bed. Again, the latter has still the

elasticity of rolling silt, not finally consolidated, but yielding in motion. It is therefore different in effect to a solid masonry flume which has a higher exponent.

Not only have we to consider the stiffness of boundary, but also its roughness. An absolutely smooth boundary would offer only lateral restraint, but a rough boundary does more. It offers irregularities as direct obstructions at the surface of contact. These obstructions have the power of generating eddies, but in a different way to restraint. The eddies generated only by restraint are due to qualities within the mass, arising out of the disturbance of rhythm, while the eddies generated by roughness of bouudary are due to causes without the mass, rising at each obstruction, which checks flow; the kinetic energy of flow is momentarily converted into potential, and this immediately reacts in eddies. We thus have two distinct causes for the generation of eddies, *viz.*, restraint and roughness of boundary. We shall need to distinguish between the two, for the former generates eddies simultaneously throughout the mass, while the latter generates eddies more gradually, beginning at the boundary and spreading by communication into the mass. The former are evidently constant, while the latter vary with distance from boundary.

Now, it is the latter form of eddy which is associated with the ripple, for clearly it differentiates the intensity of eddies throughout the mass. This differentiation varies, not only according to the degree of roughness, but also according to the distance of boundary. We have seen that the larger eddy rising from the bed at a bigger obstruction than usual swells up and appears on the surface. All eddies are not necessarily thus continuous, but all have the power of transmitting effects from bed to surface, for certainly every feature of the bed, not only of roughness but also of changing depth, is communicated to the surface.

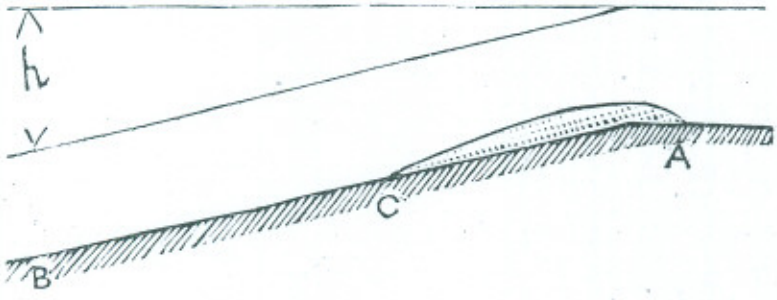
At the outset the direct cause for disturbances on the surface was traced to the white still water of swelling eddies, which rise from the bed to a prominence, appearing above the surface, where it reacts in ripples. Now these still-water prominences appeal to the engineer as heads of pressure, and he is able to recognize in them some obstruction, which, since it exists from bed to surface, must effect the whole mass in that vicinity. We have already stated the theory by which irregularities create potential, but here we have the evidence brought to us in our study of effects which appeal to navigation, for here we see that for the moment the kinetic energy of flow is converted into energy of potential, visible at each prominence. If not in a continuous column, then by a succession of eddies, the same effect is conveyed from bed to surface, where we see its result, the ripple.

Now as we have stated it is the eddy (of potential) which, by varying intensity, differentiates the ripple, as it appears on the surface. To understand this let us consider what would be the surface appearance

of a stream running over an absolutely smooth even bed. The ripples without a doubt would be distributed evenly over the whole surface. The moment however that the bed becomes uneven, the effects are transmitted to the surface in varying shades of ripples. It is the unevenness of bed which thus differentiates the intensity of eddies. The eddies of restraint, though present, do not appear except as a constant surface. To this constant surface are added the other eddies of roughness which give us the differences of shade. These differences are due we have seen to irregularity and unevenness of bed. The "mallah" therefore is able to correctly interpret the bed by means of surface ripples.

We need now to go back to the meanings which the "mallah" applies to the ripple. It means change of depth to him and we have seen that this change is indicated by two processes, *viz.*, rising prominences, and ripples which break on the surface as a consequence. The "mallah" tells us that these effects come into existence at the bed over a rising plane. To put this into more scientific language, we may say that the eddy creates potential over a rising plane, which reacts in surface adjustments. It is this potential which is so important in flowing water. It is something added to that other effect of lateral restraint, and would not exist, but for the inclined plane. There would still be eddies over the smooth bed, but these would show no shades on the surface, for, since the effect of restraint is constant, the ripples would be distributed evenly over the surface. It is therefore the inclined plane we conclude which gives us a self-created eddy, and by this we acquire potential, which is a varying force.

Now potential is dependent on position, which has already been alluded to elsewhere, but which may again be recalled. The figure below will explain the situation.



A branch channel is here presented in section, taking off from the parent at A, and flowing down to B. A shoal forming at the offtake, as A. C. cannot acquire more potential from the parent, since it has no power of raising head in the parent. Should however a shoal appear below B it may raise head to as much as h. Actually it never utilizes much of the total amount of potential at its disposal, as measured by h, but it utilizes some, and by successive small borrowings over the whole stream, supplies us with the additions to which we have alluded, and which give us the eddies of potential.

If we reconsider the " mallah's " conclusions about depths as in figure opposite page 40 we shall realise that he bases a great deal on the offtake of creeks which are essentially variable, since they cannot raise potential, but are open to all the changes of varying river silt brought down by erosions. It is the offtake of creeks which are just as unstable on rivers as the offtakes of channels are on a system of canals. The reason is that these have none or very small advantage of position by which they may borrow potential.

Now let us examine flow in the light of the above remarks. To do so we may not do better than go back to Kennedy's very useful experiments on channels in perfect regime. Here we have a bed laid out in a series of ridges, each ridge rising as a plane extending in a downstream direction. Over this plane then we have potential, which begins to be generated at the base, and increasing in reaction all up the face of the plane, limits its further formation at the ridge, where the power of the silt particles to continue to deposit breaks down. For the instant violent eddying manifests itself, which scours out a hollow, till the next plane begins to rise.

Now these planes must be representative of a certain grade of silt. A heavier grade would lay down one angle, probably steeper, while a lighter grade would lay down another angle, probably flatter. Each grade of silt we presume has its particular angle of repose. If this be correct we obtain a clue which should satisfy Kennedy's experimental conclusions.

Kennedy found that a constant relation between depth and velocity held however slope and bed width of the channel varied. This relation he expressed as an equation :—

$$V = \cdot 84\ d^{\cdot 64}.$$

The writer in a previous article entitled " Transportation of silt by flowing water " represented the same equation in form which he wrote as

$$fd = CV^n$$

and for streams in regime f becomes constant and therefore the equation might be written

$$V = c,\ d^{1/n}$$

i.e., the form of equation is the same as that of Kennedy's, but in the writer's deduction f represents resistance across a section of the stream brought about by eddying.

The important conclusion therefore is that this resistance, a measure of eddying energy, becomes constant for streams in regime.

But more than this, Kennedy found that each channel had not only a constant law for itself, but one which was the same for each channel. He moreover proved algebraically that the silt ratio was constant for the whole system of canals. By being in circulation for long it had

also become thoroughly mixed, representing one grade of silt. This was the reason at the back of his results.

We therefore conclude that one grade of silt gives us the constant law. Gilbert in his experiments in California showed that different grades of silt gave different laws, for he proved the exponent in the above equation to vary. It is therefore the grade of silt which is evidently the ruling factor.

This also is our conclusion by quite independent data. We have been guided by the " mallah's " lore, and learning that inclined planes over the bed are responsible for differentiation in ripples at the surface, we conclude that where there is no differentiation there is either an absolutely smooth bed, or one laid down in such regular rhythm of successive inclined planes, as to give us a surface in which the recurrence of ripples gives regular distribution. We know that our channel beds are not absolutely smooth, but are laid out in series of inclined planes. Our conclusion therefore is that potential over these is practically a constant quantity, or *vice versa*, the planes have an inclination characteristic of one grade of silt.

Now, Kennedy's channels have temporarily to carry different grades of silt over periods of floods and freshets. How is it then that they do not alter their laws of transportation? The answer is that they do alter laws temporarily, and would continue to do so were these other grades continuous. As however they are not, the ruling grade, which has a greater transporting power by reasons of its steeper plane, causes silt to be picked up till original conditions are restored.

From this we conclude that floods and freshets bring down lighter grades of silt. If this be right we should have some evidence about it. As a matter of fact we have, for it has been proved by other observations during freshets, that lighter silt is then found to be carried in excess.

The picking up of silt should be clearly understood. Not only different grades of silt are for the time carried, but large excesses. How are the excesses transported? They are usually very large, many times more than the normal, and are disposed of in a remarkably short time. Where does the accession of power to carry them on come from? The reply is that accession of power, represented by accession of potential, is in reality unlimited, except at the offtakes. The latter often remain permanently silted up for this reason.

There is yet one other factor of which we shall have to take account and that is Rhythm. We have said that it is primarily due to that oscillation in the filaments of flowing water which manifests itself when free to move. When boundaries are impressed on this body of water, the rhythms are broken and suppressed, but if the boundary itself be regular, as that of a pipe of one diameter, we get another set of rhythms also regular, but characteristic of that particular boundary. Because of this, discharges of pipes have been calculated by timing the rhythm. On a river the rhythm is everywhere in evidence, for it is undoubtedly

this which generates the wave like silt dunes on the bed. If rhythm were not present, there is no reason why the dunes should not form in other ways. How far the rhythm is responsible for the recurrence of planes is not certain, but it would seem to crowd them closer together where velocity is forcibly checked, as above a masonry work in a defined channel. *Vice versa*, the planes would occur further apart as the outfall becomes more free. Rhythm has probably an important part to play in all channels, but it has not been much more than recognized so far.

Now, not only do inclined planes play an active part in transportation, but the amount of silt transported enters into the problem. Assuming that grade is constant, if amount grow excessive, the planes will momentarily begin to move upstream, as the excess begins to be deposited more thickly on the upstream faces. Should the amount, on the other hand, grow less the planes will still seem to move upstream, but it will be noticed that they do so by retrogression of the ridges which are scoured at the margins. These actions, if continued long enough, will give us characteristic slopes different to the first, when the planes and amount of silt again become so related, as to give practical stability. The first action it may be concluded, will, by travelling up, cause silt to be permanently laid down in a new slope, beginning at the offtake, while the second by retrogression of levels will scour out a new slope, working up from the outfall.

Now the practical lessons for the engineer which we have learnt may be summed up under two heads, *viz.*, the turning power of silt, obtained from bank erosions, and the transporting power, when spread out in ridges over the bed. The first brings about changes in the course of the river, and gives us its tortuous course ; the second enables us to understand how it carries its immense load of silt to the ocean.

Under the first head we have noticed that bank erosion gives us excess over the normal load of silt which a river in regime may carry. It must therefore appear as a shoal, but the question is, where ? This question has been answered, for the shoal appears just below the erosion or that side of the stream at which it occurs. This then becomes a law of first importance, for it begins to lay down the course of the river on a definite plan which we may understand.

Starting out with this fact, it follows almost as a corollary that the severity of erosion gives us the intensity of shoaling. On this the " mallah " is able to base far-reaching conclusions. For instance, the length of eroding bank, or the rapidity of its caving in, tells him what amount of silt he may expect to find in the shoal. Moreover the tendency to deposit is greater at the beginning of the shoal, and diminishes as we follow it downstream. It is also clear that the intensity of charge along the eroding bank is varying. Beginning at the point where the stream comes into the bank with the minimum load, it increases all the way down, till the shoal begins to be laid down,

These facts give the engineer valuable information, for they at once tell him that the best offtake for a canal will be just above the point at which erosion starts, and the worst at the point where the shoal begins to form. He further is able to understand why the offtake of the creek below the erosion is carried downstream, and instead of starting along the edge of the high bank in continuation of that which is eroding, forms a back-water, breaking across the shoal at some distance out and lower down. It does so because it is fighting for its existence against silt, and only when the draw of the creek overcomes the intensity of shoaling, which is a diminishing quantity, may it continue to flow. Moreover, the turn-about in direction assists the offtake, for the greater it is, the more effectually will momentum carry the heavier particles past, before they can change their line of direction, and the finer particles of silt meanwhile filling the offtake, are more easily carried down the creek. There is yet a third factor which steps in, and that is the opposition of the downstream bank of the back-water intake. This, by becoming more direct, raises head more and more effectually, and increases velocity by reaction round that side into the creek. Were it not for these assisting factors the side creek would silt up solidly at the offtake. As it is, if it survive, it only just struggles through. If, as we know the intensity of shoaling is capable of turning the whole mainstream out of its course, it has much less trouble in silting up a creek.

Yet the conditions on the river are so variable that these side creeks continue to flow against great odds. The " mallah " recognizes this, for he is aware that the moment erosion ceases, the chances lie with the creek, which rapidly strengthens at offtake. The change occurs with a falling river. If the fall be slow, the creek may completely recover itself, though, on the other hand, if it be quick, the bar at the head of the creek, rising above the level of the flow, may cause the creek to run dry. These are the factors on which the " mallah " bases his conclusions, for he is alive to the struggle which is so incessant, but varying, where flowing water has silt from side erosions to deal with.

The second factor by which silt acquires the power of transporting itself by forming ridges on the bed does not worry the " mallah", but is highly important to the Engineer. It gives a clue by which he recognizes an added power in silt-bearing streams. This power has been defined as potential, since each ridge of silt has the power of raising it. In reaction potential gives us the eddy, and it is this which gives water the power to support silt and thus to transport it. All flowing water, down to minute velocities and dimensions of boundary is dominated by eddies, but where boundaries alone are considered, these are brought about by restraint, and form a constant force, being some function of V, the exponent having a value somewhere in the neighbourhood of 2. To these, eddies of potential must be added as a force which comes and goes with the planes of silt.

We have further concluded that, where the grade of silt is constant, the ridges form so as to raise constant potential all down the course of the stream. The offtake alone is uncertain, since it is placed at a disadvantage by reason of position. On the Punjab Canals a ruling grade of silt obtains which gives us a constant law expressed by Kennedy in the formula

$$V = \cdot 84\, d^{\cdot 64}$$

This constant formula is possible for the fact that freshets, which bring down other grades of silt, carry silt which is lighter than the ruling grade. This gives us the phenomenon by which water is able to pick up silt, and to restore original conditions.

Where we say that Kennedy's formula is constant for the canals of Punjab, we are aware that corrections are needed as we travel over wider localities. These corrections are applied by modifying only the co-efficient of the formula, whereas co-efficient and exponent are in reality both varying. The correct procedure would be to arrive at a new formula for that particular grade of silt by a set of new observations such as Kennedy made.

In closing, it may be noted that one factor influencing surface impressions has not been touched on, and that is wind. If blowing downstream wind has the effect of smoothening out the ripples till the surface assumes almost an oily appearance. On the other hand, wind blowing upstream, increases the ripples, and by doing so blurs the finer variations. As the " mallah " finds no difficulty in making allowances for this, we should find little. The principles remain the same, and the surface indications, though blurred are still there.

Another question may also be of interest, and that is, will a river eat laterally further into a bank of clay than into a bank of sand? The answer should be readily given after what we have learned of river principles. Since clay is lighter and more finely divided than sand, it can be carried further in suspension, before being redeposited. For this reason erosion will eat more into the bank before a turn-over is effected. This gives us an answer why some rivers have a tendency to move laterally in one direction more than in another.

Here on the Indus, where the river sometimes hugs the westerly bank of original clay, such a tendency has been noticed.

The writer has not attempted to work out theories so much as to draw attention to deductions from visible proofs. If therefore his exposition be weak in theory, it is hoped that it is stronger in practical deduction. As the heading implies, the " mallah " as the master of navigation, deserves first place, even though the Engineer may come in, a good second. It is for him to continue to develop research from here.

DISCUSSION.

MR. CLAXTON in introducing his paper said that he wished to establish the reality of "potential," that added something in flow which reduced navigation to a fine art, and correlated it to the Science of Engineering and explained the problems of flow.

Theory recognized two causes for eddies, *viz.*, lateral restraint, and potential due to roughness of boundary. These, he maintained, must be separated before we could deal with the problem of flow.

He would first deal with restraint, and consider a cross-section of the stream.

If δ w be a very narrow width of the cross section and m be a particle in that width, and if f be the forward acceleration of gravity as modified by viscosity and D the total depth.

The work=m f D

for since f is constant through D, it is the same as if f acting on particle m were moved through depth D.

Now by the first principles of dynamics work expressed by mean velocity V at the same section=$\frac{1}{2}$ m V^2

Thus acceleration @ $a = \frac{d\,v}{d\,t}$

i. e., $d\,v = a\,d\,t$

integrating, $v = a\,t$

again $a = \frac{d\,v}{dt} = d\,\frac{\frac{dS}{dt}}{dt} = \frac{d^2\,S}{dt^2}$

Integrating $\frac{d\,s}{d\,t} = a\,t$

Integrating again $S = \frac{1}{2}\,a\,t^2$

i. e., $2\,a\,s = v^2$

Mean work $= M\,a\,s = \frac{1}{2}\,M\,V^2$

therefore from above $m\,f\,D = \frac{1}{2}\,M\,V^2$

or $f\,D = \frac{V^2}{2}$

If now we consider the whole width W and omit the effect of banks, we get

$$[fd\,\delta w]_W^v = [\frac{V^2}{2}\,\delta w]_W^v$$

$$fd\,W = \frac{V^2}{2} W$$

or $fd = \frac{V^2}{2}$ again,

If we write the force f as c g Sin $\propto$, C being a coefficient for viscosity and $\propto$ the angle of slope

$$C\,g\,\text{Sin}\propto = \frac{V^2}{2\,D}$$

$$\text{or Sin}\propto = \frac{V^2}{D}\left(\frac{1}{2\,C\,g}\right)$$

and if $\frac{1}{2\,C\,g}$ be written as C^1

$$\text{then Sin}\propto = \frac{C^1 V^2}{D}$$

We may thus solve for C^1 by experimenting with smooth channels.

This is the nearest we need to go to find an equation which is essentially fundamental. If lateral restraint, without roughness, be considered, this equation expresses its law, and is perfectly rational.

We have now to consider potential arising from roughness of boundary in which we must also include changes of slope. The evidences of navigation emphasize the fact that roughness of bed is accurately communicated to the surface by the prominences of potential which gives us ripples. It is this potential with which we have to deal.

If then we write the equation $f\,D = c\,V^2$

$$\text{as } f = \frac{c\,V^2}{D}$$

We obtain on the right a useful expression of two measurable quantities V and D, by which we may examine other sections of the stream. Dealing with streams carrying loads of silt we find that as we move from section to section V and D vary, for silt is rolled up into inclined planes which cause variations. Let us further examine these planes. They are laid out on the bed thus :—



The water surface has corresponding but much lighter prominences of potential each of which occurs slightly upstream of the bed ridge.

Now if D be mean depth, then over a rising plane it is diminishing. V should therefore be proportionately increasing. But the important fact is that V does not increase for then particles of silt would not continue

to be deposited, whereas they do, till the ridge is reached. It is therefore evident that part of the energy which would appear as greater velocity up to the face of the plane is converted into some other form of energy, and this can only be potential for which we are looking.

Now another important fact is this. In release at the ridge potential creates maxima in velocity, but these maxima are never measured, since we deal only with mean velocities. Yet, these maxima govern the transportation of silt since it is clear that the amount of silt which is carried forward is entirely dependent on them.

Since the maxima then determine the quantity of silt which is transported it will only be necessary to deal with a section at the ridge of an inclined plane. By Kennedy's experiments we know that a constant law for the transportation obtains. We may, therefore conclude, that the conditions set up at one ridge are constant for all ridges for that grade of silt and that particular slope.

If then we express the discharge over a contracted section by D' Aubusson's theory we get the formula for unit width

$$Q = C\,(D - h_p)\ \sqrt{2gh_p}$$

h_p being head of potential.

It will thus be possible to obtain h_p the head of potential which appears to be the governing factor. To this head we must add head of approach h_r due to velocity as determined for lateral restraint only. By determining the sum of h_p and h_r for different grades of silt and different slopes we may obtain a table by which silt transportation may be completely determined.

If we now turn our attention to loadless streams in artificial channels we have projections of boundary instead of rolling planes of silt to deal with. These projections cover the boundary more or less regularly so that we again obtain constancy of discharge. This is now subject to a series of control points each of which determines a potential and consequently also discharge.

We may now understand how the rational fundamental question becomes irrational when expressed in terms of mean velocity and D.

Thus, if we consider the cross section just below the crest of a natural stream or just below the control point of an artificial one, and assume that potential gives an increment v_u to velocity depth being reduced by say d_v.

Then $\frac{V^2}{D}$ becomes $\frac{(V + v_u)^2}{D - d_u}$

This would still be rational until we attempt to express it in some such form as $\frac{V^m}{D^n}$ as we do,

It will thus appear that a rational formula which expresses flow in terms of V and D is impossible since V_u and D_u are unobservable. On the other hand a study of the planes or dunes of bed silt, or the nature of artificial boundaries seems to offer a clue, but it remains for this Congress to consider the matter and for the Research Department to carry the suggestions further into the field of experiment to find a complete solution.

MR. WILSDON said that he was no nearer understanding the theory of "potential" than before; and he had not been able to follow Mr. Claxton's Mathematics.

He did not agree that ripples on the surface were caused by eddies generated at the bed. Ripples must be studied by comparison with waves, and were subject to surface tension.

$$v^2 = \frac{g\lambda}{2\pi} + \frac{2\pi\tau}{\rho\lambda}$$

(Ripples)

Eddies were entirely different things. Different reasons were responsible for ripples. They were capable of being measured, and might have nothing to do with the formation of a wave.

If a glass-tube were filled with two liquids of different density, they would show a clear surface of division, but the moment the tube was tilted, this surface would become blurred; such would be the origin of ripples.

In the expression m f D, f was an unknown, and of little use; it took into account viscosity, but that told us nothing. Theorising would not carry us very far; it was only by careful examination and measurement of these ripples and by comparing their wave-lengths that we were likely to make progress. The bottoms of canals were very complex; very often reflex ripples were obtained. It was possible to fix roughly the wave-length and size of the ripples.

MR. NICHOLSON thought Mr. Claxton had worked too much on the surface. He said that the dunes of rolling silt showed two phases, one in which they were rolling forward by deposits on the upstream side, and the other in which they were cutting back by scour on the downstream side. Between these phases was an intermediary stage in which the bed had became smooth, and this would probably account for the quickening of velocity in a stream momentarily bringing down finer particles of silt.

MR. CLAXTON'S reply:

MR. Wilsdon in his first remark had dealt essentially with wind action, and the paper had taken this into account separately. The writer had stated that with the exception of wind, ripples could not be created except by eddies generated at the bed. He still could not conceive of any other cause.

The experiment in the glass-tube essentially depended on motion, when at a critical velocity the stability of viscosity broke down and eddies

at the surface of contact (being the surface of least resistance) appeared. They were in reality nothing different from those generated at all boundaries.

The expression m f D could be written as C g sin $\propto$ where $\propto$ was the angle of slope. The equation might then be reduced to the form Sin $\propto = \frac{C^1 V^2}{D}$. In this $\propto$ V and D were all observable, and C^1 only had to be determined.

If the equation were true C^1 would remain constant for all conditions, and it was for the Research Department to put it to the test. Glass boundaries, though not absolutely smooth, should give near enough results.

Mr. Nicholson was probably correct in his conclusions about an intermediary smooth stage and consequent quickening of velocity; the momentary disappearance of dunes would reduce eddying resistance.

Mr. Claxton would be glad if any member who had fault to find with his arguments would communicate with him.

Paper No. 100.
A. & C.

Page.	Line.	*For.*	*Read.*
39	6	eddying ..	eroding.
47	13	in reaction ..	(delete).
47	14	(after 'formation')	in reaction.
47	36	resistance ..	forward acceleration.
47	37	eddying ..	gravity.
47	38	this resistance ..	the resistance which rises to this acceleration.